ELECTRICIAN

NSQF LEVEL - 4

2nd Year

TRADE THEORY

SECTOR: POWER

(As per revised syllabus July 2022 - 1200 Hrs)

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

Post Box No. 3142, CTI Campus, Guindy, Chennai - 600 032

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FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising various stakeholder's viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

The National Instructional Media Institute (NIMI), Chennai, an autonomous body under the Directorate General of Training (DGT), Ministry of Skill Development & Entrepreneurship is entrusted with developing producing and disseminating Instructional Media Packages (IMPs) required for ITIs and other related institutions.

The institute has now come up with instructional material to suit the revised curriculum for **Electrician 2nd Year - Trade Theory - NSQF Level - 4 (Revised 2022) in Power Sector under Annual Pattern.** The NSQF Level - 4 (Revised 2022) Trade Theory will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF Level - 4 (Revised 2022) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 4 (Revised 2022) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

Director General of Training
Ministry of Skill Development & Entrepreneurship,
Government of India.

New Delhi - 110 001

PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Employment and Training (D.G.E & T), Ministry of Labour and Employment, (now under Directorate General of Training, Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi NSQF Level - 4 (Revised 2022) under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other support materials.

The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package (IMF) in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

Chennai - 600 032 **EXECUTIVE DIRECTOR**

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisations to bring out this instructional material **(Trade Theory)** for the trade of **Electrician -2nd Year - NSQF Level - 4 (Revised 2022)** under **Power** Sector for ITIs.

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NIMI records its appreciation for the Data Entry, CAD, DTP operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks the invaluable efforts rendered by all other NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

This manual for trade practical is intended for use in the ITI workshop. It consists of a series of practical exercises that are to be completed by the trainees during the second year of course is the **Electrician trade under Power Sector. It is National Skills Qualifications Framework NSQF Level - 4 (Revised 2022),** supplemented and supported by instructions/information to assist the trainees in performing the exercise. The exercises are designed to ensure that all the skills prescribed in the syllabus are covered including the allied trades.The syllabus for the 2nd Year **Electrician** Trade under **Power Sector** Trade Theory modules are given below:

Module 1 -	DC Generator
Module 2 -	DC motor
Module 3 -	AC Three Phase Motor
Module 4 -	AC Single Phase Motor
Module 5 -	Alternator
Module 6 -	Synchronous Motor and MG Set
Module 7 -	Electronic Practice
Module 8 -	Control panel wiring
Module 9 -	AC/DC motor drives
Module 10 -	Inverter and UPS
Module 11 -	Power Generation and Substation
Module 12 -	Transmission and Distribution
Module 13 -	Circuit Breakers and Relays
Module 14 -	Electric vehicle

The syllabus and the content in the modules are interlinked. As the number of workstations available in the electrical section is limited by the machinery and equipment, it is necessary to interpolate the exercises in the modules to form a proper teaching and learning sequence. The sequence of instruction is given in the schedule of instruction which is incorporated in the Instructor's Guide. With 25 practical hours a week of 5 working days 100 hours of practical per month is available.

Contents of Trade Practical

The procedure for working through the 106 exercises for the 1st Year with the specific objectives as the learning out comes at the end of each exercise is given is this book.

The skill objectives and tools/instruments, equipment/machines and materials required to perform the exercise are given in the beginning of each exercise.Skill training in the shop floor is planned through a series of practical exercises/experiments to support the related theory to make the trainees get hands on trainning in the Electrician trade along with the relevant cognitive skills appropriate for the level. A minimum number of projects have been included to make the training more effective and develop attitude to work in a team. Pictorial, schematic, wiring and circuit diagrams have been included in the exercises, wherever necessary, to assist the trainees broaden their views. The symbols used in the diagrams comply with the Bureau of Indian Standards (BIS) specifications.

Illustrations in this manual, help trainess visual perspective of the ideas and concepts.The procedures to be followed for completing the exercises is also given. Different forms of intermediate test questions have been included in the exercises, to enhance the trainee to trainee and trainee to instructor interactions.

Skill Information

Skill areas which are repetitive in nature are given as separate skill information sheets. Skills which are to be developed in specific areas are included in the exercises itself. Some subexercises are developed to fulfill the sequence of exercises in keeping with the syllabus.

This manual on trade practical forms part of the Written Instructional Material (WIM). Which includes manual on trade theory and assignment/test.

CONTENTS

LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

Sl.No.	Learning Outcome	Exercise No.
1	Plan, execute commissioning and evaluate performance of DC machines. (NOS: PSS/N4402)	2.1.107 - 2.1.113
2	Execute testing, and maintenance of DC machines and motor starters. (NOS: PSS/N4402)	2.2.111 - 2.2.122
3	Plan, execute commissioning and evaluate performance of AC motors. (NOS: PSS/N1709)	2.2.111 - 2.2.122
4	Distinguish, organise and perform motor winding (Mapped NOS: PSS/N4402)	2.3.123 - 2.3.133
5	Plan, Execute commissioning and evaluate performance of AC motors. (Mapped NOS: PSS/N1709)	2.3.123 - 2.3.133
6	Execute testing, and maintenance of AC motors and starters. (NOS: PSS/N1709)	2.3.123 - 2.3.133
7	Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set. (NOS: PSS/PSS/N9405)	2.4.134 - 2.4.142
8	Execute parallel operation of alternators. (NOS: PSS/N9405)	2.4.134 - 2.4.142
9	Distinguish, organise and perform motor winding. (NOS: PSS/N4402)	2.4.134 - 2.4.142
10	Assemble simple electronic circuits and test for functioning. (NOS: PSS/N9406)	2.5.143 - 2.6.151
11	Assemble accessories and carry out wiring of control cabinets and equipment. (NOS: PSS/N9407)	2.7.152 - 2.7.166
12	Perform speed control of AC and DC motors by using solid state devices. (NOS: PSS/N9408)	2.8.167 - 2.8.171
13	Detect the faults and troubleshoot inverter, stabilizer, battery charger, emergency light and UPS etc. (NOS: PSS/N6002)	2.9.172 - 2.9.174
14	Plan, assemble and install solar panel. (NOS: PSS/N9409)	2.10.175 - 2.10.180
15	Erect overhead domestic service line, outline various power plant layout and explain smart distribution grid and its components. (NOS: PSS/N0106)	2.11.181 - 2.11.187
16	Examine the faults and carry out repairing of circuit breakers. (NOS: PSS/N7001)	2.11.181 - 2.11.187
17	Install and troubleshoot Electric Vehicle charging stations. (NOS: PSS/N9410)	2.12.188 - 2.12.194
18	Read and apply engineering drawing for different application in the field of work. (NOS: PSS/N9401)	2.13.195 - 2.13.199
19	Demonstrate basic mathematical concept and principles to perform practical operations. Understand and explain basic science in the field of study. (NOS: PSS/N9402)	2.14.200 - 2.14.202

NOTE :

- **ITI students can obtain certificate of competency (Trade license) from respective Labour/ Industries department under State/ UT Govt.**
- **Refer to notification available in public domain for concern states/ UT. Principal & Trade Instructors to facilitate trainees.**

QR CODE

MODULE 2

Ex.No. 2.2.111 & 114 -119

Ex.No. 2.2.122

MODULE 3

Ex.No. 2.3.123 - 131

Ex.No. 2.3.132

MODULE 4

Ex.No. 2.4.134 - 142

MODULE 6

Ex.No. 2.6.148 & 149

MODULE 7

Ex.No. 2.7.152

Ex.No. 2.7.153

Ex.No. 2.7.154

Ex.No. 2.7.155

Ex.No. 2.7.156

Ex.No. 2.7.160

MODULE 9

Ex.No. 2.9.172

MODULE 10

Ex.No. 2.10.180

SYLLABUS

Duration	Reference Learning Outcome	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
Professional Skill 35 Hrs.; Professional Knowledge 09 Hrs.	Plan, execute commissioning and evaluate performance of DC machines. **(Mapped NOS: PSS/N4402)**	107. Identify terminals, parts and connections of different types of DC machines. (05 Hrs.) 108. Measure field and armature resistance of DC machines. (05 Hrs.) 109. Determine build up voltage of DC shunt generator with varying field excitation and performance analysis on load. (10 Hrs.) 110. Test for continuity and insulation resistance of DC machine. (5 Hrs.) 111. Start, run and reverse direction of rotation of DC series, shunt and compound motors. (10 Hrs.)	General concept of rotating electrical machines. Principle of DC generator. Use of Armature, Field Coil, Polarity, Yoke, Cooling Fan, Commutator, slip ring and Brushes, Laminated core etc. E.M.F. equation Separately excited and self-excited generators. Series, shunt and compound generators. (09 Hrs.)
Professional Skill 77 Hrs.; Professional Knowledge 24 Hrs.	Execute testing, and maintenance of DC machines and motor starters. **(Mapped NOS: PSS/N4402)**	112. Perform no load and load test and determine characteristics of series and shunt generators. (08 Hrs.) 113. Perform no load and load test and determine characteristics of compound generators (cumulative and differential). (07 Hrs.) 114. Practice dismantling and assembling in DC shunt motor. (10 Hrs.) 115. Practice dismantling and assembling in DC compound generator. (10 Hrs.)	Principle and types of DC motor. Relation between applied voltage back e.m.f., armature voltage drop, speed and flux of DC motor. DC motor Starters, relation between torque, flux and armature current. Changing the direction of rotation. Characteristics, Losses & Efficiency of DC motors. Routine and maintenance. (12 Hrs.)
		116. Conduct performance analysis of DC series, shunt and compound motors. (14 Hrs.) 117. Dismantle and identify parts of three point and four-point DC motor starters. (06 Hrs.) 118. Assemble, Service and repair three point and four-point DC motor starters. (10 Hrs.) 119. Practice maintenance of carbon brushes, brush holders, Commutator and sliprings. (12 Hrs.)	
Professional Skill 35 Hrs.; Professional Knowledge 09 Hrs.	Distinguish, organise and perform motor winding. **(Mapped NOS: PSS/ N4402)**	120. Perform speed control of DC motors - field and armature control method. (10 Hrs.) 121. Carry out overhauling of DC machines. (10 Hrs.) 122. Perform DC machine winding by developing connection diagram, test on growler and assemble. (15 Hrs.)	Methods of speed control of DC motors. Lap and wave winding and related terms. (09 Hrs.)

Professional Skill 80 Hrs.; Professional Knowledge 26 Hrs.	Plan, Execute commissioning and evaluate performance of AC motors. **(Mapped NOS: PSS/N1709)** Execute testing, and maintenance of AC motors and starters. **(Mapped NOS: PSS/N1709)**	123. Identify parts and terminals of three phase AC motors. (5 Hrs.) 124. Make an internal connection of automatic star-delta starter with three contactors. (10 Hrs.) 125. Connect, start and run three phase induction motors by using DOL, star-delta and auto-transformer starters. (17 Hrs.) 126. Connect, start, run and reverse direction of rotation of slip-ring motor through rotor resistance starter and determine performance characteristic. (13 Hrs.)	Working principle of three phase induction motor. Squirrel Cage Induction motor, Slip-ring induction motor; construction, characteristics, Slip and Torque. Different types of starters for three phase induction motors, its necessity, basic contactor circuit, parts and their functions. (13 Hrs.)
		127. Determine the efficiency of squirrel cage induction motor by brake test. (05 Hrs.) 128. Determine the efficiency of three phase squirrel cage induction motor by no load test and blocked rotor test. (05 Hrs.) 129. Measure slip and power factor to draw speed-torque (slip/torque) characteristics. (10 Hrs.) 130. Test for continuity and insulation resistance of three phase induction motors. (5 Hrs.) 131. Perform speed control of three phase induction motors by various methods like rheostatic control, autotransformer etc. (10 Hrs.)	Single phasing prevention. No load test and blocked rotor test of induction motor. Losses & efficiency. Various methods of speed control. Braking system of motor. Maintenance and repair. (13 Hrs.)
Professional Skill 23 Hrs.; Professional Knowledge 09 Hrs.	Distinguish, organise and perform motor winding. **(Mapped NOS: PSS/N4402)**	132. Perform winding of three phase AC motor by developing connection diagram, test and assemble. (18 Hrs.) 133. Maintain, service and troubleshoot the AC motor starter. (05 Hrs.)	Concentric/ distributed, single/ double layer winding and related terms.
Professional Skill 39 Hrs.; Professional Knowledge 12 Hrs.	Plan, Execute commissioning and evaluate performance of AC motors. **(Mapped NOS: PSS/N1709)** Execute testing, and maintenance of AC motors and starters. **(Mapped NOS: PSS/N1709)**	134. Identify parts and terminals of different types of single-phase AC motors. (5 Hrs.) 135. Install, connect and determine performance of single-phase AC motors. (10 Hrs.) 136. Start, run and reverse the direction of rotation of single-phase AC motors. (08 Hrs.) 137. Practice on speed control of single-phase AC motors. (08 Hrs.) 138. Compare starting and running winding currents of a capacitor run motor at various loads and measure the speed. (08 Hrs.)	Working principle, different method of starting and running of various single-phase AC motors. Domestic and industrial applications of different single-phase AC motors. Characteristics, losses and efficiency. (12 hrs.)

Professional Skill 50 Hrs.; Professional Knowledge 12 Hrs.	Distinguish, organise and perform motor winding. **(Mapped NOS: PSS/N4402)**	139. Carry out maintenance, service and repair of single-phase AC motors. (10 Hrs.) 140. Practice on single/double layer and concentric winding for AC motors, testing and assembling. (25 Hrs.) 141. Connect, start, run and reverse the direction of rotation of universal motor. (10 Hrs.) 142. Carry out maintenance and servicing of universal motor. (05 Hrs.)	Concentric/ distributed, single/ double layer winding and related terms. Troubleshooting of single-phase AC induction motors and universal motor. (12 hrs.)
Profes-sional Skill 75 Hrs.; Profes-sional Knowledge 22 Hrs.	Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set. Execute parallel operation of alternators.	143. Install an alternator, identify parts and terminals of alternator. (5 Hrs.) 144. Test for continuity and insulation resistance of alternator. (5 Hrs.) 145. Connect, start and run an alternator and build up the voltage. (5 Hrs.) 146. Determine the load performance and voltage regulation of three phase alternator. (5 Hrs.) 147. Parallel operation and synchronization of three phase alternators. (15 Hrs.)	Principle of alternator, e.m.f. equation, relation between poles, speed and frequency. Types and construction. Efficiency, characteristics, regulation, phase sequence and parallel operation. Effect of changing the field excitation and power factor correction. (10 Hrs.)
		148. Install a synchronous motor, identify its parts and terminals. (10 Hrs.) 149. Connect, start and plot V-curves for synchronous motor under different excitation and load conditions. (10 Hrs.)	Working principle of synchronous motor. Effect of change of excitation and load. V and anti V curve. Power factor improvement. (06 Hrs.)
		150. Identify parts and terminals of MG set. (5 Hrs.) 151. Start and load MG set with 3 phase induction motor coupled to DC shunt generator. (15 Hrs.)	Rotary Converter, MG Set description and Maintenance. (06 Hrs.)
Professional Skill 99 Hrs.; Professional Knowledge 31 Hrs.	Assemble simple electronic circuits and test for functioning.	152. Determine the value of resistance by colour code and identify types. (03 Hrs.) 153. Test active and passive electronic components and its applications. (05 Hrs.)	Resistors – colour code, types and characteristics. Active and passive components. Atomic structure and semiconductor theory. (04 Hrs.)
		154. Determine V-I characteristics of semiconductor diode. (05 Hrs.) 155. Construct half wave, full wave and bridge rectifiers using semiconductor diode. (08 Hrs.) 156. Check transistors for their functioning by identifying its type and terminals. (10 Hrs.)	P-N junction, classification, specifications, biasing and characteristics of diodes. Rectifier circuit - half wave, full wave, bridge rectifiers and filters. Principle of operation, types, characteristics and various configuration of transistor. Application of transistor as a switch, voltage regulator and amplifier. (12 Hrs.)

		157. Bias the transistor and determine its characteristics. (05Hrs.) 158. Use transistor as an electronic switch and series voltage regulator. (05Hrs.)	
		159. Operate and set the required frequency using function generator. (05Hrs.) 160. Make a printed circuit board for power supply. (09 Hrs.) 161. Construct simple circuits containing UJT for triggering and FET as an amplifier. (05 Hrs.) 162. Troubleshoot defects in simple power supplies. (09 Hrs.)	Basic concept of power electronics devices. IC voltage regulators Digital Electronics - Binary numbers, logic gates and combinational circuits. (06 hrs.)
		163. Construct power control circuit by SCR, Diac, Triac and IGBT. (12 Hrs.) 164. Construct variable DC stabilized power supply using IC. (08 Hrs.) 165. Practice on various logics by use of logic gates and circuits. (05 Hrs.) 166. Generate and demonstrate wave shapes for voltage and current of rectifier, single stage amplifier and oscillator using CRO. (05 Hrs.)	Working principle and uses of oscilloscope. Construction and working of SCR, DIAC, TRIAC and IGBT. (09 Hrs.)
Professional Skill 82 Hrs.; Professional Knowledge 24 Hrs.	Assemble accessories and carry out wiring of control cabinets and equipment.	167. Design layout of control cabinet, assemble control elements and wiring accessories for: (i) Local and remote control of induction motor. (09 Hrs.) (ii) Forward and reverse operation of induction motor. (09 Hrs.) (iii) Automatic star-delta starter with change of direction of rotation. (12 Hrs.) (iv) Sequential control of three motors. (09 Hrs.)	Study and understand Layout drawing of control cabinet, power and control circuits. Various control elements: Isolators, pushbuttons, switches, indicators, MCB, fuses, relays, timers and limit switches etc. (12 Hrs.)
		168. Carry out wiring of control cabinet as per wiring diagram, bunching of XLPE cables, channeling, tying and checking etc. (13 Hrs.) 169. Mount various control elements e.g. circuit breakers, relays, contactors and timers etc. (09 Hrs.) 170. Identify and install required measuring instruments and sensors in control panel. (09 Hrs.) 171. Test the control panel for its performance. (12 Hrs.)	Wiring accessories: Race ways/ cable channel, DIN rail, terminal connectors, thimbles, lugs, ferrules, cable binding strap, buttons, cable ties, sleeves, gromats and clips etc. Testing of various control elements and circuits. (12 Hrs.)
Professional Skill 50 Hrs.;	Perform speed control of AC and	172. Perform speed control of DC motor using thyristors / DC drive. (18 Hrs.)	Working, parameters and applications of AC / DC drive.

Professional Knowledge 11 Hrs.	DC motors by using solid state devices.	173. Perform speed control and reversing the direction of rotation of AC motors by using thyristors / AC drive. (18 Hrs.) 174. Construct and test a universal motor speed controller using SCR. (14 Hrs.)	Speed control of 3 phase induction motor by using VVVF/ AC Drive. (11 Hrs.)
Professional Skill 50 Hrs.; Professional Knowledge 10 Hrs.	Detect the faults and troubleshoot inverter, stabilizer, battery charger, emergency light and UPS etc. **(Mapped NOS: PSS/N6002)**	175. Assemble circuits of voltage stabilizer and UPS. (10 Hrs.) 176. Prepare an emergency light. (10 Hrs.) 177. Assemble circuits of battery charger and inverter. (10Hrs.) 178. Test, analyze defects and repair voltage stabilizer, emergency light and UPS. (05Hrs.) 179. Maintain, service and troubleshoot battery charger and inverter. (07Hrs.) 180. Install an Inverter with battery and connect it in domestic wiring for operation. (08Hrs.)	Basic concept, block diagram and working of voltage stabilizer, battery charger, emergency light, inverter and UPS. Preventive and breakdown maintenance. (10 Hrs.)
Professional Skill 23 Hrs.; Professional Knowledge 04 Hrs.	Erect overhead domestic service line, outline various power plant layout and explain smart distribution grid and its components. **(Mapped NOS: PSS/N0106)**	181. Draw layout of thermal power plant and identify function of different layout elements. (5 Hrs.) 182. Draw layout of hydel power plant and identify functions of different layout elements. (5 Hrs.) 183. Visit to transmission / distribution substation. (08 Hrs.) 184. Draw actual circuit diagram of substation visited and indicate various components. (5 Hrs.)	Conventional and non-conventional sources of energy and their comparison. Power generation by thermal and hydel power plants. (04 Hrs.)
Professional Skill 25 Hrs.; Professional Knowledge 07 Hrs.	Plan, assemble and install solar panel	185. Prepare layout plan and Identify different elements of solar power system. (05 Hrs.) 186. Prepare layout plan and Identify different elements of wind power system. (05 Hrs.) 187. Assemble and connect solar panel for illumination. (15 Hrs.)	Various ways of electrical power generation by non-conventional methods. Power generation by solar and wind energy. Principle and operation of solar panel. (07 Hrs.)
Professional Skill 50 Hrs.; Professional Knowledge 10 Hrs.	Erect overhead domestic service line, outline various power plant layout and explain smart distribution grid and its components. **(Mapped NOS: PSS/N0106)**	188. Practice installation of insulators used in HT/LT line for a given voltage range. (04hrs.) 189. Draw single line diagram of transmission and distribution system. (04Hrs.) 190. Measure current carrying capacity of conductor for given power supply. (04hrs.) 191. Fasten jumper in pin, shackle and suspension type insulators. (07Hrs.)	Transmission and distribution networks. Line insulators, overhead poles and method of joining aluminum conductors. (05 Hrs.)
		192. Erect an overhead service line pole for single phase 230V distribution system in open space. (10 Hrs.) 193. Practice on laying of domestic service line. (10 Hrs.)	Safety precautions and IE rules pertaining to domestic service connections. Various substations. Various terms like – maximum demand, average demand, load

		194. Install bus bar and bus coupler on LT line. (5 Hrs.)	factor, diversity factor, plant utility factor etc. (05 Hrs.)
Professional Skill 25 Hrs.; Professional Knowledge 04 Hrs.	Examine the faults and carry out repairing of circuit breakers. **(Mapped NOS: PSS/N7001)**	195. Identify various parts of relay and ascertain the operation. (5 Hrs.) 196. Practice setting of pick up current and time setting multiplier for relay operation. (5 hrs.) 197. Identify the parts of circuit breaker, check its operation. (5Hrs.) 198. Test tripping characteristic of circuit breaker for over current and short circuit current. (5 hrs.) 199. Practice on repair and maintenance of circuit breaker. (5 hrs.)	Types of relays and its operation. Types of circuit breakers, their applications and functioning. Production of arc and quenching. (04 Hrs)
Professional Skill 22 Hrs.; Professional Knowledge 04 Hrs.	Install and troubleshoot Electric Vehicle charging stations.	200. Demonstrate different charger specifications. (05 hrs) 201. Perform installation of EV charging Station for Public places. (10 hrs) 202. Perform installation of Home EV charging stations. (10 hrs)	EV scenario in India and EV Charging basic theory. EV Charging safety requirements (04 Hrs)

Project work / Industrial visit:

a) Battery charger/Emergency light

b) Control of motor pump with tank level

c) DC voltage converter using SCRs

d) Logic control circuits using relays e) Alarm/indicator circuits using sensors

DC generator - principle - parts - types - function - e.m.f. equation

Objectives: At the end of this lesson you shall be able to
- **state the general concepts of rotating electrical machine**
- **state the principle of the DC generator**
- **explain the faraday's of laws of electro magnetic induction**
- **explain the production of dynamically induced e.m.f., its magnitude and direction**
- **describe the parts of a DC generator and their function**
- **classify and identify the different type of generators and their terminal markings**
- **derive the emf equation and calculation of a DC generator**
- **explain about separately excited DC generator with different types of windings.**

General concept of rotating electrical machine

In rotating machines, there are two parts, the stator and rotor. Rotating electrical machines are also of two types - DC and AC machines. Electrical machines are widely used. In DC machines the stator is used as a field and the rotor is used as an armature, while reverse is the case for AC machines. That is synchronous generators and synchronous motors. The induction motor is another kind of AC machine, which is singly excited; that is AC supply voltage is only given to the stator and no supply is given to the rotor. In DC machines and synchronous machines, the field is always excited.

Generator: An electrical generator is a machine which converts mechanical energy into electrical energy.

Principle of the generator: To facilitate this energy conversion, the generator works on the principle of Faraday's Laws of Electromagnetic Induction.

Faraday's Laws of Electromagnetic Induction: There are two laws.

The first law states

First law: Whenever the flux linking to a conductor an emf will be induced in the same conductor.

The second law states: The magnitude of such induced emf depends upon the rate of change of the flux linkage.

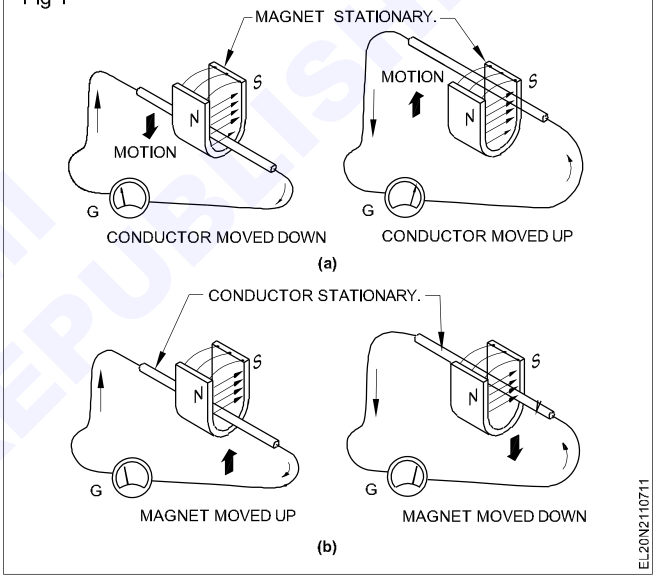
$$\text{emf} \propto \frac{\text{Change of flux}}{\text{Time taken for change}} . \quad e = N\frac{d\phi}{dt}$$

Types of emf: According to Faraday's Laws, an emf can be induced, either by the relative movement of the conductor and the magnetic field or by the change of flux linking on a stationary conductor.

Dynamically induced emf: In case, the induced emf is due to the movement of the conductor in a stationary magnetic field as shown in Fig 1a or by the movement of the magnetic field on a stationary conductor as shown in Fig 1b, the induced emf is called dynamically induced emf.

As shown in Figs 1a & 1b, the conductor cuts the lines of force in both cases to induce an emf, and the presence of the emf could be found by the deflection of the needle of the galvanometer `G'. This principle is used in DC and AC generators to produce electricity.

Fig 1



Production of dynamically induced emf: Whenever a conductor cuts the magnetic flux, a dynamically induced emf is produced in it. This emf causes a current to flow if the circuit of the conductor is closed.

For producing dynamically induced emf, the requirements are:

- magnetic field
- conductor
- relative motion between the conductor and the magnetic field.

If the conductor moves with a relative velocity 'v' with respect to the field, then the induced emf `E' will be

$E = BLV \sin\theta$ Volts

where

B = magnetic flux density, measured in tesla

L = effective length of the conductor in the field in metres

V = relative velocity between field and conductor in metre/second

θ = the angle at which the conductor cuts the magnetic field.

Let us consider Fig 2a in which conductors A to I are placed on the periphery of the armature under magnetic poles. Assume for this particular generator shown in Fig 2a, the value of BLV = 100V.

Accordingly the conductor A induces an emf

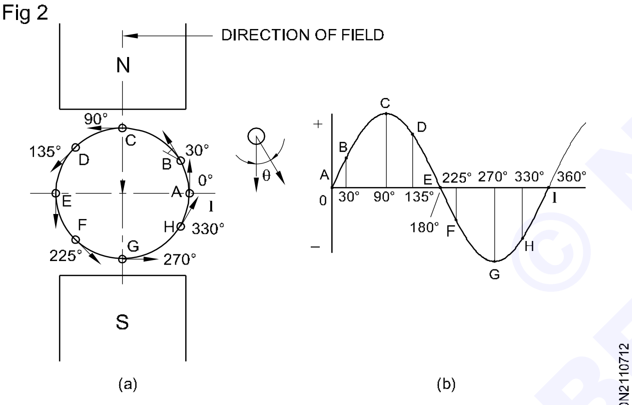
= BLV Sin θ where θ = zero and Sin zero is equal to zero

= 100 x 0 = zero.

Likewise for every position of the remaining conductors in the periphery, the emf induced could be calculated. If these values are plotted on a graph, it will represent the sine wave pattern of induced emf in a conductor when it rotates under N and S poles of uniform magnetic field.

As in Fig 2b the emf induced by this process is basically alternating in nature, and this alternating current is converted into direct current in a DC generator by the commutator.

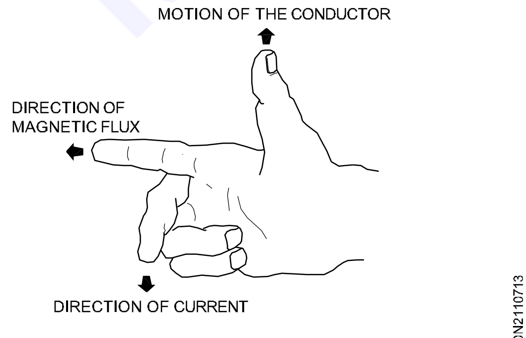
Fig 2



PRODUCTION OF THE SINEWAVE

Fleming's right hand rule: The direction of dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 3 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e. towards the observer or away from the observer.

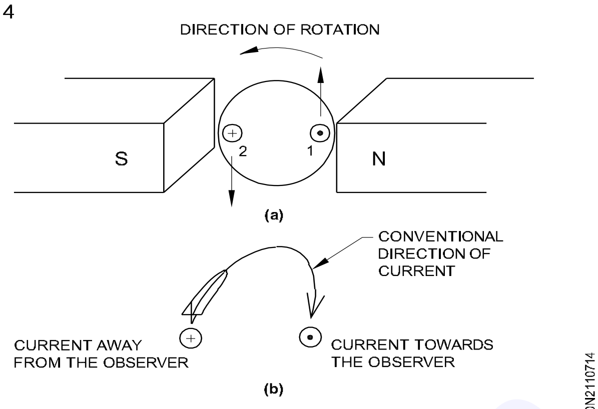
Fig 3



FLEMINGS RIGHT HAND RULE

Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 4a.

Fig 4



DIRECTION OF THE INDUCED CURRENT

Applying Fleming's right hand rule, we find that the conductor 1 which is moving upwards under the north pole will induce an emf in the direction towards the observer indicated by the dot sign and the conductor 2 which is moving down under the south pole will induce an emf in the direction away from the observer indicated by the plus sign.

Fig 4b indicates the current direction in the form of an arrow. The dot sign indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

Parts of DC generator

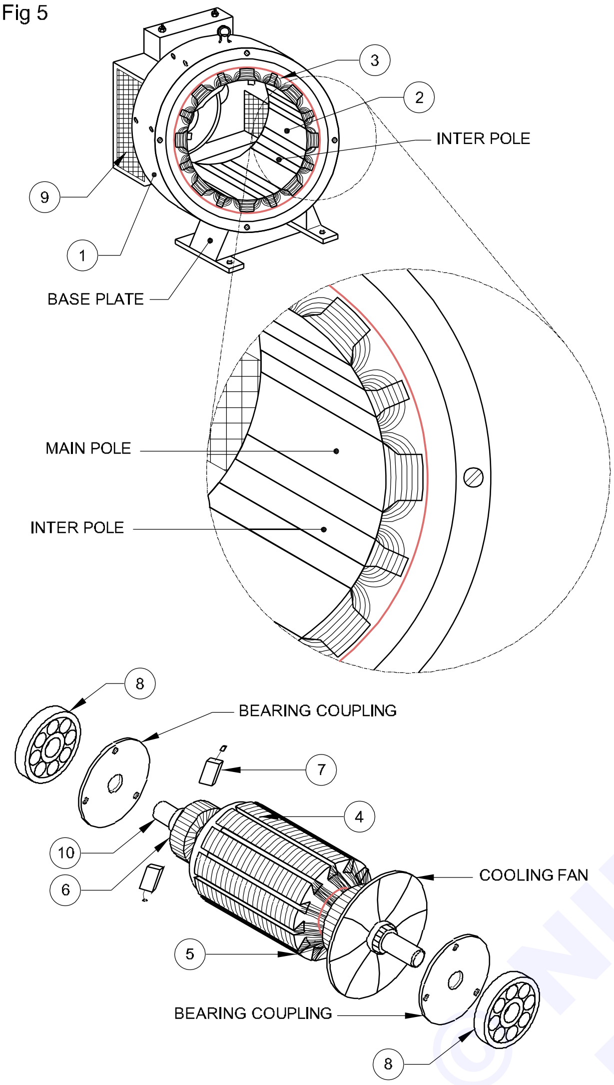
A DC generator consists of the following essential parts as shown in Fig 5.

1 Frame or yoke
2 Field poles and pole-shoes (Figs 6,7 & 8)
3 Field coils or field winding (Fig 8)
4 Armature core
5 Armature windings or armature conductors
6 Commutator
7 Brushes
8 Bearings and end plates
9 Air filter for fan
10 Shaft

Yoke: The outer frame or yoke serves a dual purpose. Firstly, it provides mechanical support for the poles and acts as a protecting cover for the whole machine. Secondly, it allows the magnetic circuit to complete through it. In small generators where cheapness rather than weight is the main consideration, yokes are made of cast iron. But for large machines usually cast steel or rolled steel is used.

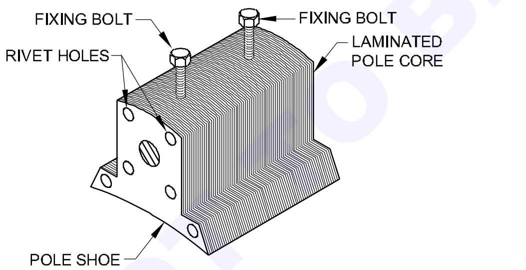
Pole cores and pole shoes (Fig 9): The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes; (i) they spread out the flux in the air gap uniformly and also, being of a larger cross-section, reduce the reluctance of the magnetic path, and (ii) they also support the field coils.

Fig 5



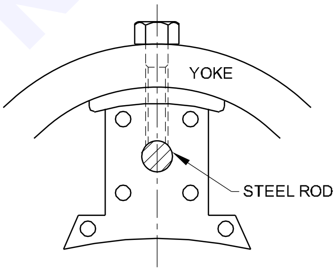
PARTS OF A DC MACHINE

Fig 6



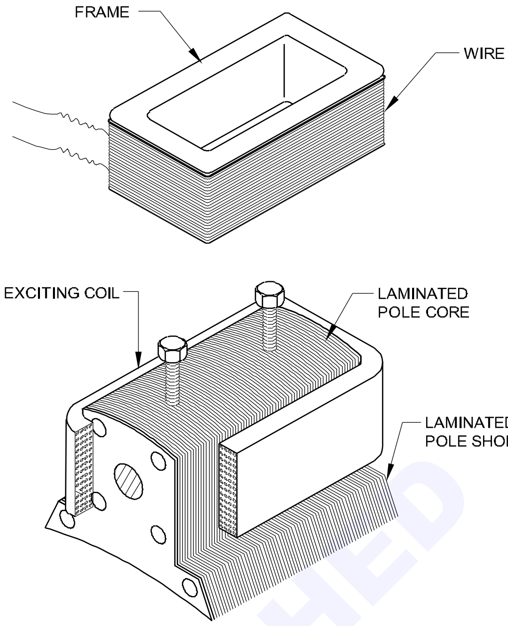
LAMINATED POLE CORE

Fig 7



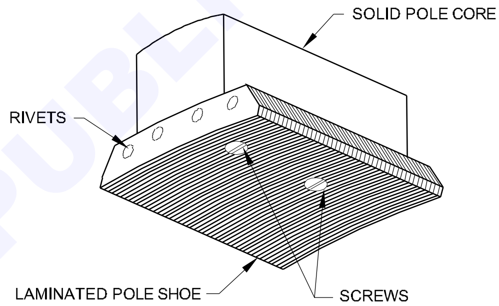
HOLDING SCREW BOLTED IN TO STEEL BAR POLE CORE ASSEMBLY

Fig 8



POLE ASSEMBLY

Fig 9



SEPERATE POLE SHOE BOLTED TO POLE CORE

Pole coils (Field coils): The field coils or pole coils, which consist of copper wire or strip are former-wound for the correct dimension. Then the former is removed and the wound coils are put into place over the core as shown in Fig 8.

When a current is passed through the coils, they magnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

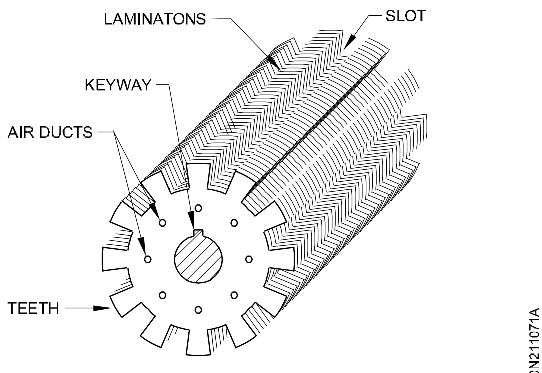
Both thick gauge wire winding (series) and thin gauge winding (shunt) are wound, one over the other with separate insulations, and the terminals are brought out separately.

Armature core: The armature core houses the armature conductors and rotate in the magnetic field so as to make the conductors to cut the magnetic flux. In addition to this, its most important function is to provide a path of very low reluctance to the field flux, thereby allowing the magnetic circuit to complete through the yoke and the poles.

The armature core is cylindrical or drum-shaped as shown in Fig 10, and build up of circular sheet steel discs or laminations approximately 0.5mm thick as shown in Fig 11.

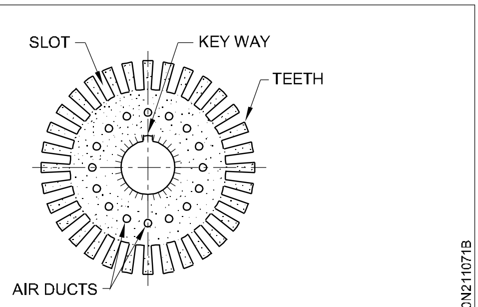
Armature windings: The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape with a coil puller.

Fig 10



ARMATURE CORE MADE OF LAMINATION

Fig 11

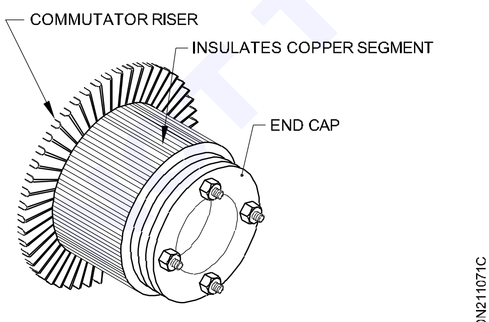


ARMATURE CORE LAMINATIONS

Commutator: The function of the commutator is to facilitate collection of current from the armature conductors. It rectifies i.e. converts the alternating current induced in the armature conductors into uni-directional current for the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity, hard-drawn or drop-forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils.

Each commutator segment is connected to the armature conductor by means of a copper lug or riser, whose general appearance when assembled is shown in Fig 12.

Fig 12

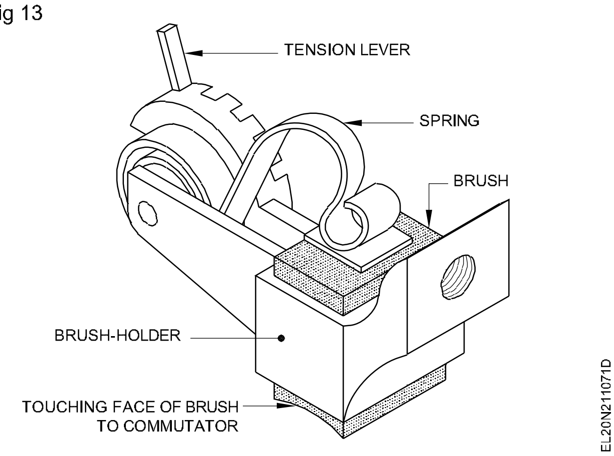


COMPLETE ASSEMBLY OF COMMUTATOR

Brushes: The brushes whose function is to collect current from the commutator are usually made of carbon and graphite and are in the shape of a rectangular block.

These brushes are housed in brush-holders, shown in Fig 13, which have a box-holder for the brush, a spring to maintain the brush tension and a hole to fix the holder to the rocker arm.

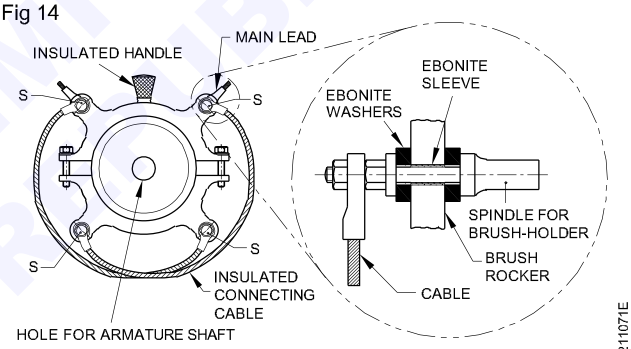
Fig 13



Brush-rocker: The spindle is used to have a number of brushes connected in a large machine. There may be only two brushes for a small machine. All the spindles are insulated and attached to the brush rocker.

The brush-rocker may either be supported by a bearing cover in a small machine or by brackets attached to the yoke as shown in Fig 14. The brush position to the neutral axis can be set by changing the position of the brush-rocker.

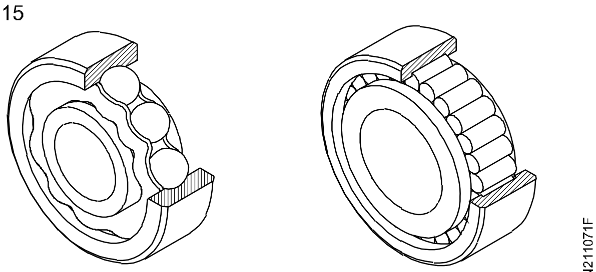
Fig 14



BRUSH-HOLDER S-SPINDLE FOR BRUSH-HOLDER

Bearings (Fig 15): Because of their reliability ball bearings are frequently employed, though for heavy duties roller bearings are preferable.

Fig 15



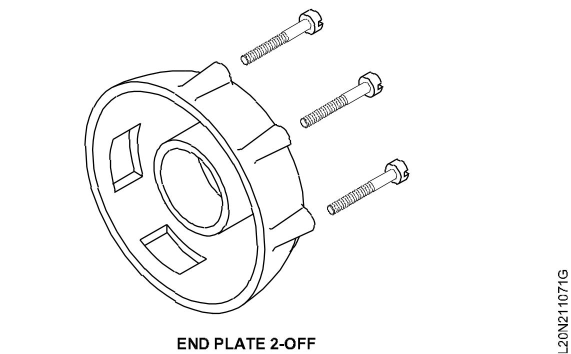
BALL BEARING ROLLER BEARING

End plates (Fig 16): The bearings are housed in these end plates, and they are fixed to the yoke. They help the armature for frictionless rotation and to position the armature in the air gap of the field poles.

Cooling fan

DC Machines are often selected based upon a particular work or load requirement. In most cases, heat dissipation is achieved through a cooling fan fitted on the DC Machine shaft. Another method to remove heat from DC machine is by providing forced air cooling.

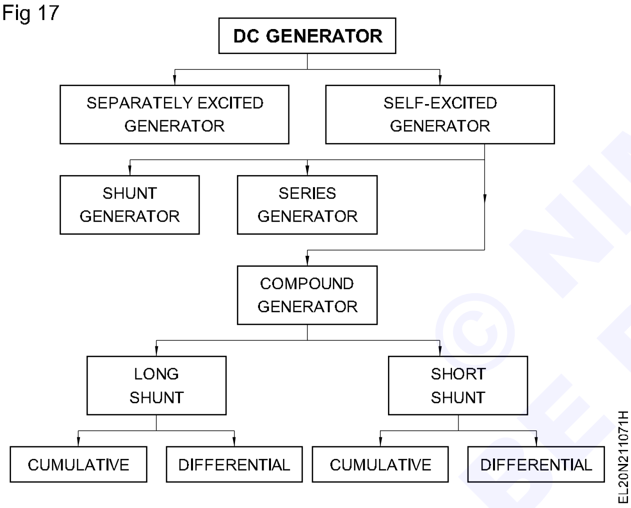
Fig 16



END PLATE 2-OFF

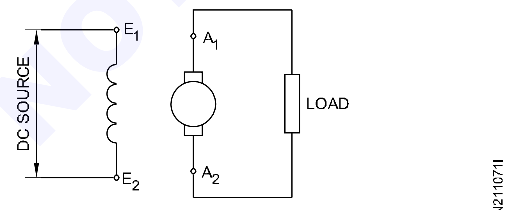
Types of DC generators: The type of a DC generator is determined by the manner in which the field excitation is provided. In general, the methods employed to connect the field and armature windings, fall into the following groups.(Fig 17)

Fig 17



Separately excited generator: The field excitation for a separately excited generator, shown in Fig 18, is supplied from an independent source, such as storage battery, separate DC generator or rectified DC supply from an AC source.

Fig 18



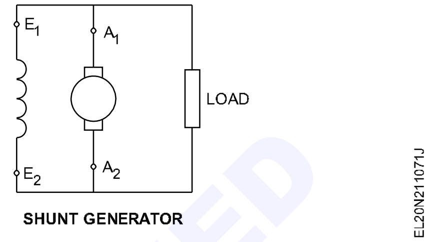
CONNECTION DIAGRAM OF SEPARATELY EXCITED DC GENERATOR

The field excitation voltage may be the same as that of generated (armature) voltage or may differ. Generally, the excitation voltage will be of low voltage, say 24, 36 or 48V DC.

Self-excited generator: The field excitation is provided by its own armature. In this type of generators, initially the voltage is built up by residual magnetism retained in the field poles. Self-excited generators may be further classified as shunt, series and compound generators.

Shunt generator: The field winding is connected to the armature terminals as shown in Fig 19. (i.e. shunt field winding is connected in parallel with armature winding). The shunt field contains many turns of relatively fine wire and carries a comparatively small current only which is a small percentage of the rated current of the generator.

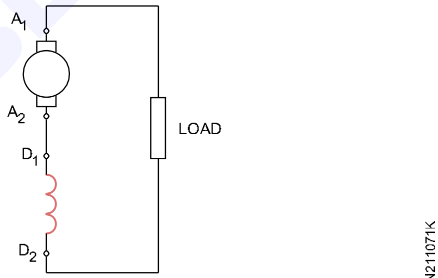
Fig 19



SHUNT GENERATOR

Series generator: The field winding is connected in series with the armature winding as shown in Fig 20. The series field winding has a few turns of heavy wire. Since it is in series with the armature it carries the load current.

Fig 20

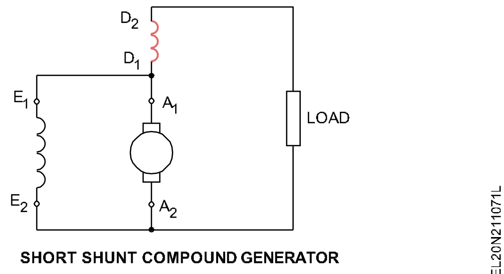


SERIES GENERATOR

Compound generator: The field excitation is provided by a combination of shunt and series field windings.

Short-shunt compound generator: This is a generator in which the shunt field is directly across the armature as shown in Fig 21.

Fig 21

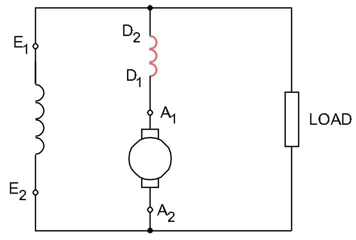


SHORT SHUNT COMPOUND GENERATOR

Long-shunt compound generator: This is a generator in which the shunt field is connected after the series field as shown in Fig 22.

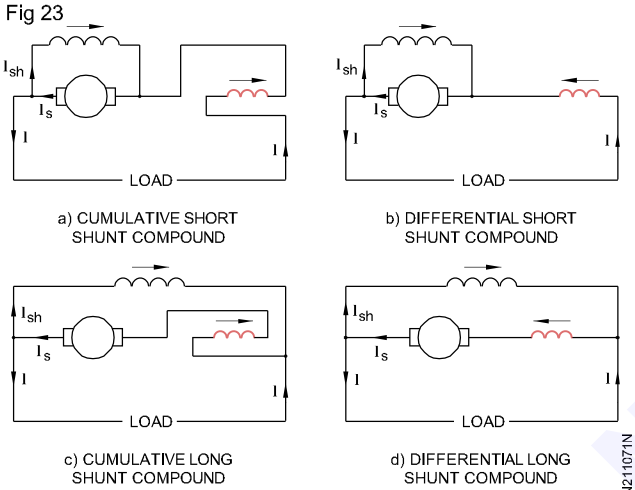
Differential and cumulative compound generator: The compound generators can also be further classified as cumulative and differential. In cumulative compound generators the magnetising forces of the shunt and the series field ampere-turns are cumulative, i.e. they both tend to set up flux in the air gap in the same direction. However, in case the ampere turns of the shunt winding oppose those of the series winding, the machine is said to be differentially compound wound generator. Both the types are shown in Fig 23.

Fig 22



LONG SHUNT COMPOUND GENERATOR

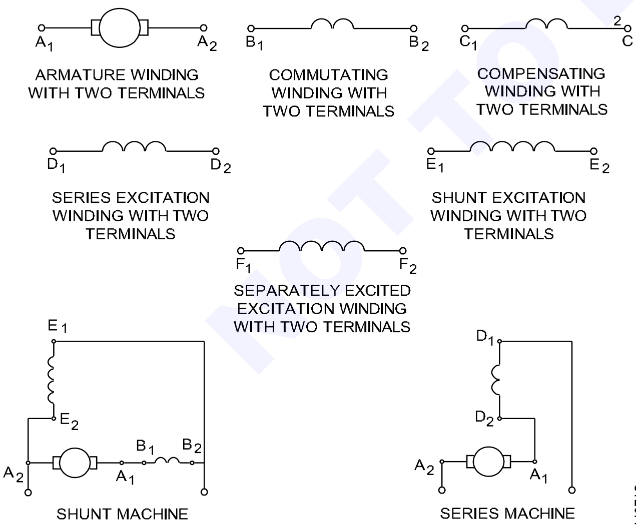
Fig 23



TYPES OF DC COMPOUND GENERATORS

Terminal markings : As per BIS 4718-1975 the terminal markings for DC commutator machines shall be according to the marking principles (Fig 24).

Fig 24



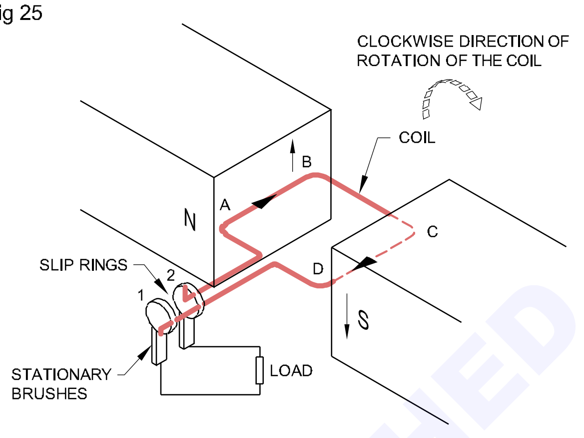
TERMINAL MARKING OF DC MACHINES AS PER BIS

Commutator (Split rings)

A generator produces electrical power with the help of the rotation of a group of conductors in a magnetic field. It uses the principle of electromagnetic induction to convert the input mechanical power into electrical power.

Slip rings: Let us consider a simple AC generator having a single loop of wire and rotated within a fixed magnetic field, as shown in Fig 25.

Fig 25



SIMPLE AC GENERATOR

Let each end of the single loop coil be connected to copper or brass rings called slip rings. These slip-rings are insulated from each other, insulated and mounted on the shaft. In a broader sense this rotating assembly (coil, shaft & slip-ring) is called armature. The wire loop (armature coil) is connected to an external circuit by means of two brushes which are positioned to rub against the slip-rings. As the armature is rotated at a uniform angular velocity, the generated voltage in the loop conductor will actually be of alternating voltage.

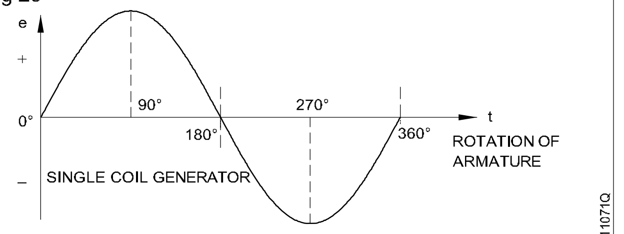
For the clockwise rotation indicated, the direction of generated voltage and the resulting current in the coil side under the north pole will be directed from A to B making the slip-ring 2 negative. This is readily confirmed by using Fleming's right hand rule. Similarly the direction of the induced voltage and the resulting current under the south pole is to be directed from C to D making the slip- ring 1 as positive. When the conductor AB moves from the north pole to the south pole, the direction of induced emf in it will reverse, so that the current will now flow from B to A making the slip-ring 2 positive. At the same time coil side CD has moved into the north pole region and its induced emf is reversed and current will flow from D to C making the slip-ring 1 negative.

Thus for one half of a revolution (for a two-pole generator) the emf is directed around the coils A to B & C to D. For the other half of the revolution the emf is directed around the coil D to C and B to A. The current in the externally connected load resistor via the stationary brushes in contact with the pair of slip rings `1'and `2' will be alternating (AC) in nature.

Wave-shape of the induced voltage: When the output voltage is plotted against Power degrees we get the output wave-form.

The output wave-form obtained across the load, shown in Fig 26, will not be of sinusoidal shape due to un-uniform magnetic field.

Fig 26



WAVE-FORM SHOWS COIL ROTATES UNDER UNIFORM MAGNETIC FIELD (SINE WAVE)

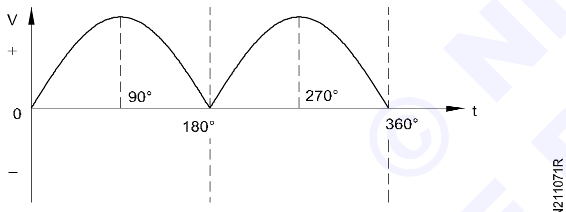
The output wave-form will be of sinusoidal shape as shown in Fig 26.

Simple generator with split-rings: A direct current generator is simply an AC generator provided with split rings instead of slip-rings.

The split ring is a ring made up of hard drawn copper cut into two segments, insulated from each other and the shaft in which it is mounted. A commercial generator uses a number of split rings called commutators. The split ring is a device for reversing the brush contact with the armature coil terminals, every time the induced current in the coil reverses, so that the output current taken by the brushes remains always in the same direction.

Fig 27 represents the generated voltage of a simple DC generator. The voltage is uni-directional due to the split ring action.

Fig 27



VOLTAGE PRODUCED IN A LOOP UNDER UNIFORM MAGNETIC FIELD

The induced emf by a single loop (one turn) coil is very small in magnitude and pulsating in nature as shown in Fig 27. Coils, having a number of turns in series, multiply the generated emf by the same number. However to get a steady (DC) current it is necessary to increase the pulses produced in the armature; thereby their average value is constant.

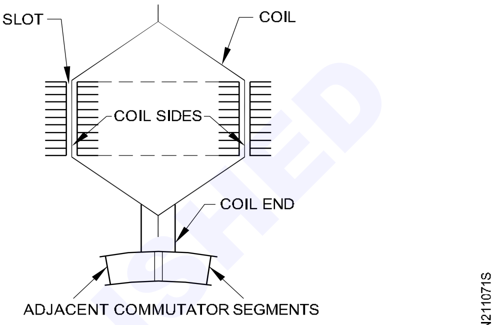
There are two ways to increase the number of pulses during each rotation of the armature.

- Increase the number of field poles.
- Increase the number of separate coils (multi-coil) in the armature.

The multi-coils necessitate a multiple segment split-rings which is called a commutator.

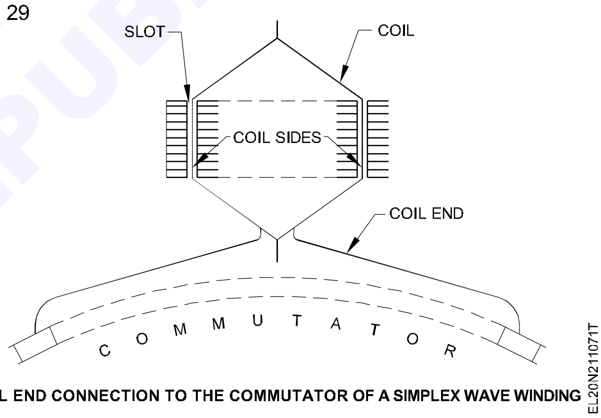
Armature windings (Fig 28 Lap winding, Fig 29 wave winding): We have seen earlier, when a single loop conductor is rotated through a magnetic field, an alternating voltage is induced in it. This alternating voltage can be changed into direct voltage (rectified) by the commutator. In practice, there are several coils in the armature, each with a large number of turns laid in the slots of the armature core. This arrangement of the coil is called armature winding. The ends of the coils are soldered to the commutator raisers, depending on the kind of winding i.e. lap or wave, which decides the number of parallel paths in the armature.

Fig 28



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX LAP WINDING

Fig 29



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX WAVE WINDING

i.e. lap or wave, which decides the numbers of parallel paths in the armature.

A preliminary knowledge about the different types of winding is essential to tackle problems related to the calculation of induced voltage in various types of generators.

Lap and wave windings could readily be identified by the manner in which the coil ends are connected to the commutator bars. As shown in Fig 28, in a simplex lap winding, the ends of a coil are connected to adjacent commutator segments. Fig 29 shows the simplex wave winding in which the coil ends are connected to the commutator segments almost equal to the distance between poles of the same polarity.

Table 1 shows the main differences between lap and wave winding.

Table 1

Lap winding	Wave winding
The two ends of each armature coil are connected to adjacent commutator segments in the case of simplex, two segments apart in duplex and three segments apart in triplex.	The two ends of each coil connect to the commutator segments placed between adjacent poles of the same polarity.
There are many parallel paths for current as there are field poles in the case of lap winding	There are two parallel paths regardless of the number of field poles in the case of simplex wave winding.
No. of parallel paths = Number of poles x plex of the winding	Number of parallel paths in wave windings = 2 x plex of the winding where plex for-simplex is 1, duplex is 2 and triplex is 3.
The number of brush positions is equal to the number of poles.	Only two brush positions are required regardless of the number of field poles.
Used for machines having low voltage and high current capacity.	Used in machines having low current and high voltage capacity.

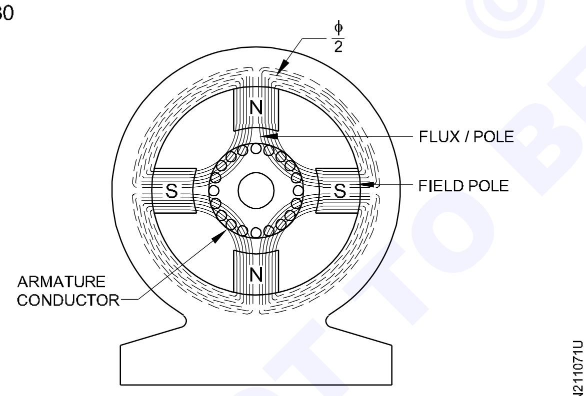
EMF equation of DC generator

When the armature of a DC generator, containing a number of conductors in the form of a winding, rotates at a specific speed in the magnetic field, emf is induced in the armature winding and is available across the brushes. The equation and the numerical problems given as examples will help an electrician to better his understanding about the construction of a DC machine.

Induced emf in a DC generator can be calculated as explained below.

Figure 30 is given for your reference.

Fig 30



4 - POLE DC GENERATOR

Let Ø = flux/pole in weber

Z = total number of armature conductors = No. of slots X No. of conductors/slot

P = No. of poles in the generator

A = No. of parallel paths in armature

N = armature revolution per minute (r.p.m.)

E = emf induced in the generator.

Average emf generated per conductor in one revolution = Rate of change of flux (Faraday's Laws of Electromagnetic induction)

$$\frac{dØ}{dt} \text{ volt (since } N = 1)$$

Now, flux cut/conductor in one revolution, (dØ) = PØ Wb

No. of revolutions/second = N/60

Time for one revolution, (dt) = 60/N second

According to Faraday's Laws of Electromagnetic Induction, we have emf generated/conductor/second

$$= \frac{dØ}{dt} = \frac{PØN}{60} \text{ volts}$$

emf generated in `Z' conductors in the armature assuming they are all in series $= \frac{PØZN}{60}$ volts.

The emf generated in the armature of the DC generator when there are

`A' parallel paths in the armature

Could be written as $= \frac{ØZN}{60} \times \frac{P}{A}$ volts.

A = 2 - for simplex wave winding

= P - for simplex lap winding.

Example: A four-pole generator, having a simplex wave-wound armature has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine, when driven at 1500 r.p.m assuming the flux per pole to be 7.0 mWb?

Solution: $E = \frac{ØZN}{60} \times \frac{P}{A}$ volts.

Here, Ø= 7x 10^{-3} Wb, Z = 51 x 20 = 1020, P=4, N = 1500 r.p.m.

A = 2 as the winding is simplex wave.

$$E = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60} \times \frac{4}{2} = 357V.$$

An 8-pole DC generator has 960 armature conductors and a flux per pole of 20mWb running at 500 r.p.m. Calculate the emf generated when the armature is connected as (i) a simplex lap-winding, (ii) a simplex wave winding.

Solution

i Simplex lap winding

$$E = \frac{\varnothing ZN}{60} x \frac{P}{A}$$

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{8} = 160V.$$

ii Simplex wave winding

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{2} = 640V.$$

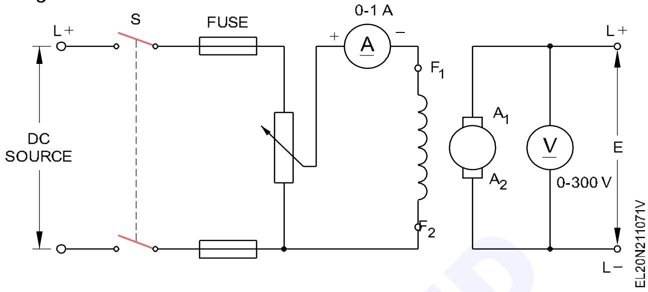
Separately excited DC generator

Introduction : A DC generator is the most commonly used separately excited generator, used for electroplating and battery charging. A separately excited generator is one in which the magnetic field is excited from an external DC source. The DC source may be a DC generator or a battery or a metal rectifier connected to an AC supply.

Generally a potential divider is connected across the DC source, and the required DC voltage is supplied to the field as shown in Fig 31.

An ammeter is connected in the field circuit to measure the field current. The shaft of the generator is coupled to a prime mover.

Fig 31



Advantages of a separately excited generator

The terminal voltage remains almost stable when compared to the self-excited generators because the field circuit is independent of the induced voltage.

As the field is independent, the $I_a R_a$ drop in the armature will not affect the field flux.

This generator can be used where a wide range of terminal voltage is required.

Disadvantage

1 The disadvantage of a separately excited generator is the inconvenience of providing a separate DC source for excitation.

2 Besides it is expensive.

Table 2

Reasons	Remedies
A break or opening in the armature or field circuit.	Test the field and armature circuits for open circuit. Locate the fault and rectify.
A short circuit in the armature or field.	Test the field and armature for short circuit. Locate the fault and rectify.
Loose brush connections or loose brush contact.	Tighten the brush connections. Check up the brush tension. Adjust, if necessary. If the brushes are worn out, replace them.
A dirty or severely pitted commutator.	Clean the commutator for dirt, dust and greasy material. Use trichloroethylene. If the segments are pitted, dress them up.
The speed is too low.	Increase the speed of the generator to its rated speed.
The DC supply for excitation is absent.	Check the DC supply across the field winding terminals. If the supply is not there, check the supply source and rectify the fault Where AC main supply is converted as DC supply through rectifiers, the fault may be located in the rectifier circuit.

Building up voltage of a DC shunt generator

Objectives: At the end of this lesson you shall be able to
- **explain the conditions and method of building up of voltage in a DC shunt generator**
- **explain the method of creating residual magnetism in the poles of a DC generator**
- **determine the magnetization characteristic of a DC shunt generator.**

Condition for a self-excited DC generator to build up voltage: For a self-excited DC generator to build up voltage, the following conditions should be fulfilled, assuming the generator is in sound condition.

- There must be residual magnetism in the field cores.
- The field resistance should be below the field critical resistance value.
- The generator should run at the rated speed.
- There must be a proper relation between the direction of rotation and the direction of field current. It could be explained as stated below.

The polarity of the induced voltage must be in such a direction as to produce the field current to assist the residual magnetism.

The polarity of the induced emf depends upon the direction of rotation and the polarity of the field poles depends upon the field current direction.

Even after fulfilling the above conditions, if the self-excited DC shunt generator fails to build up voltage, there may be other reasons as listed in Table 1.

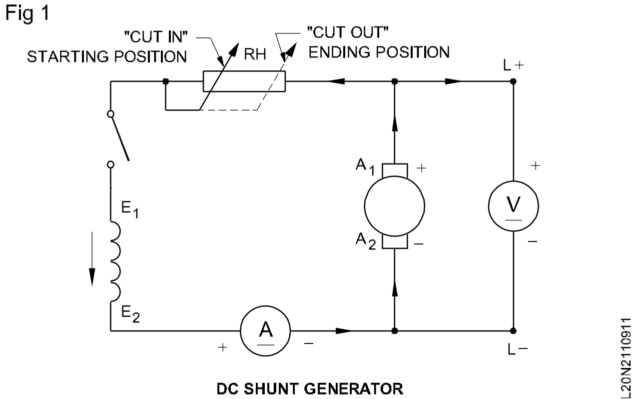
Table 1

Sl.No.	Causes	Reasons	Remedies
1	A break or opening in the field or armature circuit.	Break or loose connection in the field or in the armature winding/circuit.	Locate the open circuit and rectify.
		High resistance in the field circuit beyond the field critical resistance value.	Reduce the resistance of the field regulator.
2	Loose brush connections or contacts.	Improper brush contact/loose brush connections.	Check the brushes for excessive wear, and replace them, if necessary. Check the commutator for pitting. If necessary, turn down the commutator. Always clean the commutator when poor brush contact is discovered. Check the brush tension and readjust it, if necessary Tighten any loose connections.
3	A dirty or severely pitted commutator.	Severe sparking due to overload.	In this case, follow the same procedure as outlined above.
4	A short circuit in the armature or field	Overload or excess heating.	Do a resistance check, ascertain, locate and remove the fault.

Method of building up voltage in a DC shunt generator: Fig 1 shows the circuit diagram for building up voltage in a DC shunt generator. When the generator is made to run at its rated speed initially, the voltmeter reads a small amount of voltage say, 4 to 10 volts. It is due to the residual magnetism. Since the field coils are connected across the armature terminals, this voltage causes a small amount of current to flow through the field coil. If the current flow in the field coils is in the correct direction, it will strengthen the residual magnetism and induce more voltage.

As such, the generated voltage will rise marginally. This rise in voltage, in turn, will further strengthen the increasing field current and induce more voltage. This rise in voltage, in turn, will further strengthen the increasing field current. This cumulative action will build up voltage until saturation is reached. After saturation, any increase in the field current will not increase the induced voltage. However, the whole procedure of building up of voltage takes a few seconds only.

Fig 1



DC SHUNT GENERATOR

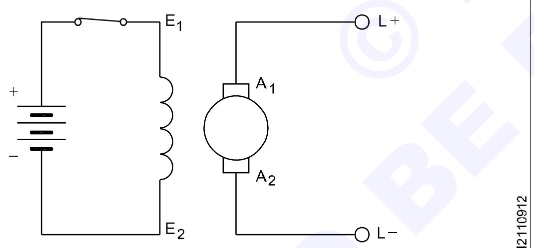
Method of creating residual magnetism: Without residual magnetism, a self-excited generator will not build up its voltage. A generator may lose its residual magnetism due to any one of the following reasons.

- The generator is kept idle for a long time.
- Heavy short circuit.
- Heavy overloading.
- The generator is subjected to too much heat.

When the generator loses its residual magnetism, it can be re-created as stated below.

Flashing of field: One of the methods to create residual magnetism is called the flashing of the `field'. This can be done by connecting the shunt field across a battery or any DC source for a few minutes as shown in Fig 2.

Fig 2

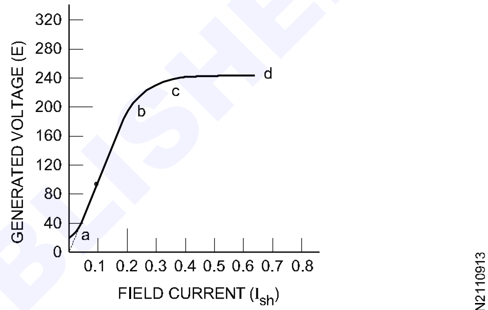


FLASHING OF THE FIELD

While flashing the field, the polarity of the magnetic field, now created, should be the same as that of the residual magnetic field it lost earlier.

Magnetisation characteristic of a DC shunt generator: The magnetisation characteristic curve shown in Fig 3 gives the relation between the field current and the induced voltage. Referring to the emf equation, the induced emf in a generator is proportional to the flux per pole and the revolutions per minute of the generator. At a constant speed, the generated emf becomes directly proportional to the field flux. In a given machine, the flux depends upon the field current. The graph (Fig 3) illustrates this feature. Because of the residual magnetism, the curved part below point `a' does not start at zero. Between the points `ab', the curve is in almost a straight line indicating that the voltage in the area is proportional to the field current.

Fig 3



MAGNETISATON CHARACTERISTIC OF A DC SHUNT GENERATOR

Power Electrician - DC Generator | **Related Theory for Exercise 2.1.110**

Test a DC machine for continuity and insulation resistance

Objectives: At the end of this lesson you shall be able to
- **state the necessity of measuring the insulation resistance of an electrical machine**
- **state the required conditions for the tests**
- **state the reasons for the low value of insulation resistance in the machines**
- **state the method of improving the insulation resistance of DC machines.**

Necessity of measuring insulation resistance: The most important aspect in the maintenance of DC machines is taking care of the insulation. Power insulation of DC machine windings is designed for the satisfactory operation at the specified voltage, temperature and to retain the Power and mechanical strength and the dimensional stability over many years of operation. The insulation resistance of DC machines in service should be checked periodically,

A common device for measuring insulation resistance is a direct indicating insulation tester or Megger. The measurements are made at voltages 500/1000 volt DC depending upon the voltage rating of the machine.

Measurement of insulation resistance: Insulation resistance shall be measured between the winding and frame (earth), and between windings.

For low and medium voltage rated machines, the insulation resistance, when the high voltage test is applied, shall not be less than one megohm as per B.I.S. 9320 - 1979. The insulation resistance shall be measured with a DC voltage of about 500 V applied for a sufficient time for the reading of the indicator to become practically steady, such voltage being taken from an independent source or generated in the measuring instrument.

> **When it is required to dry out windings at site to obtain the minimum value of insulation resistance, it is recommended that the procedure for drying out as specified in IS:900-1965 may be followed.**

Reasons for low value insulation resistance: The low value of insulation resistance in DC machines is due to excess heat developed in the winding due to their routine working with full load condition or overloading at times or frequent starting with loads. In addition to this, high ambient temperatures are also the reason for low insulation resistance.

Method of improving insulation resistance: On identifying the weak insulation resistance, during the course of preventive maintenance observation in a DC machine, it is necessary to improve the insulation resistance to restore it to a safe value.

Improvement of insulation resistance could be done by any one of the following methods after cleaning the dust and dirt from the machinery.

- By blowing hot air through the machines.
- By heating the machine with carbon filament or incandescent lamps.
- By dismantling and varnishing the winding of the machine.

Table 1

Insulation resistance test

Date	Time	Weather condition	Duty cycle	Test between terminals	Insulation resistance	Remarks

Power Electrician - DC Generator | **Related Theory for Exercise 2.1.111**

Start, run and reverse direction of DC motor

For this Exercise refer Ex.No. 2.2.116 - 119

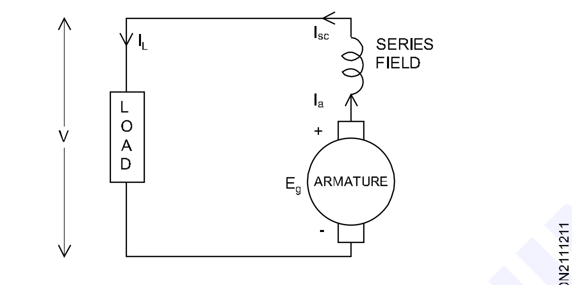
Characteristics of DC generator

Objectives: At the end of this lesson you shall be able to
- **explain the characteristics of DC series generator**
- **explain the characteristics of DC shunt generator**
- **explain the characteristics of DC compound generator**
- **explain the operation of paralleling of DC shunt generators**
- **explain the effect of armature reaction and remedies**
- **explain losses and efficiency of DC generators**
- **explain the routine and maintenance of DC generator.**

Characteristics of series generator:

In these types of generators the field windings, armature windings and external load circuit all are connected in series as shown in Figure 1.

Fig 1



SERIES WOUND GENERATOR

Therefore, the same current flows through armature winding, field winding and the load. Let, $I = I_a = I_{sc} = I_L$ Here, I_a = armature current I_{sc} = series field current I_L = load current There are generally three most important characteristics of series wound DC generator which show the relation between various quantities such as series field current or excitation current, generated voltage, terminal voltage and load current.

Magnetic or open circuit characteristic of series wound DC generator

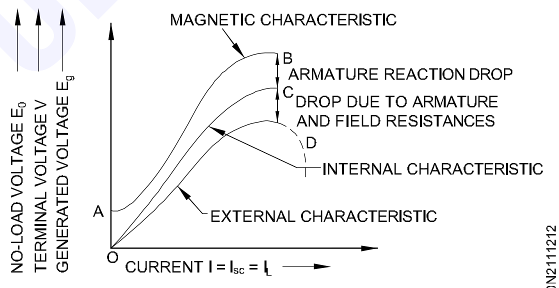
The curve which shows the relation between no load voltage and the field excitation current is called magnetic or open circuit characteristic curve. As during no load, the load terminals are open circuited, there will be no field current in the field since, the armature, field and load are series connected and these three make a closed loop of circuit. So, this curve can be obtained practically by separating the field winding and exciting the DC generator by an external source.

Here in the diagram below AB curve is showing the magnetic characteristic of series wound DC generator. The linearity of the curve will continue till the saturation of the poles. After that there will be no further significant change of terminal voltage of DC generator for increasing field current. Due to residual magnetism there will be a small initial voltage across the armature that is why the curve started from a point A which is a little above the origin O.

Internal characteristic of series wound DC generator

The internal characteristic curve gives the relation between voltage generated in the armature and the load current. This curve is obtained by subtracting the drop due to the demagnetizing effect of armature reaction from the no load voltage. So, the actual generated voltage (E_g) will be less than the no load voltage (E_0). That is why the curve is slightly dropping from the open circuit characteristic curve. Here in the diagram below OC curve is showing the internal characteristic or total characteristic of the series wound DC generator. (Fig 2)

Fig 2



CHARACTERISTIC CURVES OF SERIES WOUND DC GENERATORS

External characteristic of series wound DC generator

The external characteristic curve shows the variation of terminal voltage (V) with the load current (I_L). Terminal voltage of this type of generator is obtained by subtracting ohmic drop due to armature resistance (R_a) and series field resistance (R_{se}) from the actually generated voltage (E_g). Terminal voltage $V = E_g - I (R_a + R_{se})$ The external characteristic curve lies below the internal characteristic curve because the value of terminal voltage is less than the generated voltage. Here in the Figure 2 OD curve is showing the external characteristic of the series wound DC generator.

The external/load characteristic of a shunt generator: The external/load characteristic is important for judging the suitability of a generator for a particular purpose. When the DC shunt generator is loaded, it is found that the terminal voltage drops with increase in the load current. In a shunt generator, the field current appears to be constant, and, hence, `V' also should remain constant and be independent of the load. But, it is not so practically. There are two main reasons for the drop in terminal voltage. They are :

- armature resistance drop (directly)
- armature reaction drop (indirectly).

Because of the above two reasons, the terminal voltage is reduced. This in turn affects the field current also. The decreased field current reduces the field flux which further reduces the induced emf.

Armature resistance drop: According to formula

Terminal voltage = Induced emf – armature voltage drop

$V = E - I_a R_a$

where I_a is the armature current

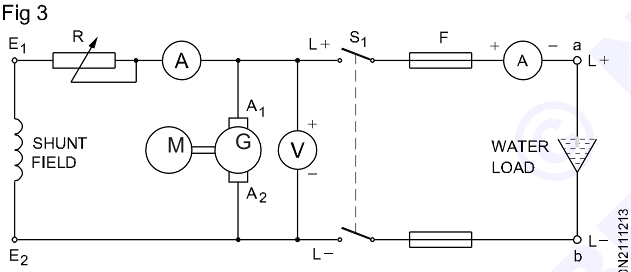
and R_a is the armature circuit resistance.

As such, when the load current is increased, more voltage is dropped in the armature circuit. Hence, the terminal voltage `V' decreases, under load condition.

Armature reaction drop: Due to the demagnetising effect of armature reaction, the main pole flux is weakened, and the induced emf (E) will be reduced in its magnitude.

The external characteristic gives the relation between terminal voltage and load current. Fig 3 gives the circuit diagram to determine this characteristic. The generator is first built up to its rated voltage. Then it is loaded in suitable steps up to full load. The terminal voltage and the corresponding load currents are noted for each step.

Fig 3

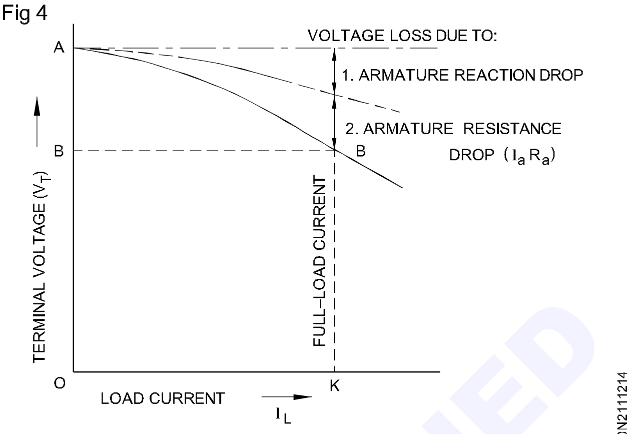


DC SHUNT GENERATOR

In this experiment, the field current has to be kept constant. This is due to the fact that when terminal potential decreases on load, the field which is connected across the armature will have a decreased current. This effect, if allowed, will reduce the field flux, thereby, decreasing the induced voltage. This effect cumulatively reduces the terminal voltage further. From the obtained values of the terminal voltage V_T and load current I_L, the external characteristic curve is plotted as shown in Fig 4, keeping in V_T on `Y' axis and I_L on X axis. From the curve it will be observed that the no-load voltage OA is maximum, and it falls to OB when loaded, to indicate that the full load current value is OK as noted in the name-plate of the generator.

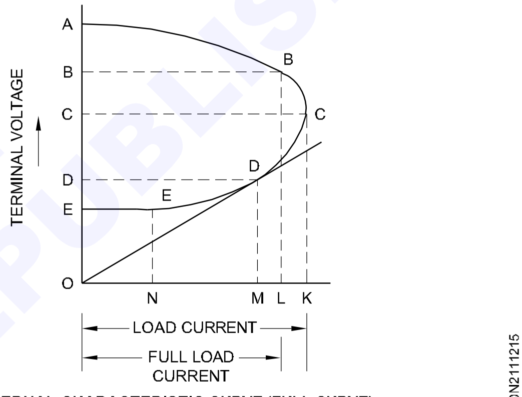
Fall of voltage from no load to full load, which is due to armature reaction, and the armature voltage drop are found to be not appreciable. Normally the generators are designed to deliver full load current I_L, and the fall of voltage will be about 5 to 8 percent of the no-load voltage which can be regarded as negligible. If the load current is further increased by decreasing the load resistance, the curve reaches a point `C' as shown in Fig 5. At this point, the terminal voltage falls to OC which will be an appreciable fall when compared to the no-load terminal voltage. At this point `C', though the load current is maximum (OK), the terminal voltage will be much less than the no-load voltage.

Fig 4



EXTERNAL CHARACTERISTIC CURVE OF DC SHUNT GENERATOR

Fig 5



EXTERNAL CHARACTERISTIC CURVE (FULL CURVE)

However, when the load resistance is further decreased the load current decreases to OM and V_T is reduced to `OD', that means the load current cannot be increased beyond OK and the point `C' is called the breakdown point. It is the maximum possible current that a generator can supply. Beyond this point `C', the curve drops rapidly with decrease in the load resistance, indicating that the load current is also decreasing, instead of increasing. At point `E' the generator is virtually short-circuited, and all the voltage induced is dropped to near zero due to IaRa drop and armature reaction. Rather, we can say OE is the residual voltage of the generator. Practically all the generators operate only on the portion `AB' of the curve where the efficiency of the generator is maximum.

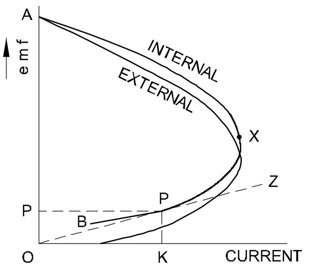
Internal characteristic: The internal characteristic gives the relation between induced voltage and the armature current. In a shunt generator,

$I_a = I_L + I_{sh} \qquad E = V_T + I_a R_a$

$$I_{sh} = \frac{V_T}{R_{sh}}$$

Load critical resistance: It is defined as the minimum value of load resistance with which the generator builds up voltage, and, just below this value of load resistance the DC shunt generator will fail to build up its voltage when started with the load. When the DC shunt generator is started with the load, the terminal voltage may not raise beyond about 10V, the reason is the load resistance is so low, as if the generator is short-circuited. In Fig 6 the tangent line `OZ' to the internal characteristic APB is drawn. Its slope will give the value of the load critical resistance. As the DC shunt generator will not build up emf when made to build up with load below this value of resistance, it is called the load critical resistance.

Fig 6



INTERNAL & EXTERNAL CHARACTERISTIC CURVE

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Load critical resistance in ohms =

$$\frac{\text{Voltage at point 'P'}}{\text{Load current at point 'P' (amps)}} = \frac{OP}{OK}$$

There are thus two critical resistances for a shunt generator, one for the field circuit and the other for the load external circuit.

Applications of DC shunt generator: According to the load characteristic of the DC shunt generator, the drop in voltage from no load to full load is not appreciable, up to its rated value of load current. Hence, it can be called a constant voltage generator. Therefore, it can be used for constant loads like:

- centrifugal pump
- lighting load
- fans
- battery charging and electroplating.

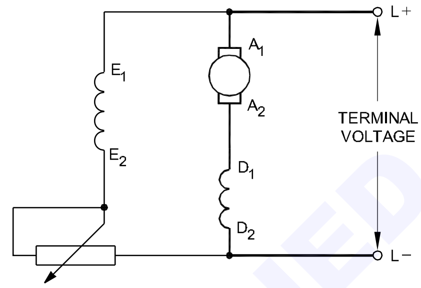
Compound generator: Combination of shunt field and series field within one generator provides two sources of excitation, and such a generator is called a compound generator.

Long shunt compound generator: When the shunt field is connected in parallel with the series combination of the armature and the series field, the generator is said to be connected as a long shunt compound generator which is shown in Fig 7.

Short shunt compound generator: When the shunt field is connected in parallel with only the armature, the generator is said to be connected as a short shunt compound generator which is shown in Fig 8.

Cumulative compound generator: The shunt field excitation flux is usually more or less steady, and is affected only slightly as the terminal voltage fluctuates. The flux of the series field is quite variable because its ampere-turns depend upon the load current. When the load current is zero, it produces less flux (long shunt) or no flux (short shunt) and when the load current is high, it creates a good amount of flux. How much flux it must develop depends upon the extent to which it must compensate for the voltage drop. In a compound machine, the series field is wound directly over the shunt field with proper separation by insulations.

Fig 7



LONG SHUNT COMPOUND GENERATOR

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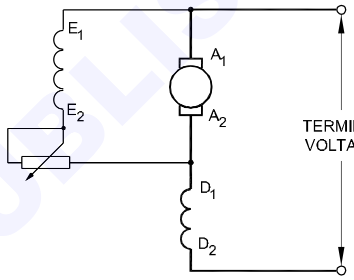
Fig 8



SHORT SHUNT COMPOUND GENERATOR

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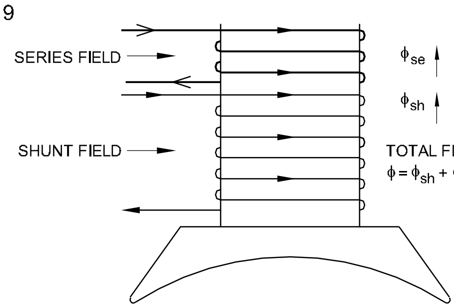
The series field coils may be connected to `assist' or `aid' the shunt field, as shown in Fig 9. Then this machine is said to be a cumulative (increasing by successive additions) compound generator. The ampere turns of the series field determines the amount of compounding.

Fig 9



CUMULATIVE COMPOUNDING

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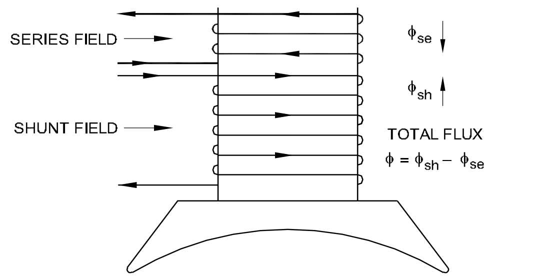
Differentially compounded generator: If the flux produced by the series field opposes the shunt field flux as shown in Fig 10, then the action is called `bucking' and the machine is said to be a differential (decreasing by successive subtractions) compound generator.

External characteristics of DC compound generator

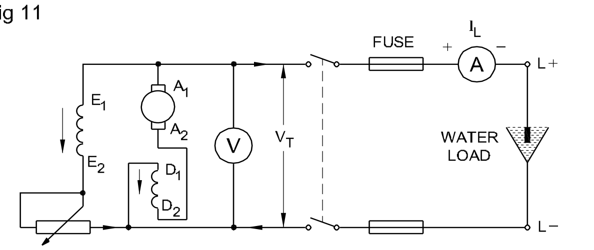
Cumulative compound generator: Fig 11 shows the connection diagram for a long shunt cumulative compound generator. In such a connection, the series field aids the shunt field and the total flux is equal to the sum of both the fluxes. By taking a set of readings for different load currents I_L and the corresponding terminal voltage V_T, we can draw a graph showing the relation between V_T and I_L. This curve is called the external characteristic curve. (Fig 12)

Fig 10



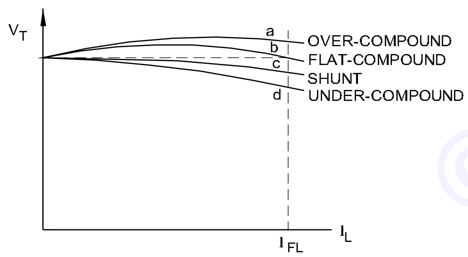
DIFFERENTIAL COMPOUNDING

Fig 11



LONG SHUNT CUMULATIVE COMPOUND GENERATOR CONNECTION DIAGRAM

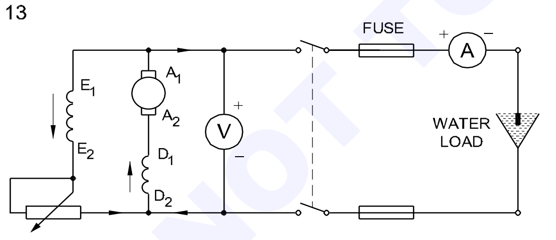
Fig 12



EXTERNAL CHARACTERISTICS OF COMULATIVE COMPOUND DC GENERATORS

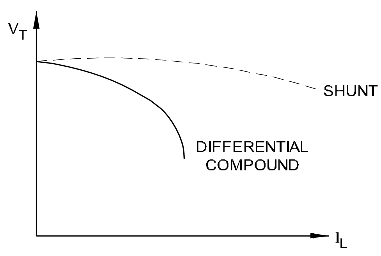
Differential compound generator: If the series field terminals are interchanged as shown in Fig 13, then the curve obtained may be as shown in Fig 14.

Fig 13



CUMULATIVE COMPOUND GENERATOR CIRCUIT

Fig 14



EXTERNAL CHARACTERISTIC OF DIFFERENTIAL COMPOUND DC GENERATOR

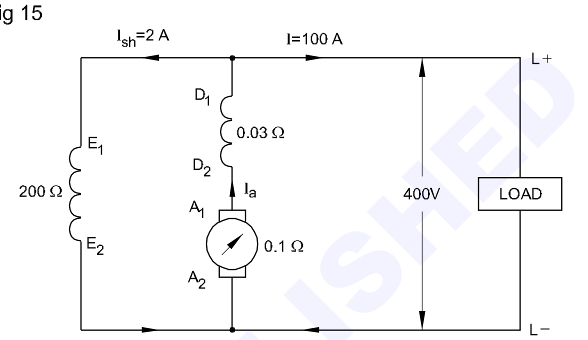
Application of a compound generator: Table 1 gives the different types of compound generators and their application in industry.

Example: A long-shunt compound generator delivers a load current of 100 A at 400 V, and has armature, series field and shunt field resistances of 0.1 ohm, 0.03 ohm and 200 ohm respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.

Solution

Generator circuit is shown in Fig 15.

Fig 15



I_{sh} = 400/200 = 2 A

Current through armature and series winding is the same. Hence $I_a = I_{se}$ = 100 + 2 = 102 A.

Voltage drop in series field winding= $I_{se}R_{se}$ =102 x 0.03 = 3.06 V

Armature voltage drop I_aR_a = 102 x 0.1 = 10.2 V.

Assuming 2 brushes,

drop at brushes = 2 x 1 = 2 V.

Now, $E_g = V + I_aR_a$ + series drop + brush drop

= 400 + 10.2 + 3.06 + 2 = 415.26 V

Parallel operation of DC generators

Parallel Operation of DC Generators: In a dc power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator.

The necessity of parallel operation

1 **Continuity of service:** If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down.

The supply can be obtained from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

2 **Efficiency:** Generators run most efficiently when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

3 **Maintenance and repair:** If generators are operated in parallel, the routine or emergency operations can be

performed by isolating the affected generator while load is being supplied by other units. This leads to both safety and economy.

4 **Increasing plant capacity:** When added capacity is required, the new unit can be simply paralleled with the old units to increase the plant capacity.

Table 1

Sl.No.	Type of compound generator	Uses
1	Cumulative compound generator	
	a. Over-compounded	Used where the load is at a considerable distance from the generator as in railways, street lights etc.
	b. Flat or level compound	Used where the load is nearby, such as lighting loads and power loads of small buildings or lathes which require constant voltage.
	c. Under-compounded	Used for electroplating, lighting, etc.
2	Differential compound generator	Used for arc welding generators.

Conditions for paralleling of DC Generators

1 Output voltage must be same

2 Polarities must be same

Connecting Shunt Generators in Parallel: The generators in a power plant are connected in parallel through bus-bars. The bus-bars are heavy thick copper bars and they act as +ve and -ve terminals. The positive terminals of the generators are .connected to the +ve side of bus-bars and negative terminals to the negative side of bus-bars. Fig. 22 shows shunt generator 1 connected to the bus-bars and supplying load. When the load on the power plant increases beyond the capacity of this generator, the second shunt generator 2 is connected in parallel with the first to meet the increased load demand.

Operation of paralleling of DC Generator

1 The prime mover of generator 2 is brought up to the rated speed. Now switch S_4 in the field circuit of the generator 2 is closed.

2 Next circuit breaker CB_2 is closed and the excitation of generator 2 is adjusted till it generates voltage equal to the bus-bars voltage. This is indicated by voltmeter V_2.

3 Now the generator 2 is ready to be paralleled with generator 1. The main switch S_3 is closed, thus putting generator 2 in parallel with generator 1. Note the generator 2 is not supplying any load because its generated emf is equal to bus-bars voltage. The generator is said to be "floating" (i.e. not supplying any load) on the bus-bars (Fig 16).

4 If generator 2 is to deliver any current then its generated voltage E should be greater than the bus-bars voltage V. In that case, current supplied by it I = (E-V)/Ra is the resistance of the armature circuit. By increasing the field current (and hence induced emf E), the generator 2 can be made to supply proper amount of load.

5 The load may be shifted from one shunt generator to another merely by adjusting the field excitation. Thus if generator 1 is to be shut down, the whole load can be shifted onto generator 2 provided it has the generator 1 to zero (This will be indicated by ammeter A_1) open CB_1 and then open the main switch S_1.

Load Sharing: The load may be shifted from one generator to another merely by adjusting the field excitation. The load sharing of two generators which have unequal no-load voltages. Let E_1, E_2 = no-load voltages of the two generators R_1, R_2 = their armature resistances

Thus current output of the generators depends upon the values of E_1 and E_2. These values may be changed by field rheostats. The common terminal voltage (or bus-bars voltage) will depend upon (i) the emfs of individual generators and (ii) the total load current supplied. It is generally desired to keep the busbars voltage constant. This can be achieved by adjusting the field excitations of the generators operating in parallel.

Armature reaction

When armature conductors carry a lower load current, the mmf set up by the armature conductors interact with the main field flux in such a way that the field of the main field flux gets distorted and this is called cross-magnetizing effect.

However, the effect could be nullified by shifting the brush position of the generator by a small angle in the direction of rotation.

When the generator is loaded further, the pole tips get saturated which results in demagnetising the main field flux, thereby reducing the induced emf. This effect is called demagnetising effect, and can be explained further.

Fig 17 shows the flux distribution by the main field flux only. Since there is no current in the armature conductors, the flux is uniform. The GNA (Geometrical Neutral Axis) and MNA (Magnetic Neutral Axis) are coincident with each other.

Fig 18 shows the flux set up by the armature conductors alone. The current direction is marked as a plus sign(+), under the N.pole and dot (•) under the south pole as shown in the figure. The strength of this armature field (mmf) depends upon the armature current which, in turn, depends upon the load current.

Fig 16

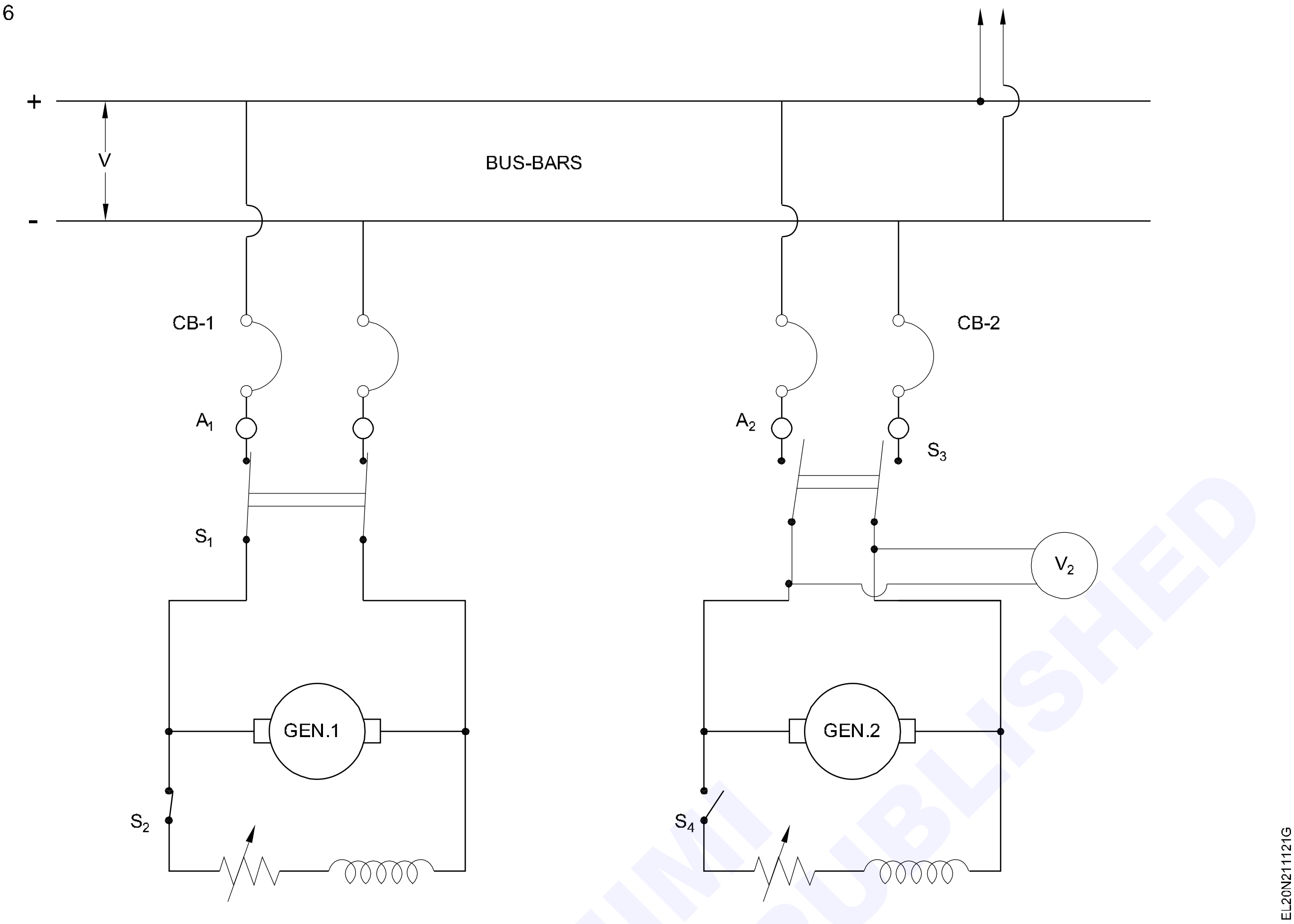
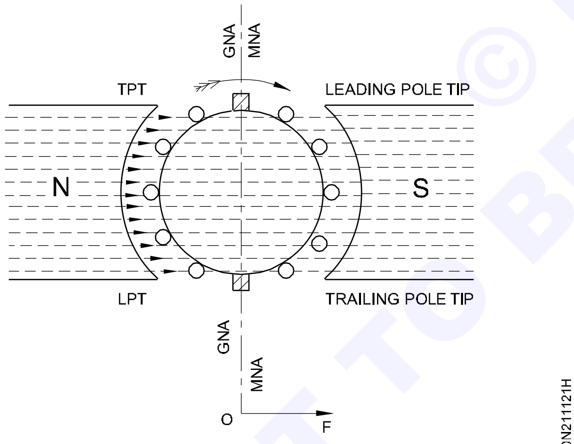
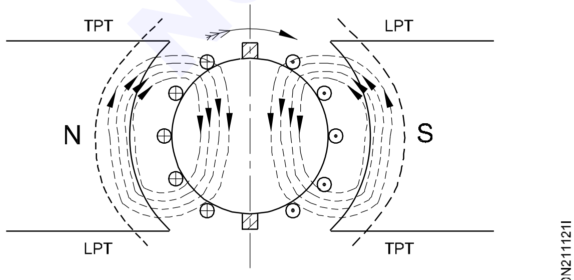


Fig 17



MAIN MAGNETIC FIELD OF A TWO - POLE DC MACHINE

Fig 18

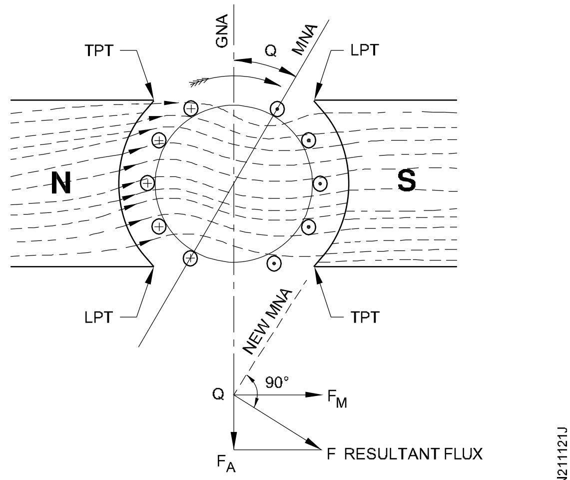


FLUX CREATED BY THE ARMATURE CURRENT

Cross-magnetising effect: Fig 19 shows the flux distribution by the combined effect of the main field and the armature mmf. The resulting field is found to have strengthened at the trailing pole tips and weakened at the leading pole tips. Due to this cross-magnetizing effect, the magnetic neutral axis (MNA) is shifted from the geometrical neutral axis (GNA) by an angle Q in the direction of rotation.

The effect of the main field flux (FF) and the armature flux (F_A) are shown by vectors in Fig 19. The magnetic neutral axis (MNA) should be at right angle to the resultant flux (F).

Fig 19



CROSS - MAGNETISING EFFECT

Remedy: The effect of the cross-magnetisation can be neutralized by shifting the brushes from GNA to MNA with the help of the rocker arm. Of course the amount of shifting depends upon the magnitude of the armature current. At the correct position of the brush, the induced emf will be maximum and the spark at the sides of brushes will be minimum.

Compensating winding: The demagnetizing effect due to armature reaction in large machines, which are subjected to fluctuation of load, can be neutralized by this winding.

This winding carries an equal current in the opposite direction to the current in armature conductors. So the flux set up by them is also in the opposite direction and of equal magnitude to that of the armature flux. Hence they neutralize each other, and thereby, the demagnetising effect is nullified at any load, even at fluctuating loads.

Commutation

When a DC generator is loaded, the current flows through the armature winding, commutator and brushes to the external circuit. During this process, whenever a brush spans the two commutator segments, the winding element connected to those commutator segments is short-circuited. The changes in current direction, which take place in the winding element, just before, during and after the short circuit is called commutation.

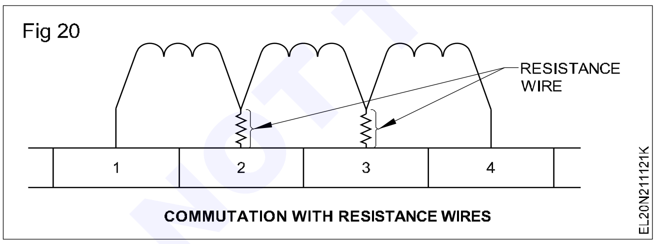
If the change in the current direction is gradual, then a smooth commutation takes place. On the other hand a sudden change in current in the winding element is called rough commutation which results in heavy sparking at the sides of brushes. If rough commutation is allowed to continue, the brushes and commutator get spoiled ultimately due to the excess heat produced by the sparks.

Remedies for rough commutation by providing interpoles

To avoid sparks in the brush position, the following methods are used which effectively change the rough commutation to smooth commutation.

- Resistance wires are introduced between the end connection of the coil to the commutator, as shown in Fig 20. This increased resistance helps the current to change its direction smoothly, increasing the timing and reducing the statically induced emf.

Fig 20

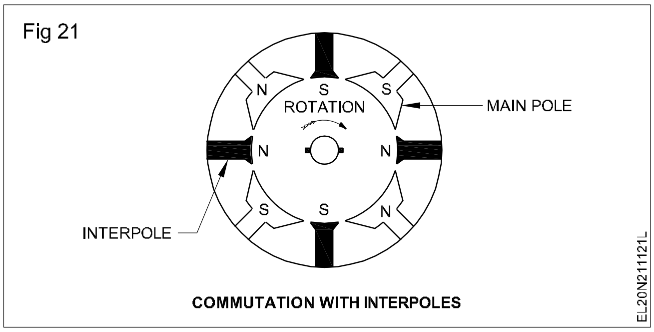


COMMUTATION WITH RESISTANCE WIRES

- High resistance brushes are used. Hence the contact resistance variation allows the current to change its direction smoothly, thereby reducing the statically induced emf.

- Small field poles called inter-poles are provided in between the main poles as shown in Fig 21. These inter-poles have their polarity the same as the next pole ahead in the direction of rotation of the, generators. Further, their winding is connected in series with the armature so that they carry the same current as that of the armature.

Fig 21

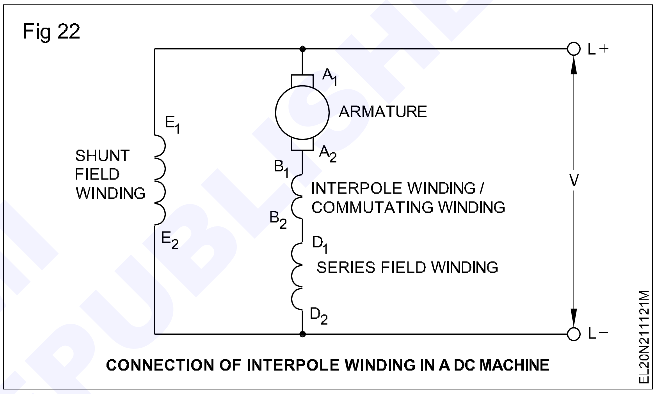


COMMUTATION WITH INTERPOLES

These inter-poles produce an emf opposite in direction to the statically induced emf, and have a magnitude depending upon the current. Thereby, the effect of statically induced emf is nullified.

These inter-poles are wound with less number of turns having thick gauge wire. Fig 22 shows the connection of inter-pole winding in a DC compound machine.

Fig 22



CONNECTION OF INTERPOLE WINDING IN A DC MACHINE

Losses and efficiency of DC machines

It is convenient to determine the efficiency of a rotating machine by determining the losses than by direct loading. Further it is not possible to arrange actual load for large and medium sized machines. By knowing the losses, the machine efficiency can be found by

$$\eta = \frac{\text{output}}{\text{output} + \text{losses}} \left(\text{For generators}\right)$$

$$\eta = \frac{\text{input - losses}}{\text{input}} \left(\text{For motors}\right)$$

In the process of energy conversion in rotating machines - current, flux and rotation are involved which cause losses in conductors, ferromagnetic materials and mechanical losses respectively. Various losses occurring in a DC machine are listed below (FIg 23 shows losses of DC machine.

Total losses can be broadly divided into two types

1 Constant losses

2 Variable losses

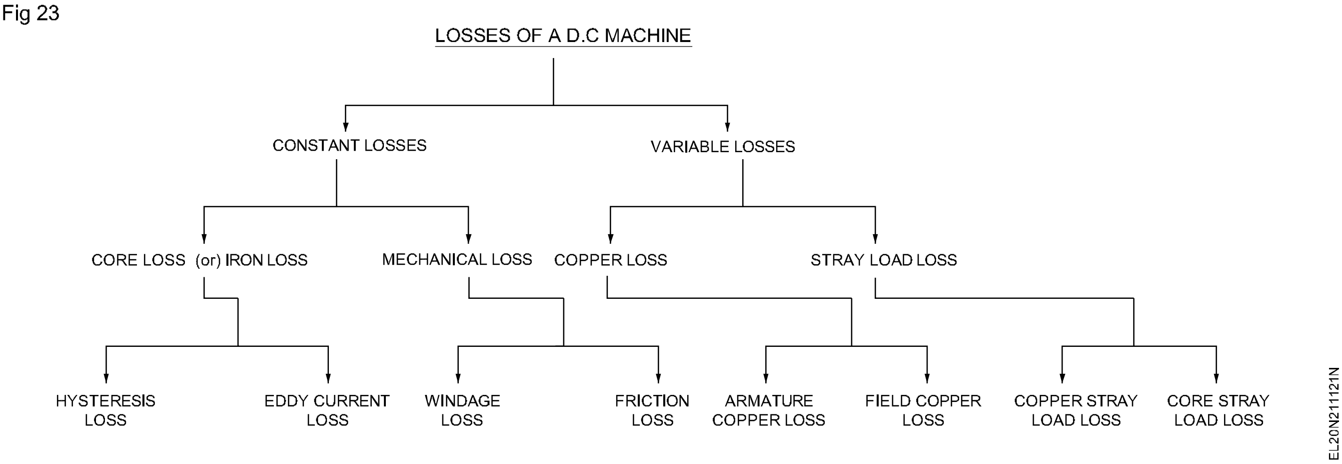
These losses can be further divided as

1 Constant losses - i) Core loss or iron loss

   a Hysteresis loss

   b Eddy current loss

Fig 23



ii Mechanical loss

a Windage loss

b Friction loss - brush friction loss and Bearing friction loss.

2 Variable losses - i) copper loss (I^2R)

a Armature copper loss

b Field copper loss

c Brush contact loss

ii Stray load loss

a Copper stray load loss

b Core stray load loss

Efficiency of a DC generator

Power flow in a DC generator

$$= \frac{\text{output}}{\text{output} + \text{losses}} = \frac{VI}{VI + I_a^2 r_a + W_e}$$

where w_e is constant loss

Condition for maximum efficiency

Generator output = VI

Generator input = output + losses

$= VI + I^2 a R_a + W_e$

$= VI + (I + I_{sh})^2 R_a + W_e \quad \therefore I_a = (I + I_{sh})$

However, if I_{sh} is negligible as compared to load current $I_a = I$ (approx.)

$$\because \eta = \frac{\text{output}}{\text{input}} = \frac{VI}{VI + I^2 a R_a + W_e} = \frac{VI}{VI + I^2 R_a + W_e}$$

Efficiency is maximum when variable loss = constant loss.

The load current corresponding to maximum efficiency is given by the relation.

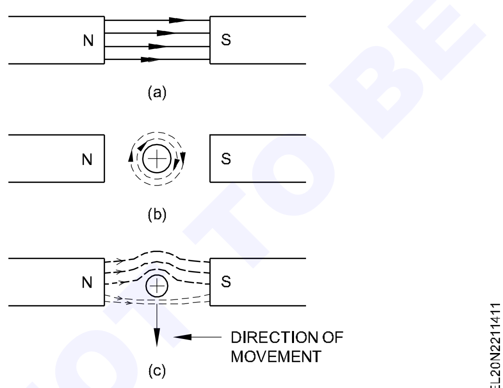
DC motor - principle and types

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of a DC motor**
- **state the different types of DC motors.**

Introduction: A DC motor is a machine which converts DC electrical energy into mechanical energy. It is similar to a DC generator in construction. Therefore, a DC machine can be used as a generator or as a motor. Even today, because of the excellent torque, speed and load characteristics of DC motors, 90% of the motors used in precision machines, wire drawing industry and traction are of this type.

Principles of a DC motor: It works on the principle that whenever a current-carrying conductor is kept in a uniform magnetic field, a force will be set up on the conductor so as to move it at right angles to the magnetic field. It can be explained as follows. Fig 1a shows the uniform magnetic field produced by a magnet, whereas Fig 1b shows the magnetic field produced around the current-carrying conductor. Combining the effects of Fig 1a and Fig 1b in one figure, Fig 1c shows the resultant field produced by the flux of the magnet and the flux of the current-carrying conductor. Due to the interactions of these two fields, the flux above the conductor will be increased and the flux below the conductor is decreased as represented in Fig 1c. The increased flux above the conductor takes a curved path thus producing a force on the conductor to move it downwards.

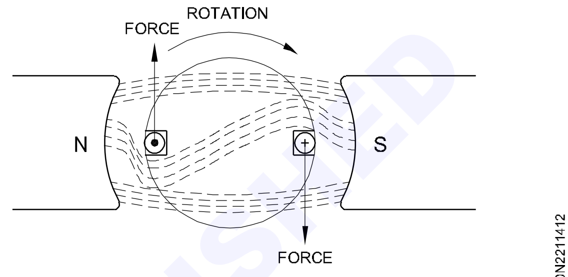
Fig 1



If the conductor in Fig 1 is replaced by a loop of wire as shown in Fig 2, the resultant field makes one side of the conductor move upwards and the other side move downwards. It forms a twisting torque over the conductors, and they tend to rotate, if they are free to rotate. But in a practical motor, there are a number of such conductors/ coils. Fig 3 shows the part of a motor. When its armature and field are supplied with current, the armature experiences a force tending to rotate in an anticlockwise direction as shown in Fig 3.

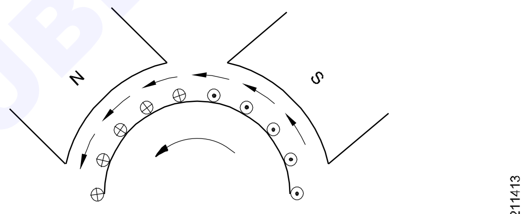
The direction of rotation or movement can be determined by Fleming's left hand rule. Accordingly, the direction of rotation of the armature could be changed either by changing the direction of armature current or the polarity of the field.

Fig 2



REACTION OVER A CURRENT CARRYING LOOP BY THE MAGNETIC FIELD

Fig 3



REACTION OVER THE ARMATURE CURRENT CARRYING CONDUCTORS BY THE MAGNETIC FIELD

Fleming's Left Hand Rule: The direction of force produced on a current-carrying conductor placed in a magnetic field can be determined by this rule. As shown in Fig 4a, hold the thumb, forefinger and middle finger of the left hand mutually at right angles to each other, such that the forefinger is in the direction of flux, and the middle finger is in the direction of current flow in the conductor; then the thumb indicates the direction of motion of the conductor. For example, a loop of coil carrying current, when placed under north and south poles as shown in Fig 4b, rotates in an anticlockwise direction.

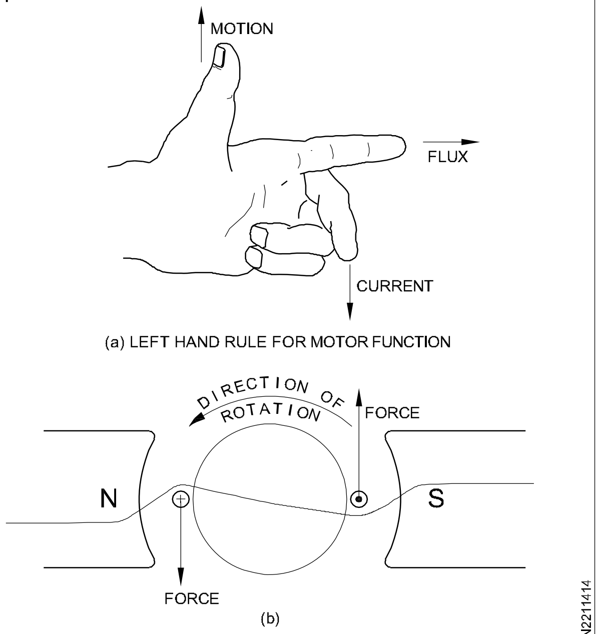
Types of DC motors: As the DC motors are identical in construction to that of DC generators, they are also classified as series, shunt and compound motors, depending upon their connection of field winding with the armature and supply.

When the armature and field are connected in series, as shown in Fig 5, it is called a series motor.

When the armature and field are connected in parallel across supply, as shown in Fig 6, it is called a shunt motor.

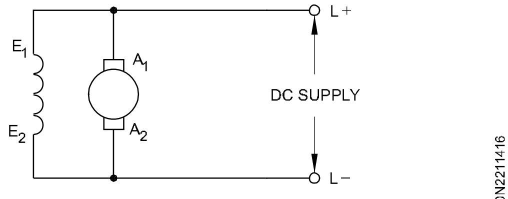
When the motor has two field coils, one in series with the armature and the other in parallel with the armature, as shown in Fig 7, it is called a compound motor.

Fig 4



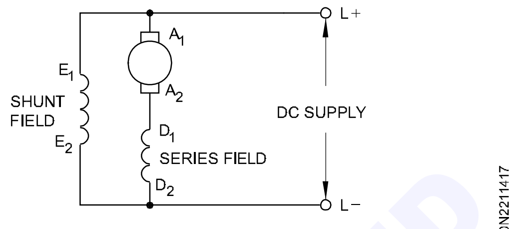
FLEMING'S LEFT HAND RULE

Fig 6



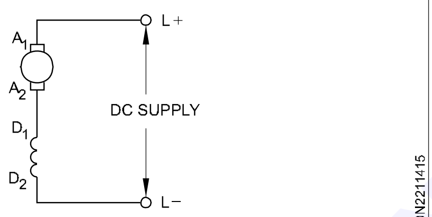
SHUNT MOTOR

Fig 7



COMPOUND MOTOR

Fig 5



SERIES MOTOR

The relation between applied voltage, back emf, armature voltage drop, speed and flux of DC motor - method of changing direction of rotation

Objectives: At the end of this lesson you shall be able to
- **explain the relation between applied voltage, back emf, armature voltage drop - speed - flux**
- **describe the method of changing the direction of rotation of a DC motor.**

Back emf: As the armature of a DC motor starts rotating, the armature conductors cut the magnetic flux produced by the field poles. Due to this action, an emf will be produced in these conductors. The induced emf is in such a direction as to oppose the flow of current in the armature conductor as shown in Fig 1. As it opposes the supply voltage it is called `BACK EMF' and is denoted by E_b. Its value is the same as that found in the generator. It could be written as

$$E_b = \frac{\varnothing ZNP}{60A} \text{ volts}$$

The direction of the induced (back) emf could be determined by Fleming's right hand rule.

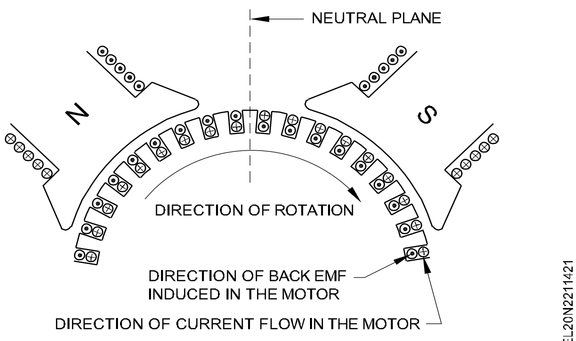
Applied voltage: The voltage applied across the motor terminals is denoted by `V'.

Armature voltage drop: Since armature conductors have some resistance, whenever they carry current a voltage drop occurs. It is called I_aR_a drop because it is proportional to the product of the armature current I_a and armature resistance R_a. It has a definite relation with the applied voltage and back emf as shown by the formula

$V = E_b + I_aR_a$.

Alternatively, $I_aR_a = V - E_b$.

Fig 1



Further the back or counter emf E_b depends upon flux per pole 'Ø' and speed `N'. Therefore, the applied voltage, back emf, armature drop, flux and speed are related to one another as follows.

$$E_b = V - I_a R_a$$

$$\frac{\varnothing ZNP}{60A} = V - I_a R_a$$

$$\therefore N = \frac{(V - I_a R_a) \times 60A}{\varnothing ZP} \text{ rpm}$$

For a given motor ZPA and 60 are constants and can be denoted by a single letter K

$$\text{where } K = \frac{60A}{ZP}$$

Therefore $N = K E_b/Ø$.

It shows that the speed of a DC motor is directly proportional to E_b and inversely proportional to the flux Ø.

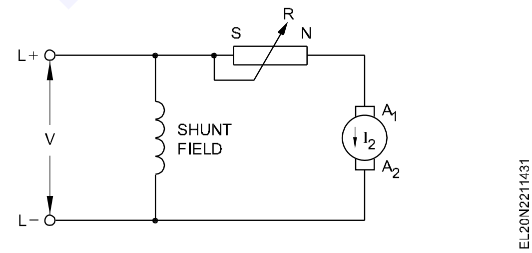
Reversing the direction of rotation of DC motors: The direction of rotation of a DC motor can be changed either by changing the direction of the armature current or by changing the direction of the field current. The direction of rotation of a DC motor cannot be changed by interchanging the supply connections because this changes the direction of the field as well as the armature current.

DC motor starters

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starter for a DC motor**
- **state the different types of starters - construction and working principle of 2-point, 3-point and 4-point starters.**

Necessity of starters: Since the armature is stationary before starting, the back emf which is proportional to speed is zero. As the armature resistance is very small, if the rated voltage is applied to the armature, it will draw many times the full load current, and thereby, there is every possibility of damaging the armature due to heavy starting current. Therefore, the starting current should be limited to a safe value. This is done by inserting a resistance in series with the armature at the time of starting for a period of 5 to 10 seconds. As the motor gains in speed, back emf is built up, and then the starting resistance could be gradually cut off. Fig 1 shows such an arrangement. Resistance R is fully included in the armature circuit by keeping the moving arm in position `S' at the time of starting, and then it is moved towards position `N' to exclude the resistance `R' when the motor has picked up its speed. But such an arrangement will be purely manual and needs constant monitoring. For example, if the motor is running, the resistance `R' will be excluded, and the moving arm position will be at position `N'. In case the supply fails, the motor will stop but the moving arm will still be in position `N'. When the supply returns, as there is no resistance included in the armature circuit through `R', the armature may draw heavy current and may get damaged. To prevent such a happening a device called starter is used in motor circuits.

Fig 1



Types of starters: Starters used to start the DC motors are generally of three types.

- Two-point starter
- Three-point starter
- Four-point starter

Two-point starter: This contains the following components.

- The series resistor required for starting a motor.
- The contacts (brass studs) and switching arm required to include or exclude the resistor in the armature circuit.
- A spring on the handle to bring the handle to the `OFF' position when supply fails.
- An electromagnet to hold the handle in the `ON' position.

The two-point starter is frequently used with a DC series motor. The starting resistance, electromagnet armature and the series field are all connected in series as shown in Fig 2.

When the arm is moved to the first contact point, the circuit is completed, and the armature begins to rotate. As the armature speed increases, the arm is slowly moved towards the right side electromagnet, thereby the starter resistance is reduced. When the arm is against the electromagnet, complete starter resistance is cut off from the circuit.

Three-point starter: Fig 3 shows the internal diagram of a three(terminal) point starter connected to a DC shunt motor. The direct current supply is connected to the starter, the motor circuit through a double pole switch and suitable fuses. The starter has an insulated handle or knob for the operator's use. By moving the starter handle from the `off' position to the first brass contact (1) of the starter, the armature is connected across the line through the starting resistance. Note that the armature is in series with the total starting resistance. The shunt field, in series with the holding coil, is also connected across the line. In this mode of operation, the rush of the initial current to the armature is limited by the resistance. At the same time, the field current is at the maximum value to provide a good starting torque.

Fig 2

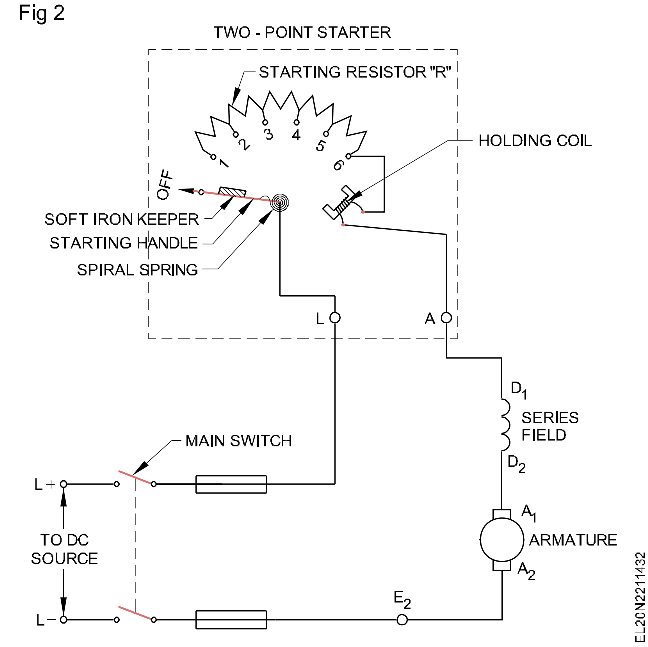
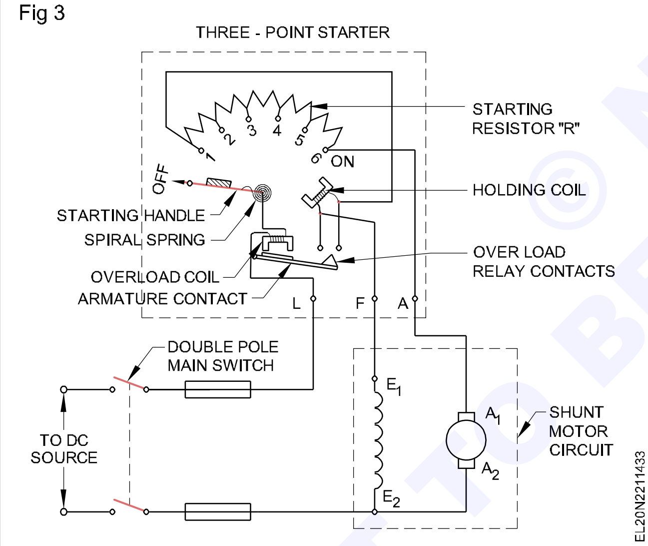


Fig 3



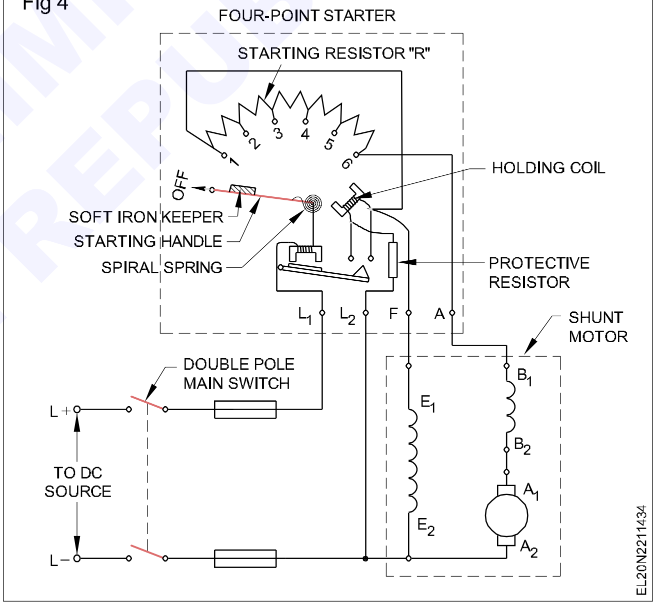
As the handle arm is moved to the right, the starting resistance is reduced and the motor gradually accelerates. When the last contact is reached, the armature is connected directly across the supply; thus, the motor is at full speed.

An overload coil is provided to prevent damage to the motor from overload. Under normal load condition, the flux produced by the over load coil will not be in a position to attract the armature contact. When the load current increases beyond a certain specified value, the flux of the over load coil will attract the armature. The contact points of the armature then short-circuit the holding coil and demagnetize it. This enables the handle to come to the `OFF' position due to the tension of the spiral spring.

This type of starter can be used to start both shunt and compound motors.

Four-point starter: In applications where many motor speeds are to be increased beyond their rated value, a four-terminal, face plate starter is used with the motor. The four(terminal) point starter, shown in Fig 4, differs from the three-point starter in that the holding coil is not connected in series with the shunt field. Instead, it is connected across the supply in series with a resistor. This resistor limits the current in the holding coil to the desired value. The holding coil serves as a no-voltage release rather than as a no-field release. If the line voltage drops below the desired value, the magnetic attraction of the holding coil is decreased, and then the spring pulls the starter handle back to the `off' position.

Fig 4



Relation between torque, flux and armature current in a DC motor

Objectives: At the end of this lesson you shall be able to

- **explain the relation between torque, flux and armature current**
- **solve problems pertaining to metric HP; load current, rated voltage, torque and speed of DC motors.**

Relation between armature current, flux and torque

Torque: The turning or twisting moment of a force about an axis is called torque. It is equal to the product of force and the radius of the pulley.

Consider a pulley of radius `r' metres acts upon by a circumferential force `F' Newton, and rotates at a speed of `n' r.p.s. as shown in Fig 1.

Then torque T = F x r Newton-metres(N-m)

Work done by this force

in one revolution = Force x distance

= F x 2πr joules.

Power developed in one second = F x 2πr x n joule/second or watts

= (Fxr)2πn watts

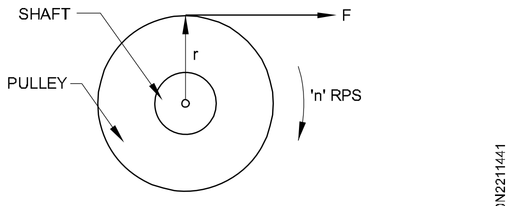
As 2πN is angular velocity ω in radian/second and

(F x r) = Torque T

Power developed = T x ω watts

P = Tω watts.

Fig 1



TORQUE PRODUCTION IN A MOTOR

Torque of a motor: Let T_a be the torque developed by the armature of a motor in newton-metre and `n' the speed of armature in r.p.s.

Then the power developed in the armature = T_a 2πn watts.

As we know the Electrical power is converted into mechanical power

Electrical power supplied to the armature = $E_b I_a$ where

E_b is the back emf

I_a is the armature current.

Electrical power supplied to the armature = Mechanical power developed in the armature

We get $E_b I_a = T_a 2\pi n$

Since $E_b = \dfrac{\varnothing ZnP}{A}$ volts (By taking `n' in r.p.s.)

$$T_a \times 2\pi n = \frac{\varnothing ZnP}{A} \times I_a$$

By cross multiplication we get

$$T_a = \frac{\varnothing ZP \times I_a}{2\pi A} \text{ Newton - metre}$$

or $T_a = \dfrac{0.159\ \varnothing ZP}{A} \times I_a$ Newton - metre

For a given motor. ZP and A are constants as they depend upon the design.

$\dfrac{0.159\ \ ZP}{A}$ *can* be regarded as constant 'K'

Then $T_a = K\text{Ø}I_a$

where Ø is the flux pole in weber

I_a is the armature current

$$K = \frac{0.159\ ZP}{A}$$

T_a is the armature torque in newton metres.

Therefore, we can say the torque of a DC motor is directly proportional to the field flux and the armature current.

The other formula which gives torque

$$T_a \text{ is } = \frac{9.55 \times E_b I_a}{N} \text{ Newton - metre}$$

where `N' is speed in r.p.m.

Shaft torque: The complete armature torque calculated above is not available for doing useful work because of the losses in the motor.

> **The torque which is available for doing work is known as shaft or output torque, and it is denoted as T_{sh}.**

The difference ($T_a - T_{sh}$) is known as loss of torque due to iron, friction and windage losses of motor.

$$\text{One H.P. metric} = \frac{2\pi n T_{sh}}{735.5} = \frac{2\pi N T_{sh}}{60 \times 735.5} \text{ HP}$$

where 'n' is the speed is in r.p.s., N is the speed in r.p.m.

and T_{sh} is the shaft torque in newton metre.

If the torque is given in kg. metre, it can be converted into newton metre as given below.

Newton metre = Kg. metre x 9.81

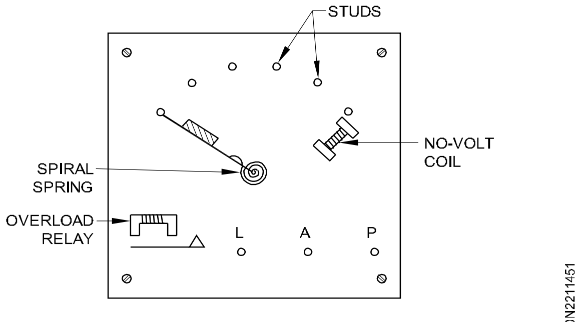
Service and maintenance of DC motor starters

Objectives: At the end of this lesson you shall be able to

- **explain the procedure of service and troubleshoot the DC motor starter**
- **state how to check the handle for its spring tension and contact pressure against the studs**
- **state how to check the no-volt coil assembly**
- **explain the overload relay for the desired current rating.**

Servicing the starter: The starting resistance of the 3-point and 4-point starters is made up of coiled Eureka wire and it is fixed between the studs of the starter. The brass studs are arranged on the face plate of the starter in a circular form as shown in Fig 1. The studs are firmly fixed on the insulated face plate. During maintenance the studs should be dressed with zero number sandpaper if the burrs are small and a smooth file should be used for pittings and big burrs, and then cleaned properly with a contact cleaner. In case the starter resistance is found open, replace it with a new resistance coil as per the original specification of the manufacturer.

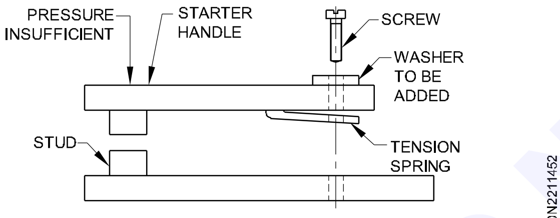
Fig 1



FACE PLATE ARRANGEMENT

Proper pressure of the movable contact of the arm is available against the brass studs of the face place. If proper tension is not found then the starter handle is to be tightened with the help of fixing screw by adding one or two flat washers on the top of the handle as shown in Fig 2

Fig 2

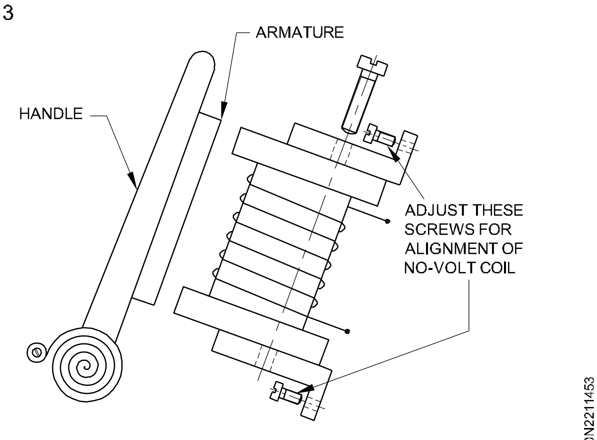


ADJUSTING THE STUD PRESSURE

When the handle of the starter is moved to the running position, the armature of the handle should be touching the core assembly of the no-volt coil. In case the core assembly is not touching properly, loosen the mounting screws of the core/coil assembly, align the core and tighten the screws. (Fig 3).

If the NVC is not energised check visually the condition of the NVC. Measure the value and resistance of the coil as well as the insulation value and make a note of these readings.

Fig 3



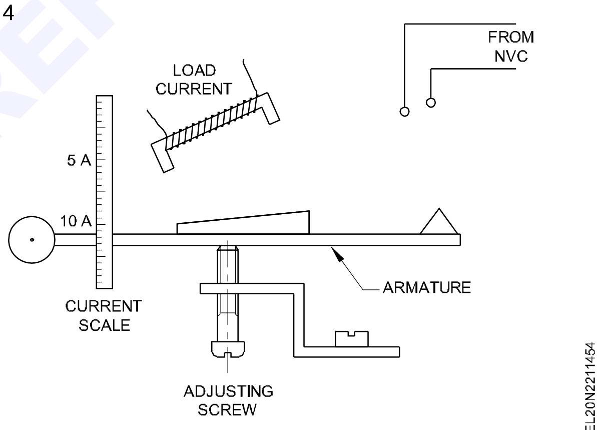
SETTING OF NO-VOLT COIL

Maintenance of overload relay (Fig 4)**:** A magnetic overload relay is provided near the handle on the left side of the starter face plate; underneath the overload relay an armature is provided and it is adjusted as per the load current of the motor.

To test the overload relay the motor has to be loaded and the tripping of the overload relay to be observed. In case the overload relay trips at a lower current or higher current value when compared to set current value the current scale has to be recalibrated.

In the case of chattering noise observed at the no-volt coil the surfaces of the core assembly and armature need to be cleaned.

Fig 4



Characteristics and applications of a DC series motor

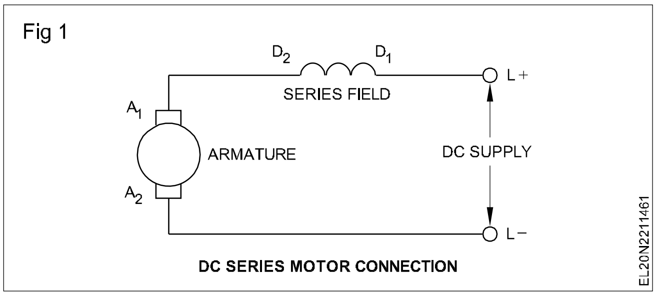
Objectives: At the end of this lesson you shall be able to
- **explain the characteristics of a series motor**
  - **torque versus load**
  - **speed versus load**
  - **speed versus torque**
- **state the uses of a DC series motor**
- **state the method of loading the motor and explain the brake test.**

DC series motors : A DC series motor has a very high starting torque. In some motors, it may be as high as five times the full load torque. Further, the speed of the DC series motor also varies with the load. (Fig 1)

Characteristics of DC series motors: The torque `T' in a DC motor is proportional to the flux `Ø' and the armature current `I_a'. The speed is inversely proportional to the flux. The relation between these factors i.e. torque vs load, speed vs load and torque vs speed are plotted on a graph, and are known as characteristic curves of motors. The study of these characteristics enables us to understand the behaviour of the motors under different conditions.

Torque load characteristics of the DC series motor: Fig 2 shows the torque load characteristic curve of a DC

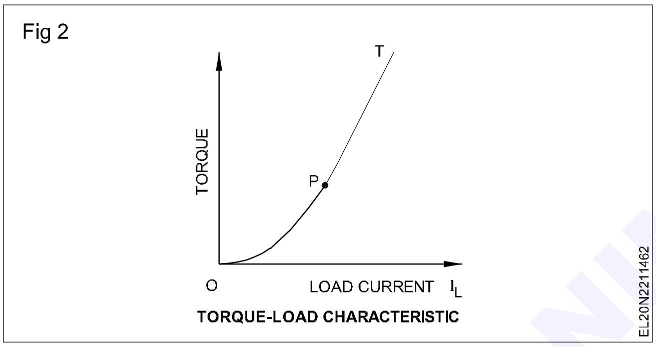
Fig 1



DC SERIES MOTOR CONNECTION

series motor. At low or light load, the torque is low due to the low armature current and low field flux. But as the load increases, the torque also increases proportionate to the square of the armature current up to the point `P' of the curve. This could be illustrated by the formula T proportional to armature current and field flux. T a I_a Øse as $Ø_{se}$ is proportional to I_{se} and, further, I_{se} is proportional to the armature current. We have

Fig 2



TORQUE-LOAD CHARACTERISTIC

$T \alpha I_a I_{se}$

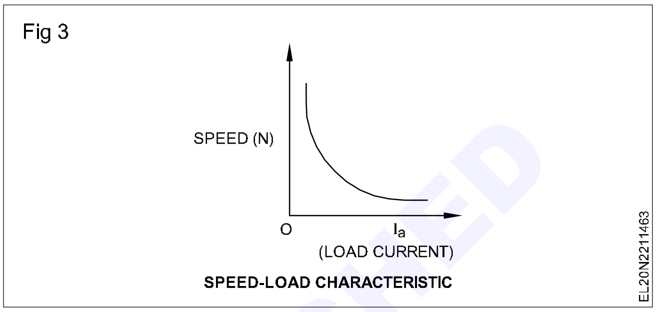
$T \alpha I_a I_a$

$T \alpha I_a^2$.

Beyond this point 'P' the curve becomes a straight line, and indicates the torque is proportional to the armature current only as the field cores are saturated. This curve shows that the torque is low at light loads and increases at heavy loads. Further the starting current of a DC series motor is about 1.5 times the full load current and the torque is about 2.25 times (1.5^2) the full load torque assuming the poles are not saturated.

Speed Vs load characteristics: Fig 3 shows the speed load characteristic curve of a DC series motor. From the curve it is clear that when the load is small the speed is high, and as the load increases the speed decreases. As the curve shown is parallel to the `Y' axis at low load currents, it can be inferred that the speed attains a dangerous value. Therefore, the DC series motors are seldom used without load. Care should be taken while using belt drives where the load can be `OFF' if the belt breaks or slips out. To avoid this, usually the load is connected directly or through gears to a DC series motor.

Fig 3

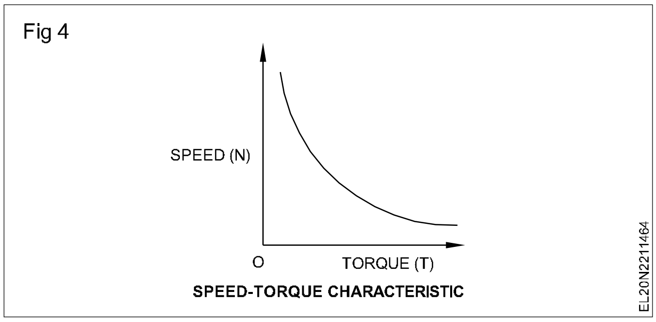


SPEED-LOAD CHARACTERISTIC

Speed-torque characteristics: Fig 4 shows the speed-torque characteristic of a DC motor. It shows that when the torque is low, the speed is high. This is due to the low field flux (N a 1/Ø). As the torque increases the motor draws more current and causes the speed to reduce. This is due to the increased field flux by increased load current in the DC series field.

Uses of a DC series motor: The DC series motor is used in applications where torque and speed requirements vary substantially, and in jobs that require a heavy starting torque and a high rate of acceleration as in traction, hoists, cranes, and heavy construction trucks.

Fig 4



SPEED-TORQUE CHARACTERISTIC

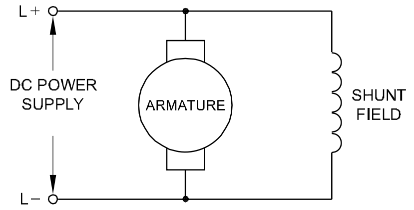
Characteristics and applications of a DC shunt motor

Objectives: At the end of this lesson you shall be able to
- **describe the characteristics of a DC shunt motor**
  - **speed vs load characteristics**
  - **torque vs load characteristics**
  - **torque vs speed characteristics**
- **state the applications of a DC shunt motor.**

Shunt motor (Fig 1) : In a shunt motor, the field is connected directly across the armature and the supply. The field current, and hence, the field flux are constant. When operating without a load, the torque requirement is small, since it is only needed to overcome windage and friction losses. Because of the constant field flux, the armature will develop a back emf that will limit the current to the value needed to develop only the required torque.

Speed load characteristic of the DC shunt motor: Shunt motors are classified as constant speed motors. In other words, there is very little variation in the speed of the shunt motor from no load to full load. Equation 1 may be used to determine the speed of the DC motor at various loads.

Fig 1



DC SHUNT MOTOR

EL20N2211471

where

N - speed of the armature in r.p.m.

V - applied voltage

I_a - armature current at a specific load

R_a - armature resistance

Ø - flux per pole

K_1 - a constant value for the specific motor

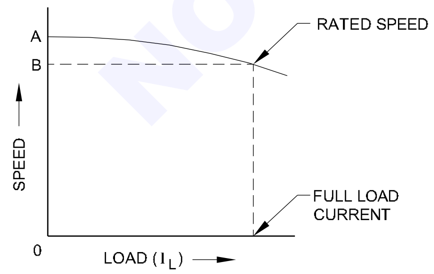
E_b - the back emf

In a shunt motor, V,R_a,K_1 and Ø are practically constant values, and the armature current is the only variable. At no load the value of `I_a' is small, leading to the maximum speed. At full load, I_aR_a is generally about 5 percent of V. The actual value depends upon the size and design of the motor. Consequently, at full load, the speed is about 95 percent of the no-load value.

However the speed will drop slightly to reduce the back emf such that the armature can draw more current to develop an increased torque from no load to full load.

Fig 2 shows the speed-load characteristic of a DC shunt motor. From the curve it is observed that the speed slightly drops from its no-load speed OA to OB when the motor delivers full load. This is due to the increased $I_a R_a$ drop in armature. As the drop is small, the DC shunt motor is regarded as a practically constant speed motor.

Fig 2



LOAD VERSUS SPEED CHARACTERISTIC OF DC SHUNT MOTOR

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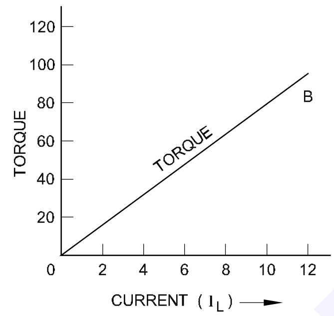
Torque vs load characteristics of the DC shunt motor: Motor torque is proportional to the product of the field flux and the armature current. As the field flux is constant, the torque varies as the load current varies. Fig 3 shows the torque vs load curve of a DC shunt motor. From this it is clear that the torque is directly proportional to load or armature current I_a.

Fig 3



TORQUE VERSUS LOAD CHARACTERISTIC CURVE

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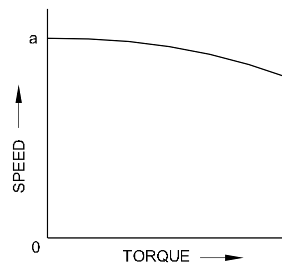
The starting torque of a shunt motor is about 1.5 times the full load torque indicating that the shunt motor does not have as high a starting torque as the series motor, but it has much better speed regulation.

Torque Vs speed characteristics: Fig 4 shows the torque speed characteristic of a DC shunt motor. From the curve it is observed that the increase in torque has negligible effect on the speed. The speed slightly drops as the torque increases.

Fig 4



SPEED VERSUS TORQUE CHARACTERISTIC OF DC SHUNT MOTOR

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Application of DC shunt motor: A DC shunt motor is best suited for constant speed drives. Some specific applications are machine tools, wood planers, circular saws, grinders, polishers, printing processes, blowers and motor generator sets.

When working with a shunt motor, never open the field circuit when it is in operation. If this happens, as the flux is only due to the residual field, the motor speed increases to a dangerous magnitude. At light loads this speed could become dangerously high, and the armature may fly off.

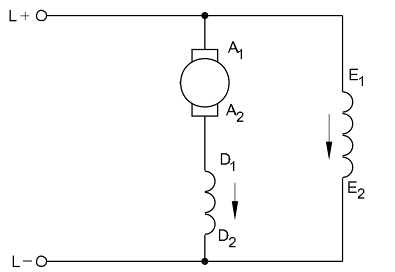
DC compound motor - load characteristics

Objectives: At the end of this lesson you shall be able to
- **state the types, applications of DC motors**
- **state the characteristic of a DC compound motor**
- **state the precautions to be observed while starting a differential compound motor.**

Cumulative compound motor: When the series field of the DC compound motor is connected in such a way that its flux aids the flux produced by the shunt field, as shown in Fig 1, then it is called a cumulative compound motor.

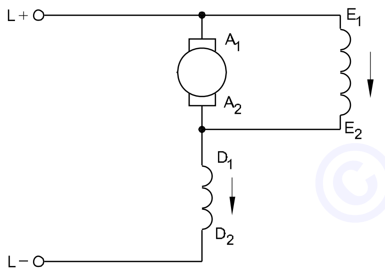
Depending on the shunt field connection, it is further sub-divided as the long shunt, (Fig 1) the short shunt (Fig 2) cumulative compound motor.

Fig 1



CUMULATIVE COMPOUND MOTOR (LONG SHUNT)

Fig 2



CUMULATIVE COMPOUND MOTOR (SHORT SHUNT)

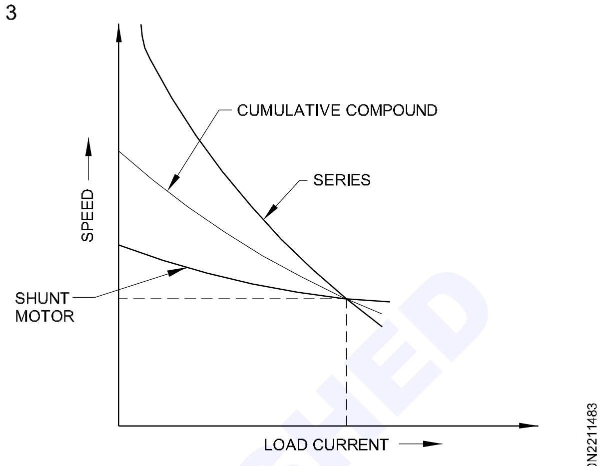
Speed-load characteristic: Fig 3 shows the speed-load characteristic of the cumulative compound motor, and also of the series and shunt motors for comparison. The speed of this motor falls more than the shunt motor but falls less than the series motor. As the speed load curve starts from Y-axis, unlike in a DC series motor, the cumulative compound motor can also run on no-load at a specified speed.

The increased drop in speed at load is due to the combined drop of the voltage due to armature and series field resistances.

Torque-load characteristic: Fig 4 shows the torque-load characteristic of the cumulative compound motor, and also that of the series and shunt motors for comparison. Up to full load, the torque developed in a cumulative compound motor is less than that in the shunt motor but more than in the series motor.

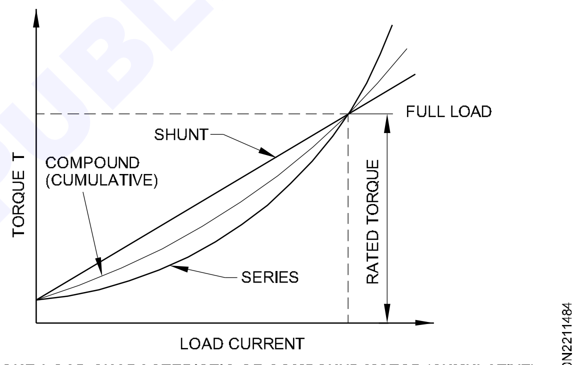
However, at the time of starting, the starting current is about 1.5 times the full load current, and hence, the cumulative compound motor produces a high torque, which is better than that of the shunt motor during starting.

Fig 3



SPEED-LOAD CHARACTERISTIC OF CUMULATIVE COMPOUND MOTOR

Fig 4



TORQUE-LOAD CHARACTERISTIC OF COMPOUND MOTOR (CUMULATIVE)

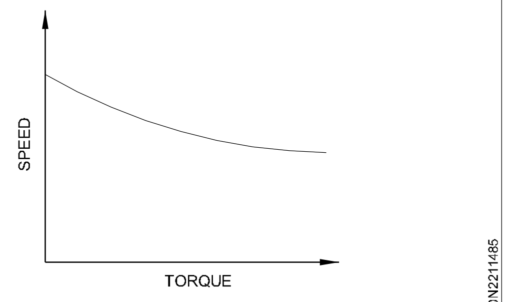
Torque-speed characteristic: Fig 5 shows the torque-speed characteristic of the cumulatively compound motor. As the total flux of the motor increases with load, the speed decreases but the torque increases. As the output power is proportional to the product of speed and torque, the cumulative compound motor will not be overloaded in case of sudden appearance of load as in rolling mills.

Application of cumulative compound motors: Compound motors are used to drive machines that require a relatively constant speed under varying loads. They are frequently used on machines that require sudden application of heavy loads, such as presses, shears, compressors, reciprocating tools, steel rolling machinery and elevators.

Never open the shunt field of a compound motor when the motor is operating at high load.

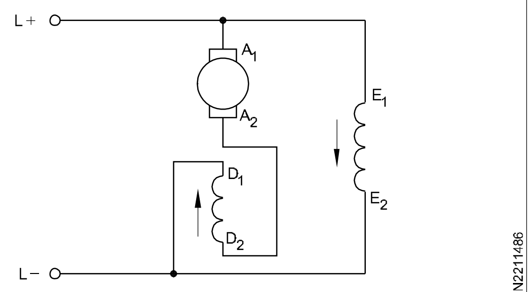
Differential compound motor: When the series field of the DC compound motor is connected in such a way that its flux opposes (bucks) the flux produced by the shunt field as shown in Fig 6, it is called a differential compound motor.

Fig 5



TORQUE SPEED CHARACTERISTIC OF A CUMULATIVE COMPOUND MOTOR

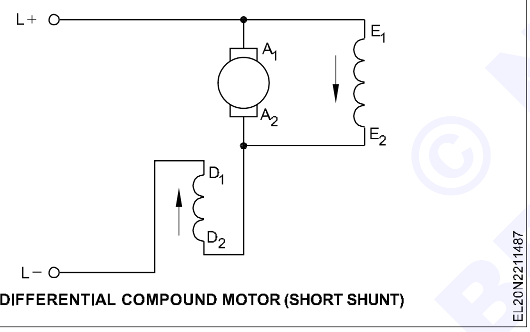
Fig 6



DIFFERENTIAL COMPOUND MOTOR (LONG SHUNT)

Depending upon the shunt field connection, the compound motor is further subdivided as long shunt (Fig 6) and short shunt (Fig 7) differential compound motor.

Fig 7

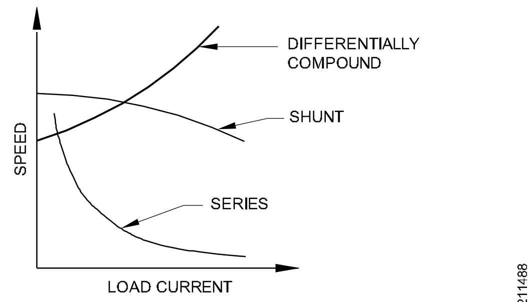


DIFFERENTIAL COMPOUND MOTOR (SHORT SHUNT)

As the series field flux is in the opposite direction to the shunt field flux, there is some inherent problem at the time of starting. At the time of starting, the shunt field takes some time to build up, whereas a heavy rush of current will be through the series field and armature. The motor will, therefore, tend to start up the wrong way. When the shunt field is fully established, the total flux, which is the difference of series and shunt field fluxes, may be so small that the motor may not produce sufficient torque to run the motor. Hence it is advisable to short-circuit the series field of the differential compound motor at the time of starting, and then put the series field in the circuit when the motor is running.

Characteristics of a differential compound motor: The speed-load characteristic of the differential compound motor, shown in Fig 8, indicates that the motor speed increases with the increase in load due to the fact that the total flux decreases at the increased load.

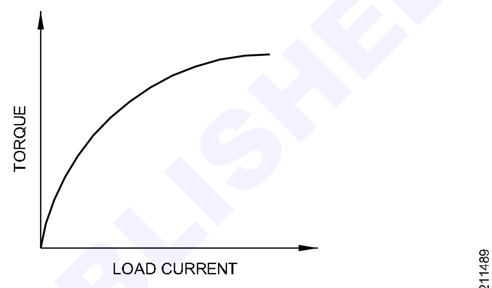
Fig 8



SPEED - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

The torque-load characteristic of the DC differential compound motor shown in Fig 9, indicates that the torque increases with the increased load.

Fig 9

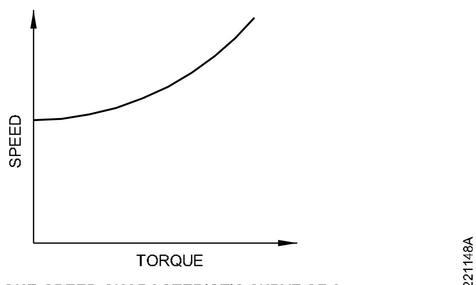


TORQUE - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 10 shows the torque-speed characteristic indicating that both speed and torque increase in the machine, resulting in the overloading of the machine initially, and thereby, reaching an unstable state.

Application of DC differential compound motor: This motor is not in common use due to its unstable behaviour at overloads. This motor is dangerous to use unless there is no possibility of the load exceeding the normal full load value as it is designed to work within full load limits.

Fig 10



TORQUE-SPEED CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Speed control methods of a DC motor and their applications

Objective: At the end of this lesson you shall be able to
- **explain the principle and the methods of controlling the speed of a DC motor.**

Principle of speed control in DC motors: In certain industrial applications, the variation of speed is a necessity. In DC motors the speed can be changed to any specified value easily. This is the main reason for certain industries to prefer DC motors for drives rather than AC motors. The speed of a DC motor can be varied, based on the following simple relationship.

It is known that the applied voltage = back e m f + armature resistance voltage drop

$V = E_b + I_aR_a$.

Hence $E_b = V - I_aR_a$ and also

$$\text{the back emf } E_b = \frac{P\varnothing N}{60} \times \frac{Z}{A} = K\varnothing N$$

where K is a constant.

$$\text{Therefore } N = \frac{E_b}{k\varnothing} = \frac{V - I_aR_a}{k\varnothing} \quad ....\text{Eqn.1}$$

From the above expression, it is clear that the speed of a DC motor is directly proportional to the back emf E_b, and inversely proportional to flux (Ø). Thus the speed of the DC motor can be varied by changing either the back emf E_b or the flux Øor both. In fact, if the back emf is decreased across the armature, the speed decreases, and if the flux is decreased the speed increases. The following are the most common methods of controlling the speed of DC motors based on the above principle.

Methods of speed control in DC shunt motors and compound motors

Armature control method: This method works on the principle that the speed of the DC motor could be varied by varying the back emf. As the back emf = $V - I_aR_a$, by varying the armature resistance we can obtain various speeds. A variable resistance called controller is connected in series with the armature as shown in Fig 1. The controller should be selected to carry the armature current for a longer period.

Let the initial and final speeds of the motor be N_1 and N_2, and the back emf be E_{b1} and E_{b2} respectively,

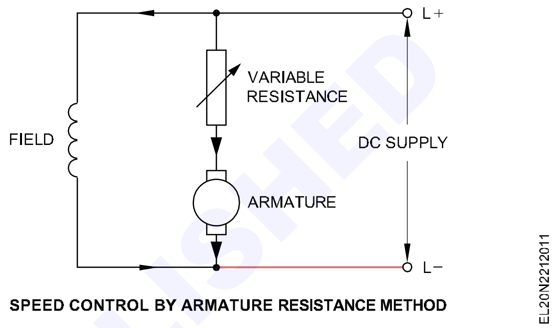
$$\text{Then } N1 = \frac{E_{b1}}{k} \quad .....\text{Eqn.2.}$$

$$N2 = \frac{E_{b2}}{k} \quad .....\text{Eqn.3.}$$

By dividing Eqn.3 by Eqn.2 we have

$$N_2 = \frac{E_{b2}N_1}{E_{b1}}.$$

Fig 1



SPEED CONTROL BY ARMATURE RESISTANCE METHOD

By varying the controller resistance value in the armature circuit, the back emf can be varied from E_{b1} to E_{b2}, thereby, the speed can be varied from N_1 to N_2.

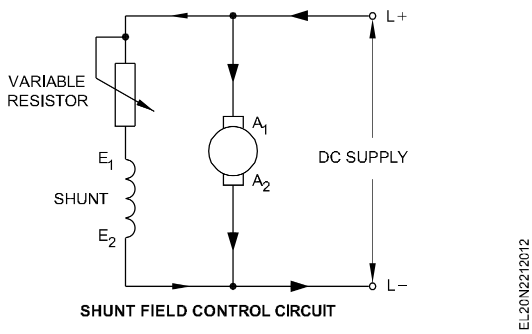
Advantages

This method is suitable for constant load drives where speed variations from low speed up to normal speed are only required.

Application of the armature control method: Suitable for DC shunt and compound motors used in printing machines, cranes and hoists where the duration of low speed operation is minimum.

The shunt field control method: This method works on the principle that the speed of the DC motor could be varied by varying the field flux. For this, a variable resistance (rheostat) is connected in series with the shunt winding as shown in Fig 2.

Fig 2



SHUNT FIELD CONTROL CIRCUIT

When the resistance is increased in the field circuit, the field current and the flux are reduced. Due to the reduction of flux, the speed is increased.

Advantages

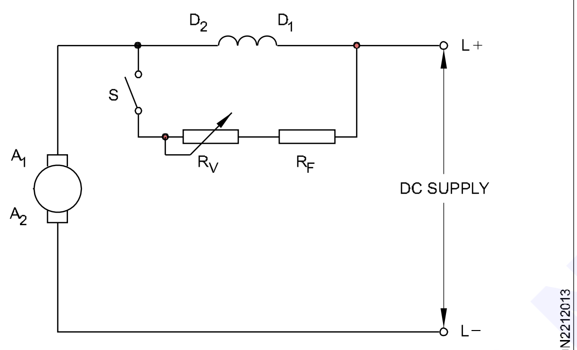
- Higher speeds i.e. above normal speed only can be obtained which will be stable from no load to full load.
- As the magnitude of the field current is low, the power loss in the field rheostat is minimum.
- Control is easy, economical and efficient.

Application of shunt field control: This method is the most widely used speed control method where speeds above normal are required, and at the same time, the load applied to the motor changes often.

Method of speed control in DC series motors

Field diverter method: A variable resistance, called a diverter, is connected in parallel with the field winding as in Fig 3. R_V represents the variable portion of the diverter and R_F the fixed portion. The function of R_F is to prevent the series winding being short-circuited, when the diverter is operated.

Fig 3



FIELD DIVERTER CONTROL CIRCUIT

The smaller the value of $R_V + R_F$, the greater is the current diverted from the series winding, and, higher the speed of the motor. The minimum speed for a given input current is obtained by opening the switch `S', thereby breaking the circuit through the diverter.

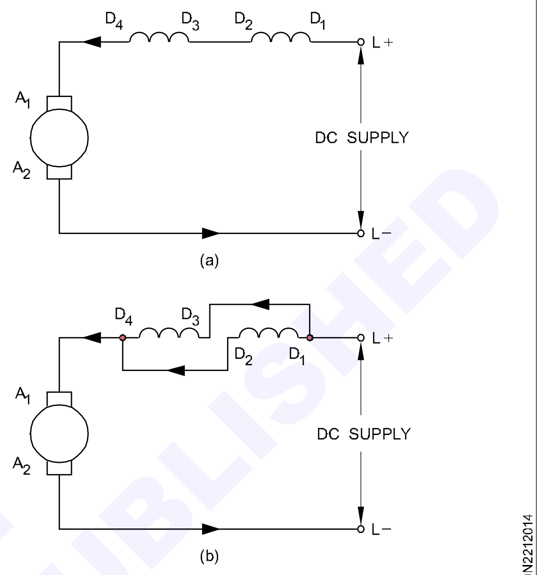
Application of the series field diverter method: This method is mainly used in the speed control of electric trains. By this method, speeds above normal only could be obtained, and the power loss in the diverter is quite considerable.

Series parallel method: Fig 4 (a) shows a series motor with two halves of the field winding connected in series. If the two halves of the field winding are connected in parallel as in Fig 4 (b), then for a given current 'I' taken from the supply, the current in each field coil is reduced to half and the flux is, therefore, reduced and the speed increased.

Application of series parallel method: This is the simplest method though only two speeds are possible. This method is often used for controlling the speed of fan motors.

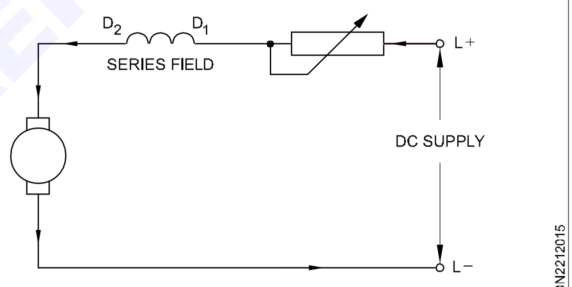
Supply voltage control method: A controller (variable resistance) is connected in series with the motor as shown in Fig 5. This method can be used to control the speed from zero up to full normal speed.

Fig 4



SERIES-PARALLEL METHOD OF CONTROL

Fig 5



VOLTAGE CONTROL CIRCUIT

The disadvantage in this method is that there is loss of energy in the control resistance in the form of heat. But with the introduction of SCR based control circuit, obtaining a variable supply voltage to motor is achieved with the least power loss. This method is widely used in larger modern machines where power loss is a major concern.

Troubleshooting in DC machines

Objective: At the end of this lesson you shall be able to
- **use the trouble shooting chart to rectify defects in i) DC machines in general ii) DC motors iii) DC generators.**

DC machines have Power problems which are not normally found in AC machines. DC motors and generators have commutators and brushes, which cause special problems. If the commutator is properly maintained, it will give many years of useful service.

Chart 1 deals with DC motors and Chart 2 is for DC generator.

Chart 1

Troubleshooting chart for DC motors

Symptoms	Cause	Remedies
Motor will not start	a) Open circuit in starter. b) Low or no terminal voltage. c) Bearing frozen. d) Overload. e) Excessive friction.	a) Check for open starting resistor, b) Check the incoming voltage with name-plate rating and correct the supply voltage. c) Recondition the shaft and replace the bearing. d) Reduce the load. e) Check the bearing lubrication to make sure that the oil is sufficient quantity and of good quality. Disconnect motor from driven machine and turn motor by hand to see if trouble is in motor. Strip and reassemble motor; then check part by part for proper location and fit. Straighten or replace bent shaft.
Motor stops after running short time	a) Motor is not getting power. b) Motor is started with weak or no field. c) Motor torque insufficient to drive load.	a) Check voltage in the motor terminals: also fuses and overload relay. Rectify the defect. b) If adjustable-speed motor, check the rheostat for correct setting. If correct, check the condition of rheostat. Check the field coils for open winding. Check the wiring for loose or broken condition c) Check the line voltage with name plate rating. Use larger motor or one with suitable characteristic to match the load.
Motor runs too slow under load.	a) Line voltage too low. b) Brushes ahead of neutral plane. c) Overload.	a) Rectify the supply voltage or under load check and remove any excess resistance in supply line, connections or controller. b) Set brushes on neutral plane. c) Check to see that load does not exceed allowable load on motor.

Motor runs too fast under load.	a) Weak field. b) Line voltage too high. c) Brushes are out of neutral plane.	a) Check for resistance in shunt-under load field circuits. Check for grounds. b) Correct high voltage condition. c) Set brushes on neutral plane.

Chart 2

Troubleshooting chart for DC Generators

Symptoms	Cause	Remedies
Generator fails to build up voltage	a) The direction of rotation must have been reversed.	a) Change the direction of rotation
	b) Brushes not resting on the commutator.	b) Brushes to be set over the commutator in correct position.
	c) Residual magnetism is completely lost.	c) Run the generator as a DC motor or sometime (few seconds) or connect the field circuit to a battery or DC voltage to reestablish the residual magnetism.
	d) Generator speed is too low.	d) Generator speed should be restored to normal speed by increasing the prime mover speed.
	e) Short circuit in the armature.	e) Rectify the short circuit in the armature.
	f) Open circuit in the armature.	f) Test and rectify the open circuit.
	g) Short circuit in the field circuit.	g) Test and rectify the short circuit which may be in the coil. Faulty coil will show much less resistance than a good coil.
	h) Open circuit in field winding.	h) Check the continuity of the circuit and rectify the defect.

Maintenance procedure for DC machines

Objectives: At the end of this lesson you shall be able to
- **state what is meant by preventive maintenance and its importance**
- **describe the recommended maintenance schedule for DC motors**
- **explain how to maintain the maintenance record.**

Preventive maintenance: Preventive maintenance of Power machines consists of routinely scheduled periodical inspections, tests, planned minor maintenance repairs and a system of maintaining inspection records for future reference. Preventive maintenance is a combination of routine and planned operations.

Routine operations: Routine operations are those which follow fixed schedules to maintain Power motors at daily, weekly or at other fixed intervals.

Planned operation: By contrast, planned operation consists of additional work which is performed at irregular frequencies, and is determined by inspection and previous operating experience or the details of defects found in the maintenance records.

Necessity of preventive maintenance: By carrying out an effective preventive maintenance programme on Power machines, we can eliminate major failures of the machines, accidents, heavy repair costs and loss of production time. Proper preventive maintenance will lead to economy of operation, less down-time, dependable machine operation, longer machine life and lower overall cost of maintenance and repair.

Scheduling of preventive maintenance: Routine periodical inspection and tests may be scheduled to be carried out daily, weekly, monthly, half-yearly and annually depending upon the following factors.

- The importance of the motor/generator in the production
- The duty cycle of the machine

- The age of the machine
- The earlier history of the machine
- The environment in which the machine operates
- The recommendations of the manufacturer.

Recommended maintenance schedule for machines: While carrying out routine periodical maintenance, an electrician will make full use of his senses to diagnose and locate problems in Power machines. The sense of smell directs attention to burning insulation: the sense of feel detects excessive heating in winding or bearing; the sense of hearing detects excessive noise, speed or vibration and the sense of sight detects excessive sparking and many other mechanical faults.

Sensory impressions must also be supplemented by various testing procedures to localize the trouble. A thorough understanding of Power principles and the efficient use of test equipment are important to an electrician during this phase of operation.

The following maintenance schedule is recommended for DC machines.

1 Daily maintenance

- Examine visually earth connections and machine leads.
- Check the sparking at the commutator.
- Check the motor windings for overheating. (The permissible maximum temperature is near about that which can be comfortably felt by hand.)
- Examine the control equipment.
- In the case of oil-ring lubricated machines
  a) examine the bearings to see that the oil rings are working
  b) note the temperature of the bearings
  c) add oil, if necessary
  d) check end play.
- Check for unusual noise at the machine while running.

2 Weekly maintenance

- Examine the commutator and brushes.
- Check belt tension. In cases where this is excessive it should immediately be reduced. In the case of sleeve-bearing machines, the air gap between the rotor and stator should be checked.
- Blow out air through the windings of protected type machines situated in dusty locations.
- Examine the starting equipment for burnt contacts where machine is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, grit, etc.(This can be roughly judged from the colour of the oil.)
- Check foundation bolts and other fasteners.

3 Monthly maintenance

- Overhaul controllers.
- Inspect and clean the oil circuit breakers.
- Renew the oil in high- speed bearings which are in damp and dusty locations.
- Wipe the brush-holders and check the bedding of brushes of DC machines.
- Test the insulation of windings.

4 Half-yearly maintenance

- Check the brushes and replace, if necessary.
- Check the windings of machines subjected to corrosive and other elements. If necessary, bake the windings and varnish.
- Check the brush tension and adjust, if necessary.
- Check the grease in the ball and roller bearings, and make it up, where necessary, taking care to avoid overfilling.
- Check the current input to the motor or the output of the generator and compare it with normal values.
- Drain all the oil bearings, wash with petrol to which a few drops of oil have been added; flush with lubricating oil and refill with clean oil.

5 Annual maintenance

- Check all the high speed bearings, and renew, if necessary.
- Blow out all the machine winding thoroughly with clean dry air. Make sure that the pressure is not that high as to damage the insulation.
- Clean and varnish the oily windings.
- Overhaul the motors which have been subjected to severe operating conditions.
- Renew the switch and fuse contacts, if damaged.
- Check the oil in the starter and the grease/oil in the bearings.
- Renew the oil in the starters subjected to damp or corrosive elements.
- Check the switch conditions, resistance to earth between motor/generator windings, control gear and wiring.
- Check the resistance of earth connections.
- Check the air gaps in between the armature and field.
- Test the insulation of windings before and after overhauling the motors/generators.

6 Records

- Maintain a register giving one or more pages for each machine, and record therein all important inspections and maintenance works carried out from time to time. These records should show past performance, normal insulation level, air gap measurements, nature of repairs and interval between previous repairs and other important information which would be of help for good performance and maintenance.

While routine maintenance could be done either during the working of the machine or during short interval `down' periods, the planned maintenance requires to be done during holidays or by taking shut-downs of small duration.

Planned maintenance schedule needs to be decided, based on the routine maintenance reports entered in the maintenance card.

Initial test results	**Page 1**
Resistance value of shunt winding ____________	
Resistance value of series winding ____________	
Resistance value of armature ____________	
Insulation resistance value between	
armature and shunt field ____________	
armature and series field ____________	
series field and shunt field ____________	
armature and frame ____________	
shunt field and frame ____________	
series field and frame ____________	
The 2nd page gives the record of maintenance carried out, and, in particular the defects noted therein.	

Maintenance record

Maintaining a system of inspection records is a must in preventive maintenance schedule. This system uses a register as stated above or cards as shown below which are kept in the master file. By referring to these maintenance cards, the foreman can schedule the planned maintenance.

Maintenance card: The 1st page gives initial test results etc pertaining to the machine.

A careful study of the maintenance card helps the foreman to plan the shut-down date to facilitate early overhauling or planned maintenance schedule to prevent a major breakdown.

Method of maintenance: During the routine maintenance inspection, the investigations and adjustment to be carried out for the parts and accessories of the motors/generators are given below to improve the efficiency of preventive maintenance.

- Clean daily the motor/generator, switch gear and associated cables free from dirt, dust and grease. Use dry compressed air to drive away the dust from the machines.
- Check the bearing daily for excessive noise and temperature. If required, re-grease or re-oil the bearing with the same grade of grease/oil as in original. Do not mix different grades of grease together as it may result in forming sludge or acids, and spoil the bearings.
- Check the machine daily against strains of water or oil or grease which may leak from the surroundings. Take the necessary protective steps to prevent the leakage.
- Check daily the belts, gears and coupling for looseness, vibration and noise. Adjust/replace the parts, if found defective.
- Check weekly the brushes and the commutator for sparking and wear.
- Check weekly the bearing for proper lubrication.
- Check weekly the terminals and switch contacts.
- Inspect the brushes and the commutator once in a month for excessive wear, chatter and sparking. Worn-out brushes need to be replaced with the same grade brushes. Check spring tension on the brushes, and adjust, if necessary. Badly worn-out commutators need to be turned in a lathe or be replaced.
- Check monthly the brushes for proper seating. If necessary, reshape the brushes to proper curvature to suit the commutator surface.
- Check monthly the end plates and the shaft for excessive end play.
- Check monthly the main and auxiliary contact points of the switch gear for wear, pitting and burns. Badly worn out contact point needs replacement. Check the connection terminals for loose connection and scales or burning. Rectify the defects.
- Test monthly once the field windings and armature for insulation and ground faults. Low reading of insulation below 1 megohm indicates weak insulation. Dry out the winding, and re-varnish, if necessary.
- Check monthly once the foundation bolt and other fasteners for tightness.
- Once a year undercut the mica in between the commutator bars. Test the commutator and armature for shorts, open and ground faults.

Maintenance card

Report on routine maintenance **Page 2**

Date of maintenance	Scheduled maintenance carried out	Defects noted	Attended by (Signature)	Reported to (Signature)	Remarks

The 3rd page gives the details of the test carried out in the motor at intervals with corresponding readings

Maintenance card

Report on test details **Page 3**

Date of Test	Schedule	Test particulars	Test results	Tested by (Signature)	Reported to (Signature)	Remarks

From the above it is clear that atleast once in a year, the motor/generator needs a thorough overhauling in addition to frequent routine maintenance.

The 4th page gives the details of the defects, causes and repair carried out

Motor service card **Page 4**

Date of repair	Repair and parts replaced	Cause	Repaired by (Signature)	Supervised by (Signature)	Remarks

Materials used for winding - field coil winding

Objectives: At the end of this lesson you shall be able to
- **list out the insulating materials used for winding and their applications.**

Insulating materials : In winding work, proper selection of insulating materials is an important criterion. The ageing factor of the insulation of Power equipment and apparatus depends upon many factors, such as temperature, Power and mechanical stress, vibration, moisture, dirt and chemical reaction.

Materials: The following are the common insulating materials used for winding purposes.

- Leatheroid paper
- Pressphan paper
- Triplex paper
- Millinex paper
- Micanite paper (mica folium)
- Empire cloth
- Glass fibre cloth
- Cotton tape
- Empire tape
- Fibre glass tape
- Cotton sleeves
- Empire sleeves
- Fibre glass sleeves
- PVC sleeves
- Bamboo
- Hemp thread
- Terylene thread
- Varnish

Winding wires

Objectives: At the end of this lesson you shall be able to
- **list out the winding wires used for winding.**

Winding wires : The annealed copper conductors, normally in round shape, are used for winding small and medium capacity Power machines and equipments. These copper wires are provided with a variety of insulation as stated below.

- Super-enamelled copper wire (S.E.)
- Single cotton-covered copper wire (S.C.C.)
- Double cotton-covered copper wire (D.C.C.)
- Single silk-covered copper wire (S.S.C.)
- Double silk-covered copper wire (D.S.C.)
- PVC-covered copper winding wire

Generally super-enamelled copper winding wire with medium covering is used for most of the winding applications, whereas for some special applications super-enamelled copper wire with thick covering may be used.

Field coils and armature of certain DC machines might be wound with super-enamelled, DCC or DSC copper winding wires.

PVC covered copper winding wire is mainly used for submersible pumps.

The winding wires are available in different sizes and grades of insulation.

Armature winding - terms - types - rewinding of mixer/liquidizer

Objectives: At the end of this lesson you shall be able to
- **define the general terms used in DC armature winding**
- **explain the different types of DC armature winding.**

DC armature winding : It is a closed coil winding, wherein the coil ends are connected through the commutator segments to form the closed circuit.

Terms used in DC armature winding

Coil or winding element : Length of a wire lying in the magnetic field and in which an emf is induced is called an active conductor.

Referring to Fig 1, we find the two active conductors AB and CD along with their end connections constitute one coil or winding element of the armature winding. The coil may consist of a single turn only as shown in Fig 2 or multi-turns as shown in Fig 3. A single-turn coil or winding element will have two conductors only. But a multi-turn coil may have many conductors per coil side. In Fig 2 for example, each coil side has 3 conductors. The group of conductors constituting a coil side of a multi-turn coil is tied together with a tape as a unit (Fig 3) and is placed in the armature slot. It may be noted that each winding element has two connecting leads and each commutator bar has two connecting leads brought from the winding. As such there are as many commutator bars as the number of winding elements.

Active sides : These are the sides which lie within the slots. They are also known as coil sides. The induction takes place only in the active sides of the coil while they move in the magnetic field. (Fig 3)

Fig 1

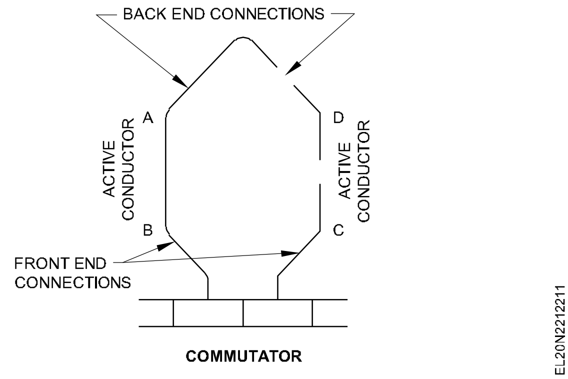


Fig 2

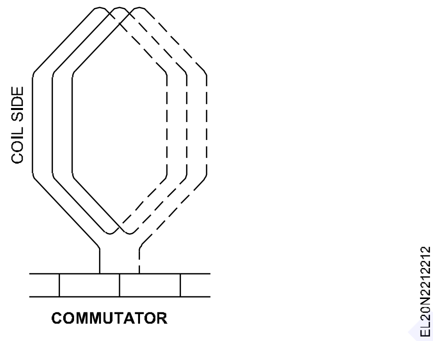
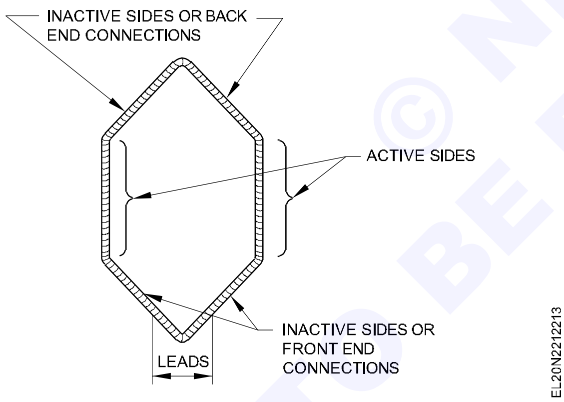


Fig 3



In winding calculation these active sides are considered as conductors. The coil has got two conductors irrespective of the number of turns.

Inactive sides : That part of a coil which does not lie in the slot is known as the inactive side of a coil. No induction takes place in the inactive sides.

Example: Back and front end connections. (Fig 3)

Leads of coil : The ends coming out from a coil are known as leads of a coil. Every coil has got two leads.

Pole-pitch(Y_p) : It may be variously defined as:

- the periphery of the armature divided by the number of poles of the machine i.e. the distance between two adjacent poles. It is denoted by Y_p.
- it is equal to the number of armature conductors (or armature slots) per pole. For example, if there are 48 conductors, 24 coils, 24 slots and 4 poles, then the pole pitch is

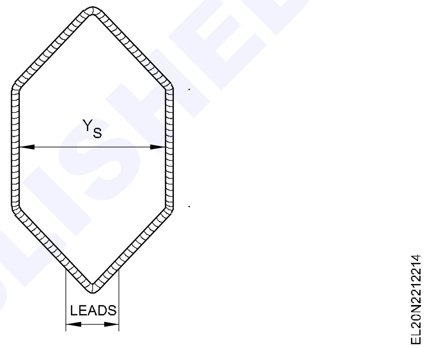
$$Y_P = \frac{\text{Number of slots}}{\text{Number of poles}} = \frac{24}{4} = 6 \text{ in terms of slots}$$

or

$$Y_P = \frac{\text{No. of conductors}}{\text{No. of poles}} = \frac{48}{4} = 12 \text{ in terms of conductors}$$

Coil-span or coil-pitch(Y_S) : The coil-span or coil-pitch is the distance, measured in terms of armature slots or armature conductors between two sides of a coil. It is in fact the periphery of the armature measured in terms of slots or conductors spanned by the two sides of the coil. It is denoted by Y_S as shown in Fig 4.

Fig 4



Coil-pitch Y_S is calculated in the same way as is done for Pole pitch.

Hence the modified calculation will be

$$Y_S = \frac{\text{No. of slots}}{\text{No. of poles}} - K = \frac{S}{P} - K \text{ (in terms of slots)}$$

$$= \frac{\text{No. of conductors}}{\text{No. of poles}} - K = \frac{C}{P} - K \text{ (in terms of conductors)}$$

where K = any part of S/P or C/P that is subtracted to make Y_s an integer.

Back pitch (Y_B) : The distance measured in terms of the armature conductors which a coil advances on the back of the armature is called back pitch and is denoted by Y_B. This is illustrated in Figs 5 and 6. The back pitch is also equal to the coil-pitch.

Fig 5

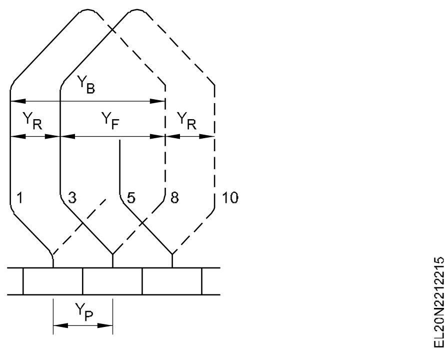
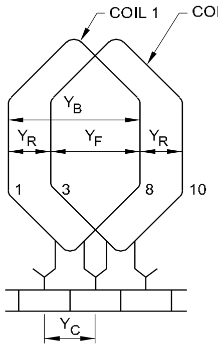
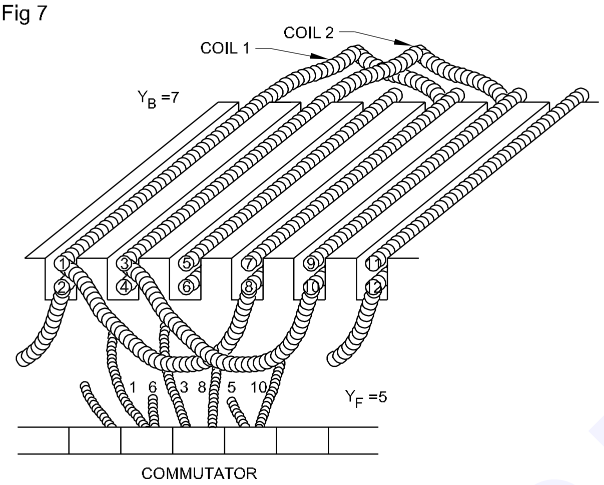


Fig 6



As shown in Fig 7, coil side 1 is connected on the back of armature to coil side 8 (same coil). Hence $Y_B = 8 - 1 = 7$ conductors.

Fig 7



Front pitch(Y_F) : The number of armature conductors or elements spanned by a coil on the front (commutator end of an armature) is called the front pitch and is designated by Y_F. This is shown in Figs 5,6 and 7. Coil side 8 is connected to coil side 3 (second coil) through the commutator segment. Hence $Y_F = 8 - 3 = 5$ conductors.

Average pitch (Y_A) : The average of the front pitch Y_F and the back pitch Y_B is called average pitch. Y_A

$$\text{i.e., } Y_A = \frac{Y_B + Y_F}{2}$$

It is expressed in number of conductors.

Resultant pitch (Y_R) : In general, it may be defined as the distance between the beginning of one coil and the beginning of the next coil to which it is connected or it is the distance between the beginnings of two consecutive coil sides as shown in Figs 7 and 8 and denoted by letter Y_R. As in Fig 9, $Y_R = Y_B - Y_F$, i.e. $Y_R = 7 - 5 = 2$ conductors. The resultant pitch Y_R depends upon the type of winding like lap or wave, as well as simplex or multiplex.

Commutator pitch(Y_c) : It is the distance (measured in commutator bars or segments) between the segments to which the two ends of a coil are connected. It is denoted by Y_c. From the Figs 5,6 and 7, it is clear the commutator pitch Y_c = 1 segment.

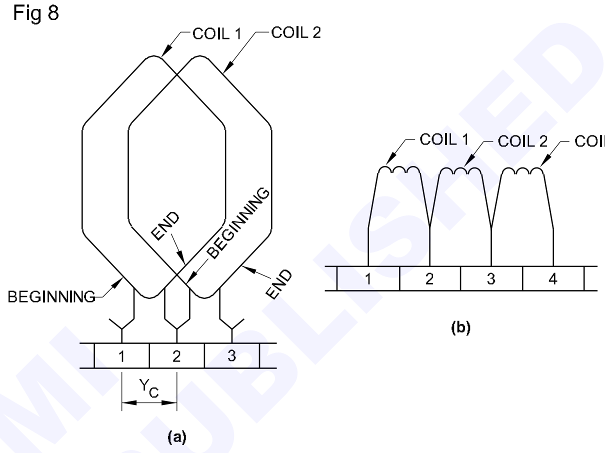
The commutator pitch Y_c varies with the type of winding, like lap or wave as well as simplex or multiplex.

Types of DC armature windings

Lap and wave winding : The DC armature windings are classified into two main groups, lap and wave windings. The difference between them is the manner in which, the leads are connected to the commutator segments.

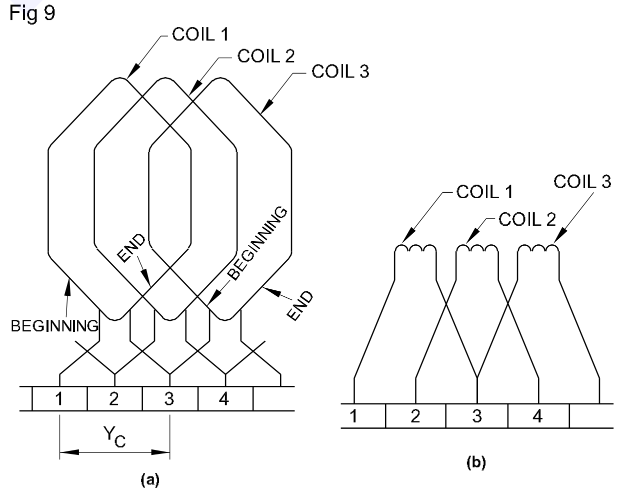
Simplex lap winding : In a simplex lap winding, the end lead of coil 1 is connected to the beginning lead of the adjacent coil(coil 2) through the commutator segments. The commutator pitch of one segment is maintained. Fig 8 shows the lead connection of a simplex lap winding.

Fig 8



Duplex lap winding : In duplex lap winding, the end lead of coil 1 is connected to the beginning lead of coil 3, through commutator segments. The commutator pitch of two segments is maintained as shown in Figs 9a and b.

Fig 9



In triplex lap and quadruplex lap windings, the end leads of coil 1 are connected to the beginning leads of coil 4 and coil 5 respectively through commutator segments. In general commutator pitches

Y_c = 1 segment for simplex lap winding

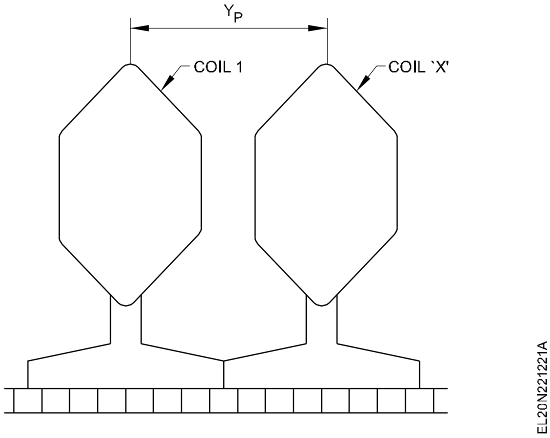
Y_c = 2 segments for duplex lap winding

Y_c = 3 segments for triplex lap winding

Y_c = 4 segments for quadruplex lap winding.

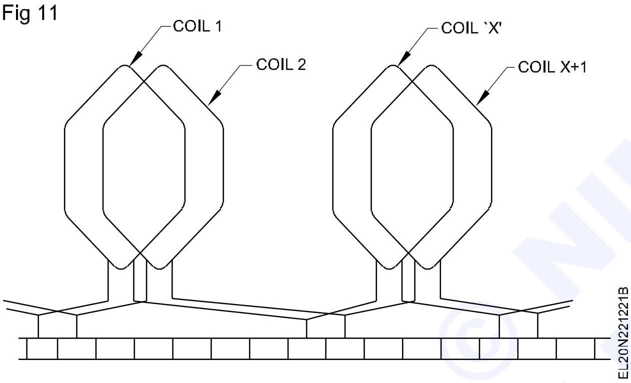
Simplex wave winding : In simplex wave winding, the end lead of the coil 1 is connected to the beginning of a coil placed at a distance equal to one pole pitch. (Fig 10)

Fig 10



Duplex wave winding : In duplex wave winding there is parallel combination of two simplex wave windings as shown in Fig 11.

Fig 11

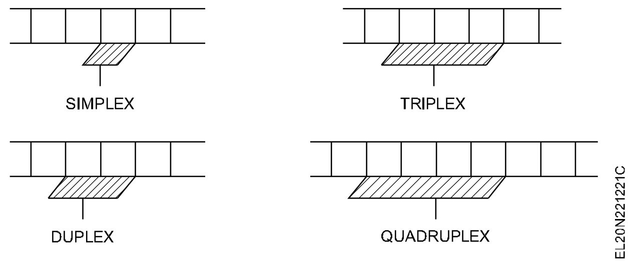


Triplex wave winding : Triplex wave winding will have a parallel combination of three simplex wave windings, and so on.

> **The width of the brush will be such that in simplex lap or wave winding, the brush will make contact with only one segment. The brush will contact two segments in duplex, three in triplex and four in quadruplex. (Refer to Fig 12)**

Progressive lap or wave winding : In progressive lap or wave winding, the front pitch Y_F will be less than the back pitch Y_B, i.e. as you lay the coils clock-wise, the connections to the commutator segments will also proceed clockwise as in Figs 13a and b. In progressive winding, Y_c is referred to as +1.

Fig 12



Retrogressive lap or wave winding: In retrogressive lap or wave winding, the front pitch Y_F will be greater than the back pitch Y_B, i.e. as you lay the coils clockwise, the connection to the commutator segments will proceed anticlockwise as shown in Figs 14 a & b. In retrogressive winding Y_c is represented as -1.

Fig 13

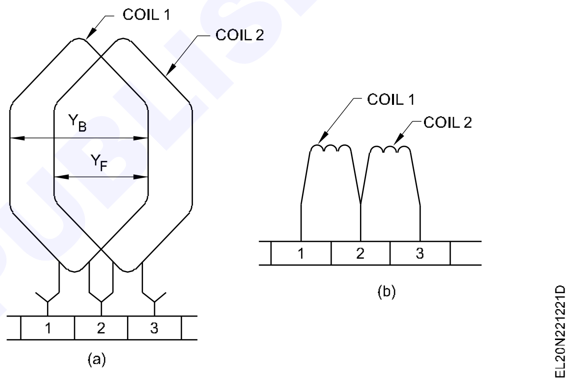
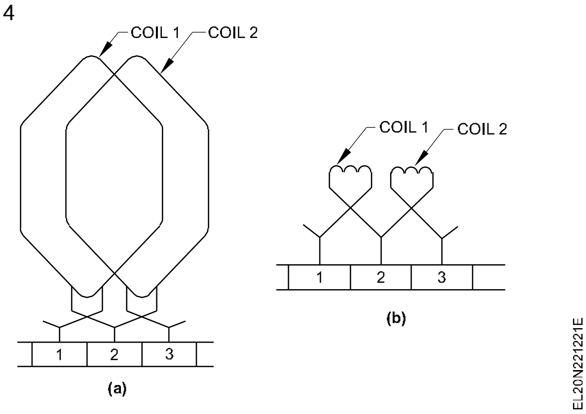


Fig 14



Simplex lap and wave winding - developed diagram

Objectives: At the end of this lesson you shall be able to
- **state the conditions for Lap winding and wave winding**
- **calculate and draw the developed ring diagram for simplex lap and wave winding.**

Development winding diagram : To draw the development winding diagram, the winding particulars like number of conductors, number of poles, pitches, types of windings etc. are required. For any DC armature winding, there shall be as many coils as the number of commutator segments. Further, the number of coils will be the multiple of the number of slots, i.e. for a single layer, there will be double the number of slots as that of the commutator segments and for a double layer there will as many slots as the commutator segments.

Lap winding

Conditions for lap winding : For lap winding the following terms and conditions are to be fulfilled.

- The front pitch Y_F and the back pitch Y_B should be approximately equal to the pole-pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F should differ by 2 conductors, for simplex lap winding. In the case of multiplex winding, it is equal to 2 x No. of `plex'.

Ex. For duplex 2x2 = 4 conductors.

For triplex 2x3 = 6 conductors and so on.

The average pitch should be as given by the formula

Commutator pitch should be

Y_C = ± 1 for simplex

= ± 2 for duplex

= ± 3 for triplex and so on.

- The number of parallel paths `A' in the armature will be the multiple of the number of poles. A = P, in the case of simplex lap winding, i.e 2-pole armature winding will have 2 parallel paths, 4-pole armature winding will have 4 parallel paths and so on. However, the number of parallel paths for multiplex winding will be equal to A = P x No. of `plex'.
- There must be as many brushes as there are poles.
- The brushes must be wide enough to cover atleast *m* segments, where '*m* ' is the 'plex' (multiplicity) of the winding.

Progressive winding

$$\text{Back pitch} Y_B = \frac{Z}{P} + 1$$

Front pitch $Y_F = Y_B - 2$ x plex

Reprogressive winding

$$\text{Front pitch} Y_F = \frac{Z}{P} + 1 \qquad \text{Back pitch } Y_B = Y_F - 2 \text{ x plex}$$

To make the winding possible as lap-winding, Z/P must be an even number.

Considering the above points, only the armature having the designated slots can be wound for lap winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex lap winding.

Example

No. of commutator segments 6

No. of slots 6

No. of poles 2

Type of winding simple lap.

As pointed out earlier the winding should be in double layer only.

Solution

No. of coils = No. of commutator segments = 6 coils

No. of conductors or coil sides = No. of coils x 2
= 6 x 2 = 12 conductors.

$$\text{Pole pitch} Y_P = \frac{\text{No. of slots}}{\text{No. of poles}} = 6/2 = 3 \text{ slots}$$

$$\text{Also } Y_P \text{ in terms of conductors } = \frac{\text{No. of conductors}}{\text{No. of poles}} = 12/2 = 6 \text{ conductors}$$

No. of conductors/slot = 12/6 = 2 conductors/slots.

Hence the winding is double layer winding.

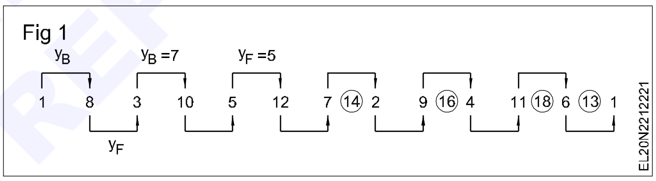
$$\text{Back pitch } Y_B = \frac{Z}{P} + 1 = 12/2 + 1 = 6 + 1 = 7$$

Front pitch $Y_F = Y_B - 2$ x Plex = 7 − 2 = 5

Y_B = 7 and Y_F = 5 for progressive winding

Y_B = 5 and Y_F = 7 for retrogressive winding

The winding sequence of conductors for progressive lap winding is shown in Fig 1.



Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	II
2	3	10	2	5	II	III
3	5	12	3	6	III	IV
4	7	2	4	1	IV	V
5	9	4	5	2	V	VI
6	11	6	6	3	VI	I

Development winding diagram for 12 conductors, 2 poles, 6 slots, 6 segments, simplex double layer lap winding

Fig 2 shows the arrangement of coils in the respective slots and the connection of the coils with the segments.

Development diagram with conductors : Fig 3 shows the arrangement of armature conductors in the slots and connections to commutator segments.

Fig 2

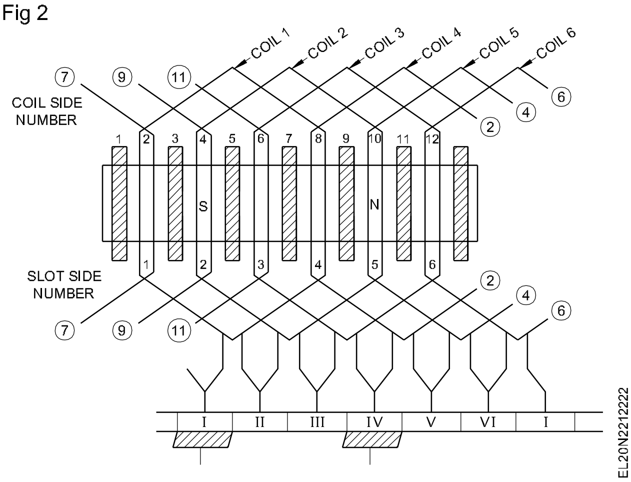
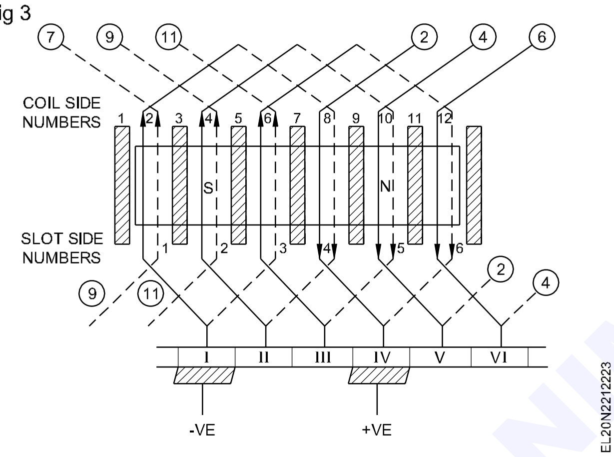
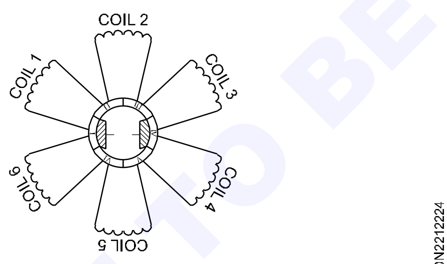


Fig 3



Ring diagram : Fig 4 shows the connection of 6 coils with the commutator segments in the form of a ring diagram.

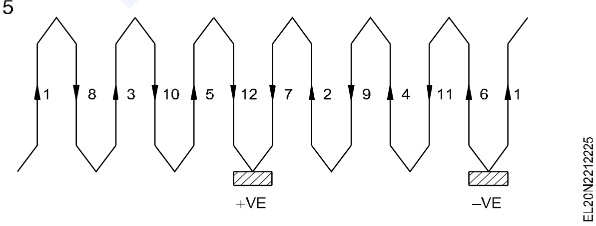
Fig 4



RING DIAGRAM

Sequence diagram : This diagram is mainly used to trace the direction of current in the coil sides (conductors). With the help of this diagram the brush position can be located. (Fig 5)

Fig 5



Wave winding

Conditions for wave winding : For wave winding, the following terms and conditions should be fulfilled.

- The front pitch Y_F and back pitch Y_B should be approximately equal to the pole pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F may be of the same value or may differ by 2 conductors, in the case of simplex, and the same or 2 or 4 conductors for multiplex wave winding, depending upon the condition

$$Y_A = \frac{Y_B + Y_F}{2} \text{ approximately}$$

- The average pitch should be as given by the formula

$$Y_A = \frac{Y_B + Y_F}{2} \text{ (or)}$$

$$Y_A = \frac{\text{No.of conductors} \pm 2 \text{ x plex}}{\text{No. of poles}}$$

$$Y_A = \frac{Z \pm 2}{P} \text{ for simplex wave winding}$$

$$= \frac{Z + 2}{P} \text{ for progressive simplex wave winding}$$

$$= \frac{Z - 2}{P} \text{ for retrogressive simplex wave winding}$$

$$Y_A = \frac{Z \pm 4}{P} \text{ for duplex wave winding}$$

$$Y_A = \frac{Z \pm 6}{P} \text{ for triplex wave winding and so on}$$

$$Y_C = \frac{\text{No.of commutator segments} \pm m}{\text{Pairs of poles}} = \frac{C \pm m}{p/2}$$

where Y_c is the commutator pitch

C = total number of commutator segments

p = number of poles

m = the plex of the winding.

The commutator pitch Y_c shall be equal to the average pitch Y_A . $Y_c = Y_A$

The resultant pitch is the sum of the front and back pitches. $Y_R = Y_B + Y_F$

- The number of coil sides must satisfy the following relations.

  $Z = P \times Y_A \pm 2$ where P is the number of poles.

- In the case of simplex wave winding the number of parallel paths `A' is equal to 2 only, irrespective of the number of poles. However the number of parallel paths increases in multiples of the plex of the windings.

  Eg. A = 2 x plex.

Considering the above points, only an armature having designated slots can be wound for wave winding.

- Two brushes are necessary, but as many brushes as there are poles may be used, and they must be set so that they short-circuit only the coils cutting no flux.
- The brushes must be wide enough to cover atleast `m' segments where 'm' is the 'plex' of the winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex wave winding.

Example

Number of commutator segments	7 Nos.
Number of slots	7 Nos.
Number of poles	2 Nos.
Type of winding	Wave.

Winding table

1 The number of coils = Number of commutator segments = 7 coils.

2 The number of conductors or No. of coil sides = No. of coils x 2 = 7 x 2 = 14 conductors.

3 Pole pitch $Y_P = \frac{\text{No.of slots}}{\text{No. of poles}} = 7/2 = 3.5$ slots, say 3 slots

Also, $Y_P = \frac{\text{No.of conductors}}{\text{No. of poles}} = 14/2 = 7$ conductors

4 No. of conductors/slot = 14/7 = 2 conductors/slot. Hence, the winding is double layer.

5 Average pitch $Y_A = \frac{Z \pm 2}{P}$

$= \frac{14+2}{2} = 16/2 = 8$ (for progressive winding).

$= \frac{14-2}{2} = 12/2 = 6$ (for retrogressive winding).

Hence $Y_A = Y_C = 8$ or 6.

6 Taking $Y_A = 8$ for progressive winding we have

$2Y_A = 2 \times 8 = 16 = Y_B + Y_F$

$Y_B - Y_F = 2$

$Y_B + Y_F = 16.$

Hence back pitch $Y_B = 9$ and front pitch $Y_F = 7$.

Taking $Y_A = 6$ for retrogressive winding we have

$2Y_A = 2 \times 6 = 12 = Y_B + Y_F$

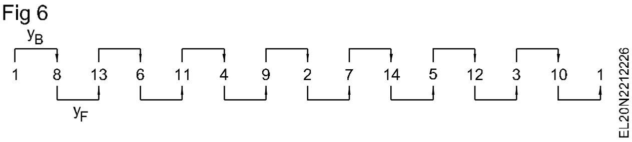
$Y_B - Y_F = 12.$

Hence, back pitch $Y_B = 7$ and front pitch $Y_F = 5$ for retrogressive wave winding.

The winding sequence of conductors for retrogressive wave winding is shown in Fig 6.

$Y_B = 7$, $Y_F = 5$.

Fig 6



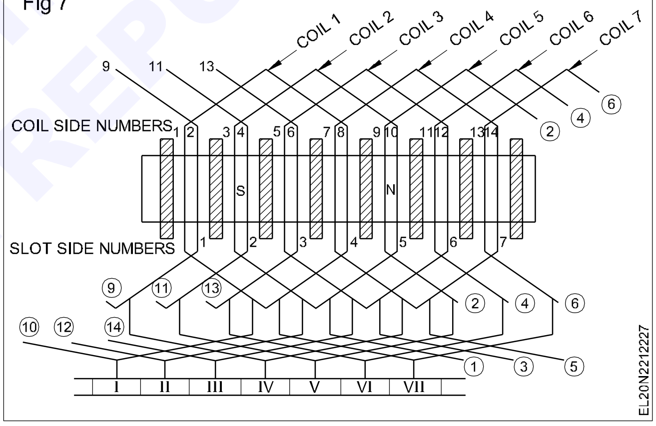
Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	VII
2	13	6	7	3	VII	VI
3	11	4	6	2	VI	V
4	9	2	5	1	V	IV
5	7	14	4	7	IV	III
6	5	12	3	6	III	II
7	3	10	2	5	II	I

Development winding diagram for 14 conductors, 2 poles, 7 slots, 7 segments, simplex, double layer wave winding

Development diagram with coil connection : Fig 7 shows the arrangement of coils in their respective slots and their connection to the segments.

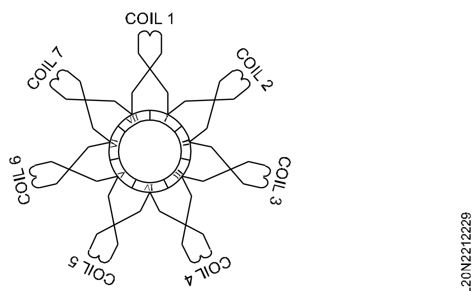
Fig 7



Development diagram with conductors : Fig 8 shows the arrangement of armature conductors in the slots and the connection to commutator segments.

Ring diagram : The ring diagram of wave winding in the case of a 2-pole armature will appear similar to that of lap winding, but the coil ends will be connected as shown in Fig 9.

Fig 9



Sequence diagram : This diagram (Fig 10) is mainly used to trace the current direction of the coil sides (conductors) and, thereby, locate the brush position. Please note the brush is placed at a distance of 3 commutator segments i.e. less than 180° geometrical (app.155°).

Fig 10

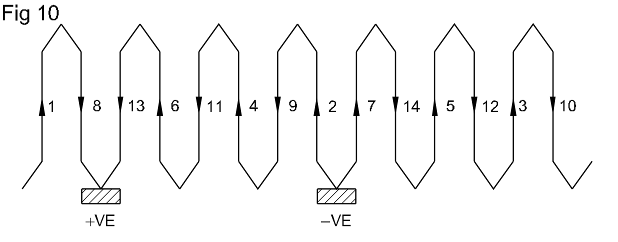
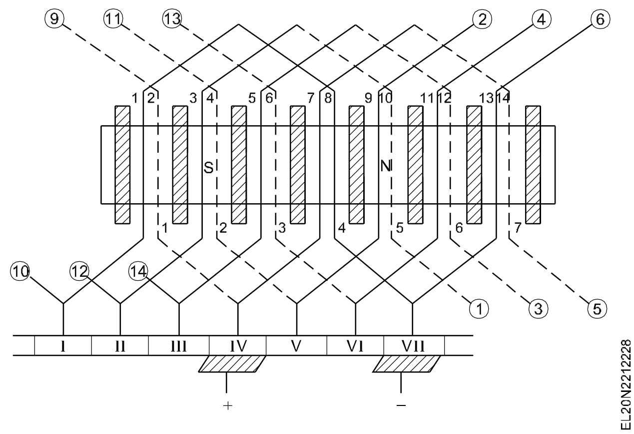


Fig 8



Testing of armature winding

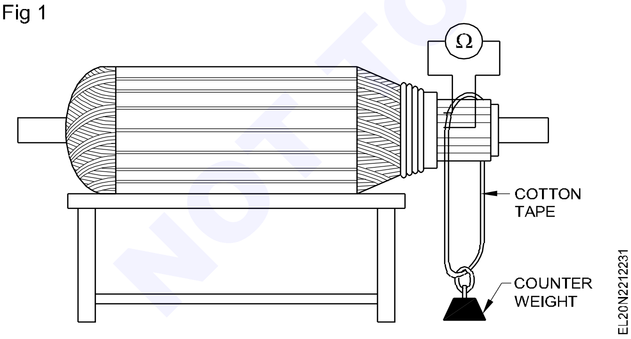
Objectives: At the end of this lesson you shall be able to

- **describe the methods of testing armature, such as the**
  - **– winding resistance test**
  - **– insulation resistance test**
  - **– growler test**
  - **– voltage drop test.**

Testing the winding : After an armature is wound and the leads are connected to the commutator, a test should be conducted. From this test, defects may be revealed, which might have occurred during winding. The common defects in armature windings are grounding, shorts in the coils, open in the coil and reversal in the coil connection. These defects can be located by different test procedures.

Armature winding resistance test : Resistance of the armature coil is measured by using a low range ohmmeter and preferably with the Kelvin bridge. Resistance between consecutive segments in the case of simplex lap winding (for wave and multiplex windings at a distance of commutator pitch Y_c) is measured. Fig 1 shows a simple arrangement to measure the resistance between the successive commutator segments.

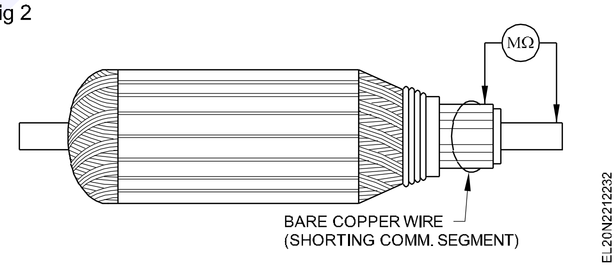
Fig 1



As shown in Fig 1, a cotton tape with a counterweight is passed around the commutator to hold the connecting leads to the segments. Measurement of resistance is done in all the coils by changing the position of the connecting leads to successive commutator segments. The resistance measured should be the same in all coils. Lower resistance shows short in turns, while a higher resistance shows higher numbers of turns or open in the coil.

Insulation resistance test : With a bare copper wire short all the commutator segments. (Fig 2) Test the insulation resistance between the body and the commutator segments by a 500V Megger, for armatures rated up to 250 volts. The IR so measured shall be greater than 1 megohm. If the value is less than 1 megohm, moisture in the winding or a weak insulation is to be suspected.

Fig 2



This test is sometimes conducted by a series test lamp and is called the 'ground test'. It will only indicate if any coil is grounded, and not the insulation resistance.

Growler test : A simple and most common method to test armature winding for short and open coils is by a growler.

Growler : There are two types of growlers - 1) internal and 2) external growlers. An external growler is used for testing small armatures and an internal growler for large DC armatures and AC motor stator windings.

External growler : An external growler, shown in Fig 3, is an electromagnetic device that is used to detect and locate grounded, shorted and open coils in an armature.

This growler consists of a coil wound around an iron core and is connected to a 240 volt AC line. The core is generally H shaped and cut out on top so that the armature will fit on it, as shown in Fig 4.

Fig 3

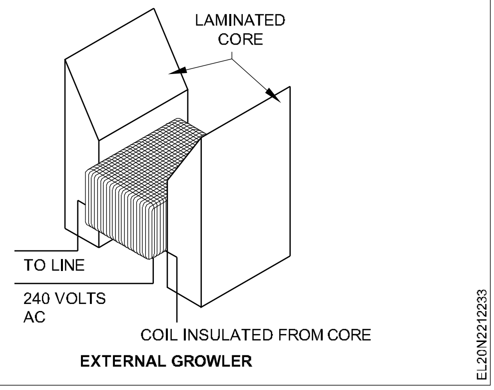
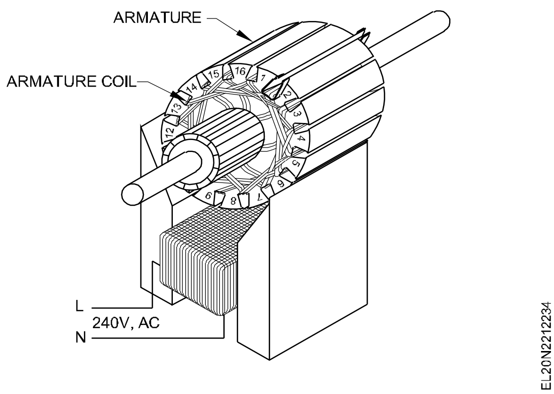


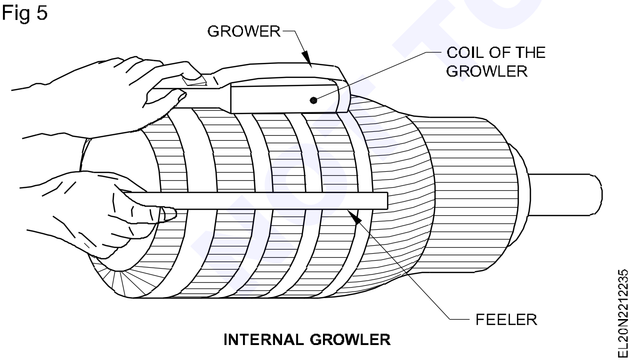
Fig 4



When an alternating current is applied to the growler coil, the voltage will be induced in the armature coils by transformer action.

Internal growler : An internal growler, such as the one used for stators, may be used for armatures as well. These are made with or without built-in feelers. The growler with a built-in feeler has a flexible blade attached to the growler so that a hacksaw blade or similar instrument is not necessary. This type is especially desirable in smaller stators that have no room for a separate feeler. Fig 5 shows an internal growler with a separate feeler, used for large armatures.

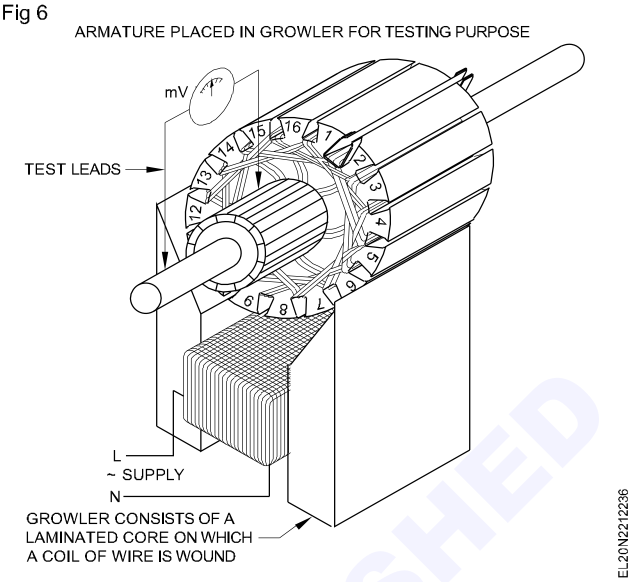
Fig 5



Growler test for grounded coil : The armature to be tested is placed on the growler and then the growler is switched 'ON'. Place one lead of an AC milli-voltmeter on the top commutator bar and the other meter lead on the shaft, as shown in Fig 6.

If a reading is noticed on the meter, turn the armature so that the next commutator bar is in the same position as the earlier one, and test as before. Continue in this manner until all the bars are tested. Where the meter gives no deflection, it is an indication that the grounded coil is connected to this particular bar.

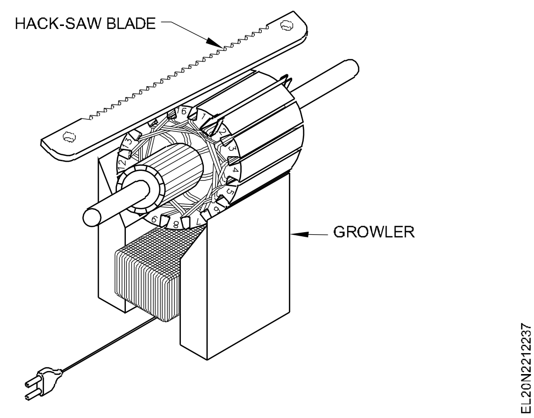
Fig 6



Growler test for shorted coil : The procedure to test for short circuits in an armature is as follows.

The armature to be tested is placed on the growler and then the growler is switched on. A thin piece of metal, such as a hacksaw blade, is held over the top slot of the armature as shown in Fig 7. In case of short in the winding, the blade will vibrate rapidly and create a growling noise. If the blade remains stationary, it is an indication that no short exists in the coil under test. After several top slots have been given the hacksaw blade test, turn the armature so that the next few slots are on top. Test as before and continue this procedure for the entire armature.

Fig 7

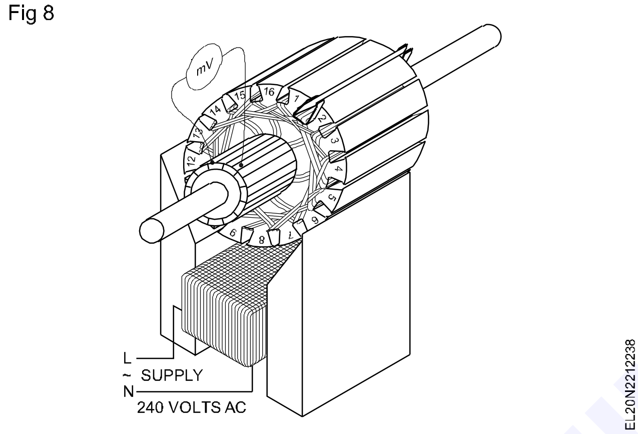


An armature having cross connections or equalizers cannot be given the hacksaw blade test. This type of armature will cause the blade to vibrate at every slot, which would seem to indicate that possibly every coil is shorted.

Test for open coil : Growlers are also provided with meters (milli-volt or ammeter) on the panel with variable resistance. In this case an open in the armature coil can be found out as follows.

Growler test for an open coil : To locate an open coil with a growler, set up the armature on the growler in the usual manner. Test the top two adjacent bars with an AC milli-voltmeter as shown in Fig 8. Rotate the armature and continue testing the adjacent bars. When the milli-voltmeter bridges the two bars connected to the open coil, the meter pointer will not deflect. All the other bars will give a deflection. This test for an open coil can be made without the meter by shorting the two top bars with a piece of wire. Absence of a spark indicates that the coil is open. The open may be either at the commutator bar or in the coil itself. The procedure may be used to determine the location of the leads of a shorted coil. However, the hacksaw blade test is the most satisfactory method of determining a shorted coil.

Fig 8



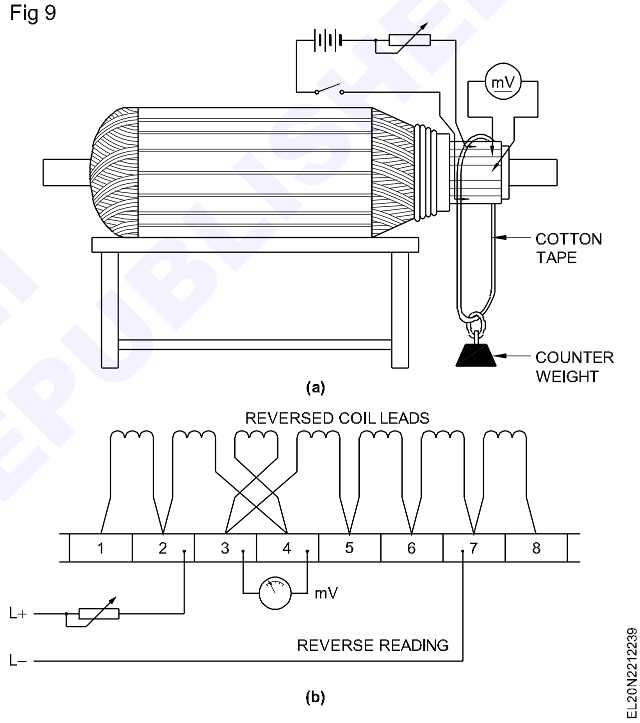
Drop test : The most accurate method of testing the armature for correct resistance, number of turns, short and open and reversed coil connection is by the drop test. Connect a low voltage DC supply across the commutator segments at a distance of pole pitch. Insert a variable resistance in series with the circuit. Switch 'ON' the DC supply and connect a milli-voltmeter to the adjacent segments as in Fig 9a and b.

Adjust the readings to a specified value, by using a variable rheostat. Record the milli-voltmeter readings on the consequent commutator segments by rotating the armature in one direction. The position of the segments and the connection should be the same as in the first set up. The result could be concluded as enumerated below.

- If all the readings are the same, the winding is correct.
- If the milli-voltmeter reads zero or low voltage, the coil connected to the segment is short.
- If the milli-voltmeter reads high voltage, the coil connected to the segment is open.
- If the milli-voltmeter deflects in the reverse direction as shown in Fig 9b, the coil connected with the segment is reversed.

Generally armatures are tested as a routine for insulation resistance and for shorted coils. Only when a fault in the armature winding is suspected, a drop test is conducted.

Fig 9



Principle of induction motor

Objectives: At the end of this lesson you shall be able to
- **state the principle of a 3-phase induction motor**
- **explain briefly the method of producing a rotating magnetic field.**

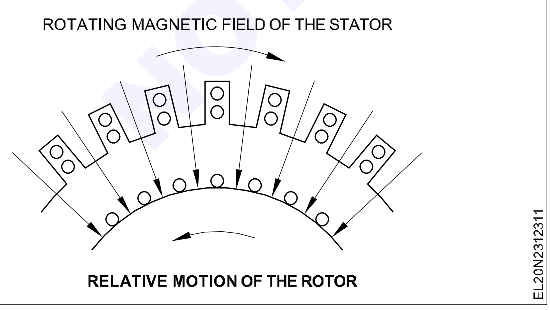
The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

Principle of 3-phase induction motor: It works on the same principle as a DC motor, that is, the current-carrying conductors kept in a magnetic field will tend to create a force. However, the induction motor differs from the DC motor in fact that the rotor of the induction motor is not electrically connected to the stator, but induces a voltage/ current in the rotor by the transformer action, as the stator magnetic field sweeps across the rotor. The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The stator of the 3-phase induction motor is similar to that of a 3-phase alternator, of revolving field type. The three-phase winding in the stator produces a rotating magnetic field in the stator core as it will be explained later. The rotor of the induction motor may have either shorted rotor conductors in the form of a squirrel cage or in the form of a 3-phase winding to facilitate the circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in a clockwise direction as shown in Fig 1. This makes for the relative motion of the rotor in an anticlockwise direction as shown in Fig 1. Applying Fleming's right hand rule, the direction of emf induced in the rotor will be towards the observer as shown in Fig 2. As the rotor conductors have a closed electric path, due to their shorting, a current will flow through them as in a short-circuited secondary of a transformer.

Fig 1



The magnetic field produced by the rotor currents will be in a counter-clockwise direction as shown in Fig 2 according to Maxwell's Corkscrew rule. The interaction between the stator magnetic field and the rotor magnetic field results in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator, as shown in Fig 3. As such the rotor follows the stator field in the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating magnetic field.

Fig 2

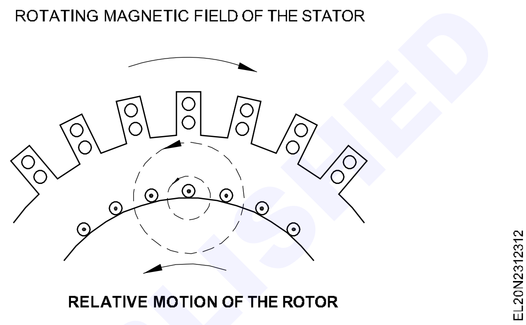
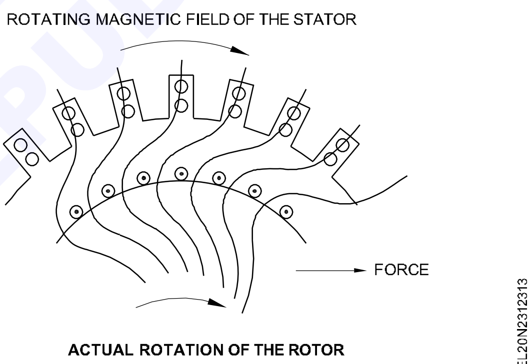


Fig 3



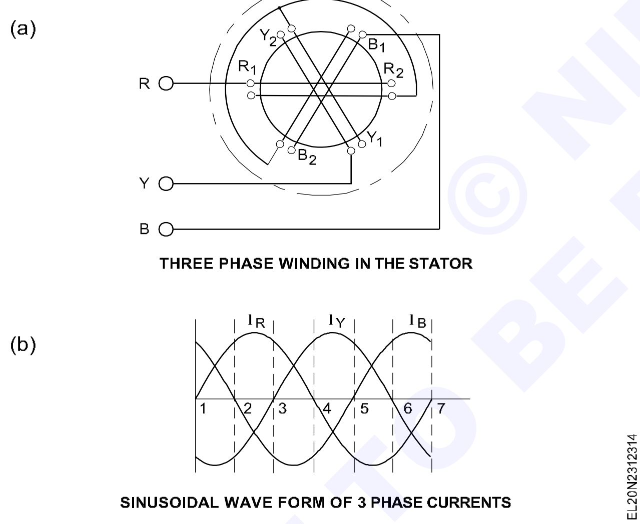
At higher speeds of the rotor nearing to synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator reduces and results in a smaller induced emf in the rotor. Theoretically, if we assume that the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and the rotor, and thereby no induced emf or current will be there in the rotor. Consequently there will not be any torque in the rotor. Hence the rotor of the induction motor cannot run at a synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force; thereby the relative speed increases, and the induced emf and current increase in the rotor resulting in an increased torque.

To reverse the direction of rotation of a rotor: The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is to be changed by changing any two leads connected to the stator.

Rotating magnetic field from a three-phase stator: The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three-phase windings placed at 120 Power degrees apart from each other. These windings are placed on the stator core to form non-salient stator field poles. When the stator is energized from a three-phase voltage supply, in each phase winding will set up a pulsating field. However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement of the flux is called the **`rotating magnetic field'**, and its speed is called the **`synchronous speed'**.

The manner, in which the rotating field is set up, may be described by considering the direction of the phase currents at successive instants during a cycle. Fig 4a shows a simplified star-connected, three-phase stator winding. The winding shown is for a two-pole induction motor. Fig 4b shows the phase currents for the three-phase windings. The phase currents will be 120 electrical degrees apart as shown in Fig 4b. The resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current.

Fig 4



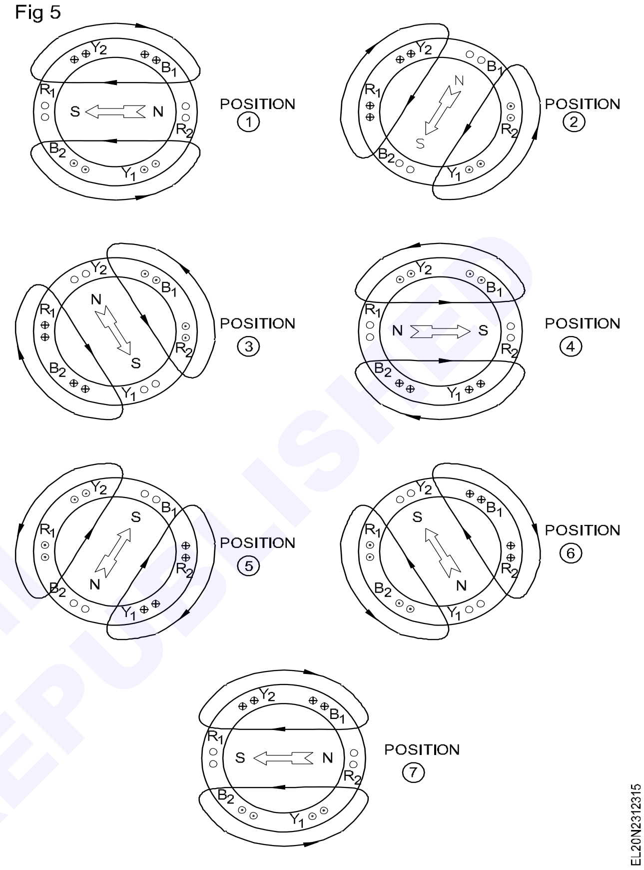
At position (1) in Fig 4b, the phase current I_R is zero, and hence coil R will be producing zero flux. However, the phase current I_B is positive and I_y is negative.

Considering the instantaneous current directions of these three phase windings, as shown in Fig 4b at position 1, we can indicate the current direction in Fig 5(1).

For convenience the +ve current is shown as +ve sign, and the -ve current is shown as dot (•) sign. Accordingly Y_2 and B_1 are shown as positive and Y_1 and B_2 are shown as negative. Using Maxwell's corkscrew rule, the resulting flux by these currents will produce a flux as shown in Fig 5(1). The arrow shows the direction of the magnetic field and the magnetic poles in the stator core.

At position 2, as shown by Fig 5(2), 60 Power degrees later, the phase current I_B is zero, the current I_R is positive and the current I_Y is negative. In Fig 5 (2) the current is now observed to be flowing into the conductors at the coil ends R_1 and Y_2, and out of the conductors at coil R_2 and Y_1. Therefore, as shown in Fig 5(2), the resultant magnetic poles are now at a new position in the stator core. In fact the poles in position 2 have also rotated 60° from position (1).

Fig 5



Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7, it will be seen that for each successive increment of 60 Power degrees, the resultant stator field will rotate a further 60° as shown in Fig 5. Note that from the resultant flux from position (1) to position (7), it is obvious that for each cycle of applied voltage the field of the two-pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° Power degrees apart, and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed, and, it depends upon the frequency of supply and the number of poles for which the stator is wound.

Hence

N_s = Synchronous speed in r.p.m.

$$= \frac{120\,f}{P}\ \text{rpm}$$

where `P' is the number of poles in the stator, and `f' is the frequency of the supply.

Construction of a 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque

Objectives: At the end of this lesson you shall be able to
- **describe the construction of a 3-phase, squirrel cage induction motor**
- **describe the construction of double squirrel cage motor and its advantage**
- **explain slip, speed, rotor frequency, rotor copper loss, torque and their relationship.**

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

– Squirrel cage induction motors

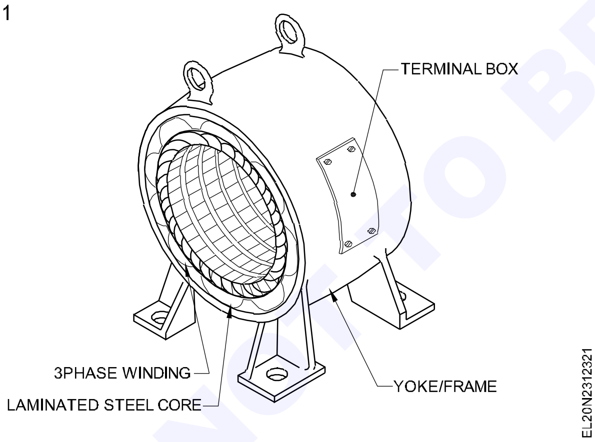
– Slip ring induction motors.

Squirrel cage motors have a rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

Stator of an induction motor: There is no difference between squirrel cage and slip-ring motor stators.

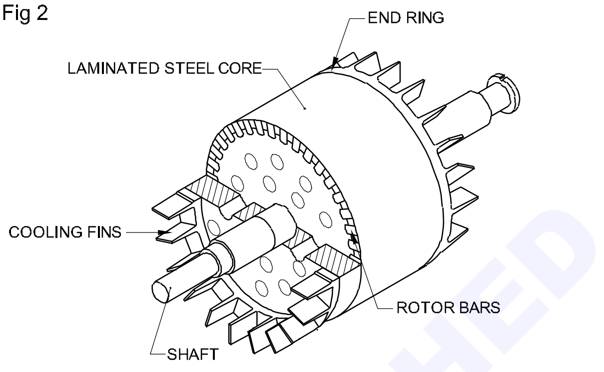
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Fig 1



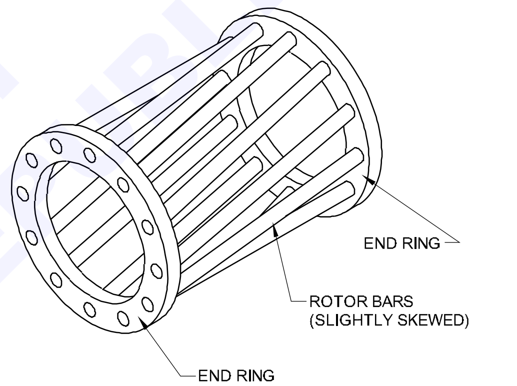
Rotor of a squirrel cage induction motor: The rotor of the squirrel cage induction motor shown in Fig 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig 3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

Fig 2



CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

Fig 3



VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor. Since the motor operates on the principle of induction; and as the construction of the rotor, with the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

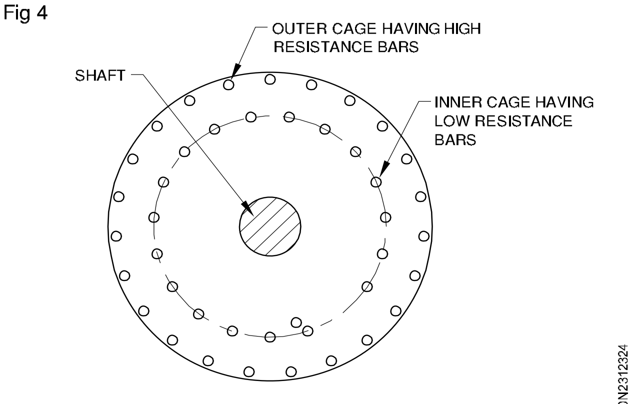
The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields: The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

Double squirrel cage induction motor

Rotor construction and its working: This consists of two sets of conductor bars called outer and inner cages as shown in Fig 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cage consists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

Fig 4



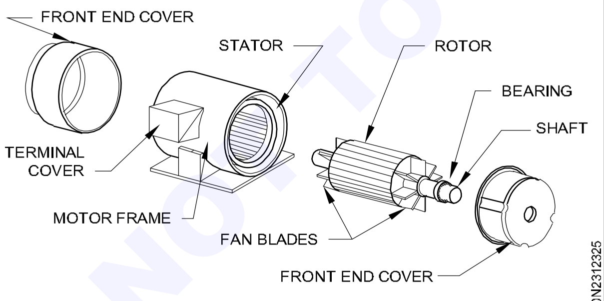
ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque.

Fig 5 shows the exploded view of 3 phase squirrel cage induction motor.

Fig 5



PARTS OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Slip and rotor speed: The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the `slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

$$\therefore \text{ fractional slip } S = \frac{N_s - N_r}{N_s}$$

$$\text{Then percentage slip (\% slip)} = \frac{N_s - N_r}{N_s} \times 100$$

where N_s = synchronous speed of the stator magnetic field

N_r = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

Example

Calculate the percentage slip of an induction motor having 6 poles fed with 50 cycles supply rotating with an actual speed of 960 r.p.m.

Given:

Poles (P) = 6

N_r = Rotor speed = 960 r.p.m.

F = frequency of supply = 50 Hz

N_s = Synchronous speed

$$= 120\frac{f}{P}$$

$$= \frac{120 \times 50}{6} = 1000\text{r.p.m.}$$

$$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$= \frac{1000 - 960}{1000} \times 100 = 4\%$$

Torque : The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current. Similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

Thus we have,

Torque is proportionally = Stator flux x rotor current x rotor power factor.

Let E_1 be the applied voltage

Ø be the stator flux which is proportional to E_1

S be the fractional slip

R_2 be the rotor resistance

X_2 be the rotor inductive reactance at standstill

SX_2 be the rotor inductive reactance at fractional slip S

K be the transformation ratio between stator and rotor voltages

E_2 be the rotor induced emf and equal to SKE_1

I_2 be the rotor current,

$Cos\theta$ be the rotor power factor.

Z_2 be the rotor impendence.

We can conclude mathematically the following final results.

$$T \ \alpha \ Ø \, I_2 \, Cos\theta$$

This can be deduced in to a formula

$$T \ \alpha \ \frac{SKE_1{}^2 R_2}{R_2{}^2 + S^2 X_2{}^2}$$

$$T \ \alpha \ \frac{\text{Rotor copper loss}}{\text{Fractional slip}}$$

$$\text{Starting torque } \alpha \ \frac{R_2}{R_2{}^2 + X_2{}^2} \text{ as fractional slip S = 1}$$

$$\text{Maximum torque } \alpha \ \frac{1}{X_2}$$

where X_2 in inductive reactance of the rotor at standstill and is constant.

Rotor copper loss: Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

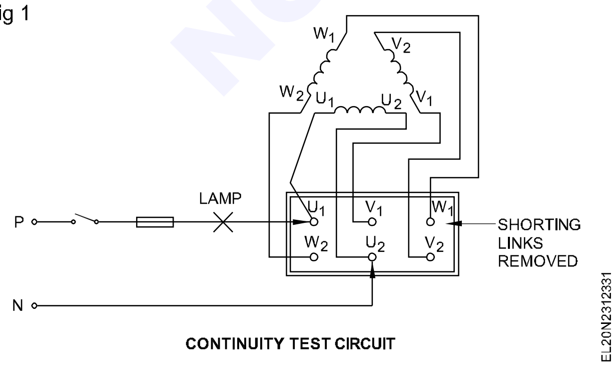
Insulation test on 3 phase induction motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity for and the method of testing continuity and insulation resistance in a 3-phase induction motor**
- **state the necessity of continuity test before insulation test.**

Necessity of continuity test before insulation test: While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

Continuity test: The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

Fig 1

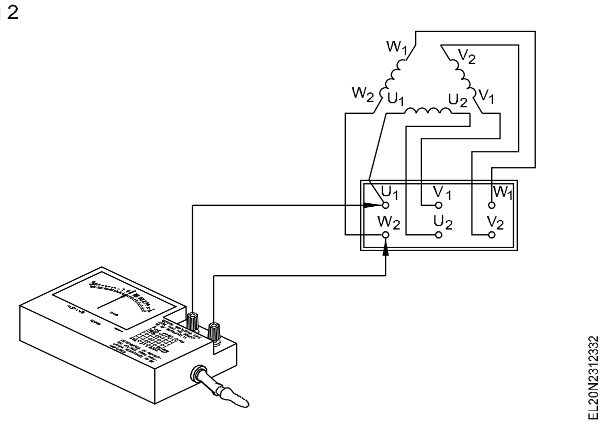


The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say U_1 in Fig 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U_2 in Fig 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

Limitations of lamp continuity test: However, this test only shows the continuity but will not indicate any short between the turns of the same winding.

Insulation test between windings: As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U_1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W_2 in Fig 2).

Fig 2

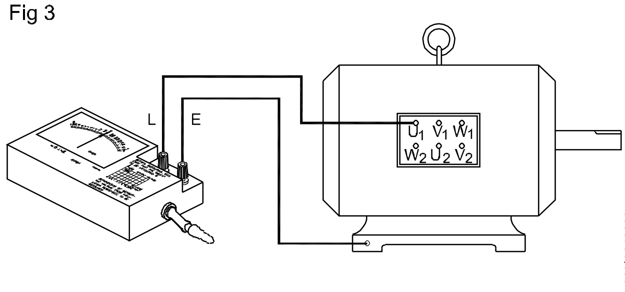


When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested.

Insulation resistance between windings and frame: As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Likewise the other windings are tested.

Fig 3



Starter for 3-phase induction motor - power control circuits - D.O.L starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop.**

Necessity of starter: normal voltage is applied to the stationary motor, then, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.
- Direct on-line starter
- Star-delta starter
- Auto-transformer starter

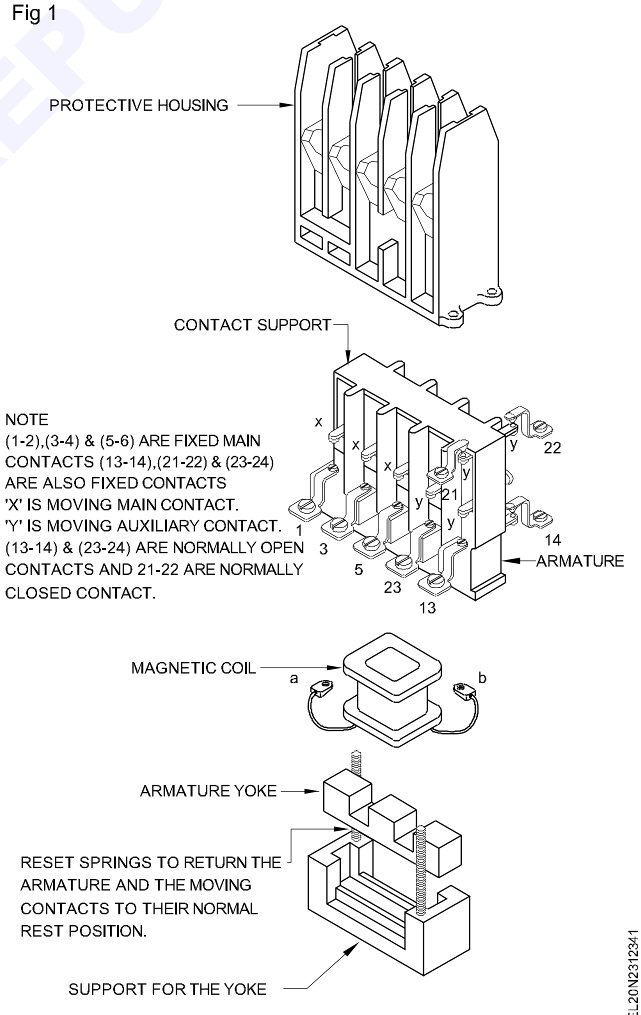
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1



The main parts of a magnetic contactor are shown in Fig 1 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

D.O.L. starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its construction, operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 2.3.125 and the D.O.L. starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 240 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Example

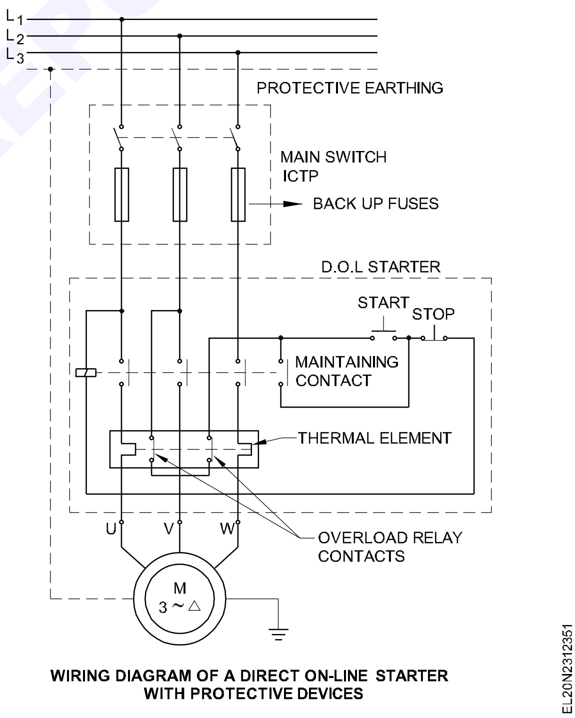
A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

$$\% \text{ of efficiency} = \frac{\text{Output x 100}}{\text{Input}}$$

$$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$$

$$= 83.3\ \%$$

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Manual star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **explain the construction, connection and working of a star-delta switch and starter**
- **specify the back-up rating of the fuse in the motor circuit.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

- Star-delta switch or starter
- Auto-transformer starter
- Step-down transformer starter

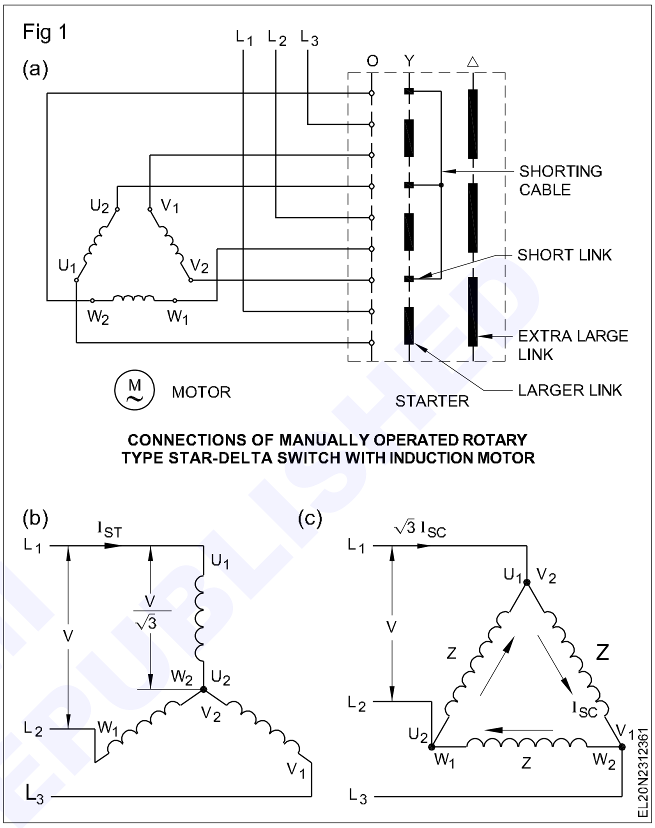
Star-delta starter: A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L_1, L_2 and L_3 are connected to the beginning of windings U_1, W_1 and V_1 respectively by the larger links, whereas the short links, which connect V_2 U_2 and W_2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)

Manual star-delta starter: Fig 2a shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U_2 and W_2, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

Fig 1



CONNECTIONS OF MANUALLY OPERATED ROTARY TYPE STAR-DELTA SWITCH WITH INDUCTION MOTOR

The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to beginning of the 3-phase winding W_1, V_1 and U1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 through the shorting cable to form the star point. (Fig 1b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L_1, L_2 and L_3 to the winding terminals W_1U_2, V_1W_2 and U_1V_2 respectively to form the delta connection. (Fig 1c)

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.

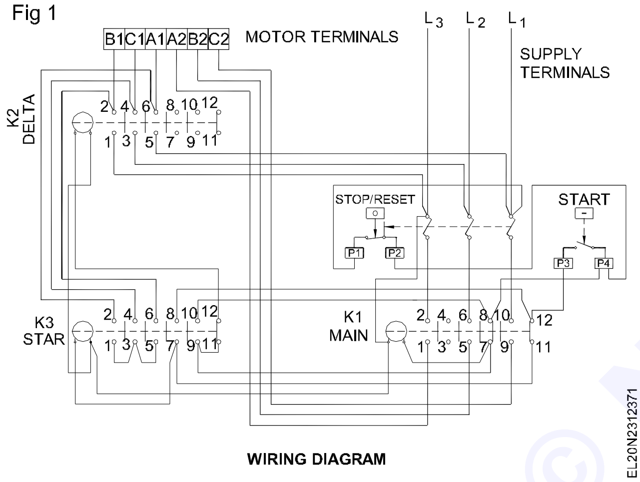
Semi-automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Fig 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.

Fig 1



Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

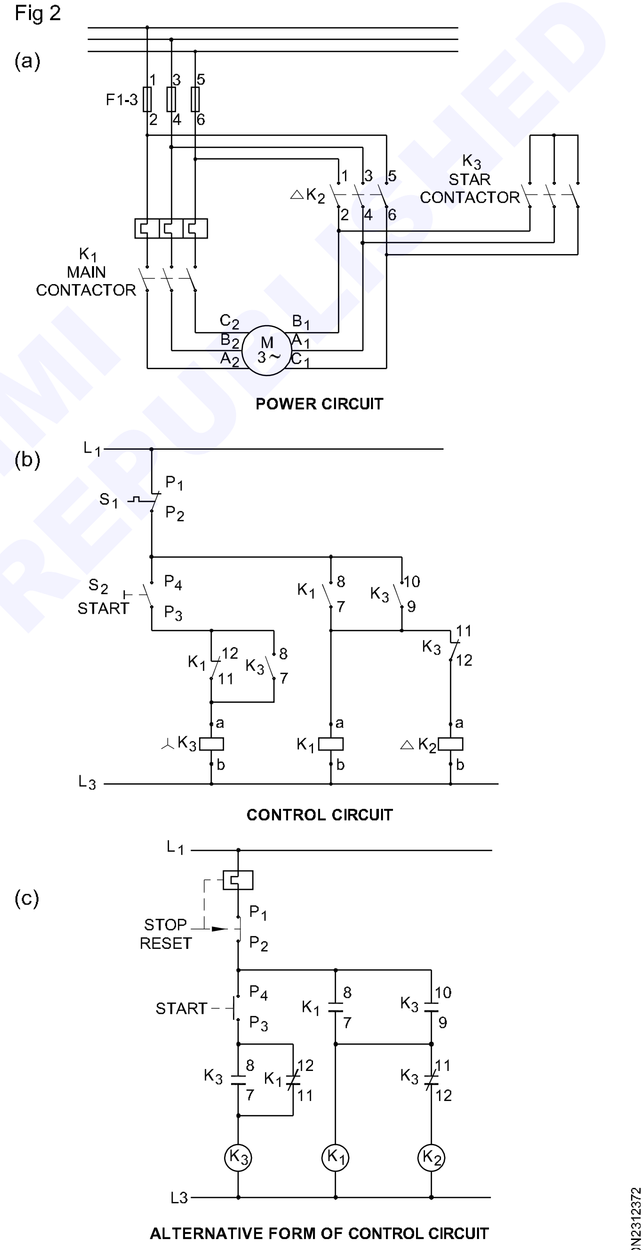
The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.

When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

The operator has to observe the motor starting and reaching about 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2c shows the alternative form of drawing control circuit.

Fig 2



LINE DIAGRAM OF SEMI - AUTOMATIC STAR - DELTA STARTER

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the applications of automatic star-delta and overload relay setting**
- **describe the operations of automatic star-delta starter.**

Applications : The primary application of star-delta motor is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Fig 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K_3. (Current flows through K_4T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 2 shows the current direction and closing of contacts as explained above.

Similarly Fig 3 shows the action taking place after the timer relay operating the contact K_4T.

Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed. Delta contact closes.

Fig 2

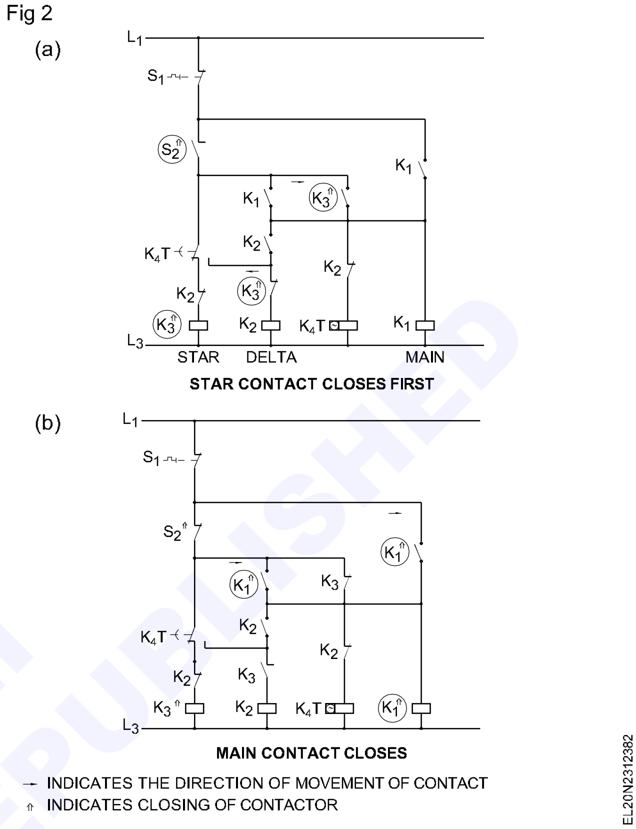


Fig 3

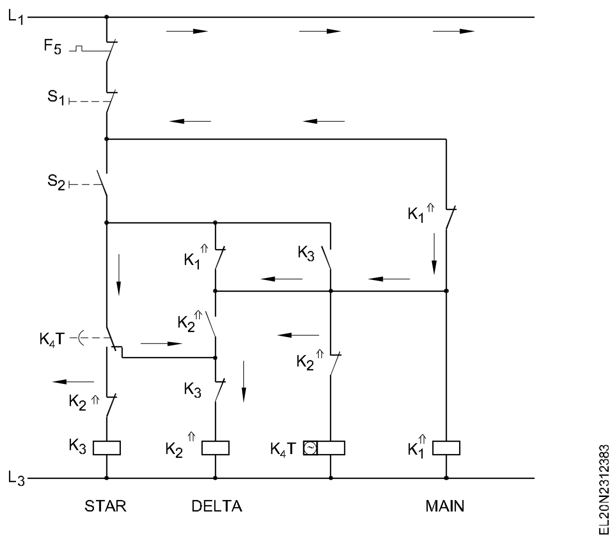


Fig 4

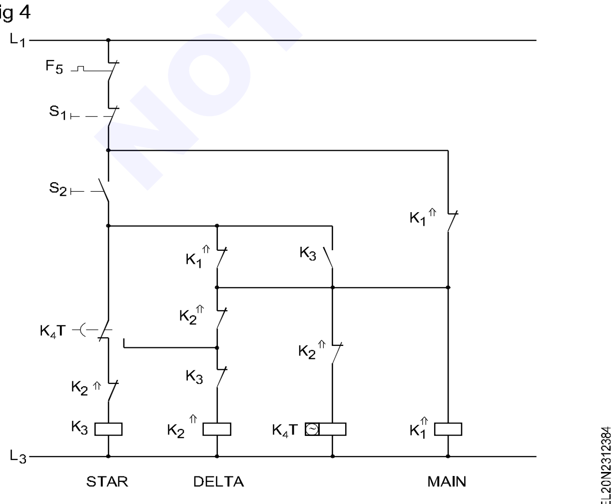
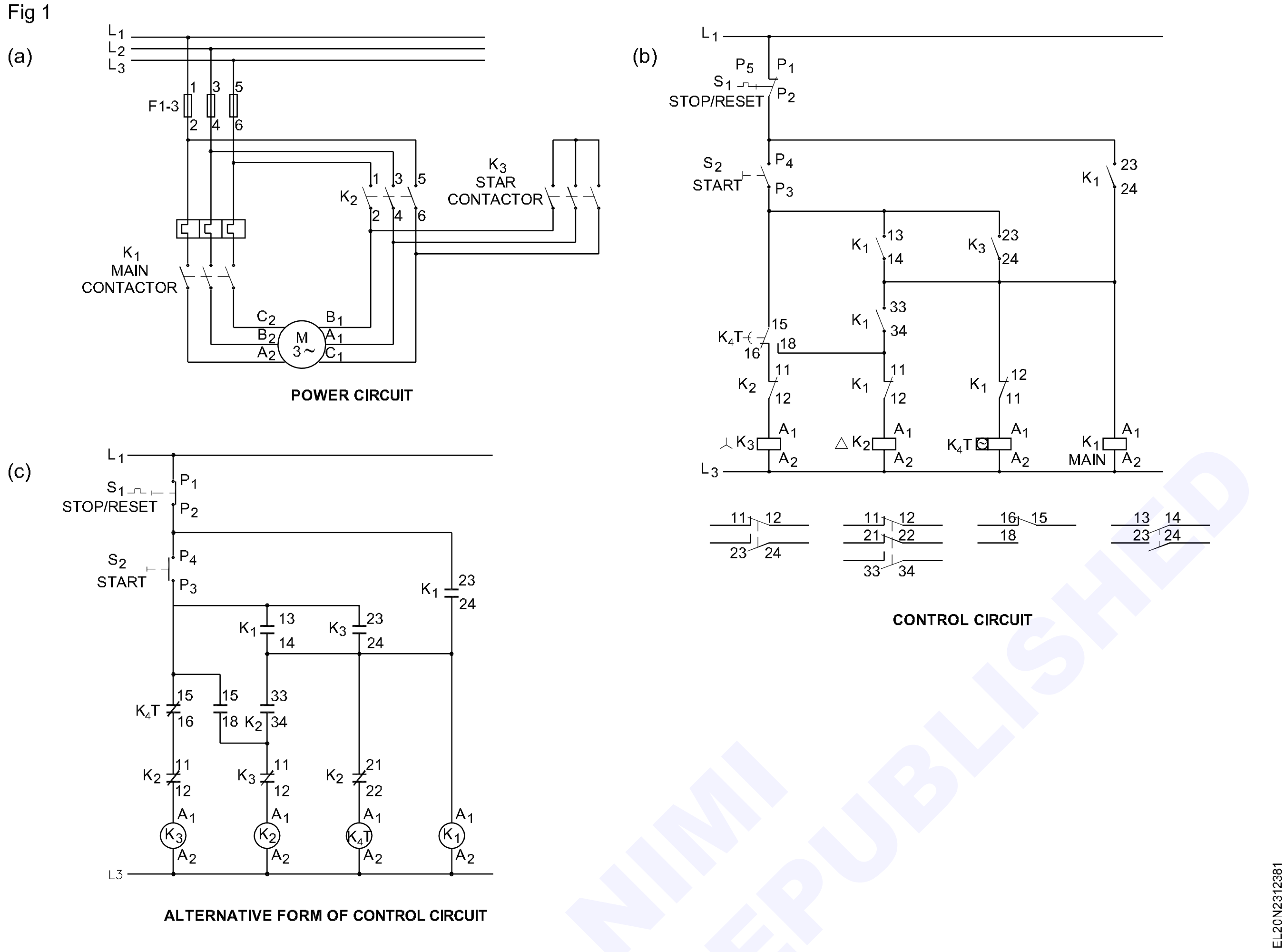


Fig 1



Three-phase, slip-ring induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the construction and working of a three-phase, slip-ring induction motor**
- **explain how the starting torque is high due to insertion of rotor resistance**
- **state the characteristic of the slip-ring induction motor**
- **compare the slip-ring induction motor with the squirrel cage induction motor.**

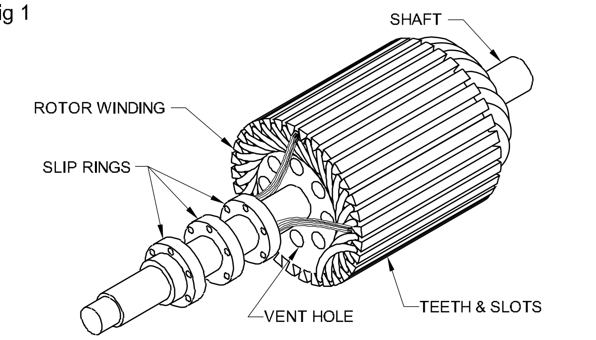
Construction : The slip-ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip-ring induction motor is very much the same as that for a squirrel cage motor but the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in a stator. The rotor winding is connected in star and the open ends are connected to three slip-rings mounted in the rotor shaft, as shown in Fig 1. The rotor circuit is, in turn, connected to the external star-connected resistances through the brushes, as shown in Fig 2.

Working : When the stator-winding of the slip-ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings, and a rotor current will flow through the closed circuit, formed by the rotor winding, the slip-rings, the brushes and the star-connected external resistors.

At the time of starting, the external resistors are set for their maximum value. As such, the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor, and thereby, the torque developed at the start becomes much higher than the torque developed in squirrel cage motors.

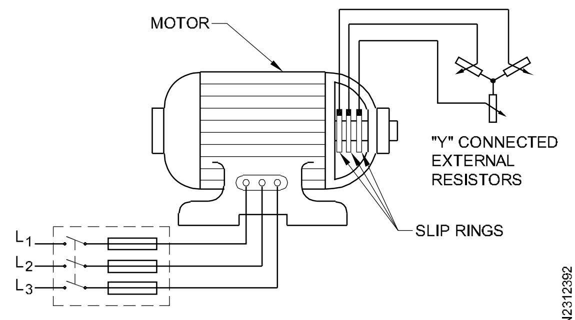
As the motor speeds up, the external resistance is slowly reduced, and the rotor winding is made to be short-circuited at the slip-ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. However at increased rotor resistance, the motor's slip will be greater, the speed regulation poorer and it will have low efficiency. The resistance in the external circuit could be designed and varied to change the speed of the slip-ring motor between 50 to 100 percent of the rated speed. However, the I^2R losses in the rotor due to increased resistance is inevitable.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

Fig 2



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

Starting torque : The torque developed by the motor at the instant of starting is called the starting torque. In some cases it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let E_2 be the rotor emf per phase at standstill

X_2 be the rotor reactance per phase at standstill and R_2 be the rotor resistance per phase.

Therefore $Z_2 = \sqrt{(R_2)^2 + (X_2)^2}$ = rotor impedance per phase at standstill.

$$\text{Then } I_2 = \frac{E_2}{Z_2}, \cos\theta_2 = \frac{R_2}{Z_2}$$

Standstill or starting torque $T_{st} = K_1 E_2 I_2 \cos q_2$ or

$$T_{st} = K_1 E_2 \text{ x } \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \text{ x } \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

If the supply voltage V is constant, then the flux, f and hence E_2 is constant.

Therefore $T_{st} = K_2 \frac{R_2}{Z_2}$ where K_2 is another constant.

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed.

Rotor emf and reactance under running condition : When the starter is stationary i.e. S = 1, the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running, the relative speed between the rotor and the rotating stator flux is decreased. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become equal to the speed of stator rotating flux.

Hence, for a slip (s), the rotor induced emf will be s times the induced emf at standstill.

Therefore, under running condition $E_r = sE_2$.

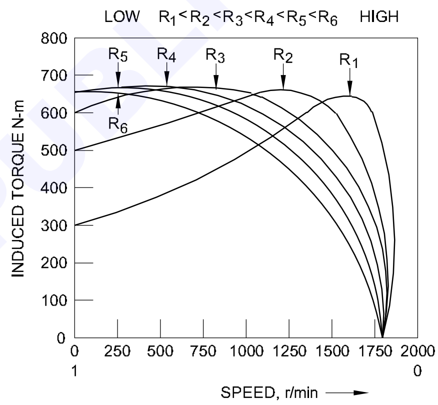
The frequency of induced emf will likewise become $f_r = sf_2$ where f_2 is the rotor current frequency at standstill.

Due to decrease in frequency of the rotor emf, the rotor reactance will also decrease.

Therefore $X_r = sX_2$.

Characteristic and application of slip-ring induction motor: Insertion of higher, external resistance alters the starting torque to a higher value, as shown in Fig 3, by the torque speed characteristic.

Fig 3



THE TORQUE-SPEED CHARACTERISTIC FOR A WOUND - ROTOR INDUCTION MOTOR

By inserting the suitable value rotor resistance, the speed of the slip ring motor could be controlled in spite of power loss in resistance.

As shown in the curve, higher, external resistance improves the starting torque to a higher value. However the maximum torque remains constant for the variation of the rotor resistance.

By these curves, it is clear that the slip-ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

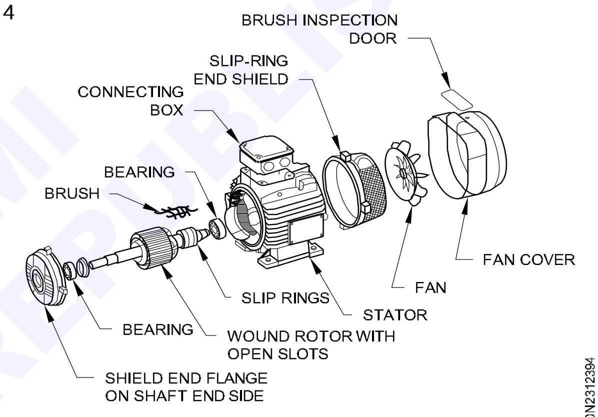
This motor could be used for drive which demands a higher starting torque and also a variable speed control - like compressors, conveyors, cranes, hoists, steel mills and printing presses.

Comparison between squirrel cage and slip-ring induction motors is given below.

Sl. No.	Property	Squirrel cage	Slip-ring motor
1	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slip-rings.	Winding wire is used. Wound rotor requires attention Slip-ring and brush gear need frequent main-tenance.
2	Starting	Can be started byDOL star-delta, auto-transformer starters.	Rotor resistance starter is required
3	Starting torque	Low	Very high
4	Starting current	High	Low
5	Speed variation	Not easy, but could be varied in larger steps by pole-changing or smaller incre- -mental steps through thyristors or by frequency variation.	Easy to vary speed, but speed change through pole-changing is not possible. Speed change possible by - insertion of rotor resistance - using thyristors - using frequency variation - injecting emf in the rotor circuit - cascading
6	Acceleration on load	Just satisfactory	Very good
7	Maintenance	Almost nil	Requires frequent maintenance
8	Cost	Low	Comparatively high

Fig 4 shows the exploded view of the slip ring induction motor.

Fig 4



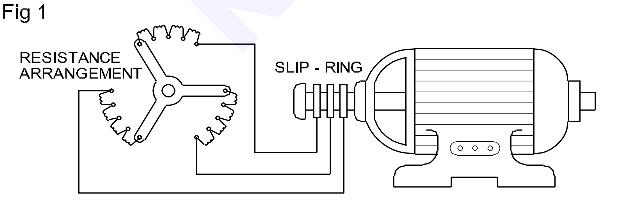
PARTS OF 3 PHASE SLIP RING INDUCTION MOTOR

Resistance starter for 3-phase, slip-ring induction motor

Objective: At the end of this lesson you shall be able to
- **explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.**

Slip-ring induction motors are started with full-line voltage across the stator winding. However, to reduce the heavy rush of the starting current, a star-connected external resistance is added in the rotor circuit as shown in Fig 1. The external resistances are cut out, and the rotor winding ends are shorted once the motor picks up its speed.

Fig 1



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER

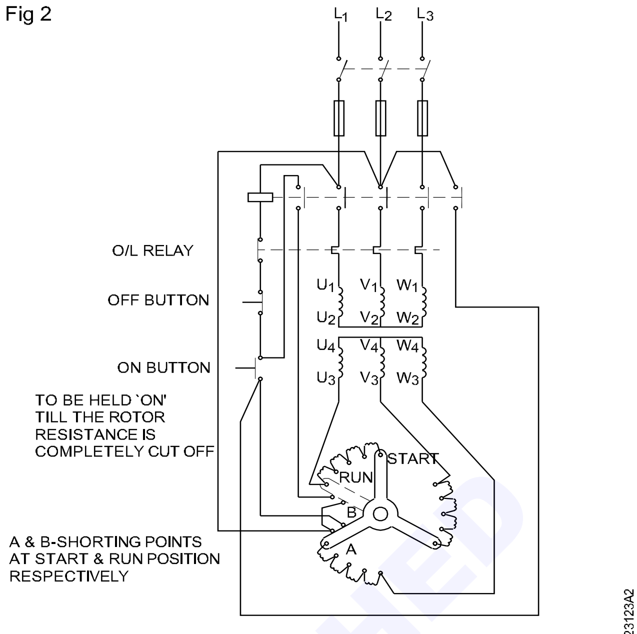
If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Fig 2



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

Efficiency - characteristics of induction motor- no load test - blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **state the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I_2 to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s\ I_2 \cos\ \phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Fig 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Torque, Mechanical power and Rotor output : Stator input P_i = stator output + stator losses.

Fig 1

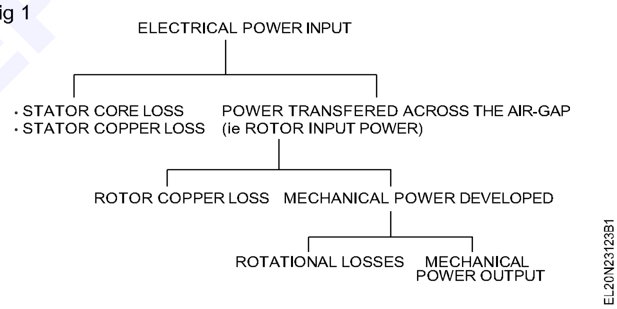
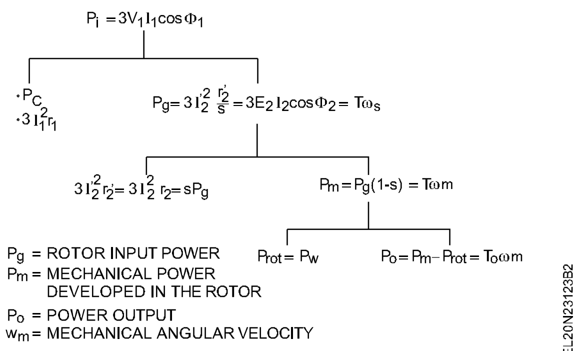


Fig 2



The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input P_g = stator output.

Rotor gross output, P_m = rotor input P_g - rotor cu. losses.

This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque T_o.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

T x $2\pi n$ = rotor gross output in watts, P_m.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts, } P_m}{2\pi\, n} \text{ N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\, n} \text{ Kg m}$$

$$= \frac{P_m}{9.81 \times 2\pi\, n} \text{ Kg m}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\,\pi\, n_s}$$

From the above two equation we get,

Rotor gross output = P_m = Tw = T x $2\pi n$

Rotor input = P_g = TW_s = T x $2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input

= s x power across air gap

= sP_g.

$$\text{Also rotor input, } P_g = \frac{\text{rotor copper loss}}{s}$$

Rotor gross output P_m = Input P_g - rotor cu.loss

= (1 - s) P_g

$$\text{or } \frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$$

rotor gross output. Pm = (1 - s)P_g

$$\text{Therefore rotor efficiency} = \frac{n}{n_s}$$

Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the windage and friction losses are 0.2 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

No. of poles	P = 4
Frequency	f = 50 Hz
Phases	= 3
Input power	= 50kW
% Slip	s = 5%
Stator losses	= 1.2 kW
Friction & Windage losses	= 0.2 kW

Find:

Rotor speed	= N
Rotor copper loss	= s x input power to rotor
efficiency	= η

SOLUTION

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor

= 0.05 x 48.8

= 2.44 kW.

Rotor output = Rotor input - (Friction and windage loss + rotor cu.loss)

= 48.8 - (0.2 + 2.44)

= 46.16 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 92.32\%.$$

Characteristics of squirrel cage induction motor

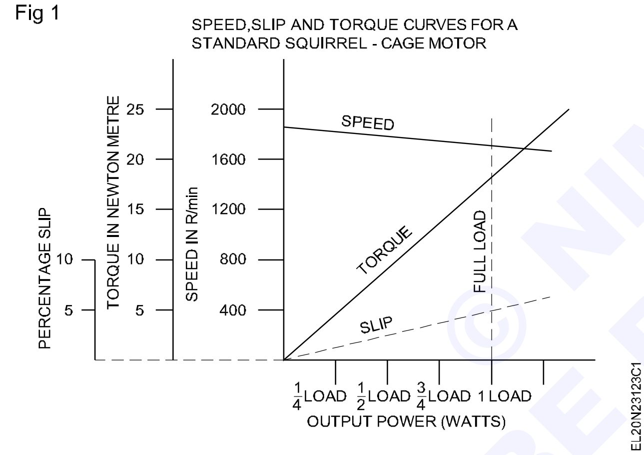
Objective: At the end of this lesson you shall be able to
- **describe the characteristics and application of a 3-phase squirrel cage induction motor.**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

Speed, torque and slip characteristics : It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1



Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig 1.

Relationship between torque, slip rotor resistance and rotor inductive reactance : It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K \phi_s I_R \cos\phi$

where T = torque in Newton metre

K = a constant

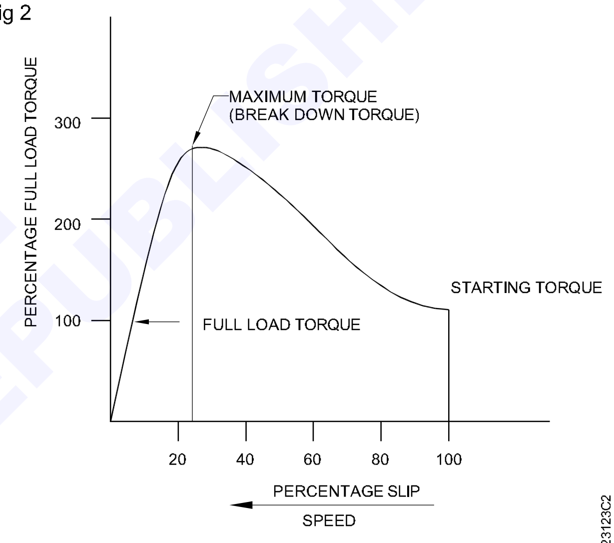
ϕ_s = stator flux in weber

I_R = rotor current in ampere

$\cos\phi$ = rotor power factor

From no load to full load, the torque constant (K), the stator flux (ϕ_s) and the rotor power factor ($\cos\phi$) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current (I_R) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig 2.

Fig 2



TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

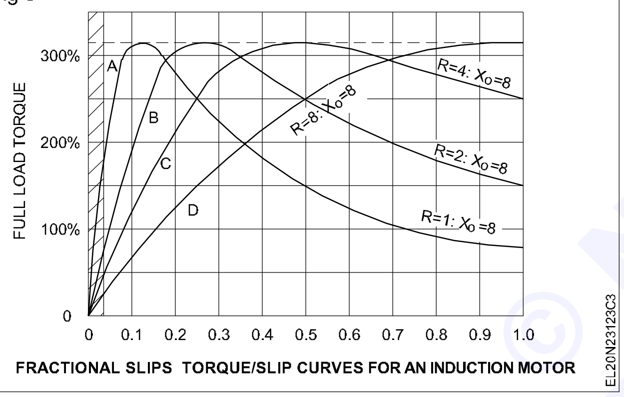
The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig 2, the rotor torque will increase in almost a straight relationship with the slip.

In between 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

Effect of rotor resistance upon the torque/slip relationship: Fig 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.

Fig 3



FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

Breakdown torque : In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

Starting torque : At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the full load torque for the rotor having maximum resistance as shown by curve D of Fig 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

Running torque : While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

Application of squirrel cage induction motor : Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

No-load test of induction motor

Objectives: At the end of this lesson you shall be able to
- **determine the constant (mechanical and iron losses of induction motor) by no-load test**
- **calculate the total equivalent resistance per phase.**

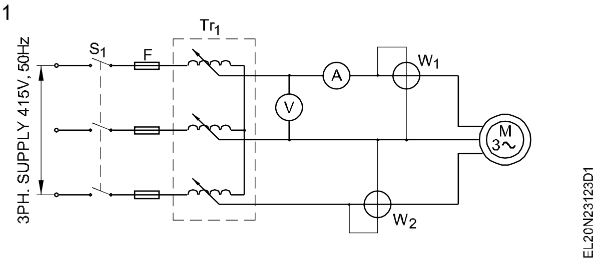
No-load test

The induction motor is connected to the supply through a 3-phase auto-transformer (Fig 1). The 3-phase auto-transformer is used to regulate the starting current by applying low voltage at the start, and then gradually increased to rated voltage. The ammeter and voltmeters are selected based upon the motor specification. The no-load current of the motor will be very low, up to 30% of full load.

As the power factor of the motor on no-load is very low, in the range of 0.1 to 0.2, the wattmeters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will be approximate equal to the product of the ammeter and voltmeter full scale deflection values.

The calculation is done as follows to determine the constant losses of the induction motor.

Fig 1



At no-load, the output delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Calculation

V_{NL} is ® line stator voltage

I_{NL} is ® line current

P_{NL} is ® Three-phase power input.

The input power consists of the core loss P_c, friction and windage loss $P_{(rot)}$, and the stator copper loss.

$P_{NL} = P_c + P_{rot} + 3 I^2_{NL} R_S$

This permits the sum of rotational loss to be evaluated.

$P_{rot + C} = P_{NL} - 3 I^2_{NL} R_S$

where the stator resistance Rs per phase obtained from a resistance measurement at the stator terminal.

In star connection R_S = R/2.

Delta connection R_S = 2/3 R.

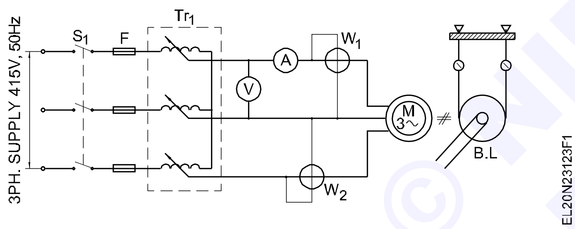
Blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **determine the full load copper loss of a 3-phase induction motor by blocked rotor test**
- **calculate the total equivalent resistance per phase and efficiency.**

The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeters will be of a suitable range and its power factor is 0.5 to unity.

An auto-transformer is used to give a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. One such arrangement is shown in Fig 1. The belt is over-tightened on the pulley to prevent rotation.

Fig 1



As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. Therefore, a small induced voltage in the rotor cage winding will be sufficient to cause a large current to flow in the cage.

It is very essential to limit the supply voltage to a value less than 5% at start and then gradually increase until the starter current is equal to the full load current. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 HP 400V, 50 Hz, four-pole, three-phase induction motor was tested and the following data were obtained.

Blocked rotor test: V_s = 54. P_s = 430, I_s = 7.5 A.

The resistance of the stator winding gives a 4 V drop between the terminals' rated DC current flowing.

Find the power factor at short circuit and R_e and X_e and full load copper loss.

Given:

Output	= 5 HP
Voltage	= 400 V
Frequency	= 50 Hz.
Blocked rotor voltage, V_S	= 54 V
Power P_S,	= 430 W
Current, I_S	= 7.5 A

Find:

Power factor at short circuit = $\cos \theta_S$

Equivalent resistance, R_e/phase

Equivalent reactance X_e/phase

Full load copper loss = $3I^2 R_e$.

Known:

$$W_S = \sqrt{3}\, V_S I_S \;\; \cos \varnothing_S$$

$$\text{Equivalent impedance } Z_e = \frac{V_s}{\sqrt{3} I_s} = \sqrt{R_e^2 + X_e^2}$$

$$R_e = \text{equivalent resistance} = \frac{P_s}{3 I_s^2}$$

$$X_e = \text{equivalent reactance} = \sqrt{Z_e^2 - R_e^2}$$

Solution:

$$W_S = \sqrt{3}\, V_S I_S \;\; \cos \varnothing_S$$

$$\cos\phi_s = \frac{W_s}{\sqrt{3}\, V_s I_s}$$

$$\cos \phi_S = \frac{430}{1.72 \times 54 \times 7.5}$$

$$= \frac{430}{696.6}$$

$$= 0.61$$

$$\text{Equivalent resistance } R_e/\text{phase} = \frac{P_s}{3 \times I_s^2}$$

$$= \frac{430}{3 \times (7.5)^2}$$

$$= \frac{430}{168.75} = 2.5\Omega$$

$$X_e = \text{equivalent reactance/phase} = \sqrt{Z_e^2 - R_e^2}$$

$$Z_e = \frac{54}{\sqrt{3} \times 7.5} = \frac{54}{12.90} = 4.1\Omega.$$

$$X_e = \sqrt{4.1^2 - 2.5^2} = \sqrt{16.81 - 6.25}$$

$$= \sqrt{10.56} = 3.24\Omega.$$

Full load copper loss $= 3 I^2 R_e$

$= 3 \times 7.5^2 \times 2.5 = 421.875$ watts

Answer

i $\cos \phi_s = 0.61$

ii Equivalent resistance R_e/phase = 2.5 Ω

iii Equivalent reactance X_e/phase = 3.24 Ω

iv Full load copper loss = 421.875 watts

Auto-transformer starter

Objectives: At the end of this lesson you shall be able to

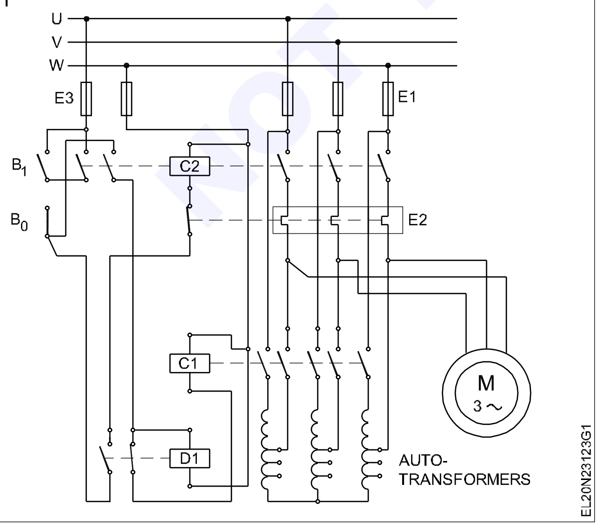
- **explain the construction and operation of auto-transformer starter**
- **explain power circuit and control circuit of auto-transformer starter.**

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements. Since the contacts frequently break, large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

Fig 1



The power circuit of the auto-transformer is shown in Fig 2a and control circuit of auto-transformer is shown in Fig 2b.

Auto-transformer starter - operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. While starting, the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.

Fig 2

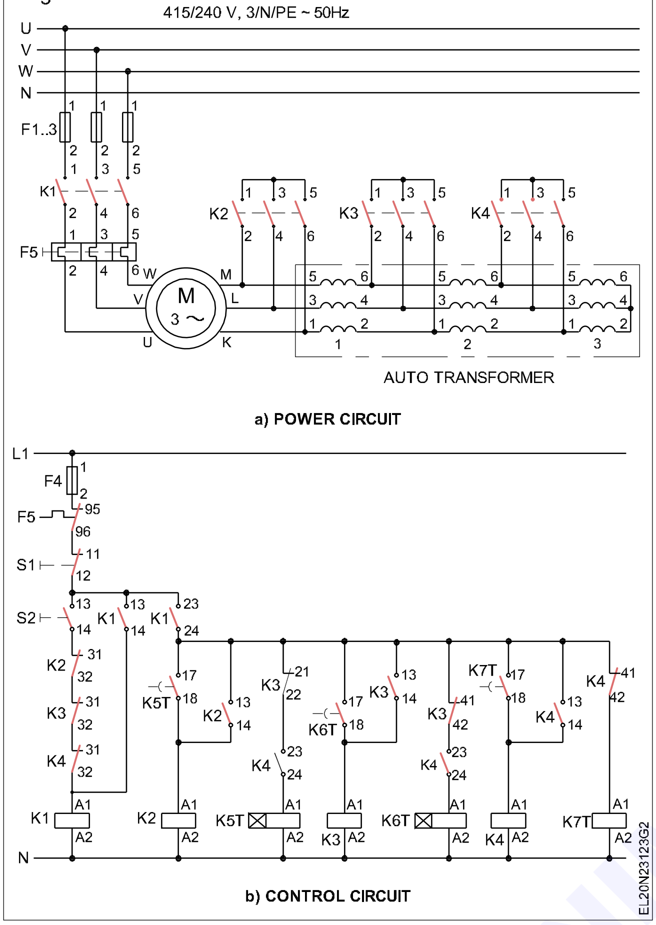
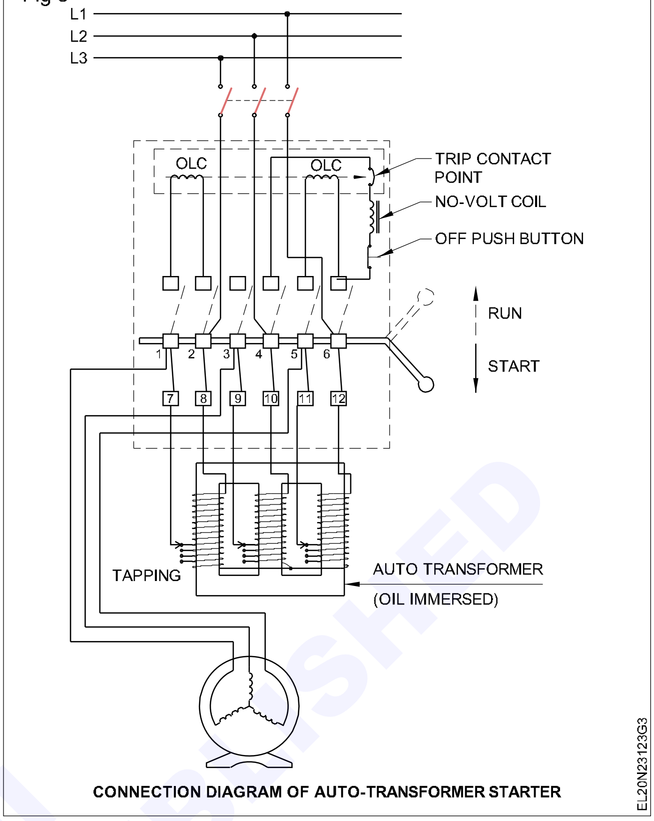


Fig 3



Single phasing preventer/phase failure relay

Objectives: At the end of this lesson you shall be able to

- **define single phasing**
- **state the effects of single phasing**
- **explain the necessity of a single phasing preventer**
- **classify the single phasing preventers**
- **explain the installation procedure**
- **explain the procedure for troubleshooting and servicing of single phasing preventer.**

Single phasing preventer/phase failure relay : When one of the three lines of a three-phase supply system fails or opens, the load current flows between the other two lines only and the fault is known as single phasing.

Effect of single phasing: The effect of single phasing is different with different types of loads as follows

- In 3-phase heating loads, the heat produced decreases to around 50% at the same time it does not harm the equipment.
- In three-phase motors, the effect of single phasing is different on different occasions. i) During starting, if single phasing occurs, the motor fails to start or stalls as proper rotating magnetic field is not created. But the motor draws a very large current and motor windings gets heated up. ii) During running, if single phasing occurs, the motor may or may not run depending upon the load condition and the phase in which supply is available will draw a large current and the winding is likely to burn out due to overheating.

Necessity of single phasing preventer/phase failure relay: If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire connected to the motor breaks while the motor is running, the motor will continue to operate on two phase but will experience serious overheating. To protect motors against these conditions of phase failure, a single phase preventer is used.

Types of preventers: Single phasing preventers are available in three types.

- Mechanical

- Current sensing
- Voltage sensing

Single phasing preventer - voltage sensing : In an AC three-phase supply the order in which three-phase voltages reach the maximum value is known as phase sequence. The phase voltage reaches their maximum positive value one after another at 120° in clockwise known as positive phase sequence and in anti-clock wise known as negative phase sequence. In the case of phase reversal or unbalanced voltages or no voltage in a line it results in a super-imposition of negative phase sequence over the normal positive phase sequence of supply voltages. This negative sequence is filtered by a resistance capacitance or resistance, capacitance and inductor network and de-energise the relay in the voltage the sensing single phasing preventer.

Fig 1 and Fig 2 shows the block diagram and circuit diagram of a typical voltage sensing single phasing preventor. In this a resistance, capacitance network is utilized to sense the negative phase sequence. When phase sequences and voltages are correct, no voltage will be generated across the filtered output i.e. across capacitor. C_4 in the circuit which drives the transistor Q_1 to cut off transistor Q_2 to drive the relay.

Fig 1

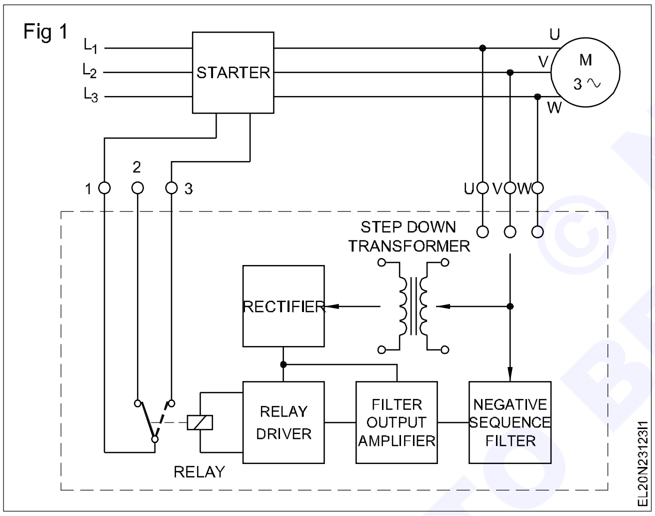
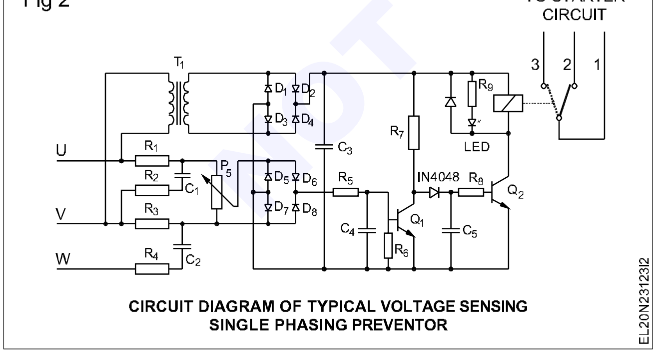


Fig 2



CIRCUIT DIAGRAM OF TYPICAL VOLTAGE SENSING SINGLE PHASING PREVENTOR

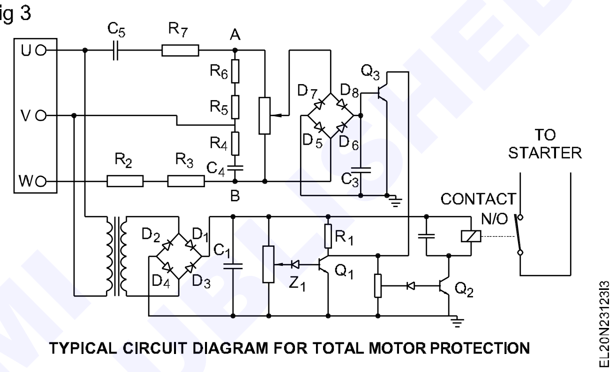
When the negative sequence occurs due to unbalanced supply voltage or phase reversal, a voltage is developed across the capacitor C_4 which drives the transistor Q_1 to saturation and transistor Q_2 to cut off. This results in switching off the relay circuit.

Some of the single phasing preventors are provided with the facility to adjust unbalanced settings. For example when the relay is found to operate very frequently for the set value, the unbalanced pre-set can be changed by operating the pre-set P_5 in Fig 2.

Single phasing preventor with over-voltage and under voltage cut off (Total motor protection) : When a motor is fed with reduced voltage, the motor draws excess current to drive the load and with an over -voltage, also it draws excess current. To protect the motor from under-voltage or over-voltage and also from single phasing a preventer with over and under voltage protection is used for total motor protection.

Fig 3 shows an arrangement of over-voltage and under -voltage cut off circuit along with single phasing preventer.

Fig 3



TYPICAL CIRCUIT DIAGRAM FOR TOTAL MOTOR PROTECTION

In the circuit transistor Q_1 serves as over-voltage cut off and transistor Q_2 serves as under-voltage cut off where- as transistor Q_3 serves as single phasing preventer.

Installation of single phasing preventer : Installation and connection of single phasing preventor shall be done as recommended by the manufacturer. Preferably single phasing preventers shall be located nearer to the equipment and not subjected to abnormal vibration. Care should be taken to locate the unit away from a heat generating source such as oven, furnace etc.

A single phase preventer shall be connected with the supply line and starter to the appropriate terminals and circuits.

Some of the commonly used single phasing preventors and their connection with starter are shown in Figs 4 & 5 for your reference.

Troubleshooting and maintenance of single phasing preventer : The arrangement of components and their circuits of single phasing preventers vary from one make to another make as well as from one type to another type.

It is preferred to follow the manufacturer's recommendations for troubleshooting and maintenance of single phase preventers. A few general guide lines for troubleshooting of single phase preventers are given in the Table-1.

Fig 4

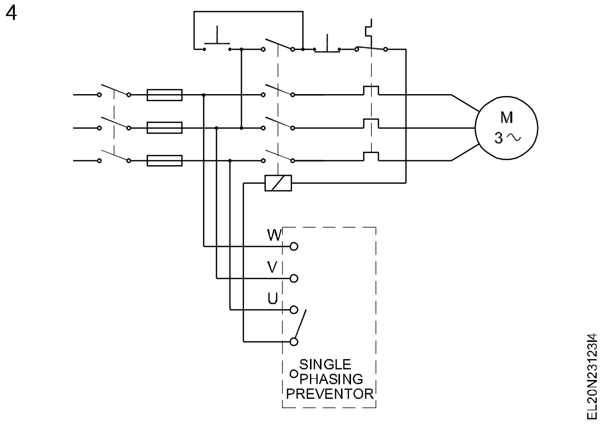


Fig 5

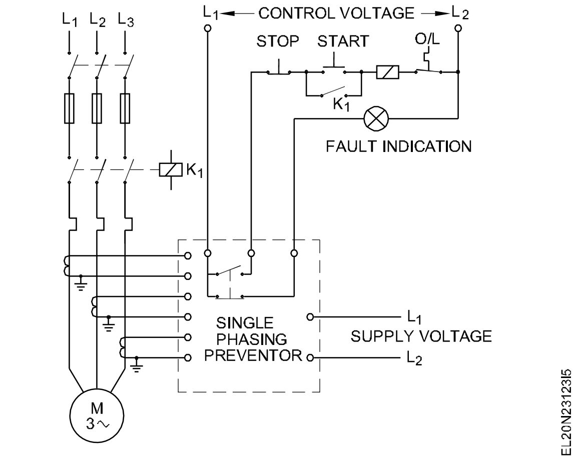


Table 1

S.No.	Symptoms	Possible causes	Remedy
1	Starter with single phase preventer does not start.	No supply. Low supply voltage.	Check and resume supply. Verify and correct the voltage.
		Unbalanced line voltages.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence by interchanging any two incoming lines.
		Single phasing	Check and rectify.
		No control circuit voltage.	Check and rectify.
2	Starter with single phase preventer does not hold on.	Low supply voltage. Unbalanced line voltages.	Verify and correct. Verify and correct.
		Single phasing.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence.
		Defect in single phase preventer electronic circuit.	Check, repair or replace.
		Relay of single phase preventer is not energised.	Check, rectify or replace.
		Improper function of relay contacts.	Check, rectify or replace.
		Open in holding circuit.	Check and correct.
3	Starter with single phase preventer trips frequently.	Abnormal fluctuations in line voltages.	Check and rectify.
		Improper settings or unbalanced settings.	Adjust the unbalanced settings.
		Loose contact in supply lines/ control circuit.	Check and rectify.

Braking system of motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of braking system for motors**
- **list and explain each type of braking system.**

Necessity of braking system

The term braking comes from the term brake. The brake is an equipment to reduce the speed of any moving or rotating equipment, like vehicles, locomotives etc. The process of applying brakes can be termed as **braking.**

The term braking in two parts **i) Mechanical braking** and the **ii) Power braking.** In mechanical braking the speed of the machine is reduced solely by mechanical process but in Powerbraking the whole process is depended on the flux and torque directions. Each type of Power braking is the reversal of the direction of the flux. **Braking** is the process of reducing speed of any rotating machine. The application of braking is in factories, industrial areas or be it in locomotives or vehicles. Everywhere the use of mechanical and Power brakes is inevitable.

Types of braking

Brakes are used to reduce or cease the speed of motors. There are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other. Braking can be divided in to three methods mainly, which are applicable for almost every type of motors.

1 Plugging type braking

2 Regenerative Braking

3 Dynamic braking.

1 Plugging type braking: In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

2 Regenerative braking: Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This braking method is called regenerative braking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

3 Dynamic braking: Another method of reversing the direction of torque and braking the motor is dynamic braking. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self -excited generator. When the motor works as a generator the flow of the current and torque reverses.

Method of speed control of 3 phase induction motor

Objectives: At the end of this exercise you shall be able to
- **list the speed control methods from stator and rotor side**
- **explain the speed control methods of 3 phase induction motor.**

In 3 phase induction motor, speed can be controlled from both stator and rotor side

1 Speed control methods from stator side
   - By changing the applied voltage
   - By changing the applied frequency
   - By changing the number of stator poles

2 Speed control from rotor side
   - Rotor rheostat control
   - Cascade operation
   - By injecting EMF in rotor circuit

1 Speed control from stator side

a By changing the applied voltage: Torque equation of induction motor is

$$T = \frac{k_1 sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$= \frac{3}{2\pi N_s} \frac{sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Rotor resistance R_2 is constant and if slip s is small then sX_2 is so small that it can be neglected. Therefore, $T \alpha$ sE_2^2 where E_2 is rotor induced emf and $E_2 \alpha V$

And hence $T \alpha V^2$, thus if supplied voltage is decreased, torque decreases and hence the speed decreases.

This method is the easiest and cheapest, still rarely used because-

1 A large change in supply voltage is required for relatively small change in speed.

2 Large change in supply voltage will result in large change in flux density, hence disturbing the magnetic conditions of the motor.

b By changing the applied frequency: Synchronous speed (N_s)of the rotating magnetic field of induction motor is given by,

$$N_s = \frac{120f}{P} \text{rpm}$$

where, f = frequency of the supply and P = number of stator poles.

Thus, synchronous speed changes with change in supply frequency, and thus running speed also changes. However, this method is not widely used. This method is used where, only the induction motor is supplied by a generator (so that frequency can be easily changed by changing the speed of prime mover).

c **Changing the number of stator poles:** From the above equation, it can be also seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors, as squirrel cage rotor adapts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

For example, a stator is wound with two 3phase windings, one for 4 poles and other for 6 poles.

For supply frequency of 50 Hz

i Synchronous speed when 4 pole winding is connected, Ns = 120 x (50/4) = 1500 RPM

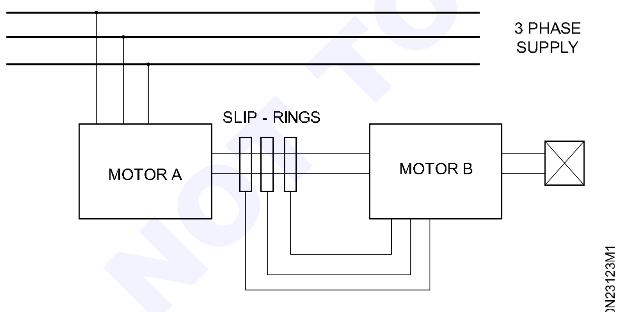
ii Synchronous speed when 6 pole winding is connected, Ns = 120 x (50/6) = 1000 RPM

2 Speed control from rotor side

a **Rotor rheostat control:** This method is similar to that of armature rheostat control of DC shunt motor. But this method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible.

b **Cascade operation:** In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed. One motor is fed from a 3phase supply and other motor is fed from the induced emf in first motor via slip-rings. The arrangement is as shown in Fig 1.

Fig 1



CASCADE OPERATION

Motor A is called main motor and motor B is called auxiliary motor.

Let, N_{s1} = frequency of motor A

N_{s2} = frequency of motor B

P_1 = number of poles stator of motor A

P_2 = number of stator poles of motor B

N = speed of the set and same for both motors

f = frequency of the supply

Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced emf in motor A, $f_1 = S_1 f$. Now, auxiliary motor B is supplied with the rotor induce emf therefore, $N_{s2} = (120f_1) / P_2 = (120S_1 f) / P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$

$$N_{s2} = \frac{120f\left(N_{s1} - N\right)}{P_2 N_{s1}}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. $N = N_{s2}$. From the above equations, it can be obtained that

$$N = \frac{120f}{P_1 + P_2}$$

With this method, four different speeds can be obtained

1 When only motor A works, corresponding speed = $N_{s1} = 120f / P_1$

2 When only motor B works, corresponding speed = $N_{s2} = 120f / P_2$

3 If cumulative cascading is done, speed of the set = $N = 120f / (P_1 + P_2)$

4 If differential cascading is done, speed of the set = $N = 120f (P_1 - P_2)$

c **By injecting EMF in rotor circuit:** In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage (emf) being injected must have same frequency as of slip frequency. However, there is no restriction to the phase of injected emf. If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased. If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease. Thus, by changing the phase of injected emf, speed can be controlled. The main advantage of this method is a wide range of speed control (above normal as well as below normal) can be achieved. The emf can be injected by various methods such as Kramer system, Scherbius system etc.

Fundamental terms used in AC winding

Objectives: At the end of this lesson you shall be able to
- **state the terms used in AC winding**
- **explain the different types of AC winding.**

Fundamental terms used in AC Winding: Before taking up AC winding, the trainee should be familiar with the terms used in AC winding as explained in the following paragraphs.

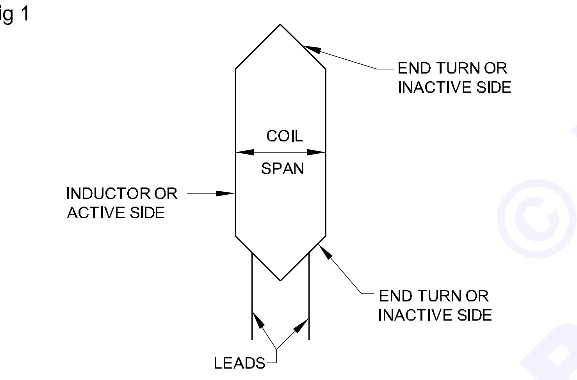
Coil : A number of turns connected in series is called a coil. A coil has two active sides and two inactive sides.

Turn: It is the closed path of the conductor which is formed by connecting the two inductors under two dissimilar poles N and S. (Fig 1)

Active side of a coil : It is that part of the coil which lies in the slots of the core. It is also known as an inductor. (Fig 1)

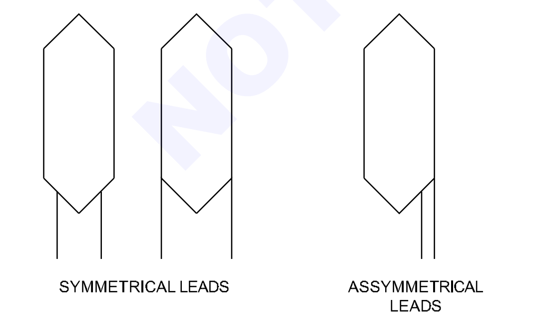
Inactive side of a coil : It is the portion of the coil which joins the two active sides of a coil. (Fig 1)

Fig 1



Leads of a coil : These are the two ends of a coil which are used for the connection. Leads are also known as jumpers which may be symmetrical or unsymmetrical as shown in Fig 2.

Fig 2

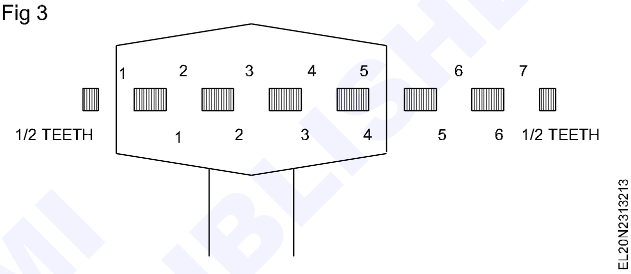


Pole pitch : The distance between the centre of two adjacent opposite poles is called the pole pitch. Pole pitch is measured in terms of slots or coil sides.

$$\text{Pole pitch} = \frac{\text{No. of slots in the stator}}{\text{No. of poles}}$$

Coil pitch/span and coil throw : The distance between the two active sides of a coil under adjacent dissimilar poles is called coil pitch/span. Fig 3 shows the coil pitch/span and coil throw (i.e. coil pitch/span = 4 and coil throw is 1-5).

Fig 3



Pitch factor : Winding pitch need not be equal to the pole pitch. If the pole pitch and winding pitch are equal, the winding is called full pitched winding. If the winding pitch is less than the pole pitch, the winding is called fractional pitch winding or short pitch winding. While rewinding, the original winding pitch should not be changed. The machine designer would have chosen the winding pitch after considering the different factors required for the better performance of the machine. Any change in the original winding pitch of a machine will affect the performance of that machine. If the winding pitch is 4, then the coil throw is 1 to 5, and one side of the coil is placed in slot No.1 and the other side of the coil is inserted in slot No.5 as shown in Fig 3. Then the winding pitch is 5-1 = 4. The ratio between the winding pitch and pole pitch is called the pitch factor.

$$\text{Pitch factor} = \frac{\text{Winding pitch}}{\text{Pole pitch}}$$

Short pitch winding is usually used in almost all machines except variable speed motors. The reasons for adopting short pitch winding are given below.

1 Winding requires less copper.

2 Copper loss is less.

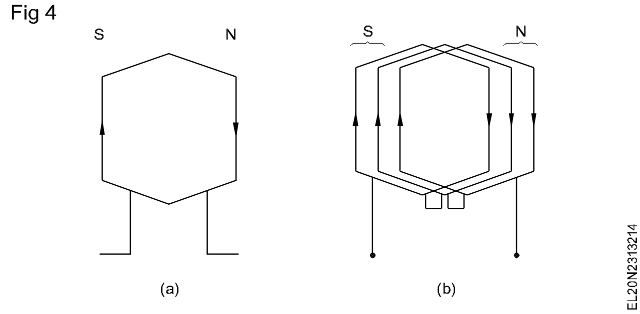
3 Efficiency of the machine is increased.

4 Winding occupies less space.

5 In alternators, the winding produces uniform sine wave.

Coil group : When you observe the direction of the current flow in a coil, you will see current in the two coil sides have opposite directions as shown in Fig 4(a).

Fig 4



Accordingly the current in a single coil produces two dissimilar poles. In an ordinary winding, according to the design, one or more coils may be connected in series to form a group as shown in Fig 4(b).(Three coils form one group) The total number of coil groups in a winding is equal to the number of phases multiplied by the number of poles.

Total No.of coil groups = No. of phases x No. of poles

$$\text{Coil group per phase} = \frac{\text{Total No. of coil groups}}{\text{No. of phases}}$$

Coil group per phase per pole =

$$\frac{\text{Total No. of coil groups}}{\text{No. of phases x No. of poles}}$$

Further the number of coils in a group per phase per pole

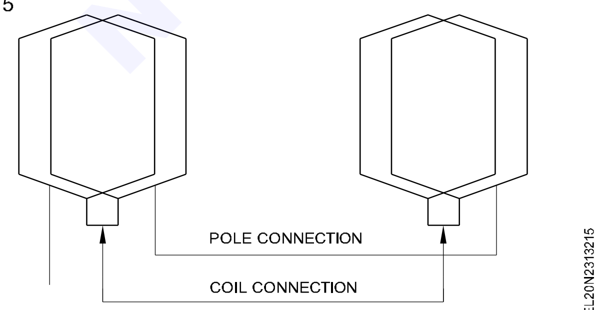
$$= \frac{\text{Total number of coils}}{\text{No. of phases x No. of poles}}$$

$$= \frac{\text{Total number of coils}}{\text{Total number of groups}}$$

Coil connections : The connection which joins a coil lead of one coil to the other coil lead of the same coil group is called 'coil connection' and is shown in Fig 5.

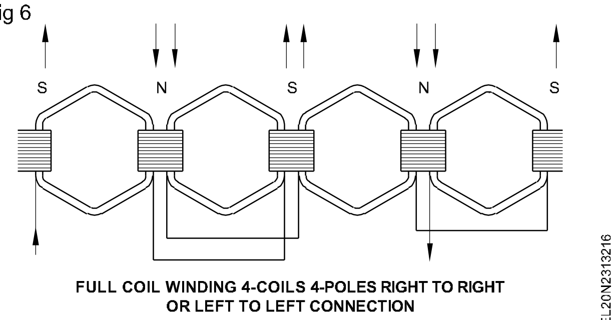
Pole connection : The connection which joins a coil group of one phase to another coil group of the same phase of the winding is called pole connection or group connection, and is shown in Fig 5.

Fig 5



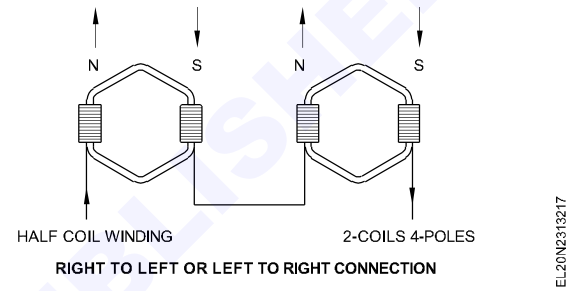
Whole-coil winding: A whole coil winding is one in which the number of coils per phase is equal to the number of poles in the machine. Refer to Fig 6.

Fig 6



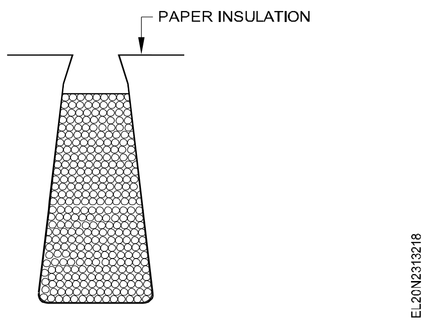
Half coil winding : A half coil winding is one in which the number of coils per phase is equal to half the number of poles in the machines. Half coil winding is generally done in the winding of ceiling fans, double speed motors etc. Refer to Fig 7.

Fig 7



Single layer winding : In single layer winding each slot contains only one coil side as shown in Fig 8 and the number of coils in the machine is equal to half the number of slots in the stator or armature. In single layer winding the coil pitch is usually taken in odd numbers.

Fig 8



Double layer winding : In double layer winding each slot contains two coil sides (i.e.one upper and one lower) as shown in Fig 9 and the number of coils is equal to the number of slots in the stator.

Balanced winding : When the coil groups contain the same number of coils per phase per pole the winding is termed as 'balanced winding'. It is also known as 'Even Group' winding and is shown in Fig 10.

Unbalanced winding : If the coil group contains an unequal number of coils per phase per pole then the winding is called 'unbalanced winding'. It is also sometimes called 'odd group' winding and is shown in Fig 11.

It is important that there must be an equal number of coils in each phase whether the winding is balanced or unbalanced as shown in Figs 10 and 11.

Fig 9

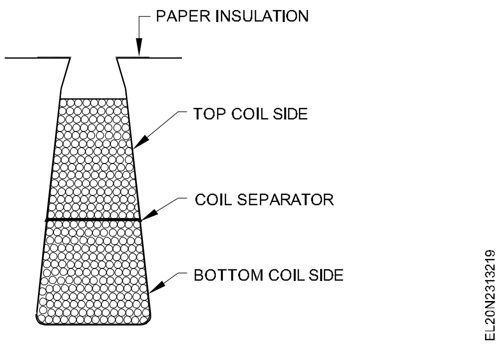
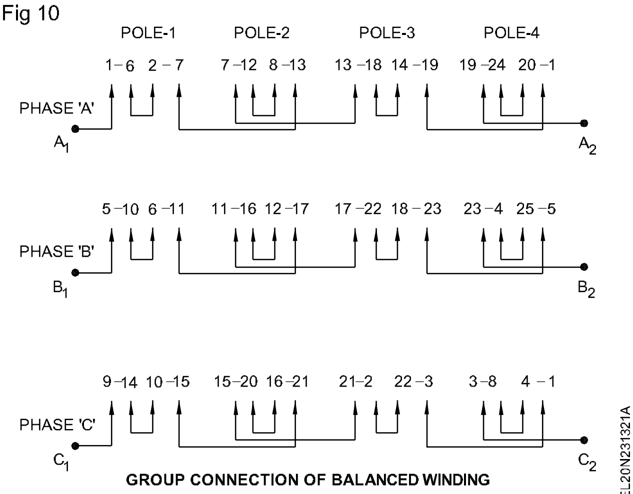
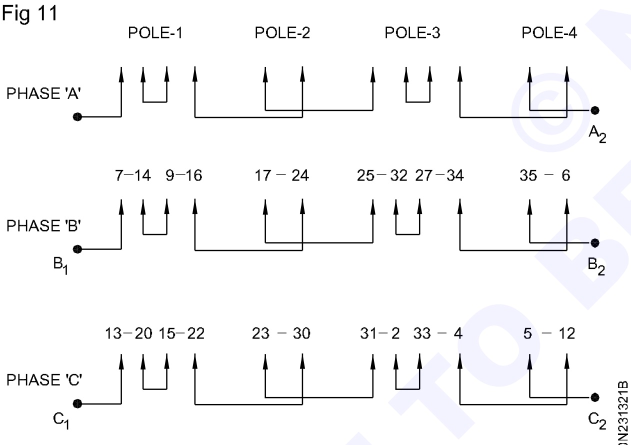


Fig 10



GROUP CONNECTION OF BALANCED WINDING

Fig 11



GROUP CONNECTION OF UNBALANCED WINDING

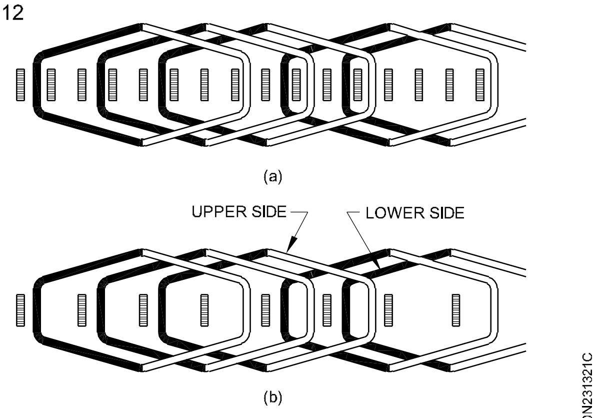
Concentrated winding : If in any winding the number of coils/pole/phase is one, then the winding is known as 'concentrated winding'. In this winding each coil side occupies one slot.

Distributed winding : In this winding the number of coil/ pole/phase is more than one - arranged in different slots. In this case each coil has the same pole pitch.

Partially distributed winding: In this winding the coil sides do not occupy all the slots, but some slots remain empty and they are called dummy slots.

Fully distributed winding : It is a winding in which not a single slot remain empty.

Fig 12



BASKET WINDING

Different types of AC Windings

The types of AC windings according to shape are as follows.

a Basket winding

b Concentric winding

c Skein winding

d Flat loop Non-overlapped winding

e Flat loop overlapped or chain winding

f Skew winding

g Diamond coil winding

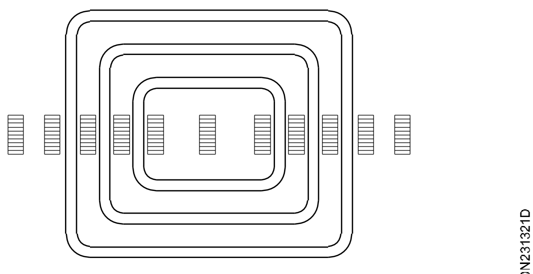
h Involute coil winding

Basket winding : After the completion of the winding, the ends of the winding resemble the weaving of a basket and hence it is known as basket winding. Basket winding is of two types. a) Single layer basket winding as shown in Fig 12a, double layer basket winding as shown in Fig 12b.

Concentric (or box type) winding : This winding has two or more than two coils in a group, and the coils in each group have the same centre. In each group, the coil pitch is not equal, and, therefore, do not overlap each other.

In this winding the coil pitches are not equal and each coil of the group has a difference of 2 slots in its pitch. Though it requires more labour to insert coils due to different coil spans, the design allows more cooling space. This winding is usually provided in single phase motor winding. This is shown in Fig 13.

Fig 13



CONCENTRIC WINDING

3 phase squirrel cage induction motor winding (single layer distributed winding)

Objectives: At the end of this lesson you shall be able to
- **explain the winding terms and calculations pertaining to single layer distributed type winding**
- **explain how to draw the end and coil connection diagrams**
- **state how to draw the ring and developed diagrams.**

Distributed type winding: The most common type of winding found in 3-phase motors is the distributed type winding. A distributed type winding is one in which the size of all the coils, coil pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, the coils overlap each other. Distributed winding may be of single or double layer type.

Single layer winding : Single layer winding is one in which there will be as many coils as half the number of slots. For example 6 coils in the case of 12 slots, 12 coils in case of 24 slots, 18 coils in the case of 36 slots and so on. In short, there will be only one coil side per slot.

Calculation for single layer distributed winding : The winding data of the distributed single layer winding will be within the following limitation. (As an example 3- phase, 24 slots, 12 coils, 4 poles is illustrated below).

I Grouping

i) $\text{No. of coils/phase} = \dfrac{\text{Total No. of coils}}{\text{No. of phases}}$

As in the example

No. of coils per phase = 12/3 = 4 coils/phase.

ii For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{Total No. of coils}}{\text{No. of phases x No. of poles}}$$

As in the example

$$\text{No. of coils/phase/pole} = \frac{12}{3 \times 4} = 1\,\text{coil/phase/pole}$$

iii For half coil connection

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phases x pair of poles}}$$

As in the example

$$\text{For each phase and pair of poles} = \frac{12}{3 \times 2} = 2\,\text{coils / phase / pair of poles}$$

For the example taken, half coil connection is possible for distributed winding by taking full pitch and placing coil in alternate two slots., but it is not in practice. Hence whole coil connection is taken as an example.

II Pitch

$$\text{Pole pitch} = \frac{\text{Total No. of slots}}{\text{No. of poles}}$$

As in the example, pole pitch = 24/4 = 6 slots.

ii Coil pitch

In AC winding the relation between the coil pitch and the pole pitch is given below.

a Coil pitch = Pole pitch — Then the winding is called full pitch winding.

b Coil pitch < Pole pitch — Then the winding is called fractional pitch - short chorded winding.

c Coil pitch > Pole pitch — Then the winding is called as fractional pitch - long chorded winding.

Further, if the winding is double layer, all the above ‘a’, ‘b’ and ‘c’ are possible. But for single layer distributed winding as the coils should be placed in alternate slots only, the coil pitch ought to be in odd number.

As in the example, coil pitch = pole pitch = 24/4 = 6 slots.

Here 6 is an even number and winding cannot be of full pitch, so the next alternative is to select a fractional pitch. Therefore the coil pitch can be taken either as 5 or 7. Normally AC windings should either have full pitch or short chorded fractional pitch. Hence a suitable pitch is taken of 5 slots.

iii Coil throw

The coil throw for coil pitch ‘5’ as in the example is 1 - 6.

III Electrical degrees

i Total electrical degrees = 180° x No. of poles

(180° is the distance between poles)

ii $\text{Slot distance} = \dfrac{180^{0}\ \text{x No. of poles}}{\text{No. of slots}}$

As in the example: Slot distance = (180x4)/24 = 30°

IV Phase displacement

i For three-phase winding, displacement between the phases should be 120° .

ii Phase displacement in terms of slots = 120°/slot distance

As in the example, 120°/30° = 4 slots

V Winding sequence

In three-phase winding the distance between the starting end of one phase to the starting end of another phase should have 120 electrical degrees. Hence we should arrange the winding such that

'A' phase starts from say 1st slot

'B' phase starts from 1st slot + 120° and

'C' phase starts from 1st slot + 120° + 120°.

As in the above example, 'A' phase starts from say 1st slot

'B' phase should start from 1+4 = 5th slot

'C' phase should start from 1+4+4 = 9th slot.

VI Arrangement of coils

As the winding is in a single layer, the coil shall be placed in alternate slots i.e. if one coil side of coil number one is placed in slot number one which is an odd number, the other coil side of the first coil should be laid in an even number slot. Hence placement of coils should start in slot numbers 1,3,5,7,9 and so on leaving the slot numbers 2,4,6,8 and so on to receive the other coil sides of the coils.

As in the example the 12 coils are to be laid in slots (pitch = 5 slots)

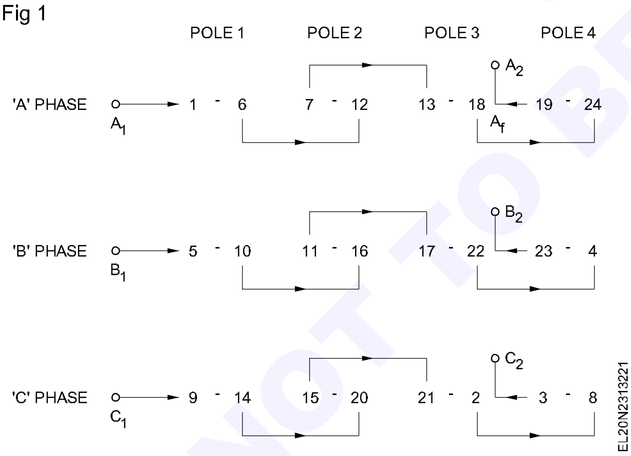
1-6, 3-8, 5-10, 7-12, 9-14, 11-16, 13-18, 15-20,

17-22, 19-24, 21-26(2), 23-28(4).

VII End connections

As discussed, for grouping of coils in normal practice, the end connections shall be whole coil connection. As in the example in Fig 1.

Fig 1



VIII Coil connections

In whole coil connection, the connection of the coil group shall be from finish to finish and start to start for the group of coils.

There are several ways of connecting the coils in groups. Fig 2 shows one method and Fig 3 shows another method. However, you are advised to check the formation of the poles with the help of a ring diagram and clock rule. The procedure is explained in the subsequent paras.

Fig 2

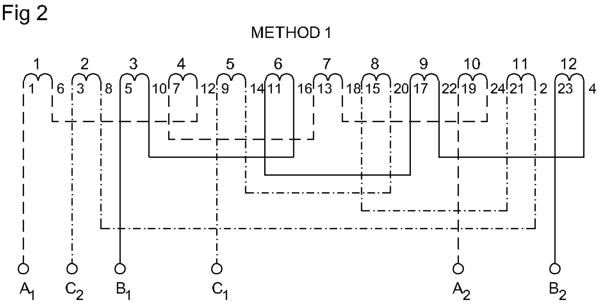
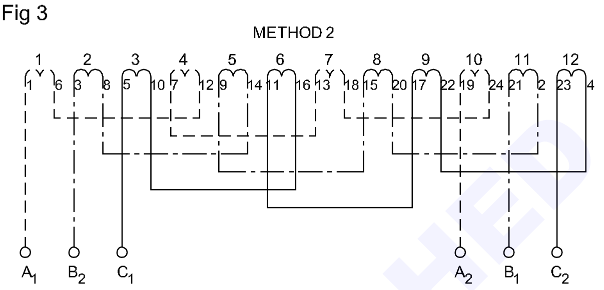


Fig 3

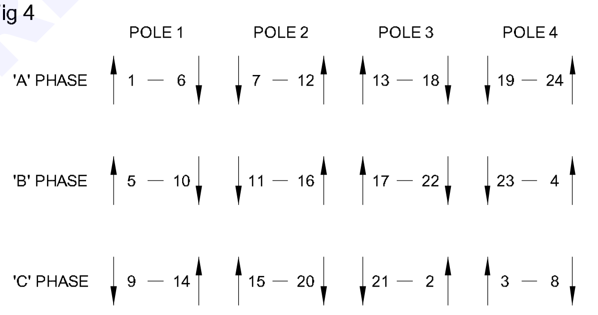


XI Ring diagram

Cross check the end connections as follows. Write the end connection table and mark the direction of current using the clock rule. Note that when three-phase supply is given to the windings, and if two phases carry current inward , the third phase will carry current outward.

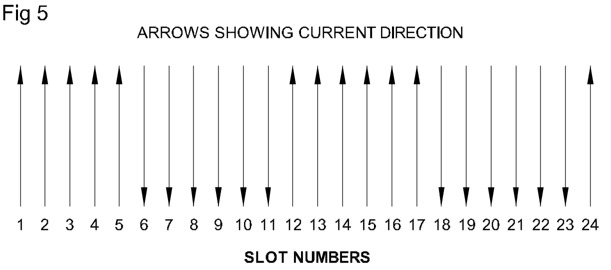
Referring to method 1 shown in Fig 2, the current direction in the coil sides could be marked as shown in Fig 4.

Fig 4



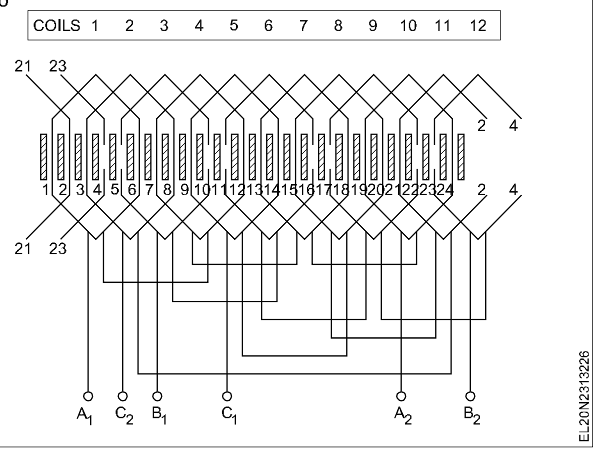
Now arrange the slots in the sequential order and mark the direction of current in the slots accordingly by arrows which ultimately shall represent production of the required number of poles as shown in Fig 5.

Fig 5



Developed winding diagram: The development winding diagram will give a clear picture of the coil sides in relevant slots grouping, coil end connections and lead termination. A 24 slots, 12 coil, 4 pole, 3 phase single layer distributed winding development diagram is shown in Fig 6 for your guidance.

Fig 6



Method of placing coils in a basket or distributed winding

Objectives: At the end of this lesson you shall be able to
- **state the various methods employed to prepare gang or group of coils**
- **explain the method of placing coils in the single layer basket winding**
- **explain the method of placing coils in a double layer basket winding.**

The procedure outlined below is common for single or three-phase distributed winding. However this type of basket (distributed) winding is very popular in three phase motors.

The coils can be wound using a single former and then they can be interconnected by coil connections as shown in Fig 1. Most of the three-phase motors with the exception of very large ones with formed windings, use coils wound in groups as shown in Fig 2.

Fig 1

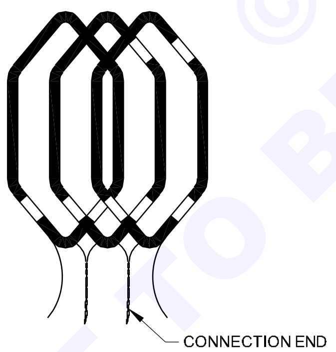
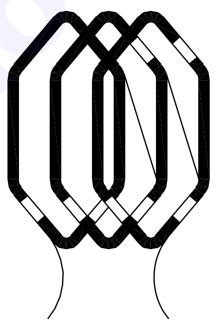


Fig 2



The number of coils in each group will depend on the number of phases and number of poles. This practice of winding coils in groups is called group or gang winding.

In group winding several coils are wound before the wire is cut. This saves time and space by eliminating the necessity of connecting coils to one another then soldering them and then insulating them.

Fig 3 shows a winding head mounted on a bench type coil winding drive. The wire is wound around six wheels mounted on a shaft. Other types of forms are also used. Fig 4 shows a coil winder for producing oval or round coils.

Fig 3

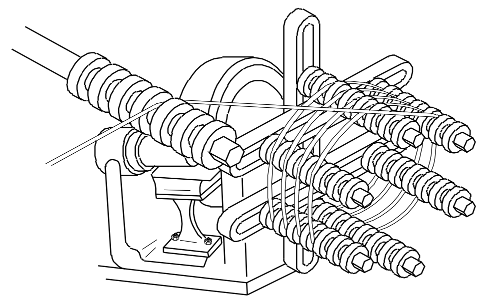
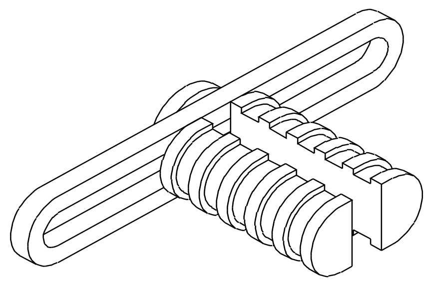


Fig 4



Coils for small motors may be wound in rectangular form and then two sides shaped into a diamond shape by pulling at the centre of the opposite ends as shown in Fig 5. Insertion of coils in single layer basket winding (formed individual coils).

In single layer winding there are half the number of coils as there are slots. For example a machine with 12 coils and

24 slots will have single layer winding. The appearance of a single layer winding is shown in Fig 6 in which the coil pitch is 1-6. While placing coils in a single layer we have to place the coil sides in alternate slots only.

Fig 5

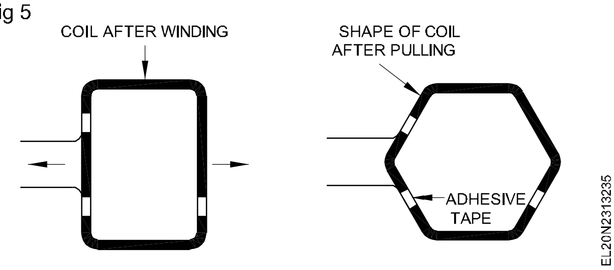
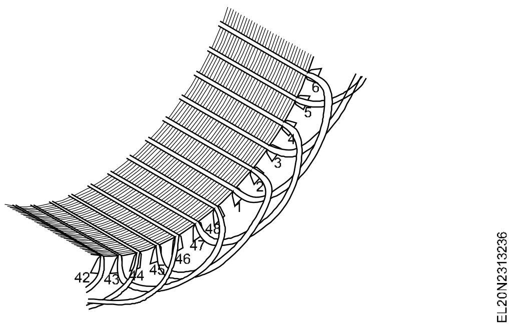
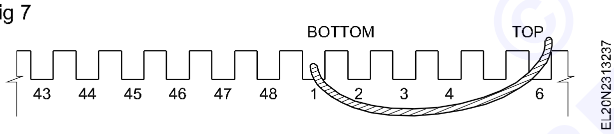


Fig 6



Let us take for example a 48 slot 24 coil 8 pole motor with the coil pitch of 1 to 6. Fig 7 illustrates the way in which the single layer winding is to be placed in the slot. This will be noticed from the diagrams there is only one coil side per slot. Fig 7 shows one coil side of the first coil placed in slot number 1.

Fig 7



Generally any slot can be identified as slot 1 with the help of chalk markings or a spot of paint. The other coil side of the same coil is left out on the core. This coil is called a throw coil. The left out coil side may lie in the right hand side as shown in Fig 7 or left hand side of the stator, when viewed from the connection end. However this depends upon the original winding pattern. The coil overhanging ends can be wrapped up to 2/3 of the length with a cotton tape of 0.175 mm thickness. To avoid the inserted coil turns from coming out of the slot while handling other coils, it is preferred to wedge temporarily the slot using a foot (Skill Information 1203) soon after the insertion of coil is over. In single layer winding the coil sides should be placed in alternate slots as shown in Fig 8.

In Fig 8 coil 1 is placed in slot No.1 and the other coil side of the same coil is left over the stampings. To avoid damage to the left out coil side, a leatheroid paper of width larger than the width of the core is placed between the core and the coil as shown in Fig 8. After placing the coil side in the slot use the awl to fold the insulation paper (slot liner) one side over the other, slip the separator paper over the folding and then slip the formed fibre or bamboo wedge over the top of the coil. The wedge should extend about 3 to 6 mm beyond the slot liner. The procedure is shown in Fig 9.

Fig 8

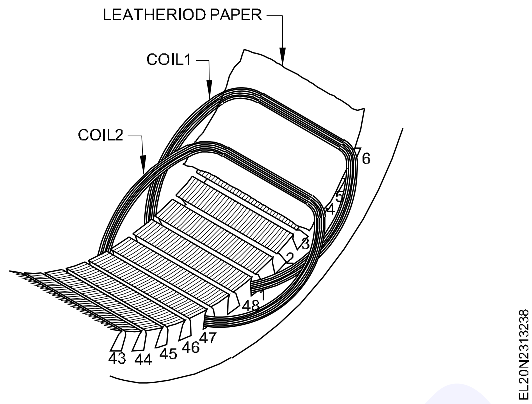
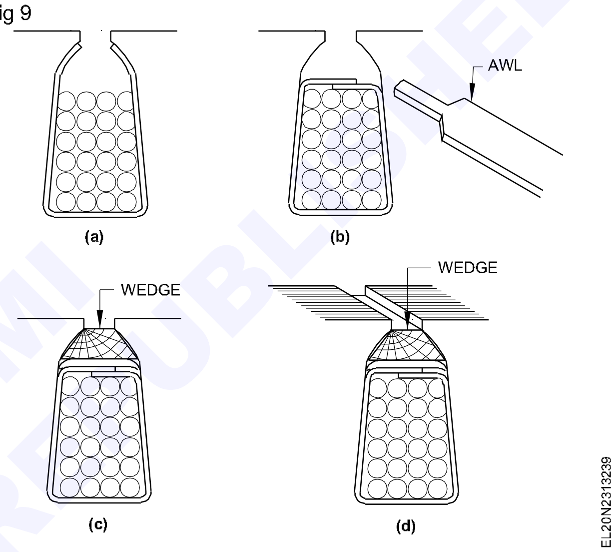


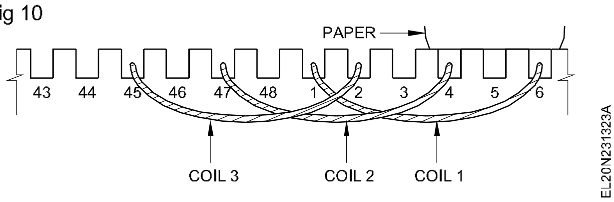
Fig 9



Some prefer to wedge the slots temporarily till all the coils are inserted and the winding is tested for grounding. Once the test results are o.k., then permanently wedge the slots.

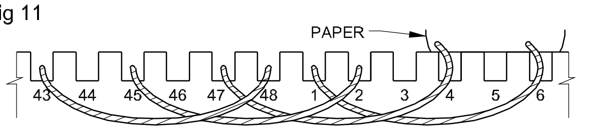
In the next step left coil side of coil 2 is placed in slot number 47 (leaving slot No.48 which is adjacent to slot No.1) and the right coil side of coil 2 is left in the core. (Fig 8) Next place left side of the coil 3 in slot number 45 and leave the right side of the coil over the core. Remember to extend the leatheroid paper insulation between the core and the coil. By examination it will be found that the left out (right) coil side of coil No.3 which has left coil side inserted in slot No.45 should be inserted in slot 2 according to the assigned coil pitch. Now insert the left out right coil side of coil 3 in slot No.2 as shown in Fig 10.

Fig 10



In general, unless the left out coil side of any coil falls, according to the assigned pitch, next to the occupied slot, proceed further to insert one coil side only. Again proceed to insert the left coil side of coil 4 in slot No.43 and the right coil side of coil 4 in slot No.48 as shown in Fig 11.

Fig 11



Proceed likewise to fill up the slots and complete the insertion of coils in the slots.

Insertion of coils in double layer (lap) winding

Let us consider a 3-phase machine with 24 slots, 24 coils, 4 poles and having a slot pitch of 1-6 and a coil pitch 1-12 in terms of coil sides.

ASSUMPTION: Individual coils numbering 24 are former wound and kept ready . Procedure given below is for the developed winding diagram shown in Fig 12.

Accordingly Fig 13 shows the numbered slots. Table 1 shows the position of the coil sides in the slots. The coil sides in the bottom are given odd numbers and the coil sides of top are given even numbers.

Fig 13

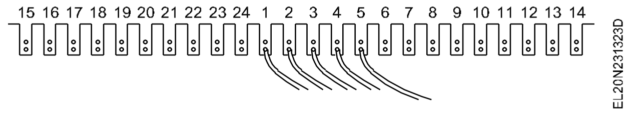


Fig 12

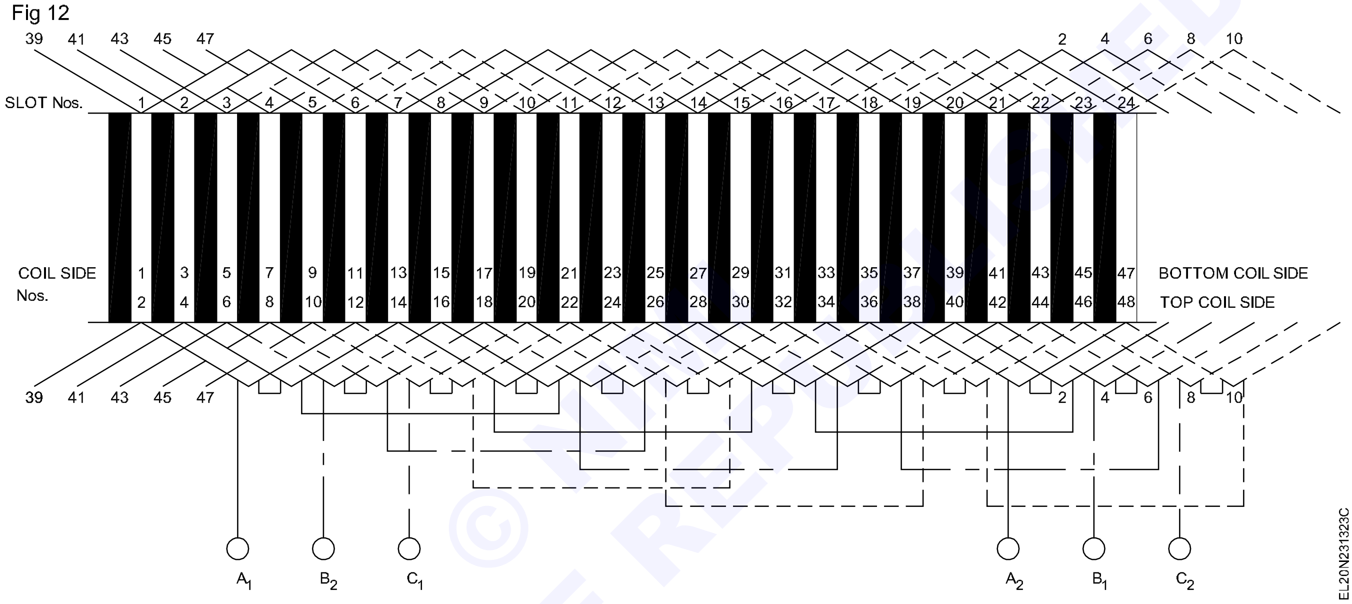
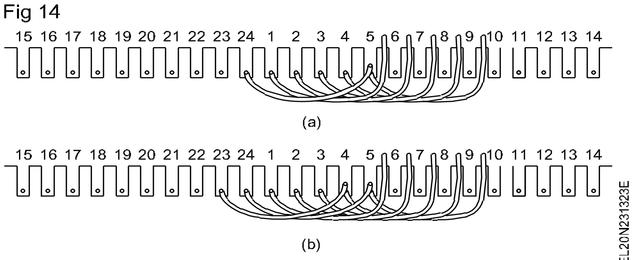


Table 1

Slot	Bottom	Top
1	1	2
2	3	4
3	5	6
4	7	8
5	9	10
6	11	12
7	13	14
8	15	16
9	17	18
10	19	20
11	21	22
12	23	24
13	25	26
14	27	28
15	29	30
16	31	32
17	33	34
18	35	36
19	37	38
20	39	40
21	41	42
22	43	44
23	45	46
24	47	48

Winding is arranged such that looking from the connection end, the bottom coil is on the left side and the top coil sides is in the right side as shown in Figs 13 and 14.

Fig 14

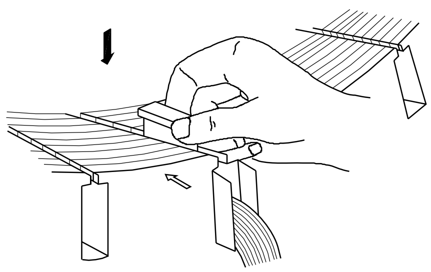


Further the connection end of the winding in the stator is to be identified from the data with respect to the terminal box.

Referring to the developed diagram (Fig 12) and Table 1, if the bottom coil side 1 is inserted in slot 1, then the other coil side of the same coil which is 12, should be inserted in the slot number 6 as a top coil side. As such there should be a certain approved procedure to start the winding.

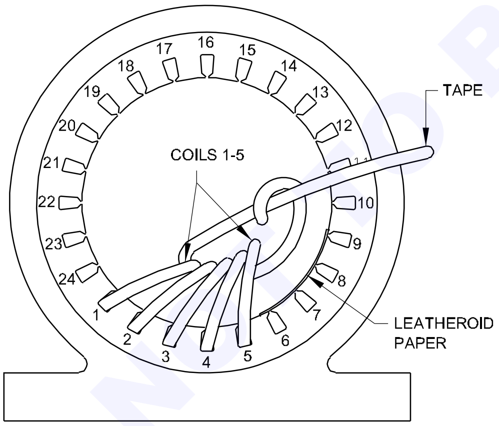
Proceed as, first insert one coil in slot number 5 and leave the other coil side on the core. Use a suitable fibre foot or wedge for slot 5 to secure the winding. (Fig 15). To avoid damage to the insulation in the process of winding, insert a thick leatheroid paper of a width larger than the core between the left out coil side and the core, as shown in Fig 8. Let the length of the leatheroid paper be sufficient enough to cover 5 coil sides at a stretch.

Fig 15



Insert the coils in slot numbers 4,3,2 and 1 in sequence as shown in Fig 13 and wedge them temporarily as shown in Fig 15. Let the other coil side lie on the core with the protected leatheroid paper between the coils and the core. These coils are called throw coils. For the protection of insulation of the throw coil you can tie the bunch of coil sides together with a cotton tape and tie the whole lot to the stator as shown in Fig 16. Remember to ensure the leatheroid paper is well kept between the bunched coils and the core.

Fig 16



Use of coil separation : Before inserting the top coil side over the bottom coil side of the same slot it is necessary to insulate the coil sides inside the slot by the use of coil seperators. This is because each coil side within one slot may belong to different phases and the voltage between them may be high.

To insulate the coil sides from each other within the slot follow the procedure shown in Fig 17 for both open and semi-closed slots. A creased separator or insulation paper of proper width, length and thickness (usually 0.25 to 0.375 mm) is used as insulation between the top and bottom coil sides in the slot. Slide an awl over the bottom coil side as shown in Fig 18a and press it over the bottom coil and slide the separator underneath the awl as shown in Fig 18b. Let the separator project about 10mm beyond the core on either side.

Fig 17

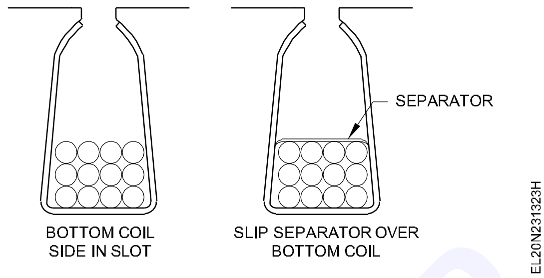
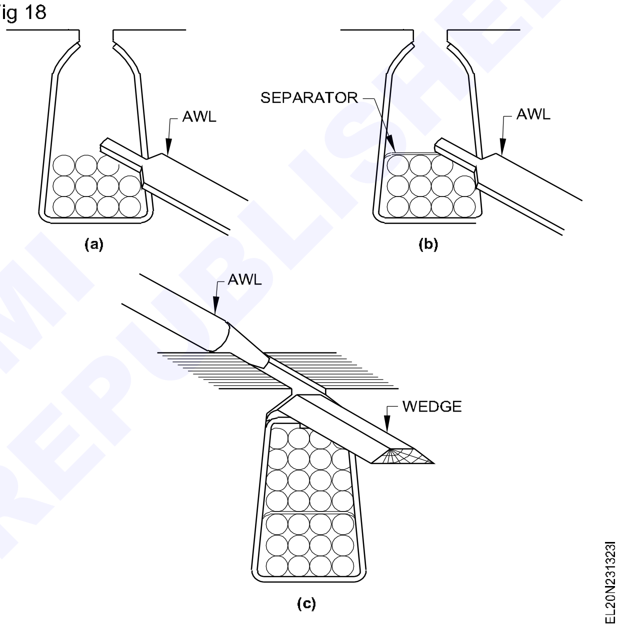


Fig 18



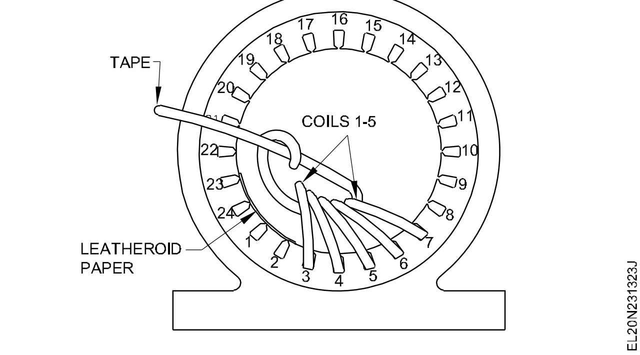
Method of overlapping : Now insert one coil side in slot number 24 (coil side 47) and the other coil side of the same coil (coil side 10) in slot number 5 as the top coil over the bottom coil side 9. Likewise insert another coil side 45 of a next coil in slot number 23 and the other coil side 7 of the same coil in slot number 4. Proceed likewise till you reach slot number 6. During this process as you reach near about the 10th slot or much earlier you will feel the hindrance of the throw coils which are tied to the stator. At that time untie the cotton tape from the stator and tie the bunch in the opposite side of the stator as shown in Fig 19 with a leatheroid paper in between the coils and the core.

While tieing the cotton tape see that the slot number 6 is easily approachable without any difficulty. After inserting the bottom coil side 11 in slot 6 insert the corresponding other coil side 22 in slot 11 as the top coil side. After inserting the top coil side fold the slot liners one side over the other, insert the separator and the wedge.

Now untie the throw coil bunch and release the free end of the coil in slot 5 and insert the same as top coil side in slot 10. Proceed likewise to insert the coils from slots 4,3,2 and 1 in the corresponding slots.

insulation and result in grounding the coils with the stator core.

Fig 19

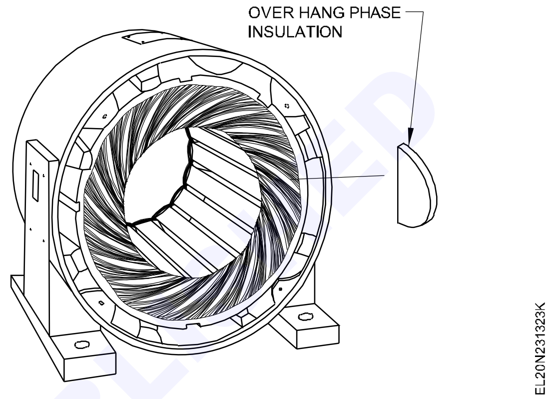


Overhang Insulation : Now cut and prepare the leatheroid paper to the shape of half moon as in the original which is to be used as phase insulation between the overhanging coils. According to the developed diagram coil sides 1 and 3 form the first phase, 5 and 7 the second phase and 9 and 11 form the 3rd phase. Identify these coils and start inserting the leatheroid paper between 3 and 5 as well as between 7 and 9.

Thus proceed to insert this phase insulation for the entire winding as shown in Fig 20. If you find the space between these coils is less, you may use a fibre wedge to prime the coils to facilitate insertion of the leatheroid paper. Do not use too much force which may crack the slot liner insulation and result in grounding the coils with the stator core.

End connections : There are three types of connections to be made - first the coil connection for coil grouping, second for connecting the coil groups in one phase, and thirdly connecting the lead wires. Better to proceed one by one in the above sequence. Any connection to be made in winding the wires should start with proper identification of the coil ends. For a beginner, it may be necessary to refer to the developed diagram, connection diagram, as well as the actual winding often to eradicate the confusion.

Fig 20



Three-phase induction motor winding (single layer - concentric type - half coil connection)

Objectives: At the end of this lesson you shall be able to
- **state the general requirements pertaining to the concentric type of winding in 3-phase motors**
- **state the merits and demerits of concentric type winding**
- **explain the preparation of a winding table for concentric type winding**
- **explain how to draw the end and coil connection diagrams**
- **explain how to draw the developed and ring diagrams.**

3-phase concentric winding : In general, concentric winding is found in single phase motors, and occasionally, this type of winding is also used for 3-phase motors.

This concentric winding has to have two or more coils in a group consisting of different pitches. Further in 3- phase concentric winding, all the three phases consist of the same number of coils, and produce similar concentric poles. Stepped formers are used to prepare coils for concentric winding.

Merits and Demerits of concentric winding: This type of winding has some merits and demerits also.

Merits

1 This type of winding has more space for cooling.

2 No need of raising (lifting) the coil sides to interleave them during the winding.

3 It is easy to shape the coils uniformly.

4 Possible to save copper, because in distributed winding all the coils are of the same size; on the other hand in concentric winding, coil groups only will be uniform, but coils of different pitches in concentric form are used.

5 As there is no interleaving of the coil sides, the winding could be done by machine resulting in faster production.

6 It is easy to make the end connection.

7 Easy to wind, as there is no overlapping of coils.

Demerits

1 Skilled labour is required to insert the coils in the slots.

2 A stepped former is required.

3 Not as efficient as basket winding.

1 Grouping

The example given below will clarify the following:

a whether concentric type of winding is possible for a given stator

b If yes, whether it should be half coil or whole coil connected winding.

Example

3-phase induction motor having 36 slots 12 coils 4 pole stator

We have

For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{No. of coils/phase}}{\text{No. of poles}}$$

$$= \frac{4}{4} = 1 \text{ coils/phase/pole}$$

As such there will be only one coil in a group. But concentric winding should have two or more coils in a group. In this case concentric winding is not possible. Alternatively grouping can be done for half-coil connection, i.e.

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phase x No. of pair of poles}}$$

$$\text{As per the example } \frac{12}{3 \times 2} = 2 \text{ coils}$$

i.e. 2 coils/phase/pair of poles.

As per the above example, only half-coil connected concentric winding is possible whereas for the following example having data 48 slots, 24 coils, 4-pole, 3-phase stator winding both whole coil and half coil connections are possible. Hence it is necessary to trace the group connection very carefully before stripping the stator to determine whether the winding connection is whole coil or half coil.

2 Pitch

1 Pole pitch $= \frac{\text{No . of slots}}{\text{No . of poles}}$

As per the example $= \frac{24}{4}$ 6 slots

As the winding is concentric, there should be 2 or more pitches normally. According to the above example 2 pitches for half-coil connections are required.

Further it is necessary to have the average pitch equal i.e. to the pole pitch.

(i.e.) coil pitch = pole pitch ± 1

As per the example coil pitch is 6 ± 1.

Therefore outer coil pitch = 6 + 1 = 7

and inner coil pitch will be = 6 - 1 = 5

(i.e.) Coil throw = 1 - 8 and 1 - 6 In practice it is written as 1 - 8 and 2 - 7.

3 Electrical degrees

i Total electrical degrees = 180° x No. of poles.

As per the example = $180^\circ \times 4 = 720^\circ$.

ii Slot distance in degrees $= \frac{180^\circ \times 4}{\text{No.of slots}}$

$$= \frac{180^\circ \times 4}{24} = 30^\circ$$

4 Phase displacement

i For three-phase winding phase displacement should be equal to 120°

ii Phase displacement in terms of slots

$$= \frac{120^\circ}{\text{slot distance in degrees}}$$

As per the example $= \frac{120^\circ}{30^\circ} = 4$ slots

5 Winding sequence

As per the example

A phase starts from 1st slot.

B phase starts from 1+4 = 5th slot and

C phase starts from 1+4+4 = 9th slot.

6 Arrangement of coils

As in the example 12 coils with pitches as 7 & 5 slots.

1-8,2-7; 5-12, 6-11; 9-16, 10-15; 13-20, 14-19; 17-24, 18-23; 21-4, 22-3.

Grouping of coils

The coil should start from every alternate 2 slots (i.e.) 2 slots for top sides and two slots for bottom sides. As per the example, coils start from 1 & 2, 5 & 6, 9 & 10, 13 & 14, 17 & 18, 21 & 22.

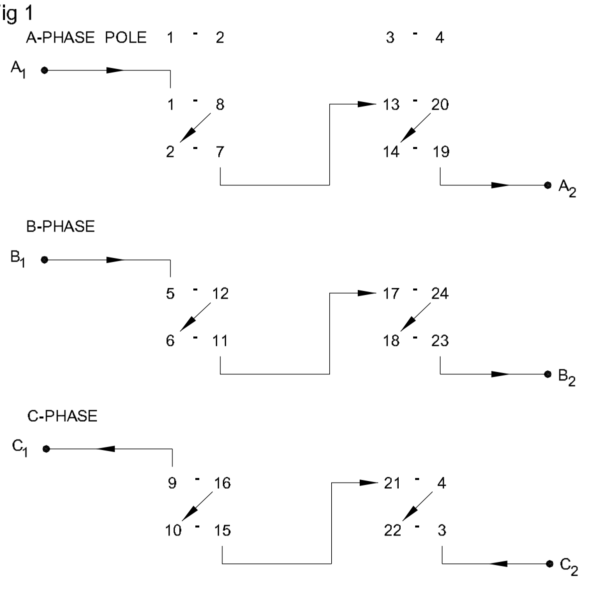
As the connection is half-coil type, with the help of one group of coils, 2 poles need to be created. Hence grouping is as follows:

A	B	C
1-8, 2-7	5-12, 6-11	9-16, 10-15
13-20, 14-19	17-24, 18-23	21-4, 22-3

In whole coil connection, the starting end connection is from the alternative groups (i.e.) if 'A' starts from the first group, 'B' starts from third group and 'C' starts from fifth group. Whereas in half-coil connection, the starting ends will be from continous group, if 'A' starts from the first group, 'B' starts from second group and 'C' starts from the third group. Refer to the developed diagram.

7 End connections (Fig 1): Half coil connection.(End to start and start to end)

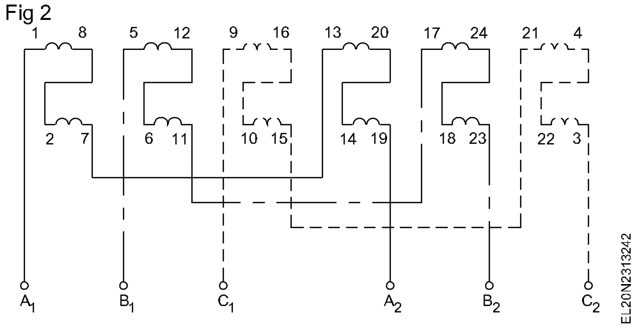
Fig 1



Coil connections : Half coil connection. (Fig 2)

In half coil connection, the connection of the coil group shall be from the finish end to the start end and then from the start end to the finish end of the group coils as shown in Fig 2.

Fig 2



Development diagram : Draw the development diagram showing the coil group and end connection. As an example a development diagram is shown in Fig 3.

10 Ring diagram

Cross check the end connection with the help of the ring diagram as explained below. Write the end connection table and mark the direction of current using the clock rule. Note that when a three-phase supply is given to the windings at an instant, and if two phases carry current in one direction, the third phase carries current in the opposite direction as shown in Fig 4.

Fig 3

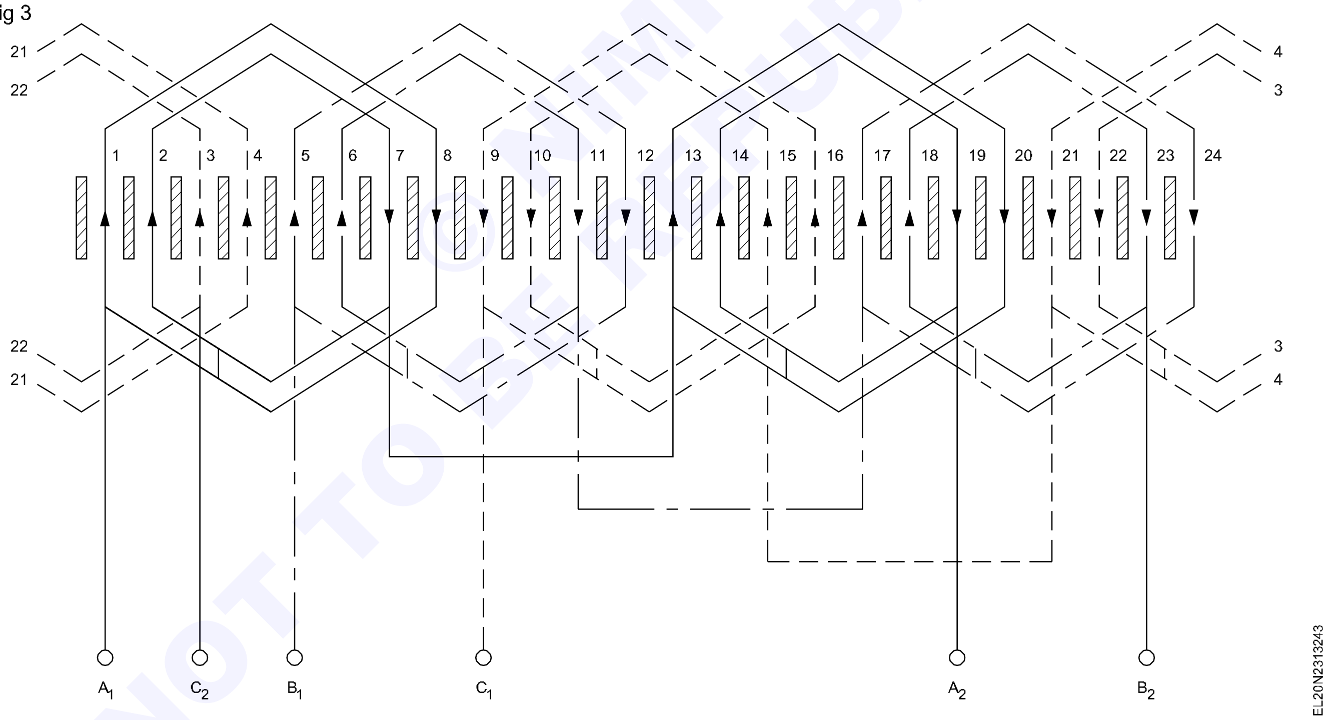
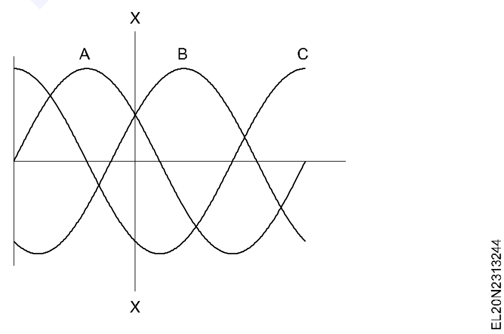


Fig 4



PHASE	P_1 & P_2	P_3 & P_4
A phase	↑1 - 8↓	↑13 - 20↓
	↑2 - 7↓	↑14 - 19↓
B phase	↑5 - 12↓	↑17 - 24↓
	↑6 - 11↓	↑18 - 23↓
C phase	↓9 - 16↑	↓21 - 4↑
	↓10 -15↑	↓22 - 3↑

Refer to Fig 4 in which at the instant shown in x-x we have phases A and B as positive polarity and C has negative polarity.

Mark the direction of current in the slot and it shall represent production of the required number of poles as per the example given below.

Whenever you come across a 3-phase induction motor having a single layer concentric type half coil winding follow the above mentioned procedure and prepare the winding table. Subsequently draw the end connection, development and ring diagrams.

↑ ↑ ↑ ↑ ↑ ↑	↓ ↓ ↓ ↓ ↓ ↓	↑ ↑ ↑ ↑ ↑ ↑	↓ ↓ ↓ ↓ ↓ ↓
1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19 20 21 22 23 24
N	S	N	S

3 phase squirrel cage induction motor - double layer distributed type winding

Objectives: At the end of this lesson you shall be able to
- **explain the meaning of double layer winding**
- **explain the winding terms and calculations pertaining to double layer distributed type winding**
- **draw the end and coil connection diagrams**
- **draw the ring and developed diagrams.**

There are different types of winding used in 3-phase AC motors. Some of the 3-phase windings are double layer, that is, there will be as many coils as the number of slots. For example 12 coils in the case of 12 slots, 24 coils in the case of 24 slots. 36 coils in the case of 36 slots, 48 coils in the case 48 slots. Further in the case of distributed winding the size of all the coils, pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, they overlap each other just like in a woven basket. This is also a type of distributed winding.

In double layer winding each slot contains two coil sides i.e. the bottom half contains the left hand coil side while the top half contains the right coil side of some other coil.

Calculations for double layer distributed winding : The winding data of the distributed double layer winding will be within the following limitations. As an example 3-phase double layer distributed winding for an induction motor having 36 slots 36 coils 4 poles is discussed below.

I Grouping

1 $\text{No. of coils/phase} = \dfrac{\text{Total No. of coils}}{\text{No. of phase}}$

As per the example,

$$\text{No. of coils/phase} = \frac{36}{3} = 12 \text{ coils per phase.}$$

2. No. of coils/phase/per pole = $\dfrac{\text{Total no. of coils}}{\text{No. of phase} \times \text{No. of poles}}$

$$\text{No. of coils/phase/pole} = \frac{36}{3 \times 4} = 3 \text{ coils/phase/pole}$$

II Pitch

1 $\text{Pole pitch} = \dfrac{\text{No. of slots}}{\text{No. of poles}}$

As per the example, pole pitch = $\dfrac{36}{4}$ = 9 slots

2 **Coil pitch :** Similar to the single layer winding the coil pitch can be short-chorded, long-chorded or equal to the pole pitch. The pitch of the double layer distributed winding may be odd or even number. As per the example, the pole pitch is equal to 36/4 = 9 slots and the no. of coils per group is 3. Hence the coil pitch may vary from 9 ± 3 that is 6,7 or 8 in the case of short corded winding, 9 in the case of full pitch winding and 10,11 or 12 in the case of long chorded winding. Hence the possible coil throws can be taken as

1 to 7 and 1 to 8 for short chorded winding

1 to 9 and 1 to 10 for full pitched winding

1 to 11, 1 to 12 and 1 to 13 for long chorded winding.

Normally the winding is designed for either short chorded or full pitch. Occasionally a long chord is used by the designer in double speed winding. The reason for not using long chorded winding is, it requires more chord length resulting in the requirement of more copper, and hence, increased heat losses.

3 **Coil throw :** According to the above example the coil throw for the coil pitch of 8 will be 1-9.

III Electrical degrees :

Total electrical degrees = 180° x No. of poles

[180° distance between poles]

Slot distance in degrees =

$$= \frac{180° \times \text{No. of poles}}{\text{No. of slots}}$$

$$\text{As per the example } \frac{180 \times 4}{36} = 20°$$

IV Phase displacement

i. For three-phase winding each phase winding should be displaced by 120 electrical degrees.

ii. Phase displacement in terms of slots =

$$\frac{120° \text{ (Electrical)}}{\text{Slot distance in degrees}}$$

$$\text{As per the example } \frac{120°}{20°} = 6 \text{ slots}$$

V Winding sequence : In three-phase winding, the starting end of one phase winding to the starting end of the second phase winding should have a distance of 120 electrical degrees.

Hence if the 'A' phase starts say in the Ist slot then the 'B' phase should start from the 1st slot+120°.

Further 'C' phase should start from the 1st slot+120°+120°.

As in the example 'A' phase starts from, say, 1st slot

'B' phase should start from 1+ 6 = 7th slot and

'C' phase should start from 1+ 6 + 6 = 13th slot.

VI Placing of the coils in double layer winding: As the winding is double layer, the laying of coils should start in adjacent slots.

That is the coils should be placed in slot 1, slot 2, slot 3 and so on.

As in the above example the arrangement of coils for the selected pitch 8 will be as given below:

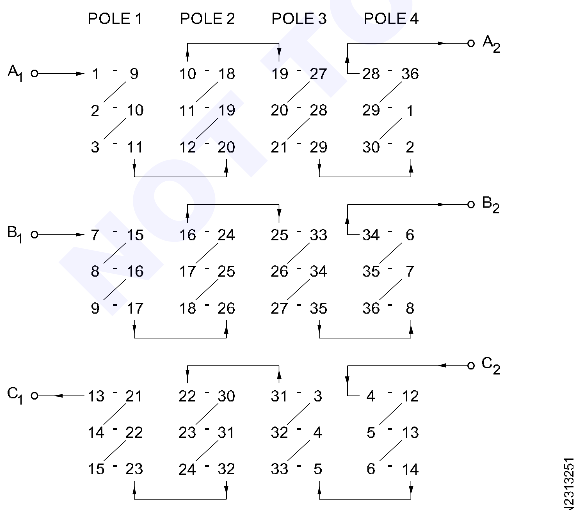
Fractional pitch Short chorded winding

	Pitch 8	Coil throw 1-9	
Pole	**A-Group**	**C-Group**	**B-Group**
P1	1-9, 2-10, 3-11	4-12, 5-13, 6-14	7-15, 8-16, 9-17
P2	10-18, 11-9, 12-20	13-21,14-22,15-23	16-24,17-25,18-26
P3	19-27, 20-28,21-29	22-30,23-31,24-32	25-33,26-34, 27-35
P4	28-36, 29-1, 30-2	31-3, 32-4, 33-5	34-6, 35-7, 36-8

Though the possible pitches are 6,7,8,9,10,11 and 12 the above example is given for the pitch equal to 8 only. Trainees are advised to write the table for other pitches to have a better understanding of the winding.

VII End connections : Draw the end connections as shown in Fig 1.

Fig 1



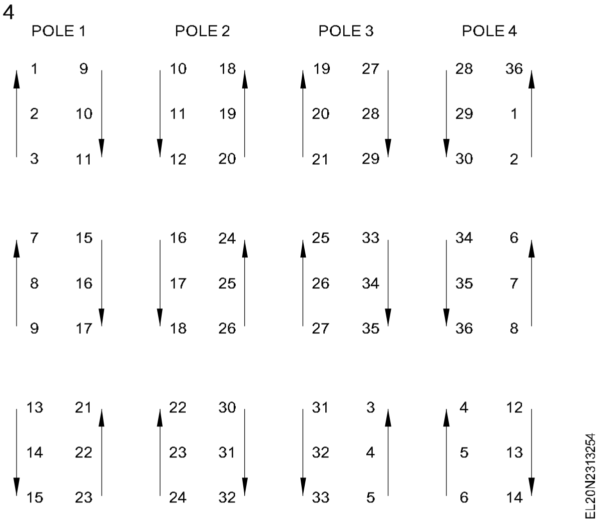
GROUP AND PHASE CONNECTION OF WINDING

VIII Coil connections : In whole coil connection, the connection of coil groups shall be from the finish end to the finish end and the start end to the start end of the group of coils of the same phase. Either of the following two methods shown in Figs 2 and 3 could be followed.

IX Cross check the end connections: Write the end connections table as illustrated below in Fig 4 and mark the direction of currents using the clock rule.

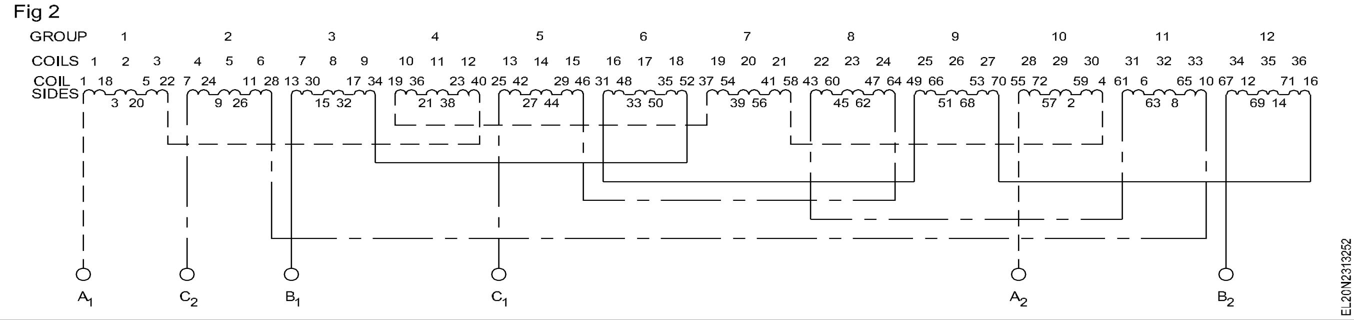
When three phase supply is given to the 3-phase winding, if two phases carry current inwards, the third phase will carry current outwards.

Fig 4



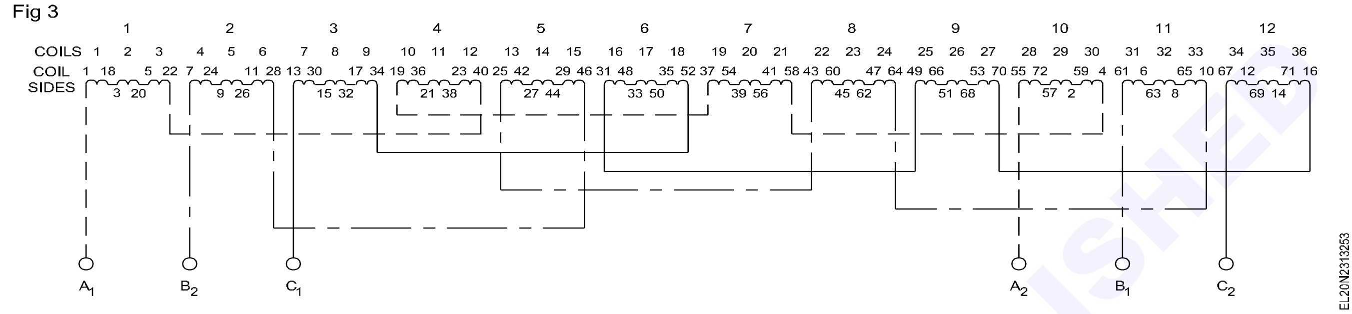
METHOD 1

Fig 2



METHOD 2

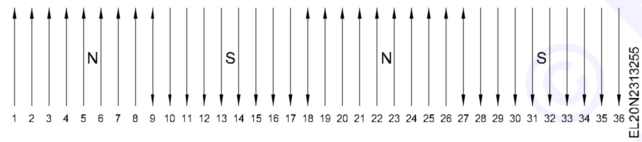
Fig 3



X Ring diagram

Mark the direction of current in the respective slots and then check the production of the required number of poles as shown with ring diagram. (Fig 5)

Fig 5



As per the above ring diagram, in all 4 poles are produced. One pole is produced at each of the area contained by the eight slots. In slots 9,18,27 and 36 coil sides carry current in the opposite directions and hence, the flux in those slots gets neutralized. This happens in the short chorded winding. Based on the above information draw the developed diagram.

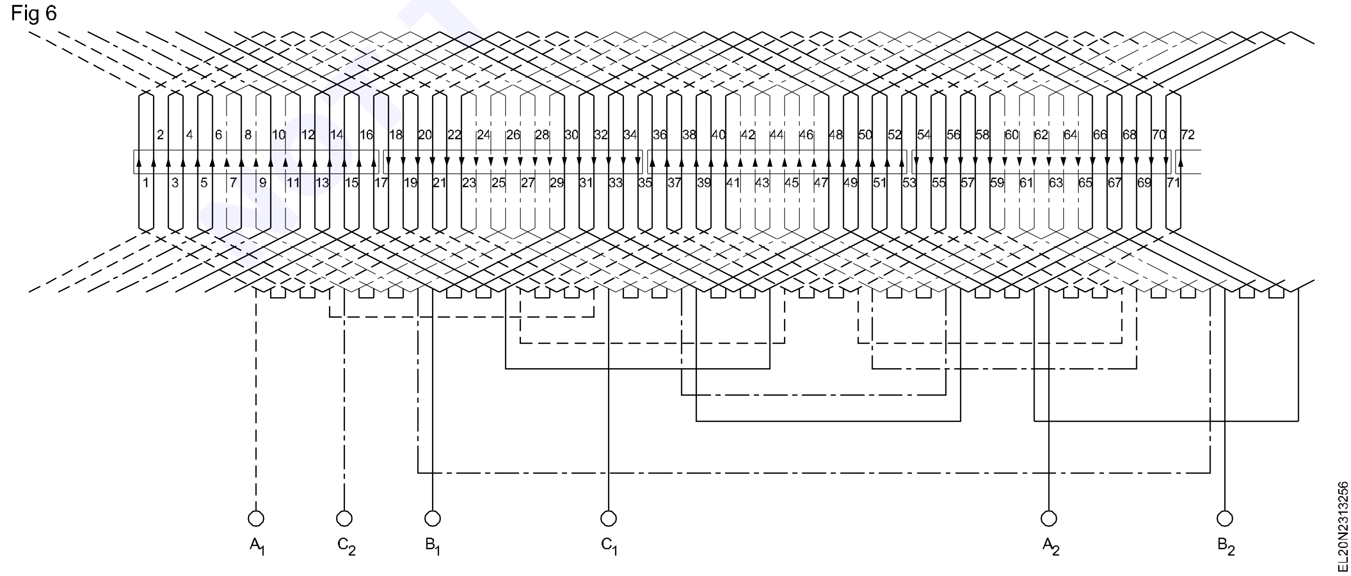
XI Developed diagram : A developed diagram is shown in Fig 6 in which the connections are shown for the method 1 referring to Fig 2.

XII Fractional pitches : After the group and lead connections are over, the sleeved joints are to be tied with the overhang with the help of hemp threads.

Winding is then to be tested and varnished.

The motor is then to be assembled and test run for at least eight hours to check its performance on no load. Wherever loading facilities are available the newly wound motor can be checked for its load performance.

Fig 6



Testing of windings

Objectives: At the end of this lesson you shall be able to
- **test the rewound motor for continuity and measure the coil resistance**
- **test the coils of the winding for short circuit using internal growler or voltmeter or ohmmeter**
- **test the winding for ground and insulation resistance**
- **test the winding for correct magnetic polarity using a magnetic compass or screwdriver or a search coil**
- **test the 3-phase winding for equal value of phase currents**
- **test the newly wound motor under no-load.**

After the motor is rewound the following tests are carried out in the windings.

1 Continuity test/resistance test.

2 Short circuit test/growler test.

3 Insulation resistance test.

4 Polarity test.

5 Unbalanced current test - for 3-phase winding.

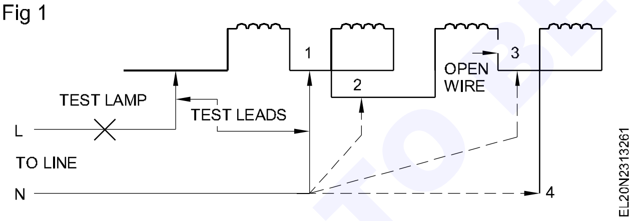
6 No-load test.

Continuity test/resistance test : This test is done to check up the continuity of each winding. If there is any open in the winding, it is to be rectified.

The usual cause of an open circuit in a winding is loose connection or break in the winding wire. The open circuit may be located by connecting one lead of the test lamp to one end of the winding and touching the other lead to the end of each coil end in sequence in the same phase.

Refering to Fig 1, if the lamp does not glow at point 3 but glows at point 2 then the third coil is faulty. If the lamp glows at 2 and 3 but not at 4 then the fourth coil is faulty. By repeating this process the coil which has the open circuit, can be identified.

Fig 1



Similarly, the other winding can also be tested for open circuit.

The resistance of each coil may be measured by a low range ohmmeter. The resistance of each coil must be the same. The high value of resistance or infinity value indicates open in the windings.

> **If there is any open in one coil, that coil can be bypassed and left out in the chain of windings. Then the motor can run, but if the open is in more than one coil, bypassing of the coil is not possible. This type of repairing is possible for small capacity motors where the winding has a large number of coils. Ex: Ceiling fans. But this procedure should be avoided as far as possible.**

> **If the polarity of one or two coils in a multiple pole fan motor is changed the fan will run slowly and produces more heat.**

Short circuit test/growler test : Two or more turns that contact each other electrically will cause a short circuit in the winding. This short circuit will cause excessive heat to be developed during the operation of the machine.

Short circuit can be detected by any one of the following methods.

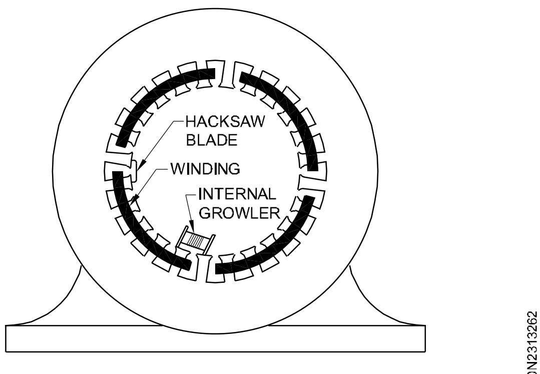
a Internal growler method

b Voltage drop test

c Ohmmeter method.

Internal growler method : The internal growler consists of a coil of wire wound on a laminated iron core and connected to 240V AC supply. After the stator is removed the growler is placed on the core of the stator and moved from slot to slot as shown in Fig 2. A shorted coil will be indicated by rapid vibration of a metal blade provided with the growler and in some types of internal growlers, glow of the neon lamp provided with the growler indicates short in winding.

Fig 2

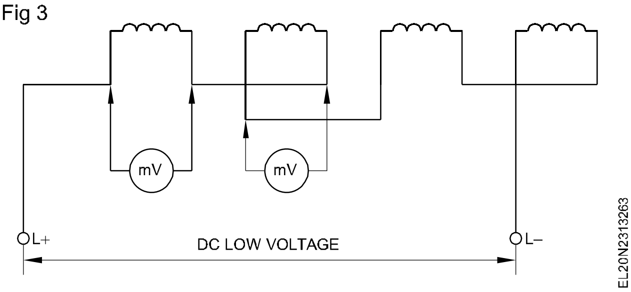


THE GROWLER METHOD OF TESTING FOR SHORTS IN THE STATOR

Voltage drop method : In this method the winding is connected to a low voltage DC supply as shown in Fig 3 and the voltage drop is measured across each coil by a milli voltmeter. The voltage drop across good coils will be the same whereas voltage drop across shorted coils will be low.

Ohmmeter method : For this method, measure the resistance of the each coil by a low range ohmmeter or Kelvin bridge or Post Office Box. All the coils should read the same value of resistance. The coil which reads lower resistance than the other coils or that which reads zero resistance is assumed to be shorted and needs replacement. On the other hand the coil which reads high resistance when compared to similar coils or which reads infinite value of resistance indicates open in that particular coil.

Fig 3

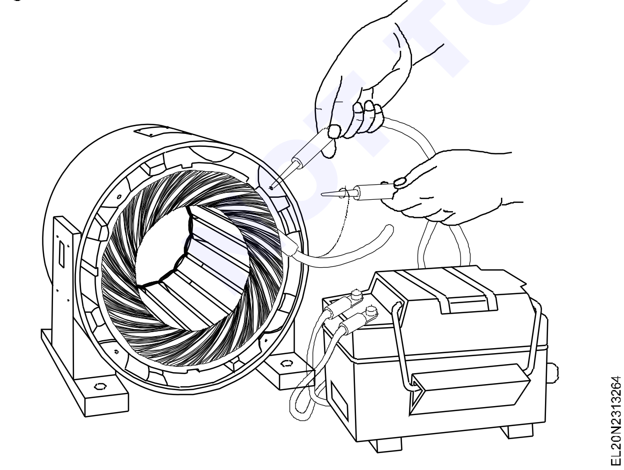


Ground test and insulation/resistance test : Grounded winding may cause a fuse to blow up or it may cause the winding to smoke, depending on the extent of the ground. It may give shock to persons when they come in contact with the frame which is not properly earthed.

The aim of this test is to check any direct connection between windings and earth(ground). For this, the neutral of the supply is connected to the body of the machine and the phase wire is connected through a series test lamp. The open end of the test lamp is touched to each end of the winding in sequence. If the lamp remains dark it means winding is not grounded and if it glows, the winding is earthed. This is a fast, rough practical method.

If a Megger is used for testing the grounded winding, one terminal of the Megger is connected to the body and other to the windings as shown in Fig 4. If the pointer of the Megger shows infinity, the winding is correct and there is no connection between the windings and the body. Insulation resistance between windings and the body of the machine is measured by a 500 volts Megger and the readings so obtained shall not be less than 1 Megohm in the case of 3-phase and single phase motors. For additional safety 2 megohms are necessary in the case of ceiling and table fans.

Fig 4



Polarity Test: Correct coil group connection in the winding ensures correct polarity. If there is any confusion in the coil group connections then the polarity test is necessary to be carried out to check proper polarity.

There are three methods recommended as explained below.

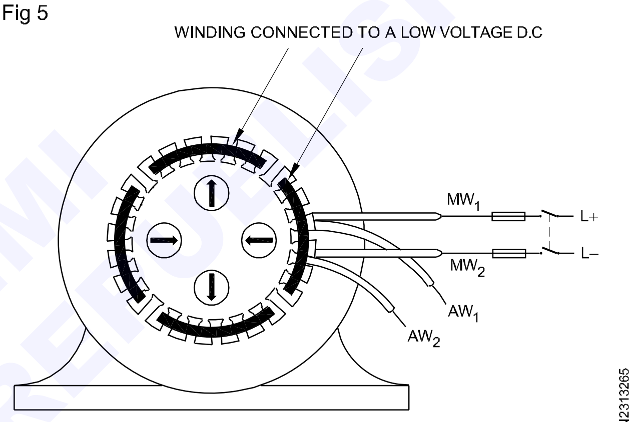
a Magnetic compass method

b Two screwdrivers method

c Search coil method

Magnetic compass method : In this method, the stator is placed in a horizontal position and a low DC voltage is applied to the winding. The compass needle is then held inside the stator and moved slowly from one pole area to another pole area as shown in Fig 5. The compass needle will reverse itself on each pole if the winding is correctly connected. If there is same direction of indication between two adjacent poles, a reverse pole is indicated.

Fig 5



THE COMPASS METHOD OF TESTING FOR REVERSED POLES

No-load test : After impregnation and assembly of motor, check the rotor for free rotation. Connect the motor to the rated supply voltage. Run the motor at no load and record the no-load voltage, current and speed of the motor. In no case these readings increase beyond name-plate values. Inspect the bearing sound and vibration. Normal sound without vibration is an indication of a good job. However, the perfection of the winding job could be ascertained only through a load test.

Maintenance, service and troubleshooting in AC 3 phase squirrel cage induction motor and starters

Objectives: At the end of this lesson you shall be able to
- **list and state about the maintenance schedule of AC 3 phase motor**
- **list out the possible faults, causes and remedies in 3 phase motors**
- **explain the mechanical problems in motor, bearings and their remedies**
- **state the lubrication techniques on learning**
- **explain the troubleshooting of AC motor starters and maintenance of starters.**

Generally due to the rugged construction of the AC squirrel cage induction motor, it requires less maintenance. However to get trouble-free service and maximum efficiency, this motor needs a scheduled routine maintenance. As found in most of the industries the AC squirrel cage motor is subjected to full load for 24 hours a day and 365 days a year. Therefore the maintenance should be scheduled to have periodic maintenance for a selected area on daily, weekly, monthly, half yearly and yearly periods for increasing the working life of the motor and to reduce the break down time.

Maintenance schedule: Suggested maintenance schedule for the AC squirrel cage induction motor is given below as a guide.

Daily maintenance

- Examine earth connections and motor leads.
- Check motor windings for overheating. (Note that the permissible maximum temperature is above that which can be comfortably felt by hand.)
- Examine the control equipment.

In the case of oil ring lubricated machines

i examine bearings to see that oil rings are working

ii note the temperature of the bearings

iii add oil if necessary

iv check end play.

Weekly maintenance

- Check belt tension. In a case where this is excessive it should immediately be reduced and in the case of sleeve bearing machines, the air gap between the rotor and stator should be checked.
- Blow out the dust from the windings of protected type motors, situated in dusty locations.
- Examine the starting equipment for burnt contacts where motor is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, dirt etc. (This can be roughly ascertained on inspection by the colour of the oil).

Monthly maintenance

- Overhaul the controllers.
- Inspect and clean the oil circuit breakers.
- Renew oil in high speed bearings in damp and dusty locations.
- Wipe brush holders and check the bedding of brushes of slip-ring motors.
- Check the condition of the grease.

Half-yearly maintenance

- Clean the winding of the motors which are subjected to corrosive or other such elements. Also bake and varnish if necessary.
- In the case of slip ring motors check slip rings for grooving or unusual wear.
- Renew grease in ball and roller bearings.
- Drain all oil bearings, wash with kerosene, flush with lubricating oil and refill with clean oil.

Annual maintenance

- Check all high speed bearings and renew if necessary.
- Blow out clean dry air over the windings of the motor thoroughly. Make sure that the pressure is not so high as to damage the insulation.
- Clean and varnish dirty and oily windings.
- Overhaul motors that are subject to severe operating conditions.
- In the case of slip ring motors, check the slip ring for pittings and the brush for wear. Badly pitted slip rings and worn out brushes should be replaced.
- Renew switch and fuse contacts if badly pitted.
- Renew oil in starters that are subjected to damp or corrosive elements.
- Check insulation resistance to earth and between phases of motor windings, control gear and wiring.
- Check resistance of earth connections.
- Check air gaps.

Records : Maintain independent cards or a register (as per specimen shown in trade practical) giving a few pages for each machine and record therein all important inspections and maintenance works carried out from time to time. These records shall show past performance, normal insulation level, gap measurements, nature of repairs and time between previous repairs, and other important information which would be of help for good performance and maintenance.

Faults which occur in AC 3-phase squirrel cage motor can be broadly divided into two groups

They are

1 Electrical faults

2 Mechanical faults.

In most of the cases both the faults may be individually present or both may be present, as one type of fault creates the other fault. The following charts give the cause, the test to be carried out and possible remedy.

Chart 1

Motor fails to start

S.No	Cause	Test	Remedy
1	Overload relay tripped.	Wait for overload coils to cool. Push the reset button if separately provided. In some starters the stop button has to be pushed to reset the overload relay.	If motor could not be started check the motor circuit for other causes as outlined in this chart.
2	Failure of power supply.	Test the power supply at the starter incoming terminals.	If the supply is present in the incoming terminals of the starter, check the starter for fault. If not, check the main switch and fuses. Replace the fuses if necessary or restore power supply.
3	Low voltage.	Measure the voltage at the mains and compare with the name-plate rating.	Restore normal supply or check the cables for underrating.
4	Wrong connection.	Compare the connection with the original diagram of the motor.	Still if motor does not start, reconnect, after disconnecting the connection of the motor.
5	Overload.	Measure the starting torque required by load.	Reduce load, raise tapping on auto-transformer, install a motor of a higher output.
6	Damaged bearings.	Open the motor and check the play of bearings.	Replace if required.
7	Faulty stator winding.	Measure current per phase and they should be equal, if required measure resistance per phase; check insulation resistance between winding and earth.	Repair the fault if possible or rewind stator.
8	Wrong control connections.	Check the control circuit and compare it with the circuit diagram.	Reconnect the control circuit according to the manufacturer's circuit diagram.
9	Loose terminal connections at mains or at starter or at motor.	Check the terminal connection of the main switch, starter and motor for discolouring and loose nuts.	Tighten the terminals.
10	Driven machine is locked.	Disconnect the motor from the load.	If the motor starts satisfactorily check the driven machine and rectify the defect.
11	Open circuit in stator or rotor.	Check visually and then with multimeter/megger.	Rectify the defect or wind.
12	Short circuit in stator winding.	Check the phases and coil groups with the help of an ohmmeter or use internal growler.	Repair the winding or rewind.

S.No	Cause	Test	Remedy
13	Winding is grounded.	Test with a Megger or test lamp.	If the fault is found, repair or rewind.
14	Bearing stiff.	Rotate the rotor by hand.	If the rotor is stalled, dismantle the motor and rectify the defect.
15	Overload.	Check the load and belt tension.	Reduce the load or loosen the tight belts.

Chart 2

Motor starts but does not share load (Runs at low speed when loaded.)

S.No	Cause	Test	Remedy
1	Too low a voltage.	Measure voltage at the motor terminals and verify it with the name-plate.	Renew bad fuses; repair circuit and remove the cause of low voltage, like loose or bad contacts in starter, switches, distribution box,etc.
2	Bad connection.	Check the connection and contact of starter for loose contact.	Remove the fault as required.
3	Too low or high tension on driving belt.	Measure the tension and verify it with the instruction of the manufacturer.	Adjust the belt tension.
4	Open circuit in rotor winding.	Examine the rotor bars and joints.	Re-solder the rotor bars.
5	Faulty stator winding.	Check for continuity, short circuit and leakage.	Repair the circuit if possible or rewind the stator.
6	Defective bearings.	Examine bearings for play.	Replace the bearings.
7	Excessively loaded.	Measure the line current of the motor and compare it with its rated current.	Reduce the mechanical load on the motor.
8	Low frequency.	Measure the line frequency with a frequency meter.	If the line frequency is low inform the supply authorities and get it corrected.

Chart 3

Motor blows off fuses

S.No	Cause	Test	Remedy
1	Incorrect size of fuses	Check the size of the fuse wire (it should be rated for 1½ times its normal current); connect the ammeter in the circuit and test for excess load current.	Replace the fuse wire if necessary; repair the motor if it is due to electrical fault of stator or rotor.
2	Low voltage	Measure the line voltage.	Remove the cause of low voltage.
3	Excessively loaded	Measure the line current and compare it with its rated current.	Rectify the cause of overload or install a motor of higher output rating.
4	Faulty stator winding	Check for open circuit, short circuit or leakage of the stator as explained earlier.	Repair the fault; if not possible then rewind the stator.
5	Loose connection in starter	Check for loose or bad connection in the starter because it may cause unbalancing of current.	Rectify the loose connection; loose all the contact points of the starter with sandpaper and align the contacts.
6	Wrong connection	Check the connection with the original diagram.	Reconnect the motor if it still does not start.

Chart 4

Over Heating of the motor

S.No.	Cause	Test	Remedy
1	Too high or low voltage or frequency.	Check the voltage and frequency at the terminal of the motor.	Rectify the cause of low or high voltage or frequency as the case may be.
2	Wrong connection.	Compare the connection with the given circuit diagram.	Reconnect the connection if required.
3	Open circuit in rotor.	Loose joints of rotor bars cause heat.	Resolder the joints of rotor bars and end rings.
4	Faulty stator winding.	Check for continuity, short circuit and leakage as stated before.	Remove the fault if possible; otherwise rewind the stator winding. Remove dirt and dust from them if any.
5	Dirt in ventilation ducts.	Inspect ventilation ducts for any dust or dirt in them.	Reduce the load or loosen the belt. Rectify the single phasing defect.
6	Overload.	Check the load and the belt.	If the defect is with the driven machine repair it. If the problem is with the bearing, investigate and repair or replace with new one.
7	Unbalanced electrical supply.	Check the voltage for single phasing. Check the connections and fuses. Remove the load and check the rotor for free rotation.	If required replace the motor designed for this purpose.
8	Motor stalled by driven machine or tight bearing.	Check the motor - starter contactor	Loose the machine bearing or grease the bearing or replace the bearing.
9	Motor when used for reversing heats up.	Check the connection	Check the manufacturer's instructions.

Chart 5

Vibration and noise in motors

S.No.	Cause	Test	Remedy
1	Loose foundation bolts or nuts.	Inspect nuts and bolts of foundation for loose fittings.	Tighten the foundation nuts.
2	Wrong alignment of coupling.	Check alignment with a spirit level through dial test indicator.	Realign the coupling.
3	Faulty magnetic circuit of stator or rotor.	Measure the current in each phase and they should be equal. Check also per-phase resistance and they should be equal. Check the insulation resistance between the windings and the frame. In a newly wound motor there may be reversed coils in a pole-phase group which can be detected by the compass test.	Repair fault if possible or rewind the motor.
4	Motor running on single phase.	Stop the motor, then try to start. (It will not start on single phase). Check for open in one of the lines or circuits.	Rectify the supply.
5	Noisy ball bearing.	Check the lubrication for correct grade and low noise in the bearing.	If found, replace the lubricant or replace the bearing.
6	Loose punching or loose rotor on shaft.	Check the parts visually.	Tighten all the holding bolts.

7	Rotor rubbing on the stator.	Check for rubbing marks on the stator and rotor.	If found, realign the shaft to centre it or replace the bearings.
8	Improper fitting of end-covers.	Measure the air gap at four different points for uneven position of rotor covers.	Open the screws of the side covers, and then tighten one by one. If trouble still persists, remove the end cover, shift for next position and tighten the screws again.
9	Foreign material in air-gap.	Examine the air-gap.	File or clean out air-gap.
10	Loose fan or bearings.	Check looseness of the fan screw or bearings.	Tighten the fan screws or refit new bearings, if necessary.
11	Slackness in bearing on shaft or in housing.	Remove the bearings and inspect the inner looseness of the race on the shaft and outer race in the housing.	Send the motor to the repair shop for removing the looseness of the shaft and housing, if any.
12	Improper fitting of bearings.	Remove the end-covers and examine the assembly of bearings on the shaft or in the housing.	Refit the bearings on the shaft or in the housing.
13	Minor bend in shaft.	Check for alignment on the lathe.	Remove the bend or replace the shaft, if required.

Troubleshooting of motor starters

Objectives : At the end of this lesson you shall be able to
- **state the troubles in the D.O.L. starter, their cause and their remedy**
- **check out the troubles in the mini manual starter, their cause and their remedy.**

Introduction : The D.O.L. starter consists of the fixed contacts, movable contacts, no-volt coil, overload relay and start button which is in green colour and a stop button in red colour with a locking arrangement. The main purpose of the contactor is to make and break the motor circuit. These contacts in the contactor suffer maximum wear, due to frequent use and hence these contacts are made of silver alloy material.

A no-volt coil acts as under-voltage release mechanism disconnecting supply to the motor when the supply voltage fails or is lower than the stipulated value. Thus the motor will be disconnected from supply under these conditions.

A thermal overload relay unit is provided for the protection of the motor. This unit consists of a triple pole, bimetallic relay housed in a sealed bimetallic enclosure. This is provided with a current setting arrangement. After tripping on overload, the relay has to be reset by pressing the stop button. The relay can be reset only after bimetallic strips get cooled sufficiently.

In case the motor does not start even though the start button is pressed, observe whether the stop button is locked with a metallic locking piece provided near the stop button. Release it and press the start button, then observe the functioning of the motor.

Suppose the three phase supply is available and starter NVC is energising but the motor does not start, check for any foreign material in between the contact points. Remove it and test the starter again. Visually observe whether the contacts are closing properly.

If any contact is not closing properly or any burns and pittings are noticed on the contact surface, then remove the contact strips. Dress up properly with zero number sandpaper or with a smooth file or replace it if necessary.

> **When the no-volt coil is activated by the start button, the auxiliary contact of the starter should close to complete the NVC circuit and should remain in the closed position even after the start button is released.**

If the overload relay is not functioning properly i.e. not tripping the motor as per setting of the current rating, then replace it with a new one as per with the original specification of the manufacturer.

If a humming and chattering noise is observed in the starter then check for the rated voltage. If the voltage is okay, then check for any gummy material adhered to the pole faces. If found, clean it properly. See whether the shading ring over the pole faces of the NVC is loose. Tighten it properly and also check the spring tension of NVC housing.

Suppose the starter trips often then, check up the load on the motor. (Might be due to overload or over tension of the belt) Reduce the load or tension of the belt. Further check up the motor current in each phase. If the motor takes higher current than specified even though the load is normal, then the fault is with the motor and not with the starter. After attending to the faults and rectifying them, reassemble the starter, connect it to the motor for proper functioning.

Starter check - chart given below could be used to locate trouble in a D.O.L. starter.

Maintenance of DOL starters

Trouble	Cause	Remedy
I Starter check chart		
1 Contacts chatter	Low voltage, coil is not picking up properly. Broken pole shading ring. Poor contact between the pole faces of the magnet. Poor contact between fixed and movable contacts.	Correct the voltage condition. In case there is persistent low voltage, check the supply of the transformer tapping. Replace. Clean the pole faces. Clean contacts and adjust, if necessary.
2 Welding or overheating.	Low voltage preventing magnet from sealing. Abnormal in rush current. Short circuit in the motor. Foreign matter preventing contacts from closing. Rapid inching.	Correct the voltage condition. In case of persistent low voltage, which is accepted normal change the NVC to lower voltage coil. Check excessive load current or use larger contactor. Remove the fault and check to ensure that the fuse rating is correct. Clean contacts with suitable solvent. Install larger device or caution the operator not to operate the inch button too quickly.
3 Short life of contact points	Weak contact pressure.	Adjust or replace contact springs.
4 Noisy magnets	Broken shading coil. Magnet faces not mating. Dirt or rust on magnet faces.	Replace magnet. Align or replace magnet assembly. Clean with suitable solvents.
5 Failure to pick up and seal the contacts.	Low voltage.	Check system voltage. In case persistent low voltage, change to a lower voltage coil.
	Coil open or short-circuited. Mechanical obstruction for the moving parts.	Replace the coil. Clean and check for free movement of contact assembly.
6 Failure of moving mechanism to drop out.	Voltage not removed. Worn or rusted parts causing binding. Residual magnetism due to lack of air gap in magnet path. Gummy substance on pole faces causing binding.	Check wiring in the NVC coil circuit. Replace parts. Replace worn out magnet parts or demagnetise the parts. Clean with suitable solvent.
7 Overheating of coil	Over-voltage. Short circuited turns in coils caused by mechanical damage or corrosion. High ambient temperature. Dirt or rust on pole faces increasing the air gap.	Check and correct terminal voltage. Replace coil. Relocate starter in a more suitable area or use a fan. Clean pole faces.
II Overload relays/ release		
1 Starter is tripping often. Sustained overload.	Incorrect setting of over load relay.	Reset properly. Check for faults/excessive motor currents.
2 Failure to trip (causing motor burn out).	Wrong setting of O.L relay. Mechanical binding due to dirt, corrosion etc.	Check O.L relay ratings and set a proper relay. Clean or replace. Incorrect control wiring. Check the circuit and correct it.

III Fuses		
1 Constant blowing of fuses	Short circuit or poor insulation in winding/wiring.	Check the motor and the circuit for insulation resistance.
2 Fuse not blowing under short circuit condition.	Fuse rating too high.	Replace with suitable fuse.
3 Fuse blowing off frequently.	Fuse rating too low. Overloading of feeder.	Replace with suitable fuse. Check for over-current, leakage and short circuit.

Single phase motors - split phase induction motor - induction-start, induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the types of AC single phase motors**
- **explain the necessity and methods of split-phasing the single phase to obtain a rotating magnetic field**
- **explain the principle, construction, operation characteristic and application of single phase resistance / induction-start / induction-run motors.**

Single phase motors perform a great variety of useful services at home, office, farm, factory, and in business establishments. These motors are generally referred to as fractional horsepower motors with a rating of less than 1 H.P.

Single phase motors may be broadly classified as split-phase induction motors and commutator motors according to their construction and method of starting.

Split-phase induction motors can be further classified as:

- resistance-start, induction-run motors
- induction-start, induction-run motors
- permanent capacitor motors
- capacitor-start, induction-run motors
- capacitor-start, capacitor-run motors
- shaded pole motors.
- stepper motor

Commutator motors can be classified as:

- repulsion motors
- series motors.

The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-splitting is to be done to make the motor to work as a two-phase motor for starting.

Producing a rotating field from two 90° out-of-phase fields: One of the methods of producing a rotating magnetic field is by split-phasing. This could be done by providing a second set of winding in the stator called the starting winding. This winding should be kept physically at 90 electrical degrees from the main winding, and should carry a current out of phase from the main winding. This, out of phase current, could be achieved by making the reactance of the starting winding being different from that of the main winding. In case both the windings have similar reactance and impedance, the resulting field, created by the main and starting windings, will alternate but will not revolve and the motor will not start.

By split-phasing, the two (main and starting) fields would combine to produce a rotating magnetic field.

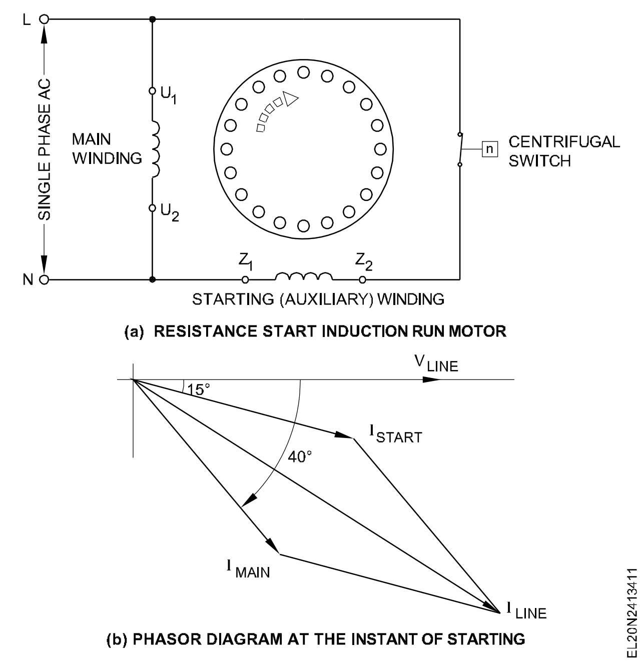
Working of split-phase motor: At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field. The rotor is of a squirrel cage type, and the revolving magnetic field sweeps past the stationary rotor, inducing an emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field. This magnetic field opposes the revolving magnetic field and will combine with the main field to produce a revolving field. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor, which was explained earlier.

Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields form a revolving magnetic field.

Resistance-start, induction-run motor: As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

The essential parts are as shown in Fig 1a.

Fig 1



(a) RESISTANCE START INDUCTION RUN MOTOR

(b) PHASOR DIAGRAM AT THE INSTANT OF STARTING

- Main winding or running winding

- Auxiliary winding or starting winding
- Squirrel cage type rotor
- Centrifugal switch

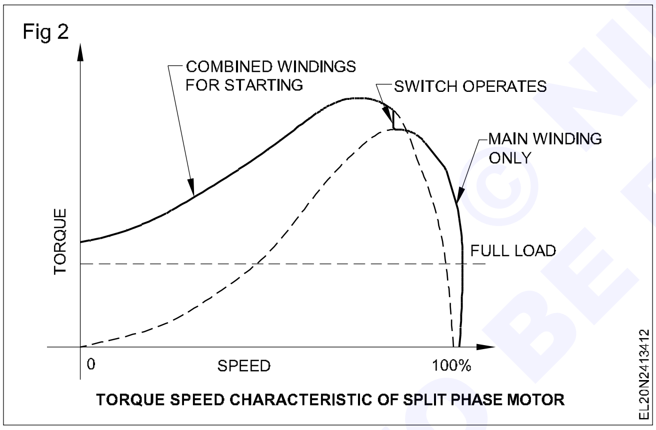
The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using smaller conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots. It is obvious that the current would split as shown in Fig 1b. The starting current `I start' will lag the main supply voltage `V' line' by 15° and the main winding current. `I main' lags the main voltage by about 40°. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch, and the motor will continue to operate as a single phase motor. At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be observed from the typical torque-speed characteristics of this motor, as shown in Fig 2.

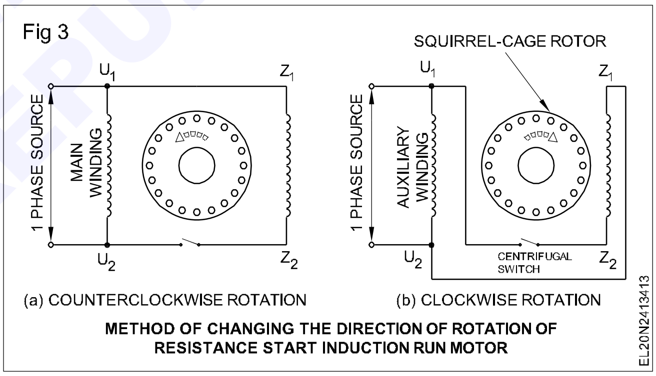
The direction of rotation of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotation could be obtained. Rotation will be, say counter-clockwise, if Z_1 is joined to U_1 and Z_2 is joined to U_2 as per Fig 3a. If Z_1 is joined to U_2 and Z_2 is joined to U_1, then the rotation will be clockwise, as shown in Fig 3b.

Application of resistance-start, induction-run motor: As the starting torque of this type of motors is relatively small and its starting current is high, these are manufactured for a rating up to 0.5 HP where the starting load is light. These motors are used for driving fans, grinders, washing machines and wood working tools.

Induction-start, induction-run motor: Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such a case, the starting winding will have more number of turns, and will be imbedded in the inner areas of the stator slots so as to have high inductance due to more number of turns, and the area will be surrounded by more iron. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurement has to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor.



TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR



METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

Centrifugal switch

Objectives: At the end of this lesson you shall be able to
- **explain the working, the method of maintenance and testing of a centrifugal switch**
- **explain the necessity of a manual D.O.L. starter and its working**
- **explain the operation of overload relays.**

The centrifugal switch: The centrifugal switch is located inside the motor and is connected in series with the starting winding in the case of capacitor-start, induction-run motors, and for disconnecting the starting capacitor in the case of a two value, capacitor-start, capacitor-run motor. Its function is to disconnect the starting winding after the rotor has reached 75 to 80% of the rated speed. The usual type consists of two main parts. Namely, a stationary part as shown in Fig 1, and a rotating part as shown in Fig 2. The stationary part is usually located on the front-end plate of the motor and has two contacts, so that it is similar in action to a single-pole, single-throw switch. When the rotating part is fitted in the rotor, it rotates along with it.

When the rotor is stationary, the insulator ring of the rotating part is in an inward position due to spring tension. This inward movement of the insulator ring allows the stationary switch contacts to be closed which is due to the movable lever pressure against the leaf-spring tension in the switch.

When the rotor attains about 75% of the rated speed, due to centrifugal force, the governor weights fly out, and this makes the insulator ring to come outward. Due to this forward movement of the insulated ring, it presses the movable lever, and the contacts connected through terminals CS_1 and CS_2 open the starting winding.

Fig 1

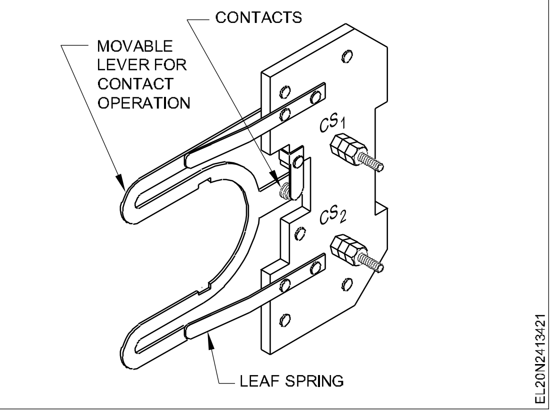
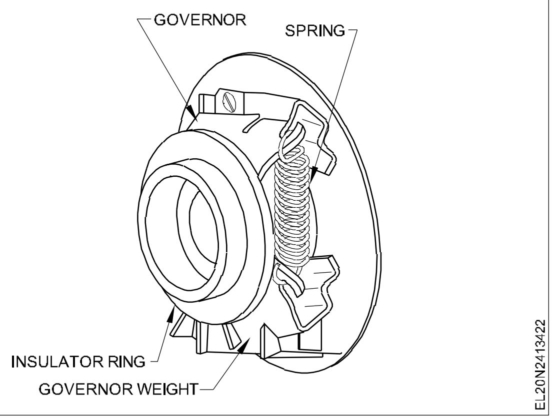


Fig 2



Manual D.O.L. starter: A starter is necessary for starting and stopping the motor, and for providing overload protection.

A manual starter, as it appears, is shown in Fig 3, an open view of the starter is shown in Fig 4, and the internal parts are shown in Fig 5, as a schematic diagram. A manual starter is a motor controller with a contact mechanism operated by hand.

Fig 3

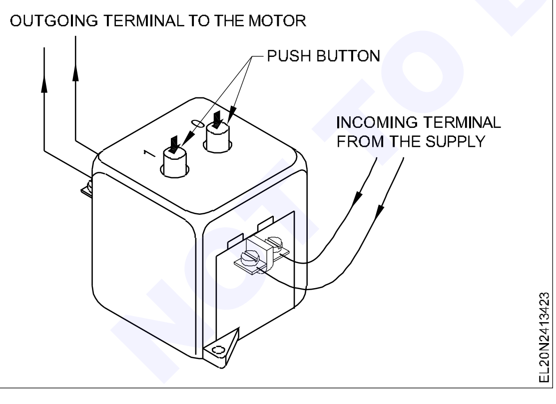
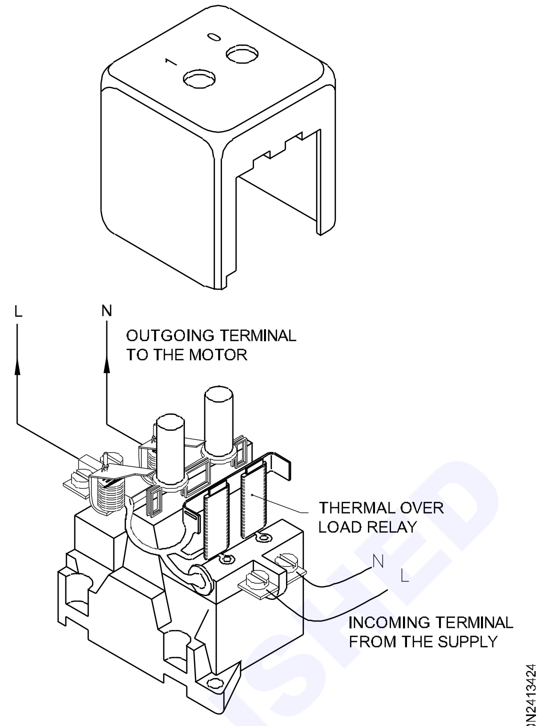
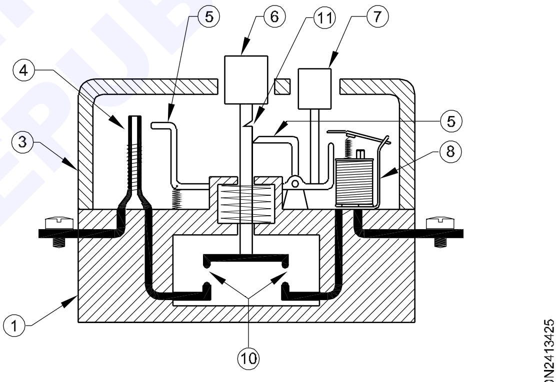


Fig 4



OPEN VIEW OF MANUAL D.O.L STARTER

Fig 5



SCHEMATIC DIAGRAM OF A MANUAL D.O.L STARTER

A push-button operates the mechanism through a mechanical linkage. As shown in Figs 4 & 5, the starter may have both a thermal overload relay and a magnetic overload relay for overload protection and short circuit protection respectively.

Both the relays are made to operate independently, in case of overload or short circuit, to release the start-button for disconnecting the motor from supply. Most of the present day, manual starters have either of the two relays only. Basically, a manual starter is an ON-OFF switch with overload relay only.

Single phase, split phase type motor winding (Concentric coil winding)

Objectives: At the end of this lesson you shall be able to
- **state the important points to be followed while winding split phase motors**
- **explain about coil distribution in concentric winding**
- **prepare the winding table, draw the connection and developed diagrams for concentric coil winding in single phase, split phase type motors.**

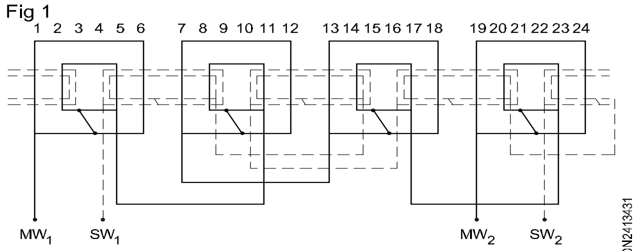
Split phase type : In general, single phase motors use a capacitor to split the phase. Some motors are, as found in fans, have the capacitor permanently connected to the supply. In some motors, the capacitor is used only for the starting period, then while running it is disconnected from the supply by the use of a centrifugal switch mechanism. In some other types of motors there are two capacitors, one for starting and the other for running. However, depending upon the power, function and the design of the motor, the capacitor value will be different in each case. Observe this point every time you come across the split phase motor.

There are certain points to be followed while winding a split phase motor.

1 The single phase winding may have different shapes of coils as explained below.

a Concentric coil winding (Fig 1): This winding requires coils of different shapes in a phase/pole group, and different sizes between the phases in order to accommodate in the slots and for placing both main and starting windings. In addition to this, the coils in the same group may have different number of turns.

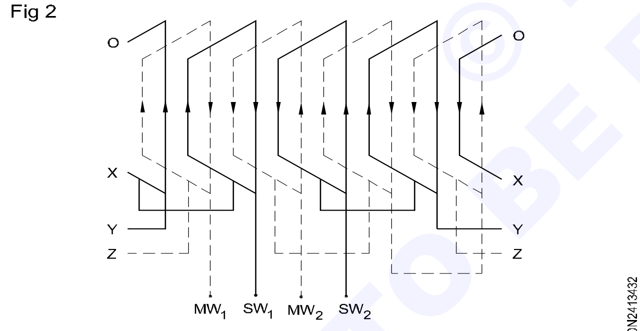
Fig 1



SINGLE PHASE CONCENTRIC WINDING 24SLOTS 4POLES

b True mesh shaped coils (Fig 2): These coils are of the same size and shape and the end windings form a very tight roll.

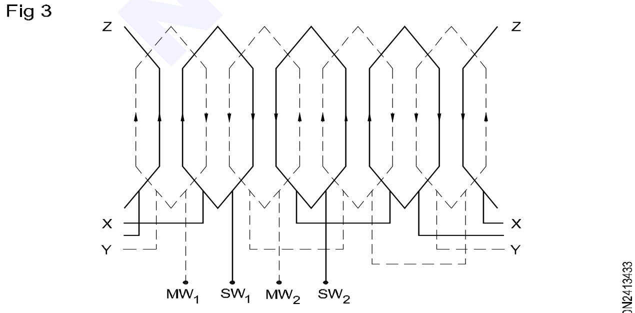
Fig 2



MESH SHAPED COILS

c Diamond mesh shaped coils (Fig 3): These coils are of the same size and shape and the end winding is longer and flatter than the true mesh type coils. The end of the coils has a loop, knuckle or nose.

Fig 3



DIAMOND MESH SHAPED COILS

2 The main and starting winding should be placed 90 electrical degrees apart from each other.

3 All the coil groups may or may not have the same number of coils.

4 The main winding is kept first in the stator slots and the starting winding is kept over the main windings.

5 Normally, the main winding consists of thick winding wire, and the starting winding of thin winding wire. In certain motors both the windings may have same size of winding wire.

6 The number of turns in the main and starting windings may or may not have the same number of turns.

7 In concentric coil winding, the coils in the same group may or may not have the same number of turns.

8 Each slot may contain one or two coil sides.

9 The overhang of the coils should be of exact in size. If it is less, the insertion of the coils will be difficult and if the size is more, the coils may not allow the end covers to be fitted.

10 While inserting concentric coils, start with the smaller pitched coil set.

11 There may be empty slots in the stator. Note their position.

Concentric winding: Concentric type of winding is probably the most common type of winding used in fractional horsepower single phase motors. The winding may be hand wound or may be form wound.

As the starting winding is designed to split the phase and is used to start the motor, it may have less slots (coils) allotted when compared to the main winding. For example there may be 8 coils for main winding and 4 coils only for the starting winding.

Further it is a standard practice to wind only about 70% of the slots of a single phase motor, as owing to the effect of the distribution or spread factor, no advantage is gained by making a single phase winding any wider. Even if the whole of the slots were to be wound, the extra winding would be useless for producing the useful torque.

Similarly it has been found that in single phase motors, no extra loss takes place if all the slots of each pole face are not wound. Thus the running winding looses nothing in efficiency, because some of the slots of each pole are taken for the starting winding.

Winding calculation and diagrams for concentric type winding : Let us discuss the following examples.

Example 1

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4 pole, whole coil connected capacitor motor having 24 slots, 12 coils (8 coils for main and 4 coils for starting winding) with pitches 5, 3 for the main and 5 for the starting winding.

Number of coils per pole in main winding =

$$\frac{\text{Total number of main winding coils}}{\text{Number of poles}} = \frac{8}{4} = 2 \text{ coils/pole}$$

In other words, there will be 8 coils in the main winding forming 4 pole groups. Each group will have two coils under each pole. Pitches assigned will be 5 and 3 for each coil group.

Number of coils per pole in starting winding = 4/4 =1 coil /pole.

There will be 4 groups in starting winding having one coil per group. Pitch assigned will be 5 for the coil.

Summarising the results we have the coil group as given below in Table 1.

Table 1

Winding	Groups	Coil per pole	Pitches	Coil throw	Connection
Main	4	2	5, 3	1-6, 2-5	Whole coil-end to end and start to start
Starting	4	1	5	1-6	Whole coil-end to end and start to start.

Calculation of electrical degrees required for phase splitting

Total electrical degrees = 180 x Total number of poles

= 180x4= 720 electrical degrees

Degrees/slot = 720/24 = 30 electrical degrees

No. of slots required for 90 electrical degrees dis-placement between main and starting winding = 90/30 = 3 slots.

Hence if the main winding starts in, say, slot number one, then the starting winding should be started in 1+3 = 4th slot.

Computing the above information in a winding table we have Table 2.

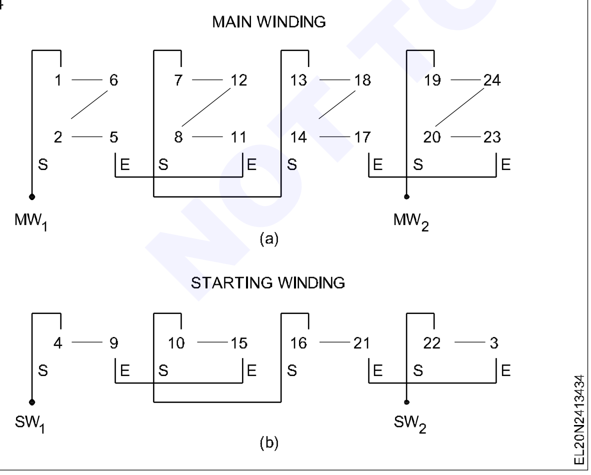
Table 2

Winding table

Winding	Slot position for poles			
	I pole	II pole	III pole	IV pole
Main	1 - 6	7 - 12	13 - 18	19 - 24
	2 - 5	8 - 11	14 - 17	20 - 23
Starting	4 - 9	10 - 15	16 - 21	22 - 3

Remembering whole coil connection the connection diagram is to be drawn as shown in Fig 4.

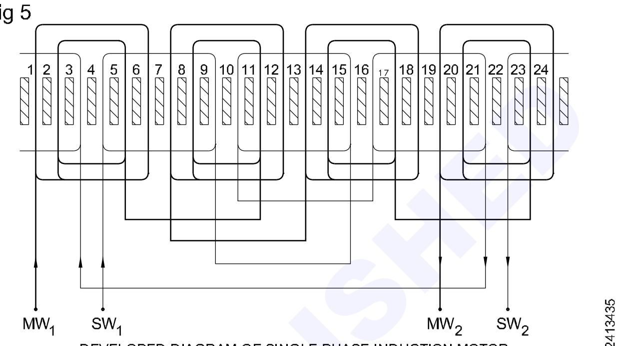
Fig 4



Remember 'S' is for starting and 'E' for end connection.

Based on the winding table the developed diagram is drawn as shown in Fig 5.

Fig 5



DEVELOPED DIAGRAM OF SINGLE PHASE INDUCTION MOTOR
(HAVING 24 SLOTS, 12 COILS, 4 POLES, BALANCED SINGLE LAYER WINDING)

Example 2 : Prepare the winding table, draw the connection and developed diagrams for a single phase, 4-pole, whole coil connected capacitor motor having 36 slots 28 coils (16 coils for main and 12 coils for the starting winding).

Coil per group in main winding 16/4=4 coils/group/poles

Coil per group in starting winding 12/4 = 3 coils/group/ poles

The coil throw for main winding will be 1-9 and the winding table will be as shown in Table 3.

Table 3

Main winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	1 - 9	10 - 18	19 - 27	28 - 36
2nd coil	2 - 8	11 - 17	20 - 26	29 - 35
3rd coil	3 - 7	12 - 16	21 - 25	30 - 34
4th coil	4 - 6	13 - 15	22 - 24	31 - 33

Calculate the degrees/slot.

Total electrical degrees = 180 x 4 = 720 electrical degrees.

Degrees/slot = 720/36 = 20 electrical degrees

For phase displacement of 90 electrical degrees we require 90/20 = 4.5 slots. As it is impossible to start at 4.5 slots, let us start the starting winding in slot No.5.

Hence the coil throw for starting winding will also be 1 - 9, but it starts in the 5th slot. As such the winding table will be as shown in Table 4

Table 4

Starting winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	5 - 13	14 - 22	23 - 31	32 - 4
2nd coil	6 - 12	15 - 21	24 - 30	33 - 3
3rd coil	7 - 11	16 - 20	25 - 29	34 - 2

There will be several slots having 2 coil sides and some slots may have single coil side only.

Remembering the whole coil connection, the connection diagram will be as shown in Fig 6.

Based on the above, the developed diagram is shown in Fig 7.

Fig 6

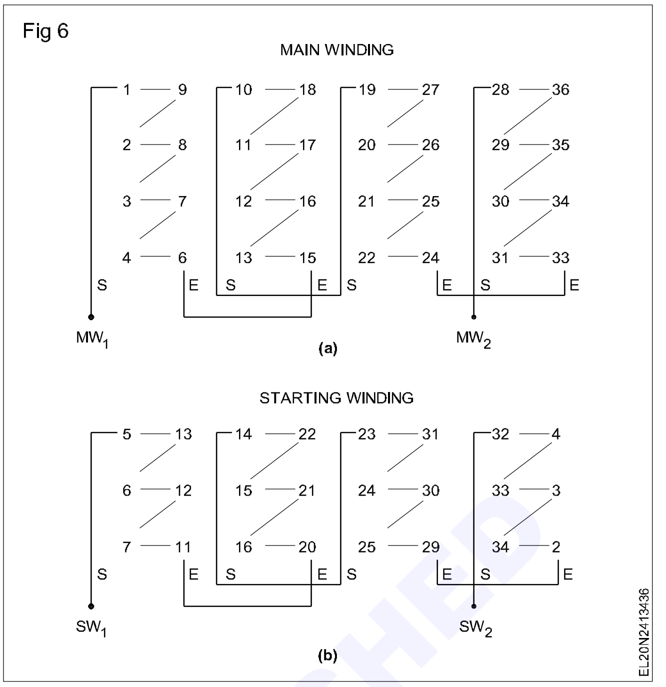
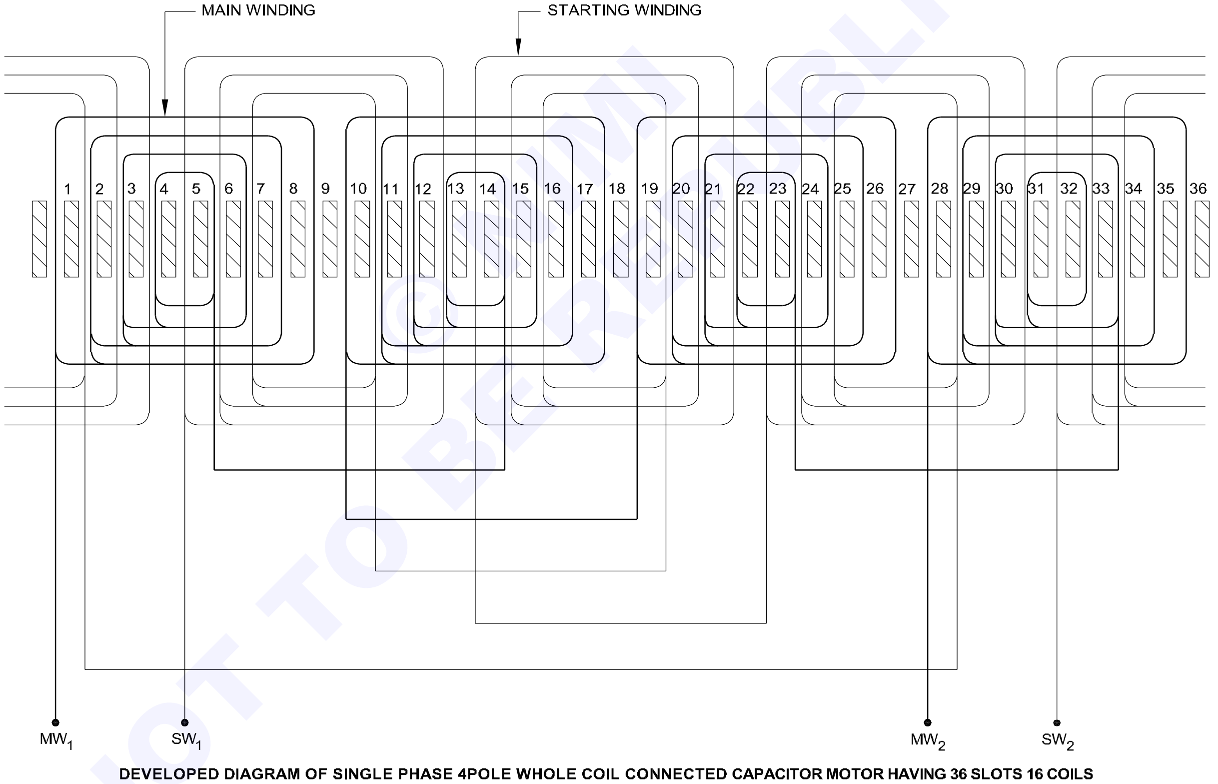


Fig 7



DEVELOPED DIAGRAM OF SINGLE PHASE 4POLE WHOLE COIL CONNECTED CAPACITOR MOTOR HAVING 36 SLOTS 16 COILS FOR MAIN WINDING 12 COILS FOR STARTING WINDING

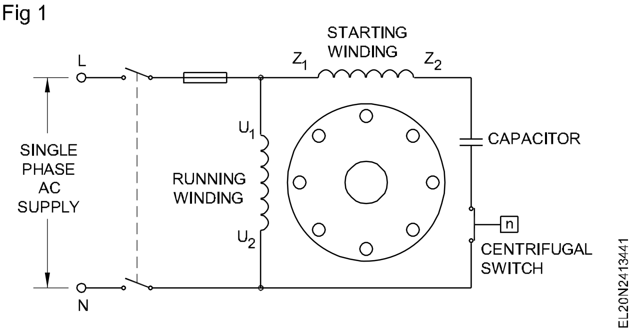
Capacitor - start, induction - run motor

Objectives: At the end of this lesson you shall be able to
- **explain the construction and working of an AC single phase, capacitor-start, induction-run motor**
- **explain the characteristic and application of a capacitor- start, induction-run motor.**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

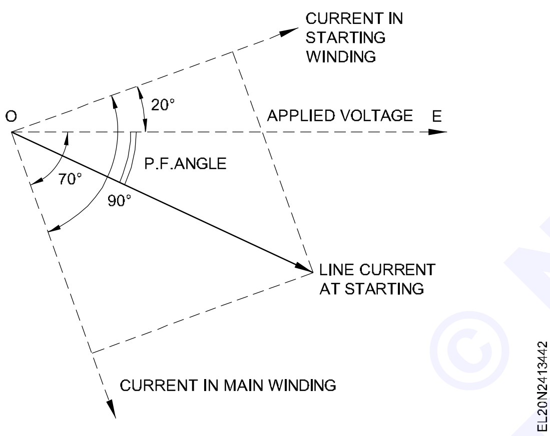
Construction and working: Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at 90 electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70 electrical degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20 electrical degrees.

Fig 2



Hence, the phase difference between the main and starting winding becomes near to 90 electrical degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

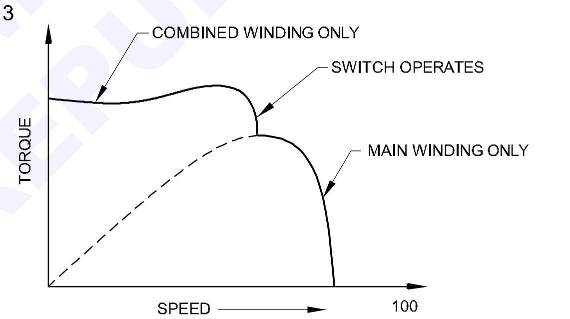
However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

Reversing the direction of rotation: In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

Characteristics: As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used in belted fans, blowers, dryers, washing machines, pumps and compressors.

Fig 3



TORQUE-SPEED CHARACTERISTIC OF
CAPACITOR START INDUCTION RUN MOTOR

Permanent capacitor motor - capacitor-start, capacitor-run motor and shaded pole motor

Objectives: At the end of this lesson you shall be able to
- **distinguish between the single and two-value, capacitor-start, capacitor-run motors**
- **explain the working of a permanent capacitor motor, state its characteristic and use**
- **explain the working of a capacitor-start, capacitor-run motor, state its characteristic and use.**

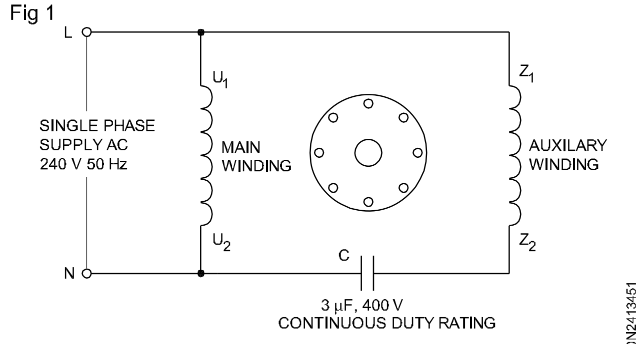
Capacitor-start, capacitor-run motors are of two types as stated below.

- Permanent capacitor motor (Single value capacitor motor)
- Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor: This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

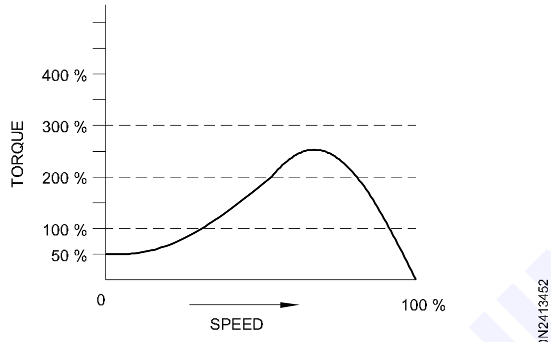
Fig 1



CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque but with higher power factor, during starting as well as in running.

Fig 2



TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

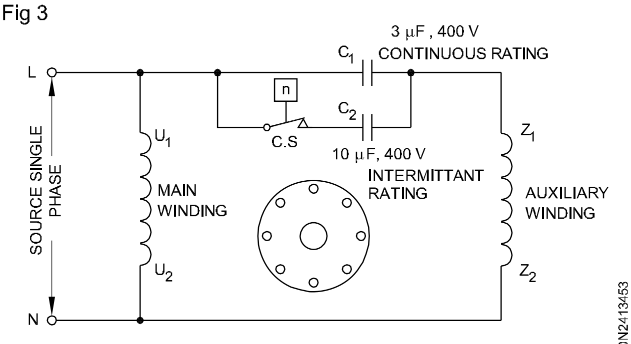
This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

Capacitor-start, capacitor-run motors: As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

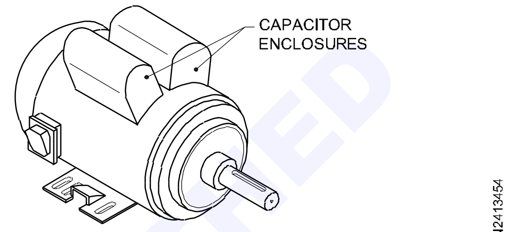
The starting capacitor which is of short-duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

Fig 3



SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 4



CAPACITOR-START CAPACITOR-RUN MOTOR

Characteristic

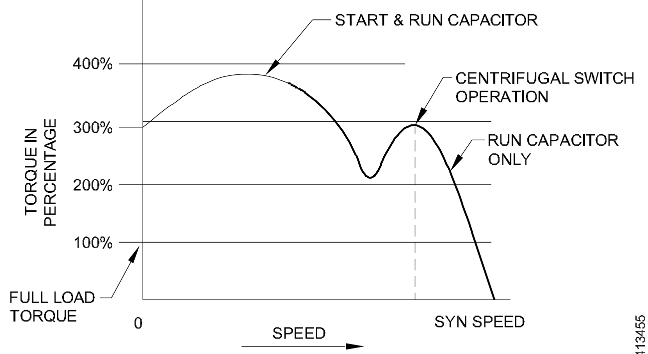
The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

Application

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

Fig 5



TORQUE-SPEED CHARACTERSTIC OF
CAPACITOR-START CAPACITOR-RUN MOTOR

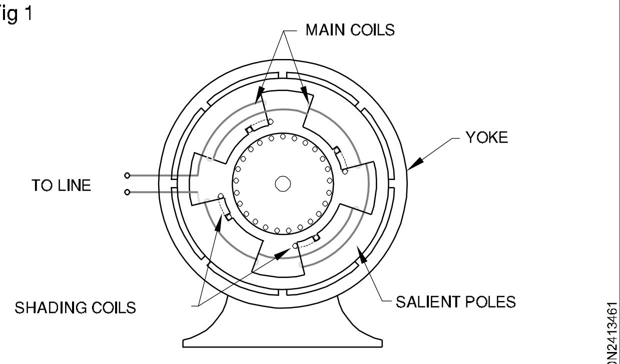
The shaded pole motor

Objectives: At the end of this lesson you shall be able to
- **explain the construction of a shaded pole motor and their functions**
- **explain the principle of working of the shaded pole motor**
- **explain the characteristics of the shaded pole motor and its application.**

Shaded pole motor (construction)

The motor consists of a yoke with salient poles as shown in Fig 1 and it has a squirrel cage type rotor.

Fig 1

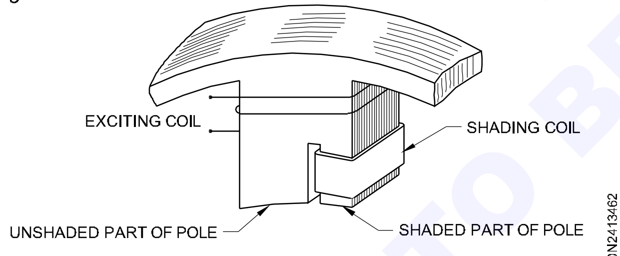


A SINGLE-PHASE MOTOR WITH SHADING COILS FOR STARTING

Construction of a shaded pole

A shaded pole made up of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole. Around the smaller portion of the pole, a short circuited copper ring is placed which is called the shading coil and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig 2.

Fig 2



A TYPICAL SHADED-POLE CONSTRUCTION

Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is given to the exciting coil the magnetic axis shifts from the unshaded part of the pole to the shaded part as explained in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole. This magnetic axis which is moving, cuts the rotor conductors, and hence, a rotational torque is developed in the rotor. Due to this torque, the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

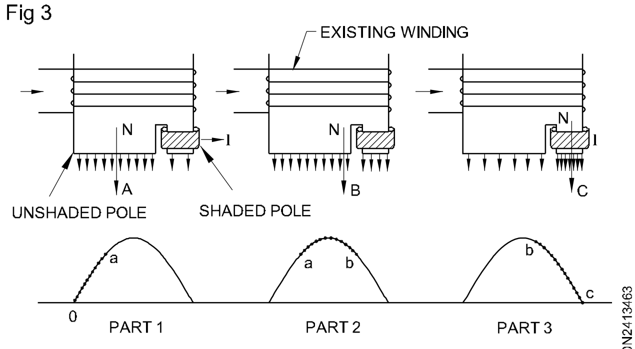
Shifting of the magnetic flux from the unshaded part to the shaded part could be explained as stated below.

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron core it will have high inductance.

When the exciting winding is connected to an AC supply a sine wave current passes through it. Let us consider the positive half cycle of the AC current as shown in Fig 3. When the current raises from 'zero' to point 'a', the change in current is very rapid (fast), hence induces an emf in the shading coil by the principle of Faraday's laws of electromagnetic induction. The induced emf in the shading coil produces a current which in turn produces a flux which is in opposite direction to the main flux in accordance with Lenz's law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig 3 in the same form of flux arrows. This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow (longer one) in part 1 of Fig 3. On the other hand as shown in Part 2 of Fig 3 when current rises from point 'a' to 'b' the change in current is slow, the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shaded portion. This makes the magnetic axis to be shifted to the centre of the whole pole as shown by the arrow in part 2 of Fig 3.

In the next instant, as shown in part 3 of Fig 3, when the current falls from 'b' to 'c', the change in current is fast and its value of change is from maximum to minimum. Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the centre of the shaded part as shown by the arrow in part 3 of Fig 3.

Fig 3

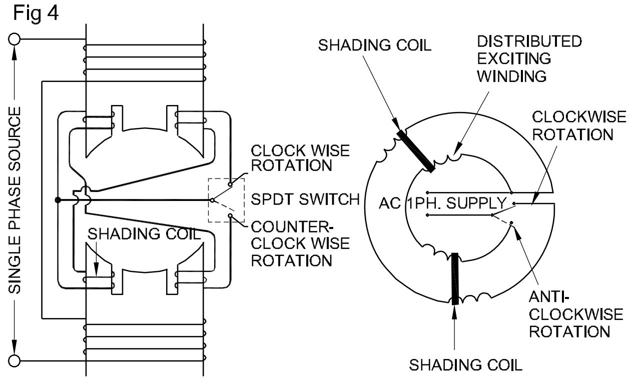


CHANGE OF MAGNETIC AXIS SHOWN FROM POSITION A TO C

From the above explanation it is clear that the magnetic axis shifts from the unshaded part to the shaded part which is more or less physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing the direction. Two such types are shown in Fig 4. In a) the double set of shading coils method is shown and in b) the double set of exciting winding method is shown.

Fig 4



a) DOUBLE SET OF SHADING COILS METHOD b) DOUBLE SET OF EXISTING WINDING METHOD

METHODS FOR REVERSING SHADED-POLE MOTORS-TWO-POLE CONSTRUCTION

EL20N2413464

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motors as stated below:

- low starting torque
- very little overload capacity
- low efficiency.

The efficiency varies from 5% to 35% only in these motors.

Because of its low starting torque, the shaded pole motor is generally used for small table fans, toys, instruments, hair dryers, advertising display systems and electric clocks etc.

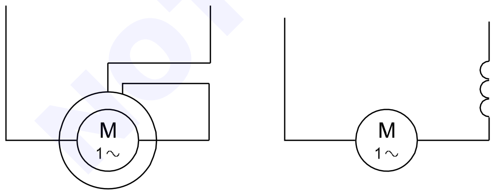
Universal motor

Objectives: At the end of this lesson you shall be able to
- **compare a universal motor with the DC series motor with respect to its construction**
- **explain the operation, characteristic and application of a universal motor**
- **explain the method of changing the direction of rotation**
- **describe the methods of controlling the speed of a universal motor.**

Comparison between a universal motor and a DC series motor: A universal motor is one which operates both on AC and DC supplies. It develops more horsepower per Kg. weight than any other AC motor, mainly due to its high speed. The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it requires suitable modification in the construction, winding and brush grade to achieve sparkles commutation and reduced heating when operated on AC supply, due to increased inductance and armature reaction.

A universal motor could, therefore, be defined as a series or a compensated series motor designed to operate at approximately the same speed and output on either direct current or single phase alternating current of a frequency not greater than 50 Hz, and of approximately the same RMS voltage. Universal motor is also named as AC single phase series motor, and Fig 1 shows the multi-line representation according to B.I.S. 2032, Part IV.

Fig 1



SIMPLIFIED MULTI-LINE REPRESENTATION COMPLETE MULTI-LINE REPRESENTATION

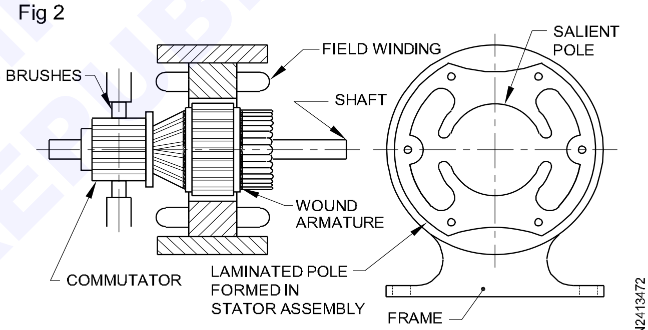
MULTILINE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

EL20N2413471

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 2.

The increased sparking at the brush position in AC operation is reduced by the following means.

Fig 2



PARTS OF A UNIVERSAL MOTOR

EL20N2413472

- Providing compensating winding to neutralize the armature M.M.F. These compensating windings are either short-circuited windings or windings connected in series with the armature.
- Providing commutating inter-poles in the stator and connecting the inter-pole winding in series with the armature winding.
- Providing high contact resistance brushes to reduce sparking at brush positions.

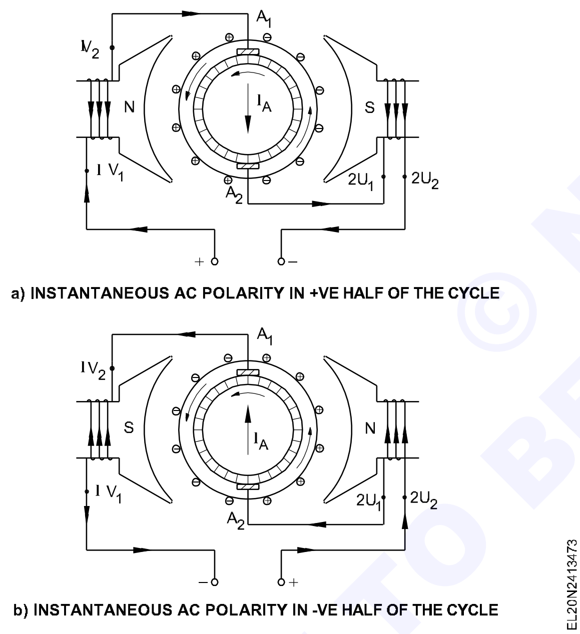
The table given below indicates the differences between a universal motor and a DC series motor.

Universal motor	DC series motor
Can run on AC and DC supplies.	Can run smoothly on DC supply. However when connected to AC supply, it produces heavy sparks at brush positions and becomes hot due to armature reaction and rough commutation.

Compensating winding is a must for large machines.	Does not require compensating winding.
Inter-poles provided in larger machines.	Does not require inter-poles normally.
High resistance grade brushes are necessary.	Normal grade brushes will suffice.
Air gap is kept to the minimum.	Normal air gap is maintained.

Operation: A universal motor works on the same principle as a DC motor, i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current-carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operates on AC or DC supply. Fig 3 shows the operation of a universal motor on AC supply. In AC operation, both field and armature currents change their, polarities, at the same time resulting in unidirectional torque.

Fig 3



a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE

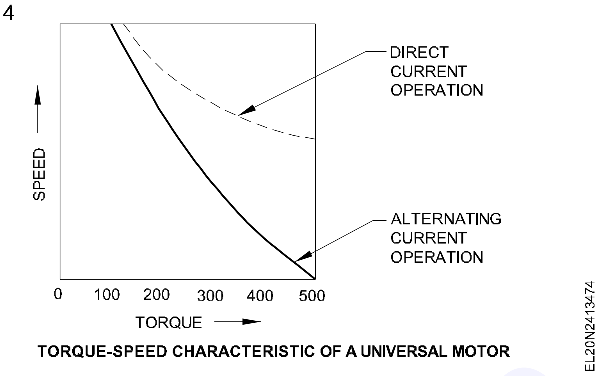
b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

Characteristic and application: The speed of a universal motor is inversely proportional to the load, i.e. speed is low at full load and high on no load. The speed reaches a dangerously high value due to low field flux at no loads. In fact the no-load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no-load, thereby avoiding high speeds.

Fig 4 shows the typical torque speed relation of a universal motor, both for AC and DC operations. This motor develops about 450 percent of full load torque at starting, as such, higher than any other type of single phase motor. Universal motors are used in vacuum cleaners, food mixers, portable drills and domestic sewing machines.

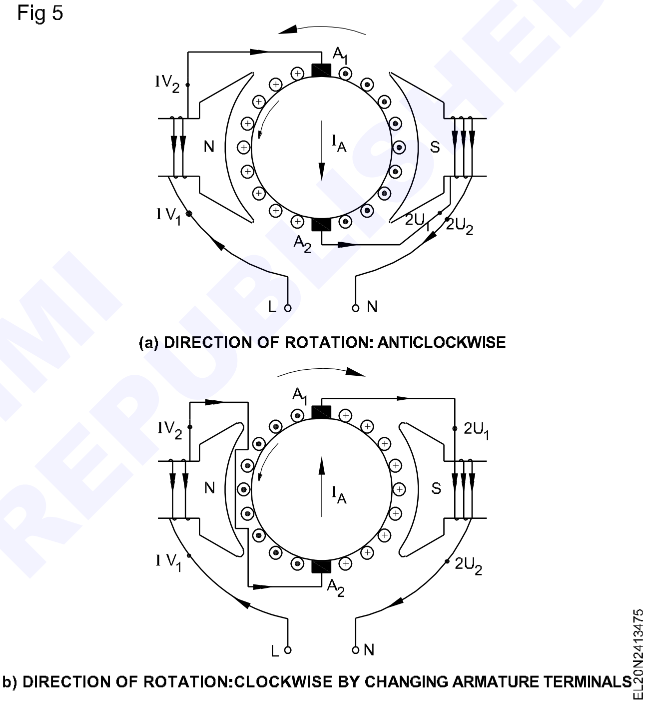
Change of rotation: Direction of rotation of a universal motor can be reversed by reversing the flow of current through either the armature or the field windings. It is easy to interchange the leads at the brush holders as shown in Fig 5.

Fig 4



TORQUE-SPEED CHARACTERISTIC OF A UNIVERSAL MOTOR

Fig 5



(a) DIRECTION OF ROTATION: ANTICLOCKWISE

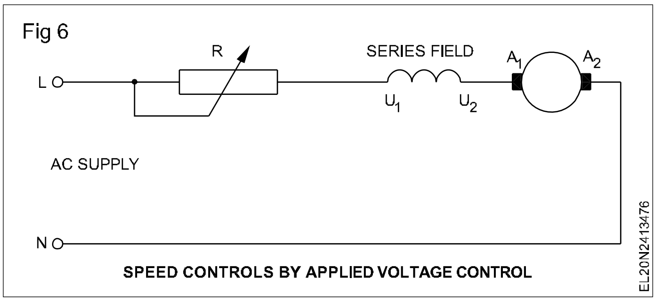
b) DIRECTION OF ROTATION:CLOCKWISE BY CHANGING ARMATURE TERMINALS

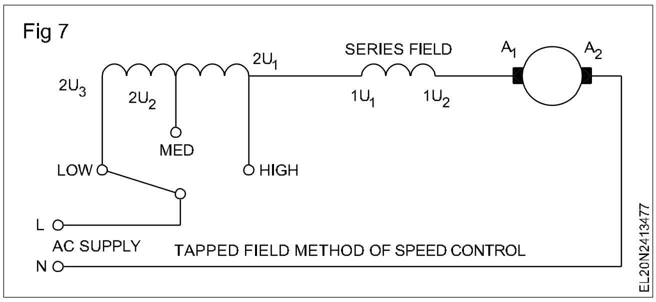
However, when the armature terminals are interchanged in a universal motor having compensating winding, care should be taken to interchange the compensating winding also to avoid heavy sparking while running.

Speed control of universal motor: The following methods are adopted to control the speed of a universal motor.

Series resistance or applied voltage control method: The motor speed is controlled by connecting a variable resistance in series with the motor. Foot-pedal operated sewing machines incorporate such a control. Fig 6 shows the connections.

Tapped field method: In this method, the field winding is tapped at 2 or 3 points and the speed is controlled by the varying field MMF. Fig 7 shows such a connection. Most of the domestic food mixers employ this method of speed control.





Troubleshooting of universal motor

Objectives: At the end of this lesson you shall be able to
- **state the advantages and disadvantages of universal motor**
- **explain the method of troubleshooting in universal motor.**

As the name suggest universal motors can operate on either AC or DC supply. By a compromise of design fractional horse power motors may be built to operate satisfactorily on either 240 V 50 Hz AC or direct current at 240 volts. Such motors are known as universal motors.

Advantages of universal motors

- These motors develop high starting torque and have the ability to adjust the torque and speed proportionally when loaded.
- Universal motors can operate on direct current or AC supply.
- Tapped fields provide an easy method of controlling speed.

Disadvantages of universal motors

- Since these motors operate at very high speed upto 40,000 rpm considerable air noise is present.
- Because of the large increase in the power input under stalled conditions and the loss of motor cooling, they can burn out within a short time when overloaded too much.
- Useful for intermittent duty application only.
- They produce radio and television interference.

Troubleshooting chart for universal motor: Table 1 gives possible faults, which occur in universal motor, their causes, mode of testing and suggested rectification. As a universal motor is similar in design to the DC machine, trainees are advised to refer trouble shooting chart pertaining to DC machines also.

Table 1

Troubleshooting chart for universal motor

Trouble	Causes	Mode of testing	Rectification
Motor fails to start	a) No voltage due to blown fuse	a) Test by test lamp or voltmeter	a) Replace the blown fuse.
	b) Open overload relay of starter.	b) Test by test lamp or voltmeter	b) Reset or rectify the overload relay contact
	c) Low voltage due to improper supply voltage.	c) Test by voltmeter.	c) Rectify the loose connections at the switch & fuse.
	d) Open circuited field or armature.	d) Test by ohmmeter or Megger.	d) If possible join properly or replace the winding.
	e) Improper contact of carbon brushes with commutator.	e) Visual inspection and test by test lamp	e) Adjust for proper contact of carbon brush with commutator.
	f) Dirty commutator.	f) Visual inspection and test by test lamp.	f) Clean by buffing the commutator using smooth sandpaper.
Shock to the operator	a) Grounded field or armature circuit due to weak insulation.	a) Test by Megger or test lamp.	a) Rectify the defect and apply shellac varnish to armature and field winding

	b) Insufficient earth.	b) Test by Megger or test lamp.	b) Provide proper earth to the motor.
Over heating of motor	a) Shorted coil of field or armature.	a) Visual inspection and resistance measurement	a) Rewind field or armature coil which is shorted
	b) Tight bearing due to worn out or locked bearing.	b) Test the shaft for free rotation. Check the shield for over heating.	b) Clean the bearings and check for damage. Replace bearing if necessary.
	c) Heavy sparking at commutator due to pitted commutator.	c) By visual inspection.	c) Clean the commutator and true the surface of the commutator.
	d) Shorted commutator.	d) Test the armature by growler.	d) Replace or repair the commutator
	e) Grounded field or armature.	e) Test by Megger.	e) Repair or rewind the field or armature.
Humming sound. Lack of torque due to overheat	a) Short circuited field.	a) Test by ohmmeter.	a) Rewind the field winding.
	b) Shorted armature coil.	b) Test by Growler.	b) Rewind shorted armature winding.

Repulsion motor

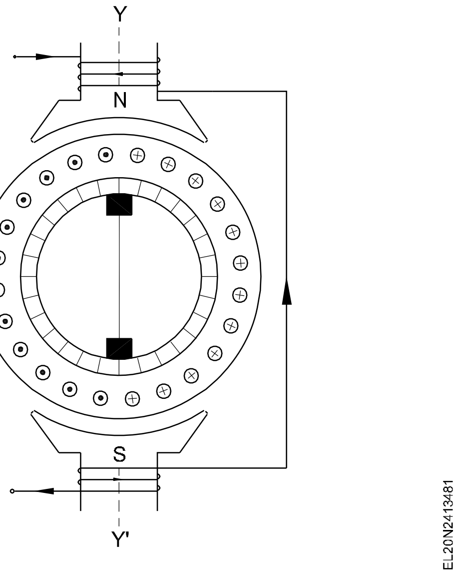
Objectives: At the end of this lesson you shall be able to
- **explain the principle, working, types and construction of the repulsion motor**
- **explain the characteristic and application of the repulsion motor.**

Repulsion motors, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, ability to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

The repulsion principle: The principle of torque production in a repulsion motor could be explained as follows. Fig 1 shows a two-pole motor with its magnetic axis vertical. An armature, having a commutator which is short-circuited through the brushes, is placed in the magnetic field. When the stator winding is connected to an AC supply, it produces an alternating magnetic field. Assume that at an instant, a north pole at the top and a south pole at the bottom are produced by this alternating magnetic field. Because of this a voltage will be induced in all the rotor conductors by the transformer action. The direction of current in the conductors will be in accordance with Lenz's law such that they create a north pole at the top just below the stator north pole, and a south pole at the bottom just at the top of the stator south pole to oppose the induction action. Hence the stator poles and the rotor poles will oppose each other in the same line. There will, therefore, be no torque developed due to the absence of the tangential component of the torque.

Let us assume that the short-circuited brush-axis is moved to a position as in Fig 2. Due to the present brush position, the magnetic axis of the armature is no longer co-linear with respect to the vertical axis of the main poles.

Fig 1



It will now be along the axis `KK' with north and south poles shifted around by an angle `A°' depending upon the shifting of the brushes. In this position, the direction of current in the conductors 1,2,3 and 13,14,15 is reversed, and hence, the armature becomes an electromagnet having the north (N) and south (S) poles in the `KK' axis just at an angle of `A°' from the main magnetic axis. Now there is a condition that the rotor north pole will be repelled by the main north pole, and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this motor is named as repulsion motor.

Direction of rotation : To change the D.O.R. of this motor, the brush-axis needs, to be shifted from the right side as shown in Fig 2 to the left side of the main axis in a counter-clockwise direction as shown in Fig 3.

Fig 2

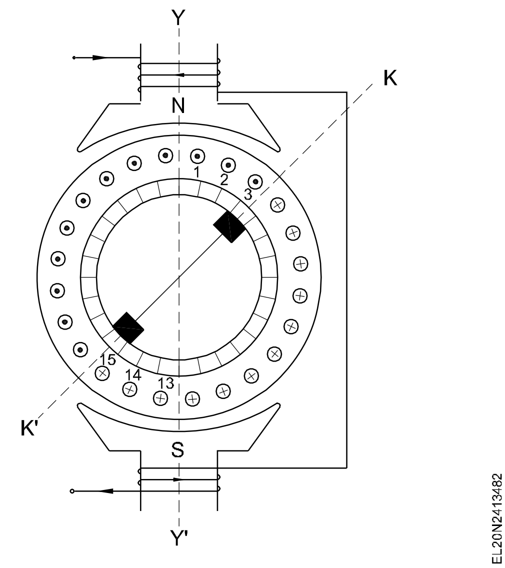
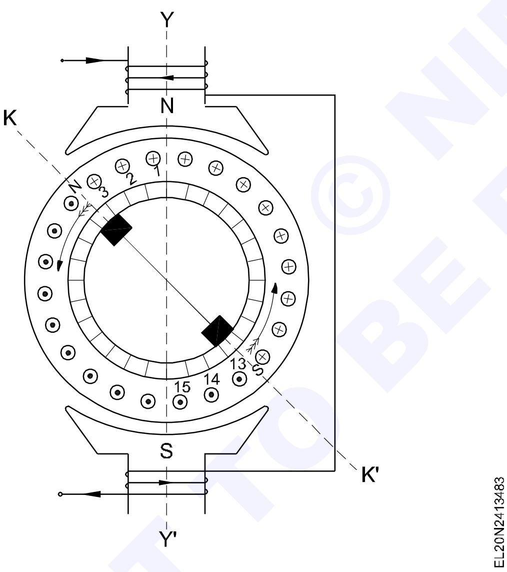


Fig 3



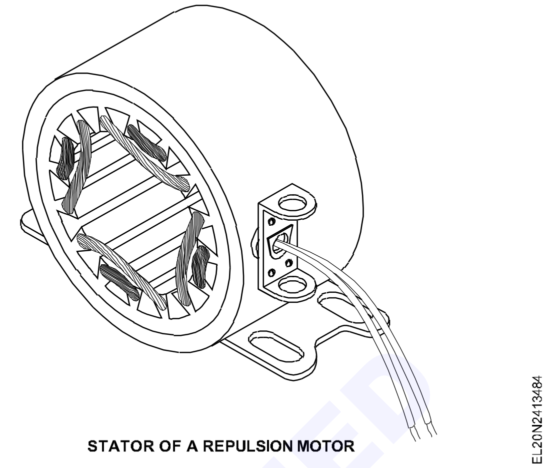
This working principle applies equally well for all types of repulsion motors having distributed windings in the stator.

Types of repulsion motors : There are four types of induction motors as stated below.

- Repulsion motor
- Compensated-repulsion motor
- Repulsion-start, induction-run motor
- Repulsion-induction motor

Construction: The construction of stators is the same in all the types, except for certain variation in the compensated-repulsion motor. In general, for all types of repulsion motors the stator winding is of the distributed, non-salient pole type, housed in the slots of the stator, and only two terminals as shown in Fig 4 are brought out. It is wound for four, six or eight poles. The rotor for each type of motor is different, and will be explained under each type.

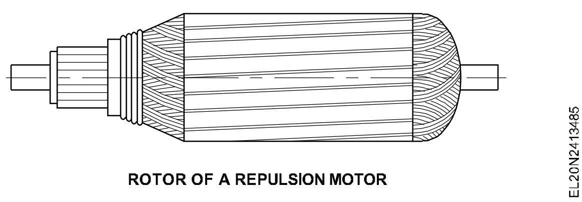
Fig 4



STATOR OF A REPULSION MOTOR

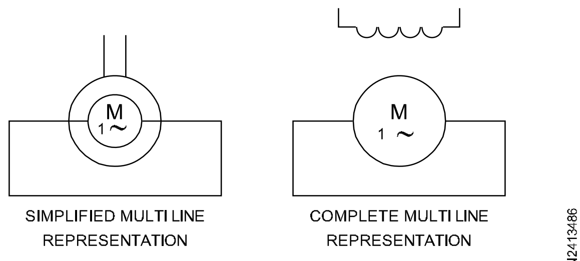
Repulsion motor: The general construction of the repulsion motor is similar to the one explained under the `Repulsive principle'. However the rotor of the repulsion motor is like a DC armature that is as shown in Fig 5, having a distributed lap or wave-winding. The commutator may be similar to the DC armature, that is axial type, having commutator bars in parallel to the shaft or radial or vertical bars on which brushes ride horizontally. The shorted brush position can be changed by a lever attached to the rocker-arm. The B.I.S. symbol for the repulsion motor is shown in Fig 6.

Fig 5



ROTOR OF A REPULSION MOTOR

Fig 6

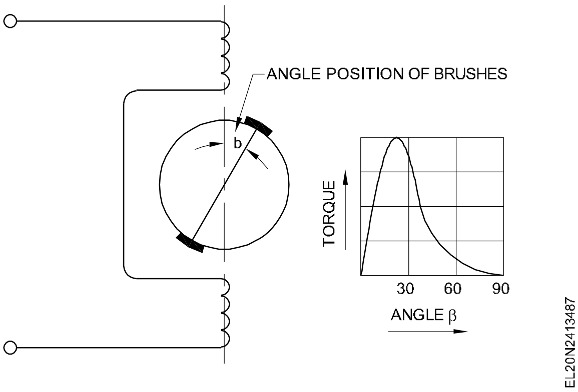


REPULSION MOTOR

As explained earlier, the torque developed in a repulsion motor will depend upon the amount of brush-shaft as shown in Fig 7, whereas the direction of shift decides the direction of rotation. Further, the speed also depends upon the amount of brush-shift and the magnitude of the load.

Repulsion-start, induction-run motor : The rotor of this motor is similar to that of a repulsion motor but the commutator and the brush mechanism are entirely different. This motor starts like a repulsion motor, and after attaining about 75% of the rated speed, there is a necklace-type shorting mechanism, activated by a centrifugal force which short circuits the entire commutator. From then on, this motor works as an induction motor with a short-circuited rotor (armature). After the commutator is short-circuited, in some machines, there is a special mechanism to lift the brushes to avoid wear and tear of the brushes and the commutator.

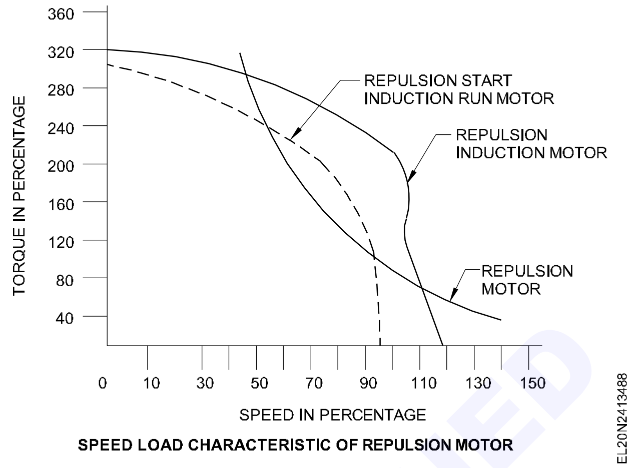
Fig 7



The torque speed characteristic of this motor is shown in Fig 8.

Repulsion-induction motor : The rotor of this motor has a squirrel cage winding deep inside the rotor, in addition to the usual winding. The brushes are short-circuited, and they continuously ride over the commutator. Generally the starting torque is developed in the wound part of the rotor, while the running torque is developed in the squirrel cage winding. The speed torque characteristic is shown in Fig 8. This develops a little less torque, say about 300% of the full load torque, and can start with a load and run smoothly on no load. This motor has its starting characteristic similar to DC compound motor, and running characteristic similar to an induction motor.

Fig 8



APPLICATION: In these motors the average starting torque varies from 300-400 percent of the full load torque, and these motors are preferred in places where the starting period is of comparatively long duration, due to heavy load. These motors are used in refrigerators, air-compressors, coil winders, petrol pumps, machine tools, mixing machines, lifts and hoists, due to their excellent starting torque, ability to withstand sustained overloads, good speed regulation and easy method of reversal of direction of rotation.

Stepper motor

Objectives: At the end of this exercise you shall be able to
- **state the basic theory and open loop operation of stepper motor**
- **list and explain the each type of stepper motor**
- **state the advantages, disadvantages and application of stepper motor.**

Basic theory

A stepper motor is basically a synchronous motor. There are no brushes. It is an electromechanical device converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shaft rotation. The speed of the motor shaft rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of pulses applied.

This device does not rotate continuously, but it rotates in the form of pulses. There are different types of motors available based on the stepper rotation, manufactured with steps per revolution of 12,24,72,144,180 and 200 in stepping angles of 300, 150, 50, 2.50, 20 and 1.80 per steps.

Open loop operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses.

Stepper motor types: There are three basic stepper motor types. They are

1 Variable-reluctance (Fig 1)

2 Permanent-magnet (Fig 2)

3 Hybrid (Fig 3)

1 Variable-reluctance (VR): This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view (Fig 1) shows a typical VR stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

Fig 1

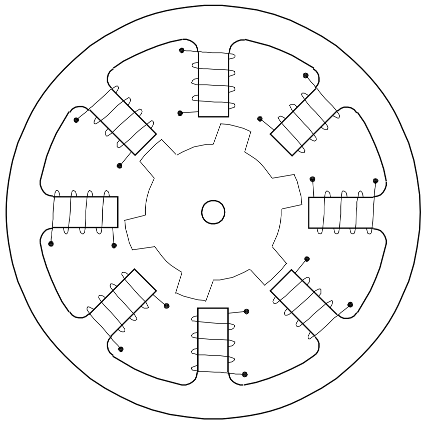


Fig 2

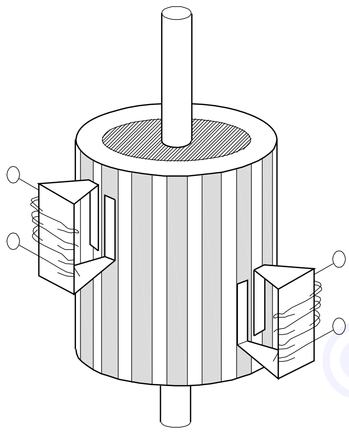
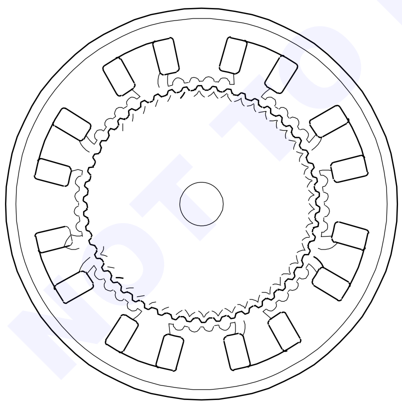


Fig 3



2 **Permanent magnet (PM):** Often referred to as a "tin can" or "can stock" motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.50 to 150 (48 - 24 steps/ revolution) PM motors as the name implies have permanent magnets added to the motor structure (Fig 2). The rotor no longer has teeth as with VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

3 **Hybrid (HB):** The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.60 to 0.90 (100 - 400 steps per revolution) The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft (Fig 3). The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types.

Advantages and disadvantages

Advantages

1 The rotation angle of the motor is proportional to the input pulse.

2 The motor has full torque at stand still (if the windings are energized)

3 Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3-5% of a step and this error is non cumulative from one step to the next.

4 Excellent response to starting/stopping/reversing.

5 Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependent on the life of the bearing

6 The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7 It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8 A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1 Resonances can occur if not properly controlled

2 Not easy to operate at extremely high speeds.

Application

There are different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

Alternator - principle - relation between poles, speed and frequency

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of an alternator**
- **explain the method of production of sine wave voltage by a single loop alternator**
- **describe the relation between frequency, number of poles and synchronous speed.**

Principle of an alternator: An alternator works on the same principle of electromagnetic induction as a DC generator. That is, whenever a conductor moves in a magnetic field so as to cut the lines of force, an emf will be induced in that conductor. Alternatively whenever there is relative motion between the field and the conductor, then, the emf will be induced in the conductor. The amount of induced emf depends upon the rate of change of cutting or linkage of flux.

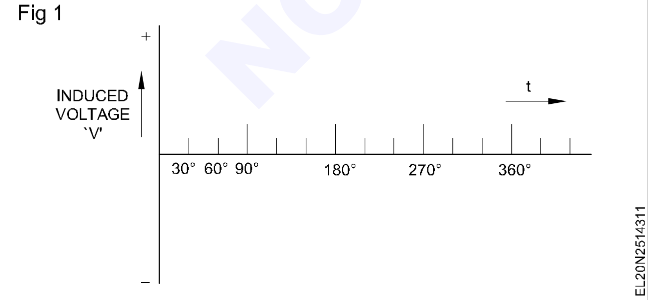
In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armature coils can be brought out to the external circuit with the help of slip-rings. Alternatively the stationary conductors in the stator can produce alternating current when subjected to the rotating magnetic field in an alternator.

Production of sine wave voltage by single loop alternator: Fig 2a shows a single loop alternator. As it rotates in the magnetic field, the induced voltage in it varies in its direction and magnitude as follows.

To plot the magnitude and direction of the voltage induced in the wire loop of the AC generator in a graph, the electrical degrees of displacement of the loop are kept in the `X' axis as shown in Fig 1 through 30 electrical degrees. As shown in Fig 2c, three divisions on the `X' axis represent a quarter turn of the loop, and six divisions a half turn. The magnitude of the induced voltage is kept in the `Y' axis to a suitable scale.

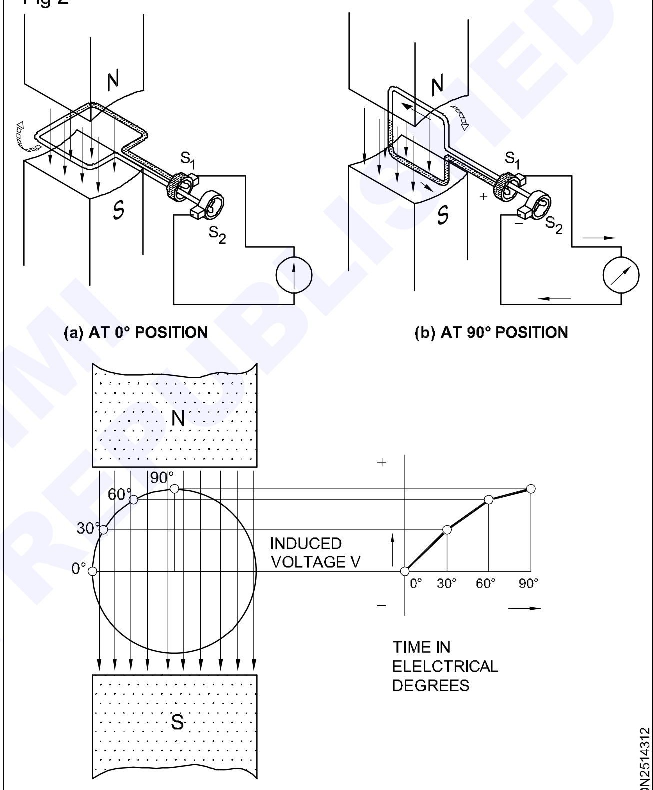
The part above the X-axis represents the positive voltage, and the part below it the negative voltage as shown in Fig 1.

Fig 1



The position of the loop at the time of starting is shown in Fig 2a and indicated in Fig 2c as `O' position. At this position, as the loop moves parallel to the main flux, the loop does not cut any lines of force, and hence, there will be no voltage induced. This zero voltage is represented in the graph as the starting point of the curve as shown in Fig 2c. The magnitude of the induced emf is given by the formula $Eo = BLV \sin \theta$

Fig 2



(c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

where

B is the flux density in weber per square metre,

L is the length of the conductors in metres,

V is the velocity of the loop rotation in metres per second and

θ is the angle at which the conductor cuts the line of force.

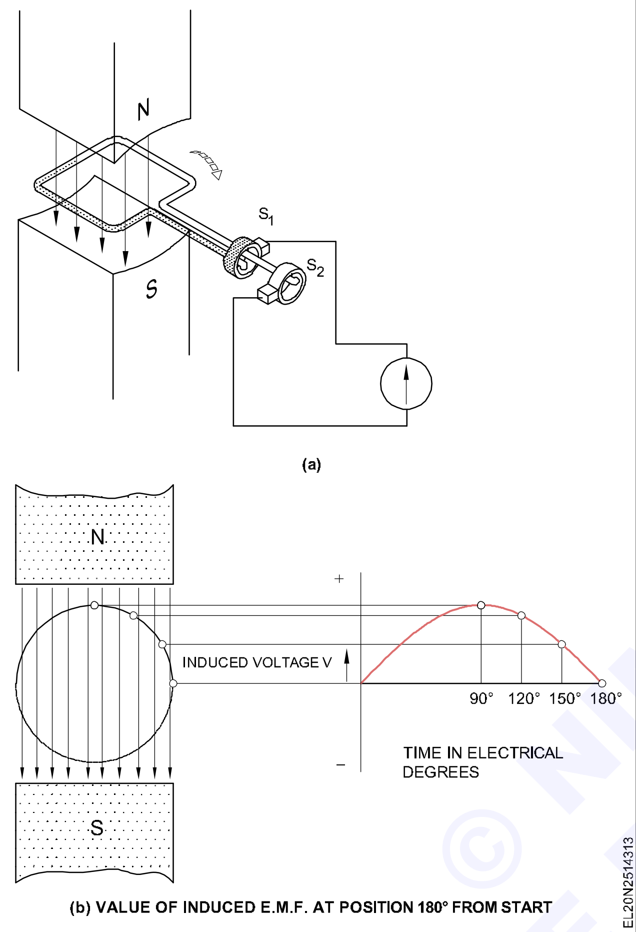
As $\sin \theta = 0$

E at 0 position is equal to zero. As the loop turns in a clockwise direction at position 30° as shown in Fig 2c, the loop cuts the lines of force and an emf is induced (E_{30}) in the loop whose magnitude will be equal to $BLV \sin\theta$ where θ is equal to 30°.

Applying the above formula, we find the emf induced in the loop at 90° position will be maximum as shown in Fig 2c.

As the loop turns further towards 180° it is found the number of lines of force which are cut will be reduced to zero value. If the quantity of emf induced at each position is marked by a point and a curve is drawn along the points, the curve will be having a shape as shown in Fig 3b.

Fig 3



(a)

(b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

During the turn of the loop, from 0 to 180°, the slip ring S_1 will be positive and S_2 will be negative.

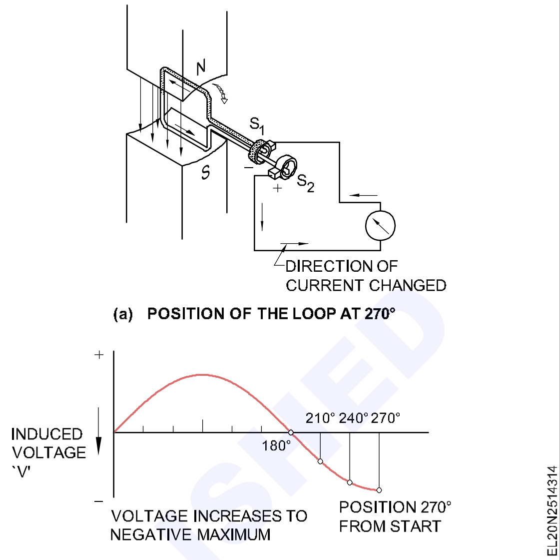
However, at 180° position, the loop moves parallel to the lines of force, and hence there is no cutting of flux by the loop and there is no emf induced in the loop as shown in Fig 3b.

Further during the turn of the loop from the position 180° to 270°, the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360°, the slip ring S_2 will be positive and S_1 will be negative as shown in Fig 4a. However, at 270° the voltage induced will be the maximum and will decrease to zero at 360°. Fig 5b shows the variation of the induced voltage in both magnitude and direction during one complete revolution of the loop. This is called a cycle.

This type of wave-form is called a sine wave as the magnitude and direction of the induced emf, strictly follows the sine law. The number of cycles completed in one second is called a frequency. In our country, we use an AC supply having 50 cycles frequency which is denoted as 50 Hz.

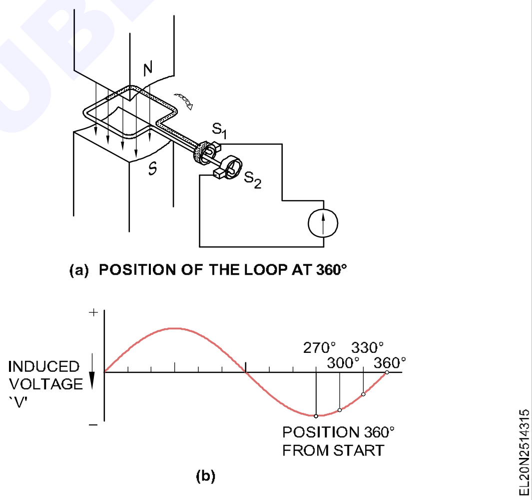
Relation between frequency, speed and number of poles of alternator: If the alternator has got only two poles, the voltage induced in one revolution of the loop undergoes one cycle. If it has four poles, then one complete rotation of the coil produces two cycles because, whenever it crosses a set of north and south poles, it makes one cycle.

Fig 4



(a) POSITION OF THE LOOP AT 270°

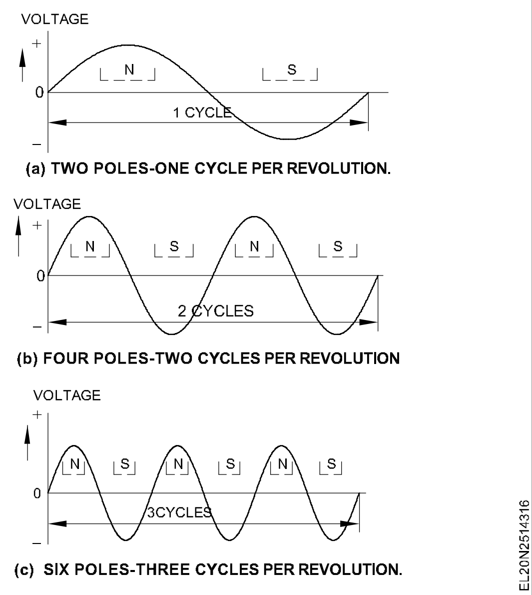
Fig 5



(a) POSITION OF THE LOOP AT 360°

(b)

Fig 6



(a) TWO POLES-ONE CYCLE PER REVOLUTION.

(b) FOUR POLES-TWO CYCLES PER REVOLUTION

(c) SIX POLES-THREE CYCLES PER REVOLUTION.

Fig 6 shows the number of cycles which are produced in each revolution of the coil, with 2 poles, 4 poles and 6 poles. It is clear from this that the number of cycles per revolution is directly proportional to the number of poles, `P' divided by two. Therefore the number of cycles produced per second depends on P/2, and the speed in revolutions per second.

Therefore frequency $F = \frac{P}{2} \times 'n'$

where `n' is in r.p.s.

`P' is the number of poles.

Generally speed is represented in r.p.m.

Then we have frequency $F = \frac{PN}{2 \times 60} = \frac{PN}{120}$

where P is number of poles and N is speed in r.p.m.

Accordingly we can state that the frequency of an alternator is directly proportional to the number of poles and speed.

Types and construction of alternators

Objective: At the end of this lesson you shall be able to
- **explain the construction, and the various types of alternators.**

Classification according to the number of phases: Another way of classifying the alternators is based on production of single or 3-phase by the alternator. Accordingly the types are 1) single-phase alternators 2) three-phase alternators.

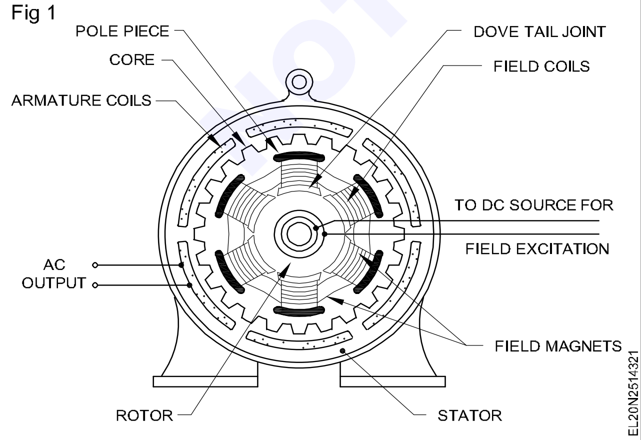
Single-phase alternators: A single-phase alternator is one that provides only one voltage. The armature coils are connected in `series additive'. In other words, the sum of the emf induced in each coil produces the total output voltage. Single phase alternators are usually constructed in small sizes only. They are used as a temporary standby power for construction sites and for permanent installation in remote locations.

Three-phase alternators: This alternator provides two different voltages, namely, phase and line voltages. It has 3 windings placed at 120° to each other, mostly connected in a star having three main terminals U,V,W and neutral `N'.

These alternators are driven by prime movers such as diesel engines, steam turbines, water wheels etc. depending upon the source available.

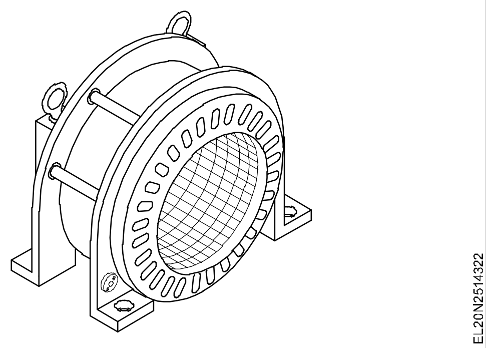
Construction of alternators: The main parts of a revolving field type alternator are shown in Fig 1.

Fig 1



Stator: It consists of mainly the armature core formed of laminations of steel alloy (silicon steel) having slots on its inner periphery to house the armature conductors. The armature core in the form of a ring is fitted to a frame which may be of cast iron or welded steel plate. The armature core is laminated to reduce the eddy current losses which occur in the stator core when subjected to the cutting of the flux produced by the rotating field poles. The laminations are stamped out in complete rings (for smaller machines) or in segments (for larger machines), and insulated from each other with paper or varnish. The stampings also have holes which make axial and radial ventilating ducts to provide efficient cooling. A general view of the stator with the frame is shown in Fig 2.

Fig 2

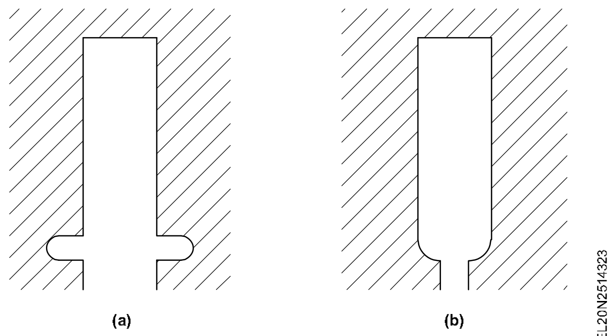


Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3a and b respectively.

The open slots are more commonly used because the coils can be form-wound and pre-insulated before placing in the slots resulting in fast work, less expenditure and good insulation. This type of slots also facilitates easy removal and replacement of defective coils. But this type of slots creates uneven distribution of the flux, thereby producing ripples in the emf wave. The semi-closed type slots are better in this respect but do not permit the use of form-wound coils, thereby complicating the process of winding. Totally closed slots are rarely used, but when used, they need bracing of the winding turns.

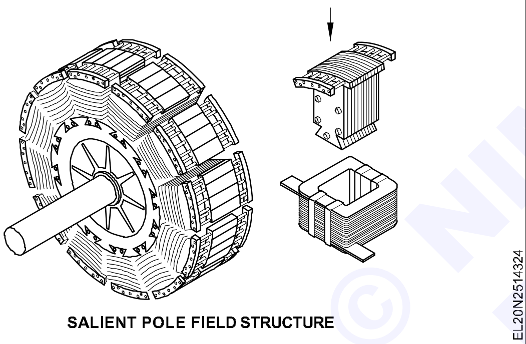
Rotor: This forms the field system, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage DC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted to the same alternator shaft. The exiting current is supplied to the rotor with the help of two slip- rings and brushes. The field poles created by the excitation are alternately north and south.

Fig 3



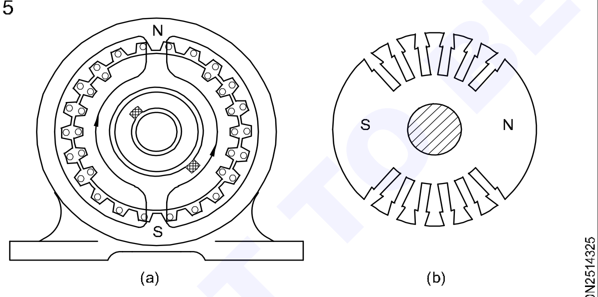
Rotating field rotors are of two types, namely (i) salient pole type as shown in Fig 4 and (ii) smooth cylindrical type or non-salient pole type, as shown in Fig 5.

Fig 4



SALIENT POLE FIELD STRUCTURE

Fig 5



NON-SALIENT POLE TYPE FIELD STRUCTURE

Salient pole type: This type of rotor is used only for slow and medium speed alternators. This type is less expensive, having more space for the field coils and vast heat dissipating area. This type is not suitable for high speed alternators as the salient poles create a lot of noise while running in addition to the difficulty of obtaining sufficient mechanical strength.

Fig 4 shows the salient pole type rotor in which the riveted steel laminations are fitted to the shaft fitting with the help of a dovetailed joint. Pole faces are curved to have uniform distribution of the flux in the air gap leading to production of sinusoidal wave form of the generated emf. These pole faces are also provided with slots to carry the damper winding to prevent hunting.

Salient pole type alternators could be identified by their larger diameter, short axial length and low or medium speed of operation.

Smooth cylindrical or non-salient pole type rotor: This type is used in very high speed alternators, driven by steam turbines. To have good mechanical strength, the peripheral velocity is lowered by reducing the diameter of the rotor and alternatively with the increased axial length. Such rotors have either two or four poles but run at higher speeds.

To withstand such speeds, the rotor is made of solid steel forging with longitudinal slots cut as shown in Fig 5a which shows a two-pole rotor with six slots. The winding is in the form of insulated copper strips, held securely in the slots by proper wedges, and bound securely by steel bonds.

One part of the periphery of the rotor in which slots are not made is used as poles as shown in Fig 5b.

Smooth cylindrical pole type alternators could be identified by their shorter diameter, longer axial length and high speed of operation.

Rating of alternators

An electrical machines is usually rated at the load, which is can carry without over heating and damage to insulation. i.e the rating of electrical machine is governed by the temperature rise caused by internal losses of the machine. The copper loss in the armature (I^2R) depends upon the strength of the armature current and is independent of power factor.

The output in kW is proportional to power factor for the alternator of a given kVA. For example output of 1000 kVA alternator on full load will be 200, 500, 800, 1000 kW at power factor 0.2, 0.5, 0.8 and unity respectively but copper losses in armature will remain the same regard less of power factor.

For the above reasons alternators are usually rated in kVA (kilo Volt Ampere).

Hunting

Hunting is a phenomenon in alternator which is caused by continuous fluctuation in load. When the load on the alternator is frequently changing, then the rotor of the alternator runs unsteadily making a noise of a whistle due to oscillations, or vibrations set up in the rotor. This phenomenon is called as hunting of alternators.

Hunting is prevented by the Damper Windings provided in the field pole core.

Generation of 3-phase voltage and general test on alternator

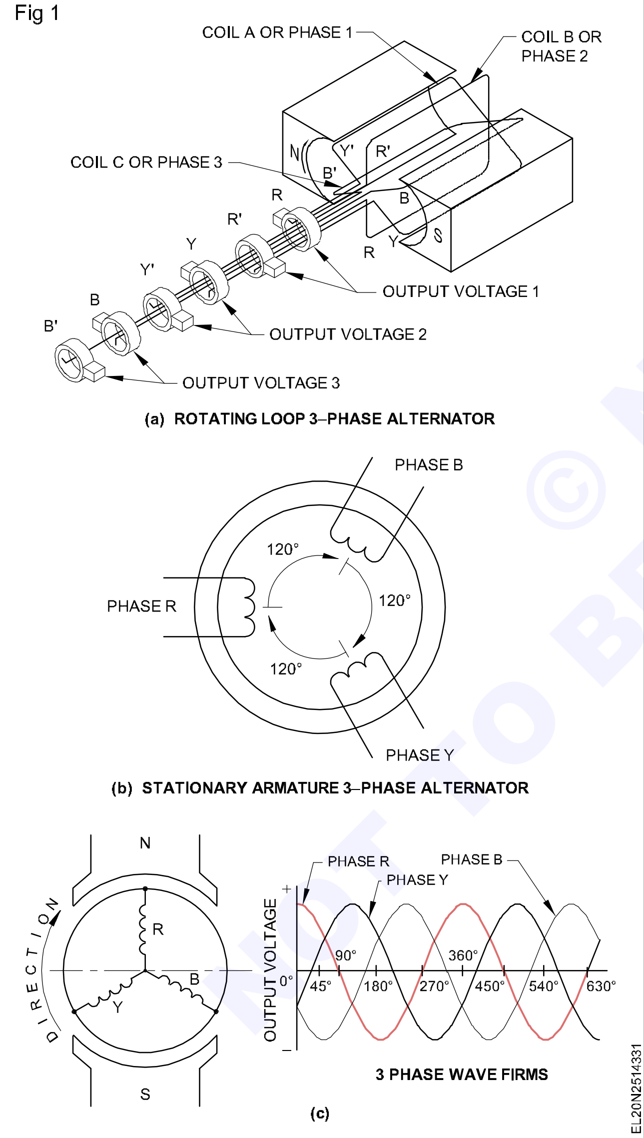
Objectives: At the end of this lesson you shall be able to

- **explain the method of generating 3-phase voltage wave-forms by a 3-phase alternator**
- **state the phase sequence of 3ϕ supply**
- **state the method of testing an alternator for continuity insulation and earth connection**
- **state e.m.f. equation of the alternator**
- **state the I.E.E. regulations and B.I.S. recommendations pertaining to earthing of the alternator.**

Generation of three-phase voltage: Basically, the principle of a three-phase alternator (generator) is the same as that of a single phase alternator (generator), except that there are three equally spaced coils or windings which produce three output voltages which are out of phase by 120° with each other.

A simple rotating-loop, three-phase generator with its output voltage wave-forms is shown in Fig 1c.

Fig 1



As shown in Fig 1a, three independent loops spaced about 120° apart are made to rotate in a magnetic field with the assumption that the alternator shown is a rotating armature type. As shown in Fig 1a, the three loops are electrically isolated from each other and the ends of the loops are connected to individual slip rings. As the loops are rotating in a uniform magnetic field, they produce sine waves. In a practical alternator, these loops will be replaced by a multi-turn winding element and distributed throughout the rotor slots but spaced apart at 120° electrical degrees from each other. Further, in practice, there will not be six slip rings as shown in Fig 1a but will have either four or three slip rings depending upon whether the three windings are connected in a star or delta respectively.

We also know, as discussed earlier, that the rotating magnetic field type alternators are mostly used. In such cases only two slip rings are required for exciting the field poles with DC supply. Fig 1b shows a stationary, 3-phase armature in which individual loops of each winding are replaced by coils spaced at 120 electrical degrees apart. However, the rotating part having the magnetic poles is not shown.

Fig 1c shows the rotating armature type alternator in which the 3 coils of the three-phases are connected in star which rotates in a two-pole magnetic field. According to Fig 1c, the coil `R' moves under the influence of the `N' pole cutting the flux at right angles, and produces the maximum induced voltage at position `O°' as shown in the graph as per Faraday's Laws of Electromagnetic induction. When the coil `R' moves in a clockwise direction, the emf induces falls to zero at 90 degrees, and then increases to -ve maximum under the influence of the south pole at 180 degrees. Likewise the emf induced in the `R' phase will become zero at 270 degrees and attain +ve maximum at 360 degrees. In the same manner the emf produced by coils `Y' and `B' could be plotted on the same graph. A study of the sine wave-forms produced by the three coils RYB shows that the voltage of coil `R' leads voltage of coil `Y' by 120°, and the voltage of coil `Y' leads voltage of coil `B' by 120°.

Phase sequence: The phase sequence is the order in which the voltages follow one another, i.e. reach their maximum value. The wave-form in Fig 1c shows that the voltage of coil R or phase R reaches its positive maximum value first, earlier than the voltage of coil Y or phase `Y', and after that the voltage of coil B or phase B reaches its positive maximum value. Hence the phase sequence is said to the RYB.

If the rotation of the alternator shown in Fig 1c is changed from clockwise to anticlockwise direction, the phase sequence will be changed as RBY. It is the most important factor for parallel connection of poly phase generators and in poly phase windings. Further the direction of rotation of a 3-phase induction motor depends upon the phase sequence of the 3-phase supply. If the phase sequence of the alternator is changed, all the 3-phase motors, connected to that alternator, will run in the reverse direction though it may not affect lighting and heating loads.

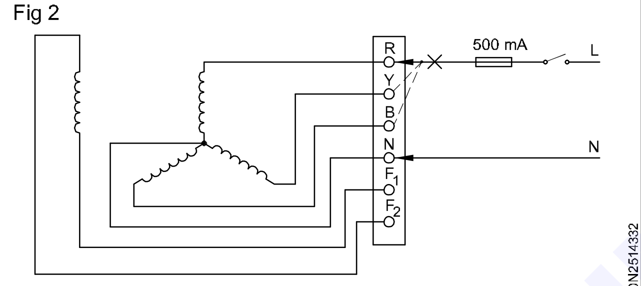
The only difference in the construction of a single phase alternator and that of a 3-phase alternator lies in the main winding. Otherwise both the types of alternators will have similar construction.

General testing of alternator: Alternaters are to be periodically checked for their general condition as they will be in service continuously. This comes under preventive maintenance, and avoids unnecessary breakdowns or damage to the machine. The usual checks that are to be carried out on an altenator are:

- continuity check of the windings
- insulation resistance value between windings
- insulation resistance value of the windings to the body
- checking the earth connection of the machine.

Continuity test: The continuity of the windings is checked by the following method as shown in Fig 2.

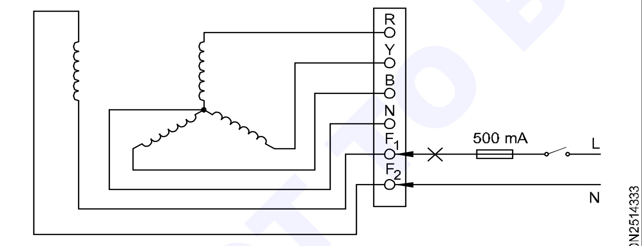
Fig 2



CONTINUITY TEST ON MAIN WINDING OF A 3-PHASE ALTERNATOR

A test lamp is connected in series with one end to the neutral (star point) and the other end to one of the winding terminals (R Y B). If the test lamp glows equally bright on all the terminals RYB then the continuity of the winding is all right. In the same way, as shown in Fig 3, we can test the field leads F_1 and F_2 for field continuity.

Fig 3



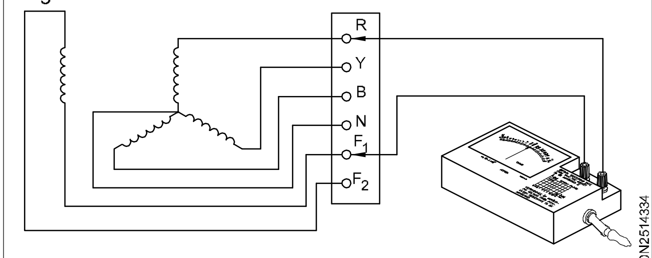
CONTINUITY TEST ON FIELD WINDING OF A 3-PHASE ALTERNATOR

Testing continuity with the test lamp only indicates the continuity in between two terminals but will not indicate any short between the same windings. A more reliable test will be to use an ohmmeter to check the individual resistances of the coils, and compare them to see that similar coils have the same resistance. The readings, when recorded, will be useful for future reference also.

For insulation resistance test

Between windings: As shown in Fig 4, one end of the Megger lead is connected to any one terminal of the RYB and the other is connected to F_1 or F_2 of the field winding. If the Megger reads one megohm or more, then the insulation resistance is accepted as okay.

Fig 4

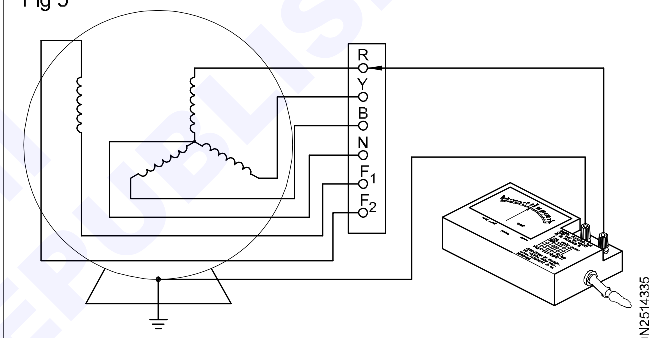


INSULATION TEST BETWEEN WINDINGS

If there is short, between the armature and field windings, the Megger reads zero ohms. If it is weak, it shows less than one megohm.

Testing insulation resistance between body and windings: As shown in Fig 5, one lead of the Megger is connected to one of the leads of the RYB, and the other lead of the Megger is connected to the body. If the insulation between the windings and the frame is all right, the Megger reads more than one megohm.

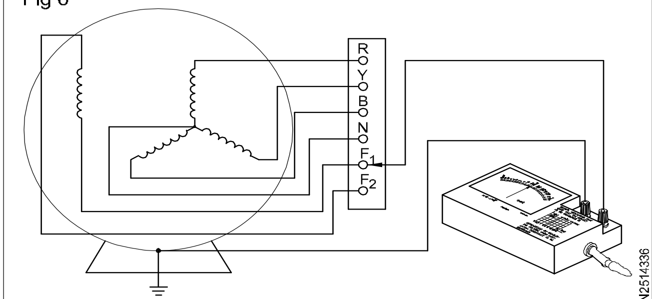
Fig 5



INSULATION TEST BETWEEN MAIN WINDING AND FRAME

The field is tested by connecting one terminal of the Megger to F_1 or F_2 of the field and the other terminal to the body as shown in Fig 6. If the insulation between the field and the frame is all right, the Megger reads more than one megohm. A lower reading than one megohm shows weak insulation and leakage to the ground.

Fig 6



INSULATION TEST BETWEEN FIELD WINDING AND FRAME

Caution

While conducting the insulation resistance test, if the Megger reads zero, then it should be concluded that the insulation of the winding has failed completely and needs thorough checking.

The permissible insulation resistance should not be less than 1 megohm.

Emf equation of the alternator

Objective: At the end of this lesson you shall be able to
- **explain the emf equation to calculate the induced emf in an alternator.**

Equation of induced emf: The emf induced in an alternator depends upon the flux per pole, the number of conductors and speed. The magnitude of the induced emf could be derived as stated below

Let Z = No.of conductors or coil sides in series/ phase in an alternator

P = No.of poles

f = frequency of induced emf in Hz

Ø = flux per pole in webers

k_f = form factor = 1.11 - if emf is assumed to be sinusoidal

N = speed of the rotor in r.p.m.

According to Faraday's Law of Electromagnetic Induction we have the average emf induced in a conductor is equal to rate of change of flux linkage

$$= \frac{d\varnothing}{dt}$$

$$= \frac{\text{change of total flux}}{\text{time duration in which the flux change takes place}}$$

In one revolution of the rotor (ie in 60/N seconds), each stator conductor is cut by a flux equal to PØ webers.

Hence the change of total flux = dØ = PØ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts} \quad \text{-------- Eq 1}$$

Substituting the value for $\frac{120f}{P}$ in eqn 1

we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120 \int}{P60} \text{ volts} = 2\varnothing \int \text{ volts} \quad \text{------ Eq. 2}$$

If there are Z conductors in series per phase we have the average emf per phase = 2ØfZ volts.

Then r.m.s. value of emf per phase = average value x form factor

$= V_{AV} \times K_F$

$= V_{AV} \times 1.11$

$= 2\varnothing f Z \times 1.11$

$= 2.22\varnothing f Z$ volts.

Alternatively r.m.s. value of emf per phase = 2.22Øf2T volts

= 4.44ØfT volts

where T is the number of coils or turns per phase and Z = 2T.

This would have been the actual value of the induced voltage if all the coils in a phase were (i)full pitched and (ii) concentrated or bunched in one slot. (In actual practice, the coils of each phase are distributed in several slots under all the poles.) This not being so, the actually available voltage is reduced in the ratio of these two factors which are explained below.

Pitch factor (K_p or K_c.): The voltage generated in a fractional pitch winding is less than the full pitch winding. The factor by which the full pitch voltage is multiplied to get voltage generated in fractional pitch is called pitch factor, and it is always less than one; and denoted as K_p or K_c. Normally this value is given in problems directly; occasionally this value needs to be calculated by a formula $K_p = K_c = \cos \alpha/2$

where α is the electrical angle by which the coil span falls short of full pitch.

Distribution factor (K_d): It is imperative that the conductors of the same phase need to be distributed in the slots instead of being concentrated at one slot. Because of this, the emf generated in different conductors will not be in phase with each other, and hence, cannot be added together to get the total induced emf per phase but to be added vectorially. This has to be taken into account while determining the induced voltage per phase.

Therefore, the factor by which the generated voltage must be multiplied to obtain the correct value is called a distribution factor, denoted by K_d and the value is always less than one. The formula for finding the value of K_d is given below.

$$K_d = \frac{\sin m\beta/2}{m \sin \beta/2}$$

where m is the number of slots per phase per pole

$$\beta = \frac{180^\circ}{\text{No. of slots per pole}}$$

Characteristic and voltage regulation of the alternator

Objectives: At the end of this lesson you shall be able to
- **explain the load characteristic of an alternator and the effect of the P.F. on terminal voltage**
- **explain the regulation of alternators and solve problems therein.**

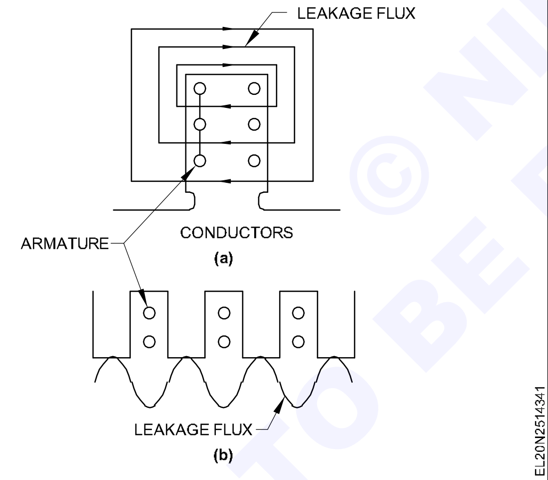
Load characteristic of an alternator: As the load on the alternator is changed, its terminal voltage is also found to change. The reason for this change is due to the voltage drop in the alternator because of

- armature resistance R_a
- armature leakage reactance X_L
- armature reaction which, in turn, depends upon the power factor of the load.

Voltage drop in armature resistance: Resistance of each phase winding of the alternator causes a voltage drop in the alternator, and it is equal to I_pR_a where I_p is the phase current and R_a is the resistance per phase.

Voltage drop in armature leakage reactance: When the flux is set up in the alternator due to the current flow in the armature conductors, some amount of flux strays out rather than crossing the air gap. These fluxes are known as leakage fluxes. Two types of leakage fluxes are shown in Figs 1a and b.

Fig 1



Though the leakage fluxes are independent of saturation, they do depend upon the current and the phase angle between the current and the terminal voltage `V'. These leakage fluxes induce a reactance voltage which is ahead of the current by 90°. Normally the effect of leakage flux is termed as inductive reactance X_L and as a variable quantity. Sometimes the value X_L is named as synchronous reactance to indicate that it refers to working conditions.

Voltage drop due to armature reaction: The armature reaction in an alternator is similar to DC generators. But the load power factor has considerable effect on the armature reaction in the alternators.

The effects of armature reaction have to be considered in three cases, i.e. when load power factor is

- unity
- zero lagging
- zero leading.

At unity P.F. the effect of armature reaction is only cross-magnetising. Hence there will be some distortion of the magnetic field.

But in the case of zero lagging P.F. the effect of armature reaction will be de-magnetising. To compensate this de-magnetising effect, the field excitation current needs to be increased.

On the other hand, the effect of armature reaction due to zero leading P.F. will be magnetising. To compensate the increased induced emf, and to keep the constant value of the terminal voltage due to this additional magnetising effect, the field excitation current has to be decreased.

Rating of alternators: As the power factor for a given capacity load determines the load current, and the alternator's capacity is decided on load current, the rating of the alternator is given in kVA or MVA rather than kW or MW in which case the power factor also is to be indicated along with the wattage rating.

Example: A 3-phase, star-connected alternator supplies a load of 5 MW at P.F. 0.85 lagging and at a voltage of 11 kV. Its resistance is 0.2 ohm per phase and the synchronous reactance is 0.4 ohm per phase. Calculate the line value of the emf generated.

Full load current = $I_L = \dfrac{P}{\sqrt{3}E_L\cos\theta}$

$$\frac{5\times1000\times1000}{\sqrt{3}\times11000\times.85} = 309 \text{ Amps.}$$

In star I_L = I_P

IR_a drop = 309x0.2=61.8 V

Ix_L drop = 309 x 0.4 = 123.6 V

Terminal voltage (line)=11000 V

Terminal voltage(phase) = $\dfrac{11000}{\sqrt{3}}$ = 6350V

Power factor = 0.85

Power factor angle = $\theta = \cos^{-1}(.85)$

= Cos 31.8°

Sin θ = 0.527.

Drawing the vector, as shown in Fig 2, with the above data, we have

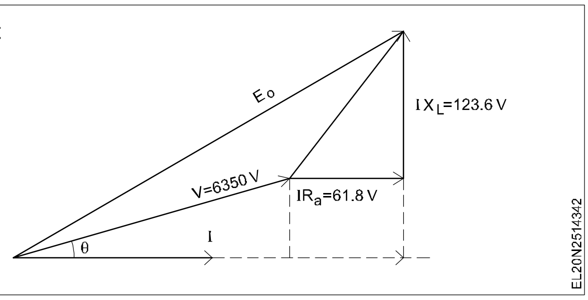
$$E_o = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

$$= \sqrt{(6350 \times 0.85 + 61.8)^2 + (6350 \times 0.527 + 123.6)^2}$$

$$= 6468.787 \text{ volts.}$$

$$\text{Line voltage} = \sqrt{3}E_P = \sqrt{3} \times 6469 = 11204\,V$$

Fig 2



The voltage regulation of an alternator: The voltage regulation of an alternator is defined as the rise in voltage when the load is reduced from the full rated value to zero, with the speed and field current remaining constant. It is normally expressed as a percentage of the full load voltage.

$$\% \text{ of voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where V_{NL} - no load voltage of the alternator

V_{FL} - full load voltage of the alternator

The percentage regulation varies considerably, depending on the power factor of the load, and as we have seen for leading P.F. the terminal voltage increases with load, and for lagging P.F. the terminal voltage falls with the load.

Example: When the load is removed from an AC generator, its terminal voltage rises from 480V at full load to 660V at no load. Calculate the voltage regulation.

$$\% \text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$\frac{660 - 480}{480} \times 100 = 37.5\%$$

Parallel operation and synchronisation of three phase alternators - brushless alternator

Objectives: At the end of this lesson you shall be able to
- **state the necessity and conditions for paralleling of alternators**
- **explain the methods of paralleling two 3 phase alternators**
- **state the effect of changes in field excitation and speed on the division of load between parallel operation.**

Necessity for paralleling of two alternators : Whenever the power demand of the load circuit is greater than the power output of a single alternator, the two alternators to be connected in parallel

Conditions for paralleling (synchronising) of two 3 phase alternators

- The phase sequence of both 3 phase alternators must be same. It can be checked by using phase sequence meters
- The output voltages of the two 3 phase alternators must be same.
- The frequency of both the alternators must be same

Dark lamp method : The following describes the method of synchronizing two alternators using the dark lamp method.

Fig 1 illustrates a circuit used to parallel two three-phase alternators. Alternator 2 is connected to the load circuit. Alternator 1 is to be paralleled with alternator 2 Three lamps rated at double the output voltage to the load are connected between alternator 2 and the load circuit as shown. When both machines are operating, one of two effects will be observed:

1 The three lamps will light and go out in unison at a rate which depends on the difference in frequency between the two alternators.

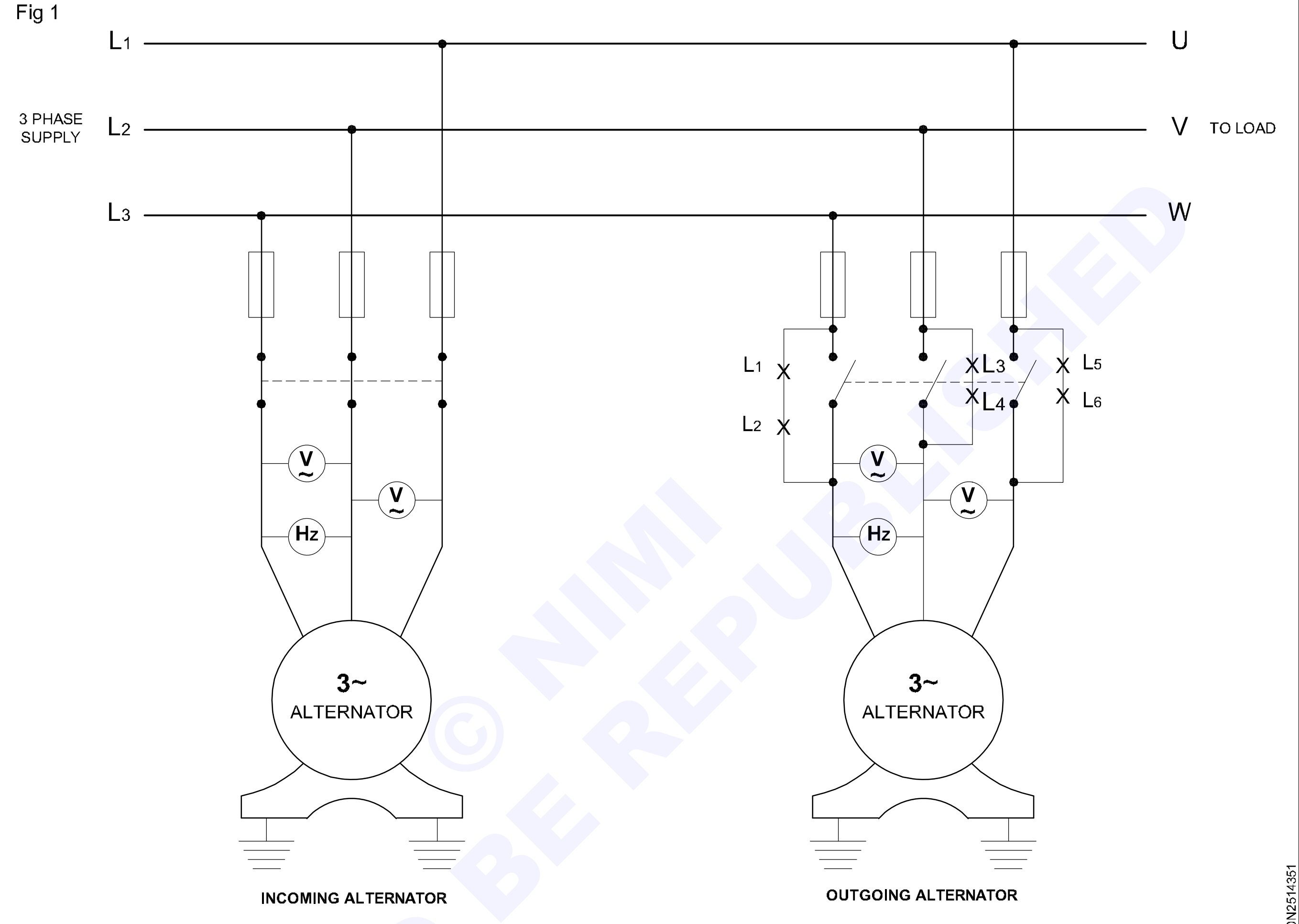
2 The three lamps will light and go out at a rate which depends on the difference in frequency between the two machines, but not in unison. In this case, the machines are not connected in the proper phase sequence and are said to be out of phase. To correct this, it's necessary to interchange any two leads to alternator 1. The machines are not paralleled until all lamps light and go out in unison. The lamp method is shown for greater simplicity of operation.

By making slight adjustments in the speed of alternator 1 the frequency of the machines can be equalized so that the synchronizing lamps will light and go out at the lowest possible rate. When the three lamps are out, the instantaneous electrical polarity of the three leads from 1 is the same as that of 2 At this instant, the voltage of 1 is equal to and in phase with that of 2 Now the paralleling switch can be closed at the middle period of the darkness of the lamps so that both alternators supply power to the load. The two alternators are in synchronism, according to the three dark method.

The three dark method has certain disadvantages and is seldom used. A large voltage may be present across an incandescent lamp even though it's dark (burned out). As a result, it's possible to close the paralleling connection while there is still a large voltage and phase difference between the machines. For small capacity machines operating at low speed, the phase difference may not affect the operation of the machines. However, when large capacity units having low armature reactance operate at high speed, a considerable amount of damage may result if there is a large phase difference and an attempt is made to parallel the units.

Two bright, one dark method (Dark and bright lamp method) : Another method of synchronizing alternators is the two bright, one dark method. In this method, any two connections from the synchronizing lamps are crossed after the alternators are connected and tested for the proper conditions for paralleling phase rotation. (The alternators are tested by the three dark method.) Fig 2 shows the connections for establishing the proper phase rotation by the three dark method. Fig 2 shows the lamp connections required to synchronize the alternator by the two bright, one dark method.

Fig 1



PARALLEL OPERATION OF 3 PHASE ALTERNATOR BY DARK LAMP METHOD

When the alternators are synchronized, lamps 1 and 2 are bright and lamp 3 is dark. Since two of the lamps are becoming brighter as one is dimming, it's easier to determine the moment when the paralleling switch can be closed. Furthermore, by observing the sequence of lamp brightness, it's possible to tell whether the speed of the alternator being synchronized is too slow or too fast and can be connected it.

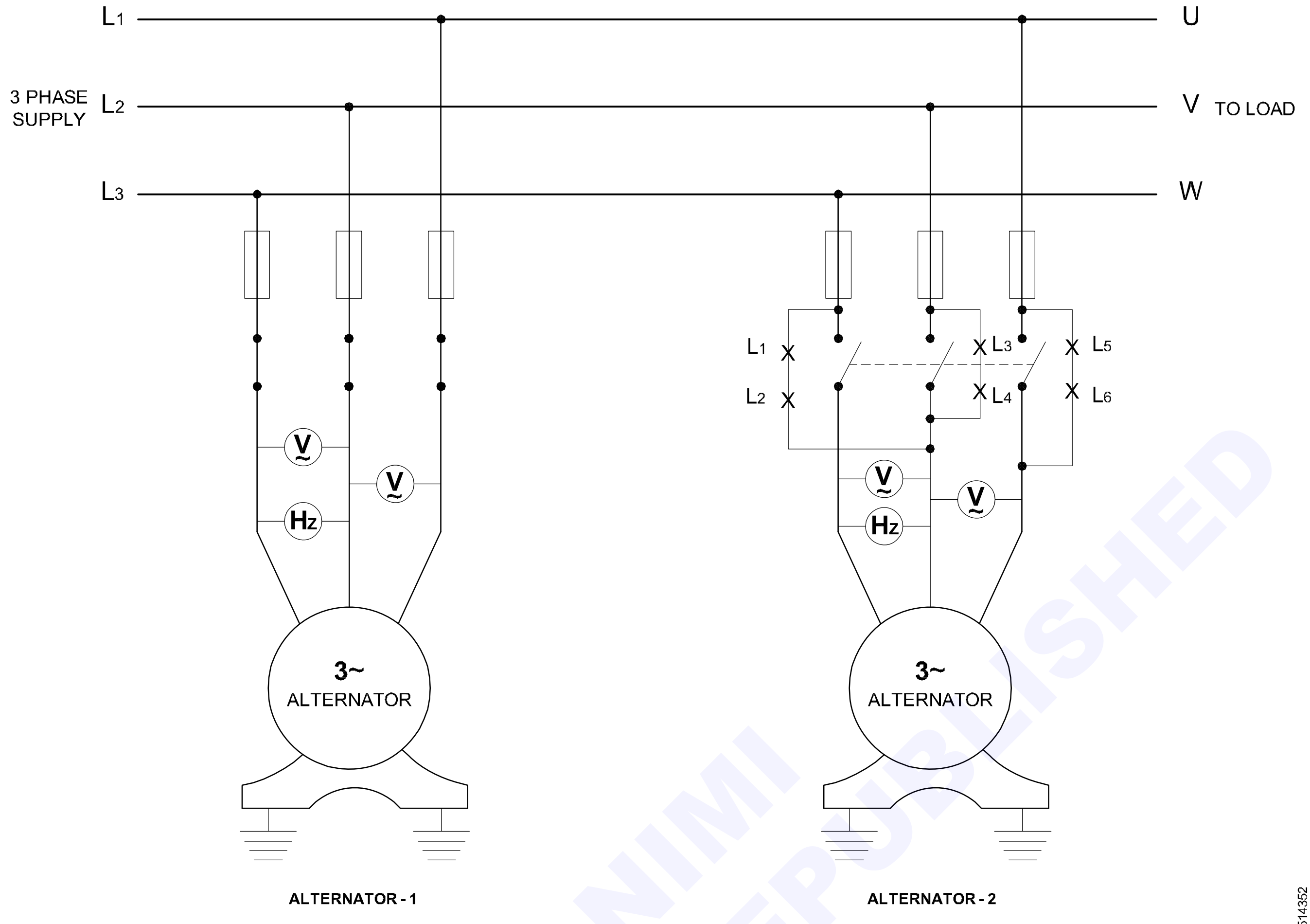
At the moment when the two lamps are full bright and one lamp is full dark, the synchronizing switch can be closed.

Now the both alternator are synchronized and share the load according to their ratings.

Effect of changing the field excitation and power factor

A change in the excitation of an alternator running in parallel with others effects only its KVA output it does not effect the KW output. A change in the excitation thus effects only the power factor of its output.

Fig 2



DARK & BRIGHT LAMP METHOD

Synchronous motor

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of synchronous motor**
- **explain the constructional details of synchronous motor**
- **state the different methods of starting a synchronous motor**
- **compare the features of synchronous motor and induction motor**
- **state the applications of synchronous motors.**

Synchronous motor

An alternator which runs as a motor is called as synchronous motor. 3-phase AC supply is required for the AC winding and suitable DC voltage is required for the field winding excitation. The synchronous motors are not self starting.

Working principle

When the stator winding of a three-phase synchronous motor is connected to a three-phase supply, a rotating field is set up in the machine. If the rotor is then started in the direction of rotation of the rotating field, the north pole of the rotating field draws the south pole of the rotor with it, and the south pole of the rotating field draws the north pole of the rotor. The rotor continues to turn at a speed of rotation which can be calculated from the familiar formula, Ns = 120f/p. It turns synchronously with the rotating field. The machine is now working as a motor.

Construction

In construction, synchronous motors are almost identical with the corresponding alternator, and consist essentially of two elements.

1 Stator (armature)

2 Rotor (field)

A synchronous motor may have either a revolving armature or a revolving field, although most synchronous motors are of the revolving field type. The stationary armature which is wound for the same number of poles as rotor is attached to the stator frame while the field magnets are attached to a frame which revolves with the shaft.

The field coils are excited by direct currents, either from a small DC generator (usually mounted on the same shaft as the motor and called as an exciter), or from other DC source. (Fig 1 & 2)

Methods of starting a synchronous motor

1 By using a pony motor

2 By using damper windings

3 By synchronisation

1 By using a pony motor

A three-phase current is fed to the stator winding of three-phase synchronous machine and its rotor is started by a pony (starting) motor, having same number of poles as that of synchronous motor. The small induction motor coupled to the synchronous machine for starting purpose is called the pony motor. The pony motor brings the motor very close to the synchronous speed, then the DC is supplied to the field and the switch of the pony motor is switched 'off'. Then the motor pulls itself to the synchronous speed.

Fig 1

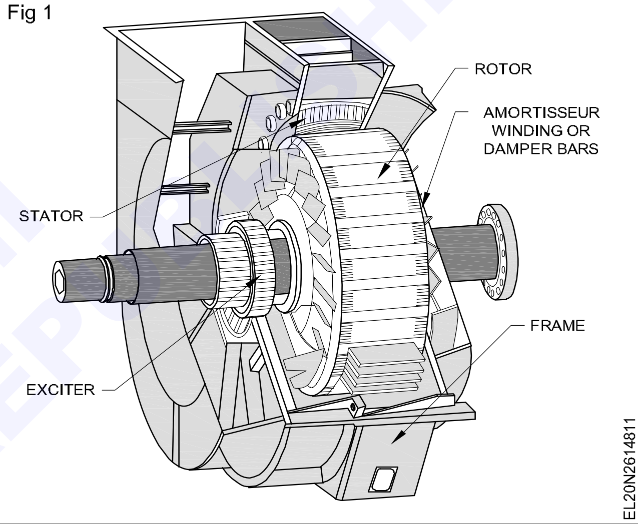
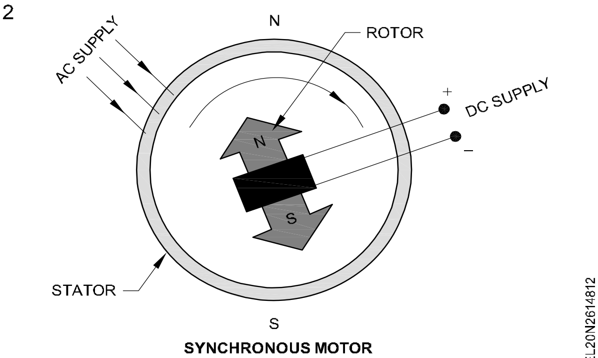


Fig 2



2 By using damper windings

The damper winding is just like squirrel cage winding consisting of copper embedded in the pole shoe and short circuited at both sides.

Action of damper winding at start

While starting a synchronous motor set up a rotating magnetic field that cuts the cage (damper) winding on the field system (rotor) and induces current in it. A torque is developed and the motor runs to a speed a little less than that of synchronous speed as an induction motor. The DC excitation is then switched on and definite poles on the rotor are set up. Now the two sets of poles suddenly lock each other by which the motor pulls into synchronous speed.

While starting a synchronous motor provided with damper windings, first the main field windings is short circuited and AC supply is switched on to stator terminals through suitable starter. The motor starts up and when a steady speed is reached DC excitation is applied after removing the short on the field winding. If the excitation is sufficient the machine will be pulled into synchronism.

3 By synchronisation

Initially the synchronisation motor is run as an alternator and it is synchronised with the main supply bus by following one of the synchronisation methods. After synchronisation the prime mover is disconnected. Now the alternator, ie the synchronous motor continues to run at synchronous speed by drawing power from supply mains.

Comparison of Synchronous and Induction motor

	Aspects	Synchronous motor	Induction motor
1	Speed	Synchronous speed constant is independent of load condition.	Less than synchronous speed. Decreases with increasing load.
2	Power factor	Operates at all power factors whether lagging or leading.	Operates at only lagging power factor.
3	Efficiency	Very good	Good
4	Cost	Costlier	Cheaper
5	Starting	Not self-starting	Self-starting
6	Speed control	No question	Can be controlled to small units.
7	Application	Used for mechanical load and also to improve power factor as synchronous condenser.	Limited to supply of mechanical load.

Application

Synchronous motors are employed exclusively as power factor correction devices, they are termed as synchronous condenser, because the effect on the power system is the same as that of a static capacitor which also produces a leading current.

1 Induction motors of all types particularly when they are under loaded

2 Power transformers and voltage regulators

3 Arc welders

4 Induction furnaces and heating coils

5 Choke coils and magnetic systems and

6 Fluorescent and discharge lamps, neon signs, etc.

Causes of low power factor

> **The principle cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power depends on the inductance and capacitance of the apparatus.**

The disadvantages of low power factor are as follows

1 Overloading of cables and transformer

2 Decreased line voltage at point of application

3 Inefficient operation of plant and

4 Penal power rates

The advantages of increasing power factor are as follows

1 Reduction in the current

2 Reduction in power cost

3 Reduced losses in the transformers and cables

4 Lower loading of transformers, switch gears, cables etc.

5 Increased capability of the Power system (additional load can be met without additional equipment)

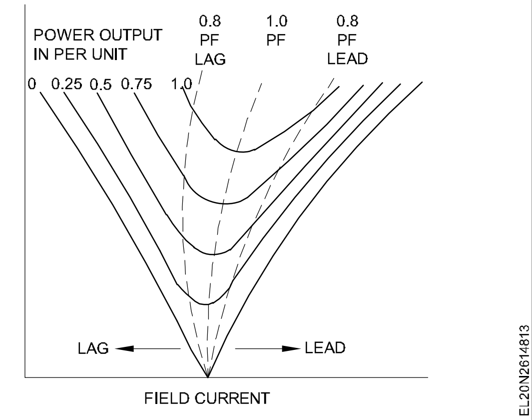
6 Improvement in voltage conditions and apparatus performance and

7 Reduction in voltage dips caused by welding and similar equipment

V Curves of synchronouos machines

V-Curve of a synchronous machine shows the relation between the armature current and excitation current, when the load and input voltage to the machine is constant. At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make VIcosθ constant. Variation of armature current with excitation are called 'V' curves (Fig 3).

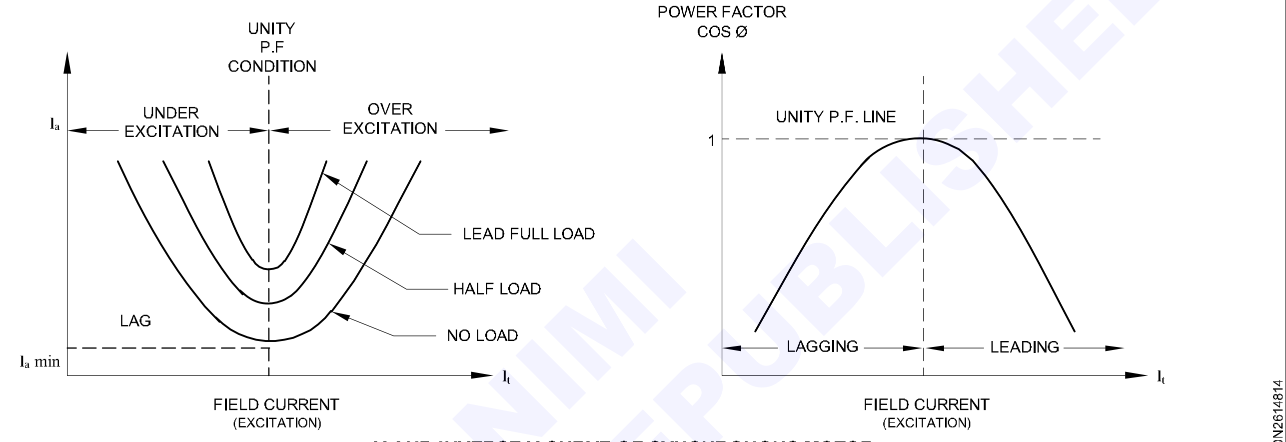
Fig 3



The Fig 4 shows V and inverse V curves of synchronous motor.

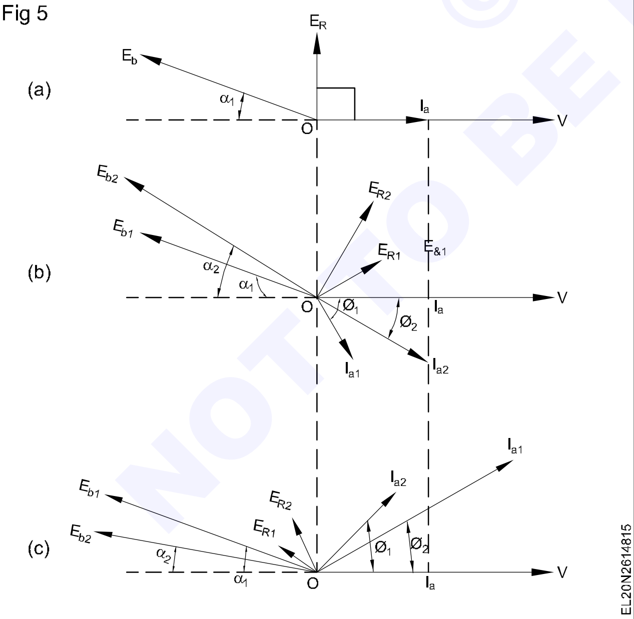
Effect of Changing Excitation on Constant load : As shown in Fig. (5a), suppose a synchronous motor is operating with normal excitation (E_b = V) at unity p.f. with a given load. If R_a is negligible as compared to X_S, then I_a lags E_R by 90° and is in phase with V because p.f. is unity. The armature is drawing a power of V.I_a per phase which is enough to meet the mechanical load on the motor. Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant

Fig 4



V AND INVERSE V CURVE OF SYNCHRONOUS MOTOR

Fig 5



a Excitation Decreased

As shown in Fig (5b), suppose due to decrease in excitation, back e.m.f. is reduced to E_{b1} at the same load angle α_1. The resultant voltage E_{R1} causes a lagging armature current I_{a1} to flow. Even though I_{a1} is larger than I_a in magnitude it is capable of producing necessary power V.I_a for carrying the constant load because I_{a1} cos ϕ_1 component is less than I_a so that V.Ia_1 cos ϕ_1< V.I_a.

Hence, it becomes necessary for load angle to increase from α_1 to α_2. It increases back e.m.f. from E_{b1} to E_{b2} which, in turn, increases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current increases to I_{a2} whose in-phase component produces enough power (VI_{a2} cos ϕ_2) to meet the constant load on the motor.

b Excitation Increased

The effect of increasing field excitation is shown in Fig 5c where increased E_{b1} is shown at the original load angle α_1. The resultant voltage E_{R1} cause a leading current I_{a1} whose in-phase component is larger than I_a. Hence, armature develops more power than the load on the motor. Accordingly, load angle decrease from α_1 to α_2 which decreases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current decreases from I_{a1} to I_{a2} whose in-phase component I_{a2} cos ϕ_2 = I_a. In that case, armature develops power sufficient to carry the constant load on the motor.

Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load anlge only.

Methods of improvement of power factor

The power factor can be improved by following methods

1 Static capacitor or capacitor bank

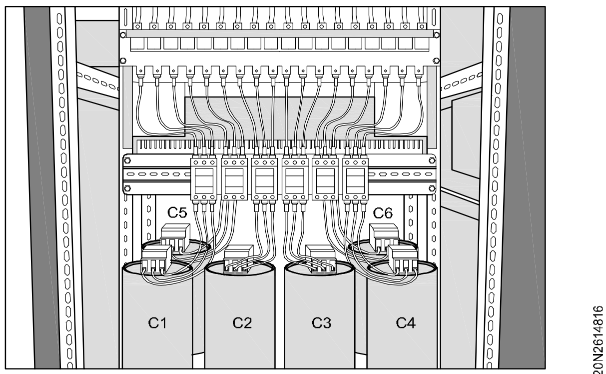
2 Synchronous motor

Capacitor bank

A capacitor bank is a group of several capacitors that are of same specifications connected in parallel to form a capacitor bank that store electrical energy. The capacitor bank so formed in then used to correct lagging power factor into leading power factor or phase shift in an AC supply as shown in Fig 6.

C1, C2, C3, C4, C5, C6 = capacitors

Fig 6



Different Torques of a Synchronous Motor

Various torques associated with a synchronous motor are as follows:

1 starting torque

2 running torque

3 pull-in torque and

4 pull-out torque

a Starting Torque

It is the torque (or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

b Running Torque

As its name indicates, it is the torque developed by the motor under running conditions. It is the driven machine. The peak horsepower determine the maximum torque that would be required by the driven machine. The motor must have a break-down or a maximum running torque greater than this value in order to avoid stalling.

c Pull-in Torque

A synchronous motor is stated as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously - rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque.

d Pull-out- Torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque.

Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90° (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.

MG set and rotary converter

Objectives: At the end of this lesson you shall be able to
- **list the advantages of direct current over alternating current**
- **list the methods of converting AC to DC**
- **state the advantages and disadvantages of MG-set**
- **describe the rotary converter construction and its working.**

The AC system has been adopted universally for the generation, transmission and distribution of electric power. It is more economical than a DC system of generation, transmission and distribution. There are applications where DC is either essential or more advantageous over AC.

DC is essential in the following applications.

- Electrochemical process such as electroplating, electro-refining etc.
- Storage battery charging.
- Arc lamp for search light and cinema projectors.

Direct current is more advantageous in the following applications.

- Traction purposes - DC series motor.
- Operating telephones, relays, time switches.
- Rolling mills, paper mills, elevators where fine speed control, frequent starting against heavy torque and rotation in both directions are required, DC motors are more suitable.

The conversion of AC to DC has become a necessity due to the above reasons.

Methods : The methods of conversion of AC to DC

- Motor-generator set
- Rotary converter
- Mercury arc rectifier
- Metal rectifiers
- Semi-conductor diodes and SCR

Out of the above five the motor generator sets and semi-conductor rectifiers are now mostly in use. The other types have become obsolete for obvious reasons.

Motor generator set : It consists of a 3-phase AC motor directly coupled to a DC generator. In the case of larger units, the AC motor is invariably a synchronous motor and the DC generator is usually compound.

Advantages

1 The DC output voltage is practically constant. The output (DC) voltage is not affected by changes in AC supply voltage.

2 DC output voltage can be easily controlled by the shunt field regulator.

3 The M.G set can also be used for power factor correction, where synchronous motor is used for driving the generator.

Disadvantages

1 It has a comparatively low efficiency.

2 It requires more floor space.

Rotary or synchronous converter

A rotary converter is used when a large DC power is required. It is a single machine with one armature and one field. It combines the function of a synchronous motor and a DC generator. It receives alternating current through a set of slip rings mounted on one side of the armature rotating synchronously (N_s = 120 f/P) and delivers direct current from the opposite end through the commutator and brushes.

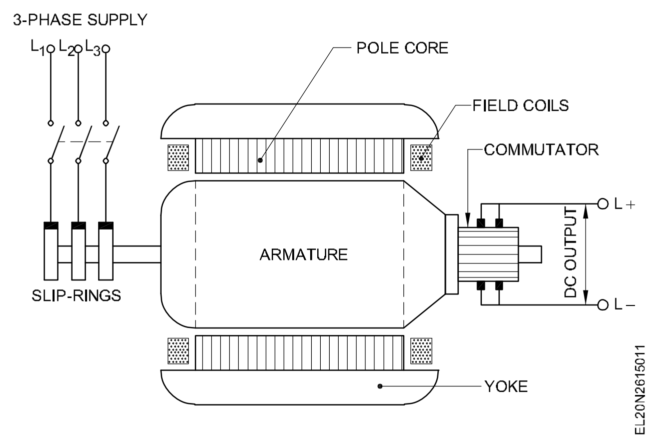
Construction : In general construction and design, a rotary converter is more or less like a DC machine. It has interpoles for better commutation. Its commutator is larger than that of a DC generator of the same size because it has to handle a larger amount of power.

The only added feature are -

- a set of slip-rings mounted at the end opposite to the commutator end
- dampers in the pole faces as in a synchronous motor.

A simple sketch illustrating the main parts of a rotary (synchronous) converter is shown in Fig 1.

Fig 1



The fact that the emf induced in the armature conductors of a DC generator is alternating and that it becomes direct (unidirectional) only due to the rectifying action of the commutator, the slip-rings are to be connected to some suitable points on the armature winding to use this machine as an alternator.

The rotary converter armature is mostly lap wound. The number of parallel paths in the armature is equal to the number of poles. Therefore the number of equi-potential points on the armature is equal to the number of pairs of poles. The number of tappings taken to each slip-ring is, therefore, equal to the number of pairs of poles. For a 3-phase lap wound rotary converter, it is essential that the number of armature conductors per pole should be divisible by 3.

Operation : In its normal role, the machine is connected to a suitable AC supply through the slip-rings and it delivers direct current at the commutator. In this application the machine runs as a synchronous motor receiving AC power from the slip-ring side and as viewed from the commutator end, it runs as a DC generator delivering DC power.

Converter aspects for comparison	M.G.Set	Rotary converter
Machinery	Two machines i.e. one AC another one DC generator	Single machine
Cost	Very costly	Costly
Noise	Noisy	Noisy
Efficiency	Very low because of two rotating machines	Low
Maintenance cost	High	High
Overloading capacity	Cannot be over loaded	Cannot be overloaded
Power factor of AC factor	Low power factor	Good power
Attention during its operation	Less attention required	No attention required
Space required	Very high	Low

Maintenance of MG set

Objective: At the end of this exercise you shall be able to
- **list out the points to be considered for maintenance of MG set.**

The MG set must be maintained by inspecting electrically and mechanically. The following points to be considered while carrying out maintenance.

Electrical inspection list

- General cleaning of all electrical components and control panels
- Check/rectify motor insulation resistance by megger
- Check/rectify earth wiring
- Check/rectify main switch fuses
- Check/rectify stator, brushes etc.
- Check/rectify bearings of motor, rotating parts and use oil grease for proper lubrication
- Check/rectify/check starting panel
- Check/rectify over load relays
- Check/rectify loose connections and tighten them
- Replace damaged flexible conductors and cables
- Check/rectify the control system
- Replace the carburized non operative contactor if necessary.

Carry out the maintenance work in MG set by referring the mechanical inspection list and lubrication instruction given below

Mechanical inspection list

- Clean thoroughly and do visual inspection
- Check/rectify motor couplings and bearings
- Check for tightness of coupling, checking formulation both,
- Checking of pipeline flanger
- Check/rectify machine for functional operation and verify with the operator
- Lubrication, Maintenance prints
- Check/rectify the bearings for the lubrication
- Use oil gun/grease to lubricate the same.

A separate register is to be maintained by the maintenance authority to keep the records for each maintenance on all working days.

Attend the breakdown maintenance of mechanical and electrical nature, during the operation of the MG set.

Resistors, Colour code, types and characteristics

Objectives: At the end of this lesson you shall be able to
• **explain construction, types, colour coding and application of resistors in circuits.**

Resistors: These are the most common passive component used in electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from 0.1 W. to hundreds of Watts.

There are four types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

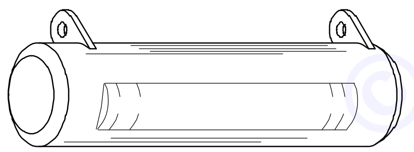
3 Metal film resistors

4 Carbon film resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc. Fig 1 shows this type of resistor.

Fig 1

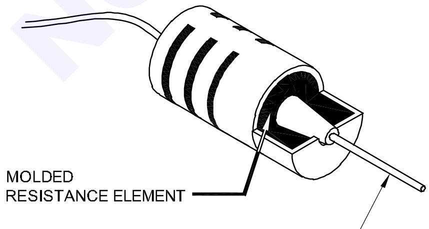


WIRE-WOUND FIXED RESISTOR

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 2 shows the construction of carbon composition resistor.

Fig 2



CARBON COMPOSITION RESISTOR

Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5 and 2 watts.

3 Metal film resistors (Fig 3)

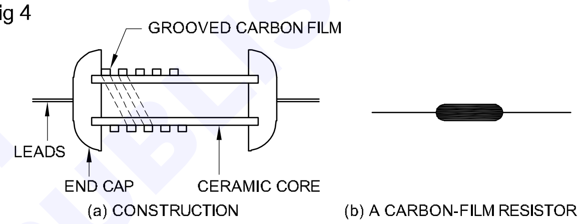
Fig 3

METAL FILM RESISTOR

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 4)

Fig 4



CARBON – FILM RESISTOR

In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to few Meg ohm and up to 2W and can work from 85°C to 155°C.

Specification of resistors: Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90 Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

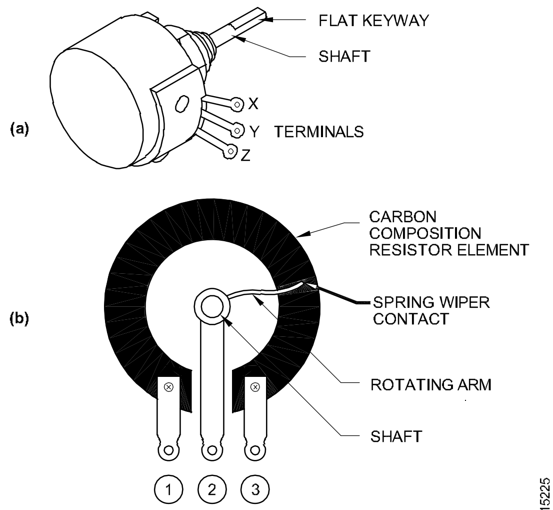
1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 2 to 4)

Variable resistors (Fig 5) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentiometer resistors or simply as a potentiometers.

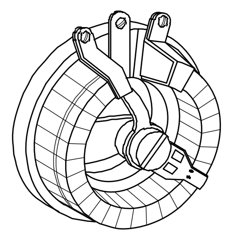
Fig 5



VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

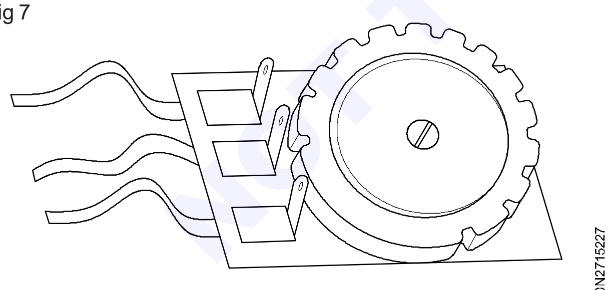
It is provided with 3 terminals as shown in Fig 5 and 6. They are available with carbon tracks (Fig 6) and wire wound (Fig 6) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 7).

Fig 6



WIRE-WOUND VARIABLE RESISTOR

Fig 7



TRIMMER RESISTOR

Resistance depends upon temperature, voltage, light: Special resistors are also produced whose resistance varies with temperature, voltage, and light.

Light dependent resistor (LDR): The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

Resistance and tolerance value of colour coded resistors.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS:8186.

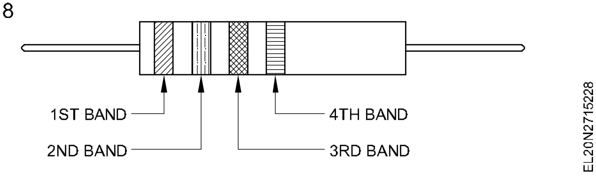
Table 1

Values to two significant figures and tolerances corresponding to colours

Colour	First Band/ Dot	Second Band/ Dot	Third Band/ Dot	Fourth Band/ Dot
	First Figure	Second Figure	Multiplier	Tolerance
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^{2}	± 2 %
Orange	3	3	10^{3}	—
Yellow	4	4	10^{4}	—
Green	5	5	10^{5}	—
Blue	6	6	10^{6}	—
Violet	7	7	10^{7}	—
Grey	8	8	10^{8}	—
White	9	9	10^{9}	—
None	—	—	—	± 20 %

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig 8.

Fig 8



The first band shall be the one nearest to one end of the component resistor. The second, third and four colourbands are shown in Fig 8.

The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier. The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Violet, Orange and Gold, then the value of the resistor is 27,000 ohms with +5% tolerance.

First colour	Second colour	Third colour	Fourth colour
Red	Violet	Orange	Gold
2	7	1000(10^3)	±5%

Tolerance value: The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

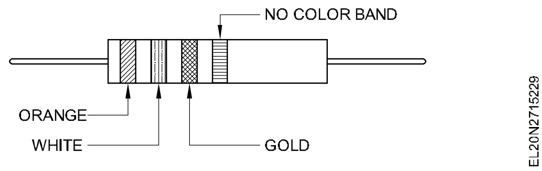
For less than ten ohms, the third band will be either golden or silver.

The colours are,

Gold -	10^{-1}	=	1/10 = 0.1
Silver -	10^{-2}	=	1/100 = 0.01

Example (Refer Fig 9)

Fig 9



Colour of 1st Band	Colour of 2nd Band	Colour of 3rd Band
Orange	White	Gold
3	9	1/10

thus, the value of resistor is 39/10 or 3.9 ohms.

Large value resistances are expressed in kilo ohms and megohms. Letter 'k' stands for kilo and M stands for mega. One kilo equals 1000 (10^3) and one mega equals 1000000 (10^6). The resistance values are expressed as

1000 ohms	=	1 k
1800 ohms	=	1k 8
100 ohms	=	0.1 k
10000 ohms	=	0.1 M
1500000 ohms	=	1 M 5.

Semiconductor theory-Active and passive components

Objectives: At the end of this lesson you shall be able to
- **explain atom conductor, semiconductor, insulator and atomic structure**
- **state the function of N and P type semiconductor, PN junction, depletion region**
- **state the coding of semiconductor devices and its meaning**
- **explain active and passive components, symbols - uses.**

Atom

The very tiny fundamental unit of an element which is capable of independent existence is the atom. An atom of any element consists of a central core called Nucleus. A number of small particles called electrons move around the central core.

The nucleus contains protons and neutrons. A proton in the nucleus possess a positive electrical charge. An electron in an atom possess negative electrical charge. In normal state, the atom is electrically neutral, that is the number of electrons is equal to the number of protons in the nucleus.

Difference between conductors insulators and semi conductors: We are familiar with conducting and insulating materials. Conducting materials are good conductors of electricity. Insulating materials are bad conductors of electricity. There is another group of materials called as semiconductors, such as germanium and silicon. These are neither good conductors nor good insulators.

The conductors on valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in semi conductors the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semi conductor materials.

Semi conductors - Atomic structure: Germanium (Ge) and silicon (Si) are examples of semi conductors. Fig 1a shows a germanium atom. In the centre is a nucleus with 32 protons. 32 revolving electrons are distributed themselves in different orbits. There are 2 electrons in the first orbit, 8 electrons in the second orbit, and 18 electrons in the third orbit. The fourth orbit is the outer or valence orbit which contains 4 electrons.

Fig 1b shows a silicon atom. It has 14 protons in the nucleus and 14 electrons in 3 orbits. There are 2 electrons in the first orbit and 8 in the second orbit. The remaining 4 electrons are in the outer or valence orbit.

In semiconductor materials, the atoms are arranged in an orderly pattern called a crystal lattice structure. If a pure silicon crystal is examined we find that the four electrons in the outer (valence) shell of an atom is shared by the neighbouring atoms as in Fig 2.

The union of atoms sharing the valence electrons is called a **covalent band**. That means a valence electron being shared by two adjacent atoms. Each atom appears to have a full outer shell of eight electrons.

Fig 1

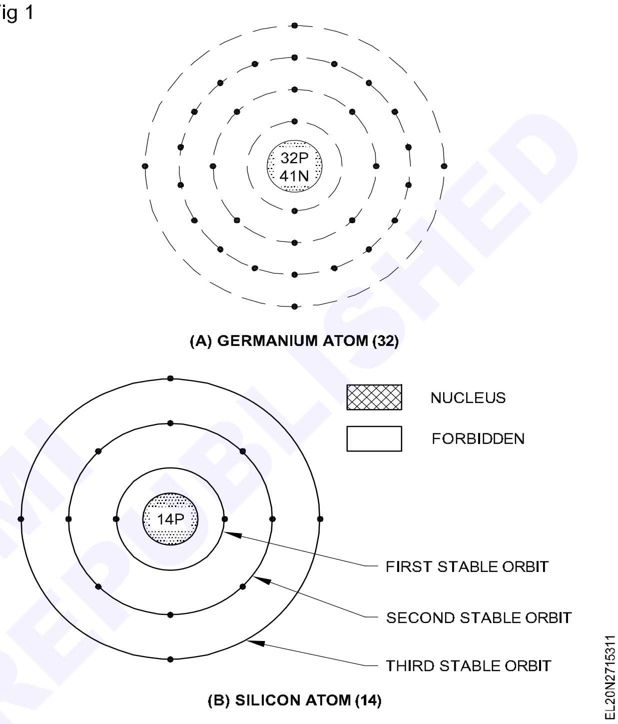
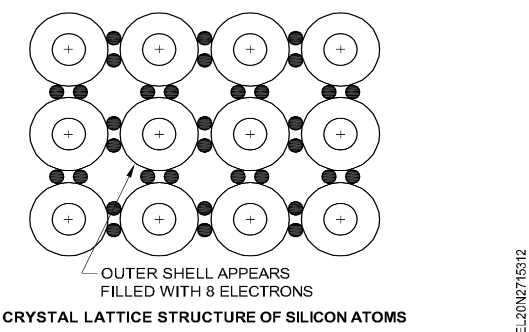


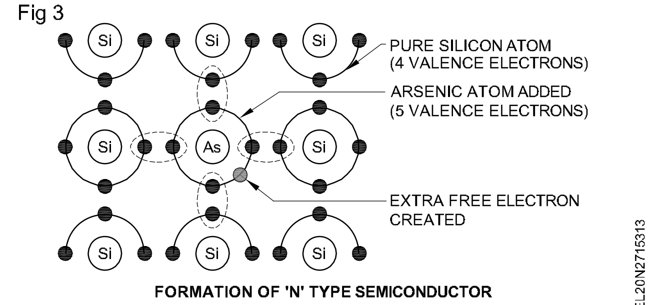
Fig 2



Types of semiconductors : A pure semiconductor is called an intrinsic semiconductor. For example, a silicon crystal is an intrinsic semiconductor because every atom in the crystal is a silicon atom. One way to increase conductivity in a semiconductor is by **'doping'**. This means adding impurity atoms to an intrinsic semiconductor. The doped semi-conductor is known as an extrinsic semiconductor.

N - type semiconductor : A semiconductor with excess of electrons is called N-type. To obtain excess free electrons the element doped with the semiconductor material is arsenic, or antimony or phosphorus. Each of these atoms has five electrons in its outer orbit. (Fig 3)

Fig 3



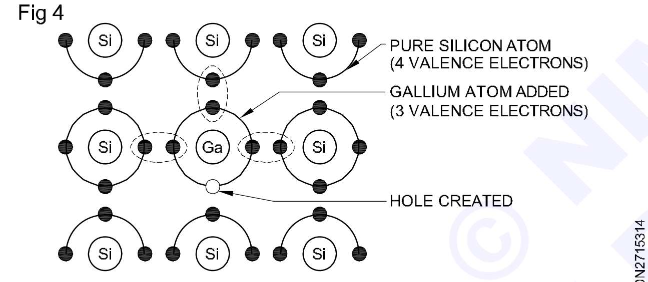
FORMATION OF 'N' TYPE SEMICONDUCTOR

Because the outer orbits of the atoms can hold eight electrons, no hole is available for the fifth electron in the arsenic atoms to move into. It, therefore, becomes a free electron. The number of such free electrons is controlled by the amount of arsenic added to the crystals.

In N-type, the free electrons are called the **majority** carriers, and the holes **minority** carriers.

P-type semiconductor : To obtain more holes, a pure silicon crystal is doped with elements such as aluminum or boron or gallium. The atoms of each of these elements have three electrons only in their outer orbit. Adding gallium to pure silicon crystals allows the atoms of the two elements to share seven electrons. (Fig 4)

Fig 4

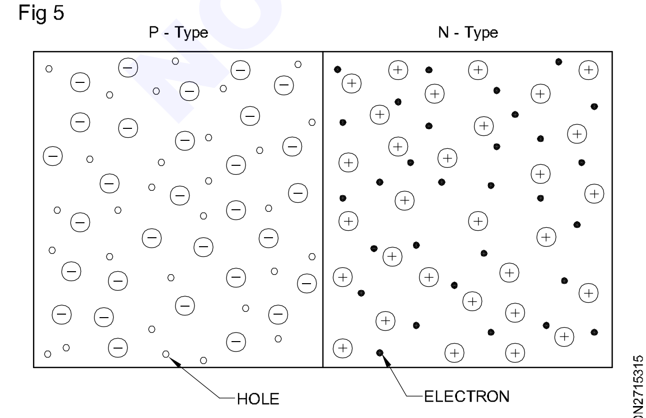


FORMATION OF 'P' TYPE SEMICONDUCTOR

A hole is created in the place of the eighth electron. Now that the number of holes exceeds the number of free electrons the substance becomes 'P' type material. The holes in P-type are the **majority** carriers, and the free electrons are the minority carriers.

PN Junction : A PN junction is formed by combining P and N type materials. The surface where they meet is called the PN junction. A PN junction is illustrated in Fig 5.

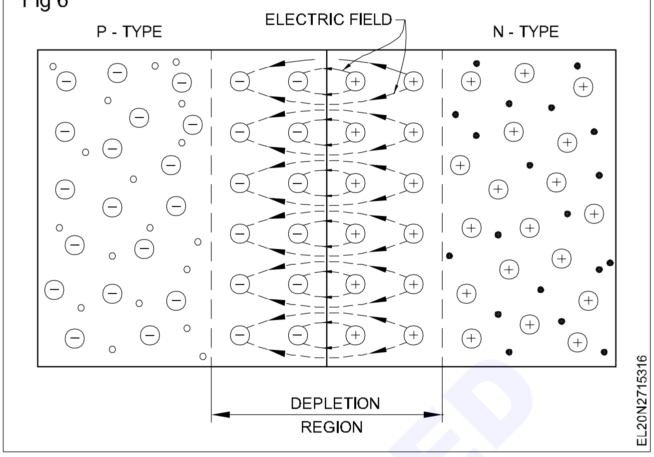
Fig 5



P – N JUNCTION

The ions in the crystal structure are fixed and cannot move. Thus, a layer of fixed charges is formed on the two sides of the junctions. This is shown in Fig 6.

Fig 6



There is a layer of positively charged ions on the N-side and on the P-side of the junction there is a layer of negatively charged ions. An electric field is created across the junction between the oppositely charged ions. This is called a junction field. The junction field is also known as 'barrier'. The distance between the sides of the barrier is the 'width' of the barrier.

Depletion region : The carrier in the vicinity of the junction are involved in forming the junction. Once the junction field is established, no carriers can move through the junction. Hence the junction field is called 'depletion region' or 'space charge region'. This layer is called the depletion layer, because there are neither free electrons nor holes present. This depletion region prevents further movement of electrons from the N-material to the P-material and thus an equilibrium is reached.

The intensity of the field is known as 'barrier height' or 'potential' hill'. The internal voltage set up due to positive and negative ions at the junction is called barrier potential. If any more electrons have to go over from the N-side to P-side, they have to over come this barrier potential. This means, only when the electrons on the N-side are supplied with energy to overcome the barrier potential they can go over to the P-side.

In order to cancel the barrier potential and the electrons to cross over a potential difference of 0.7 V is required for a silicon diode and 0.3 V for a germanium diode. The barrier voltage is more for silicon because its lower atomic number allows more stability in the covalent bonds. The barrier potential decreases at higher temperatures.

Old system : Some earlier semiconductor diodes and transistors have type numbers, consisting of two or three letters followed by group of one, two or three figures. The first letter is always 'O', indicating a semi-conductor device.

The second (and third) letter(s) indicate the general class of the device.

A – diode or rectifier

AP – photo-diode

AZ – voltage regulator diode

C – transistor

CP – phototransistor

The group of figures in a serial number indicating a particular design or development.

Present system : This system consists of two letters followed by a serial number. The serial number may consists of three figures of one letter and two figures depending on the main application of the device.

The first letter indicates the semiconductor material used.

A Germanium

B Silicon

C Compound materials such as gallium arsenide

R Compound materials such as cadmium sulphide

The second letter indicates the general function of the device.

A detection diode, high speed diode, mixer diode

B variable capacitance diode

C transistor for I.F. applications (not power types)

D power transistor for A.F. applications (not power types)

E tunnel diode

F transistor for A.F. applications (not power types)

G multiple of dissimilar devices, miscellaneous devices

L power transistor for a.f. applications

N photo-coupler

P radiation sensitive device such as photo-diode, photo-transistor, photo-conducive cell, or radiation detector diode

Q radiation generating device such as light-emitting diode

R controlling and switching devices (e.g. thyristor) having a specified breakdown characteristic (not power types)

S transistor for switching applications (not power types)

T controlling and switching power device (e.g. thyristor) having a specified breakdown characteristic.

U power transistor for switching applications

X multiplier diode such as varactor or step recovery diode

Y rectifier diode, booster diode, efficiency diode

Z voltage reference or voltage regulator diode, transient suppressor diode.

The remainder of the type number is a serial number indicating a particular design or development, and is in one of the following two groups.

a Devices intended primarily for use in consumer applications (radio and television receivers, audio-amplifiers, tape recorders, domestic appliances, etc.) The **serial number** consists of three figures.

b Devices intended mainly for applications other than (a) e.g. industrial, professional and transmitting equipments.

The serial number consists of one letter (Z,Y,X,W etc) followed by two numbers (digits)

The International System follows letters 1N, 2N, 3N etc followed by four numbers.

1N indicates single junction

2N indicates two junction

3N indicates three junctions.

The number indicates internationally agreed manufacturer's code e.g. 1N 4007, 2N 3055, 3N 2000.

Again, manufacturers use their own codes for semiconductor devices. Manufacturers in Japan use 2SA, 2SB, 2SC, 2SD etc. followed by a group of numbers e.g. 2SC 1061, 2SA 934, 2SB 77. Indian manufacturers have their own codes too.

Passive and active electronic components

Introduction: The Components used in electronic circuits can broadly grouped under two headings.

– passive components

– active components

Passive components: Components like resistors, capacitors, and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as that of active components, without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuits laws such as ohm's law, Kirchoff's Laws etc.,

Resistors: The components whose purpose to introduce resistance in the circuit is called as resistors. Other details of resistors are dealt in earlier lessons.

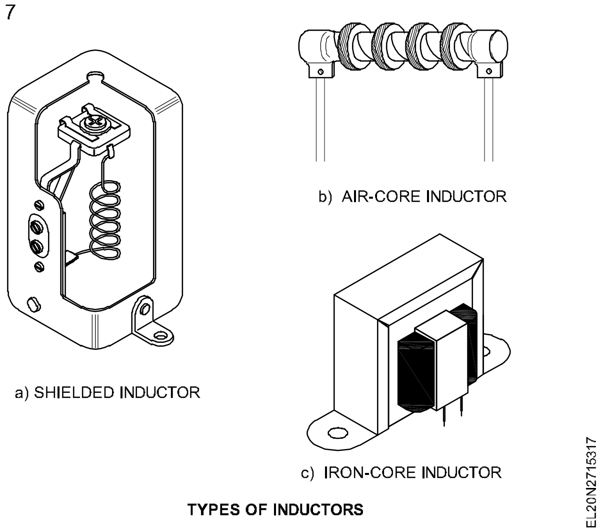
Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (μF), Nanofarad (nF) and Picofarads (pF).

The colour coding of capacitors and resistors are same. Where as, in the case of fixed capacitors, the colour coded unit shall be in Picofarads.

For letter coding, incase of capacitor, the letter 'p', 'n', 'μ' shall be used as multipliers. Where $p = 10^{-12}$, $n= 10^{-9}$ and $\mu = 10^{-6}$ farads, and letter code for tolerance on capacitor is the same as in resistor.

Inductor: The ability of the conductor to induce voltage in itself, when the current changes in it is called as self inductance (or) simply inductance. A coil introduced in a circuit to have inductance is called as inductor. Different type of inductors are shown in Fig 7. The unit of inductance is "Henry". Commercially a coil may have inductance in Millihenry (10^{-3}H), or in Microhenry (10^{-6}H).

Fig 7



TYPES OF INDUCTORS

While specifying the inductance the following factors to be considered

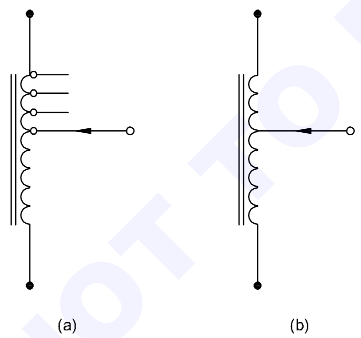
- nominal value of inductance in Henry / Millihenry / Microhenry.
- tolerance in percentage (±5/10/20%)
- type of winding like single layer, double layer, multilayer and pie (p) etc.
- type of core like air core, iron core, ferrite core
- type of application like audio frequency (AF), Radio frequency (RF) coupling coil, filter coil etc.,

In an electronic circuit some time, it is also required to vary the inductance.

The inductance of a coil can be varied by:-

- providing tapped inductive coil, as in Fig 8 or

Fig 8



- adjusting the core of a coil as in Fig 9.

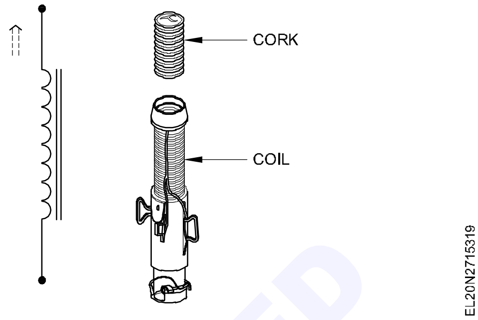
However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Active components

In electronic circuit, the components, other than passive are known as active components. Namely, transistors, diodes, SCRs Vacuum tubes etc.,

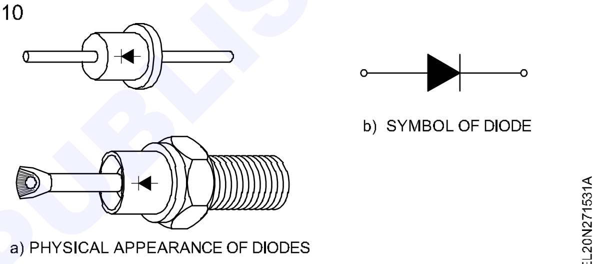
Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 10) etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey. Ohm's law, Kirchoff's law etc. These components are called active components.

Fig 9



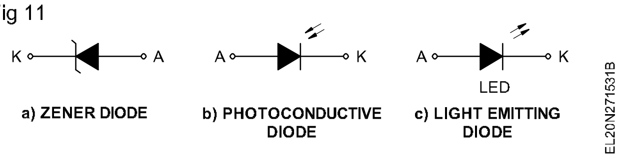
The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 10)

Fig 10



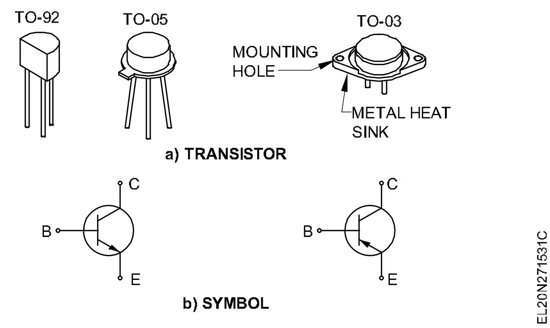
The different types of diodes (Fig 11) used for specific purposes are represented by the symbols given.

Fig 11



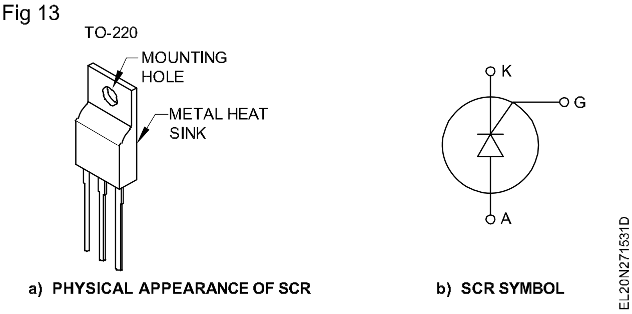
Transistor : Figure 12a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 12b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

Fig 12



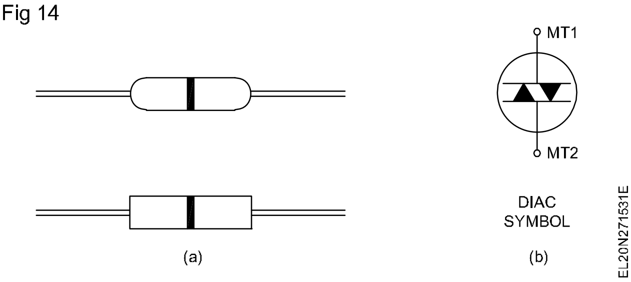
SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 13b. SCRs are also called thyristors and used as switching devices.

Fig 13



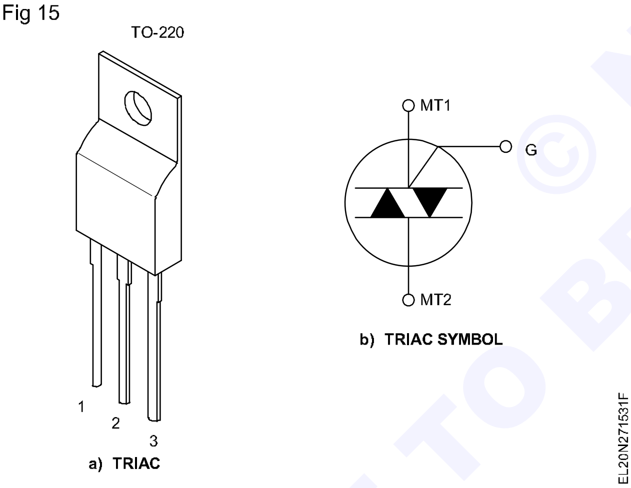
Diac : A diac (Fig 14a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 14b.

Fig 14



Triac : A triac is also a semiconductor device with three leads like two SCRs in parallel. The triac can control the circuit in either direction. (Fig 15)

Fig 15



Bridge rectifier or diode bridge : It is a single package of four semiconductor diodes connected in bridge circuit. The input AC and the output DC leads are marked and terminated as shown in the Figure 16.

UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 17).

Fig 16

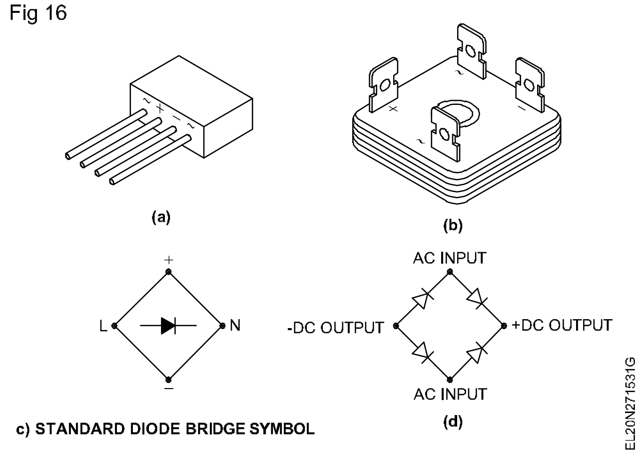
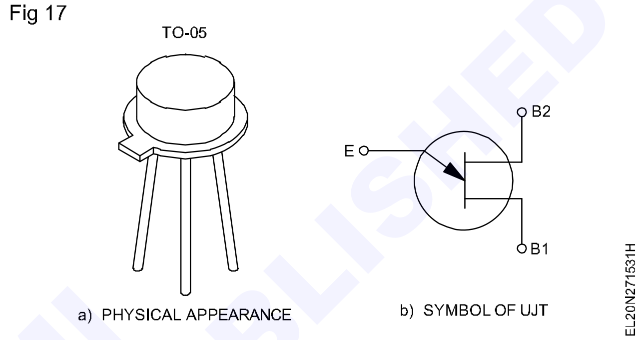


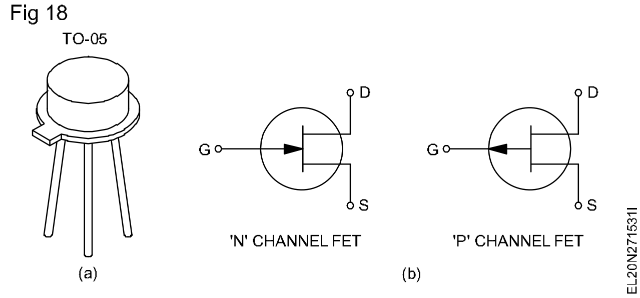
Fig 17



FET (Field effect transistor) : Fig 18a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 18b. The selection of the symbol is based on whether the FET is a 'N' channel or a 'P' channel one.

In the active components few basic components discussed have and many more advanced components associated with modern circuits are in use.

Fig 18



PN Junction - semi conductor diodes

Objectives: At the end of this lesson you shall be able to
- **explain diffusion in PN junction and barrier potential**
- **explain forward and reverse biasing of PN junction and semi conductor diodes and its VI characteristics**
- **state the applications specifications and classification of diodes**
- **state the method of testing diode and identifying the polarity**
- **state special diodes and their functions and PIV.**

PN junction: A diode is made by combining P and N materials. The surface at which these materials meet is the PN junction.

Diffusion occurs when P and N materials are joined together.(Fig 1) some electrons in the N material, near the junction, are attracted to the holes in the P material, thus leaving holes in the N material. The diffusion of electrical charges produces a potential difference in a small area near the junction (Fig 2).As a result, the material will conduct in one direction but not in the opposite direction. For this reason, the area in which this emf exists is called a barrier.

Fig 1

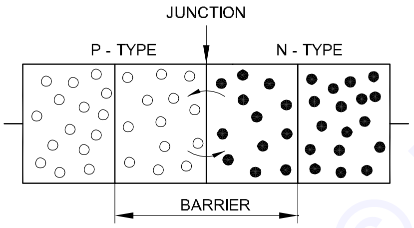
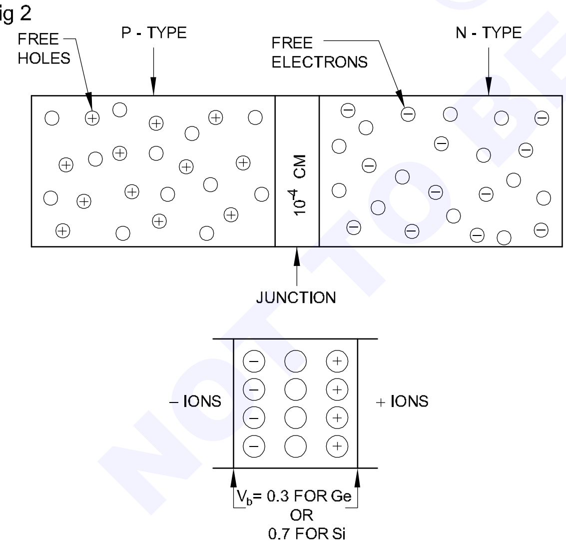


Fig 2

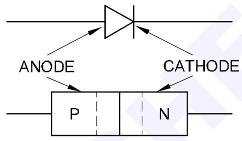


The internal barrier potential (V_b) : Although it is an internal contact potential that cannot be measured directly, the effect can be overcome by 0.3V for a **Ge** junction or 0.7 V for **Si**. The barrier voltage is more for **Si** because its lower atomic number allows more stability in the covalent bonds as already stated.

The PN junction, with the depletion zone magnified, shows the iron that has +ve and -ve charges produce the internal contact potential V_b at the barrier. (Fig 2)

A PN device is knows as a diode. The diode and its symbol are in Fig 3. This type of construction permits the current to flow in one direction but not in the opposite direction.

Fig 3

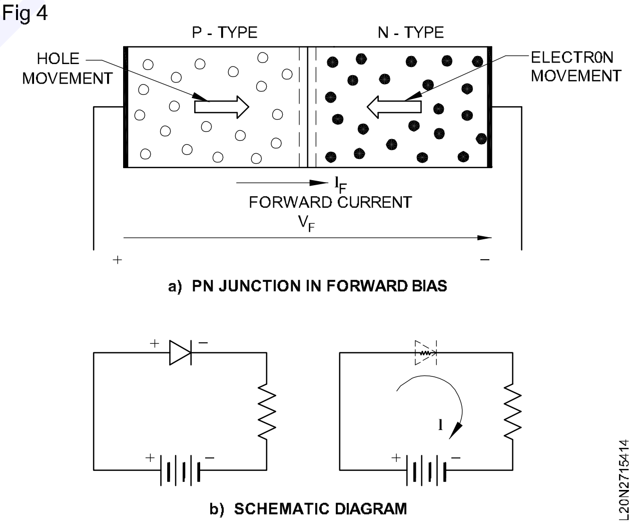


Biasing the PN junction

Forward Bias : A forward-biased PN junction is in Fig 4 The positive terminal is connected to the P-side and the negative terminal of the DC supply is connected to the N-side of the junction.

A current will flow through the diode as in the Fig 4.

Fig 4

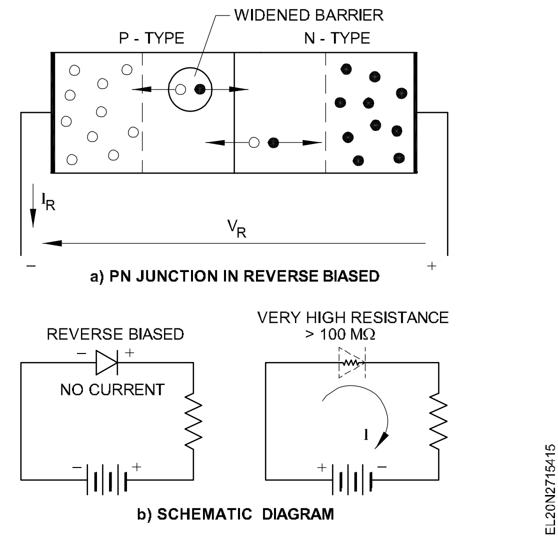


a) PN JUNCTION IN FORWARD BIAS

b) SCHEMATIC DIAGRAM

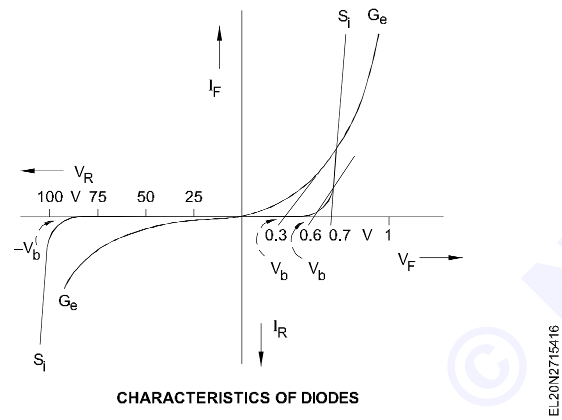
Reverse Bias: If the polarities of the DC supply are as shown in Fig 5, the PN junction is said to be reverse-biased. That is, the P side is connected to the negative and the N-side is connected to the positive terminals of the supply. Fig 5 shows the battery connection reversed (reverse bias). At the same instant, a shift in electrons in the P material causes the positive holes to appear further away from the junction near the end for the diode, which is connected to the negative terminal of the battery. This action produces a wider barrier at the PN junction through which the electrons cannot flow. (A very small current leakage may however occur).

Fig 5



V-I characteristic of PN junction : The static current voltage characteristic is in Fig 6.

Fig 6



The current in the forward direction increases rapidly upon reaching the forward voltage V_b which is known as the barrier potential or the junction potential and the barrier potential for germanium is 0.3 V and for silicon it is 0.7 V.

The behaviour of the PN junction is limited by the maximum forward current, as too much of current may destroy a diode due to the excess heat generation.

The current in the reverse direction of the junction is very small. Upon reaching —V_b in the reverse direction, the reverse current suddenly increases. —V_b in the reverse direction where the current starts increasing is called the knee potential or breakdown voltage. Normally the diode should not be operated in this region. The knee voltage depends on the type of diode which varies from 3V to 20 kV or more.

Application of diodes : Semi conductor diodes are used for various applications. Some of the major areas of application are listed below.

- Modulation and demodulation in communication receivers.
- Switching high speed digital circuits
- Low power and high power rectification
- As surge protectors in EM relay and other circuits.
- For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

The material : The diode is made-of doped semi-conductor material. This could be Silicon or Germanium or Selenium.This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3V, whereas in Si diodes the cut-in voltage is around 0.7V.

Maximum safe reverse voltage : Denoted as V_R or V_r that can be applied across the diode. This is known as peak-inverse-voltage or PIV. If a higher reverse voltage than the rated PIV is applied across the diode, it will become defective permanently.

Maximum average forward current : I_f or I_F that a diode can allow to flow through it without getting damaged.

Forward voltage drop : V_F or V_f that appears across the diode when the maximum average current, I_f flows through it continuously

Maximum reverse current : I_{vr} that flows through the diode when the maximum reverse voltage, PIV is applied.

Maximum forward surge current : I_s that can flow through the diode for a defined short period of time.

The maximum junction temperature: The temperature upto which the diode junction can withstand without mal functioning or getting damaged.

Testing diodes using ohmmeter: A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias condition is checked to confirm its condition.

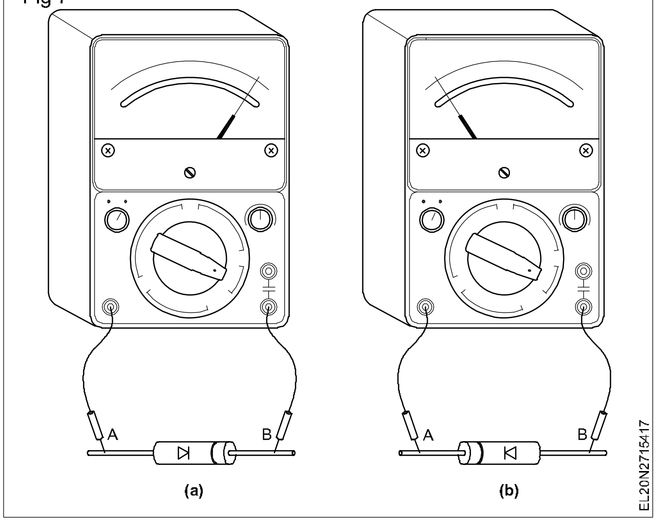
Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as in Fig 7.In Fig 7 the lead A is positive, lead B negative.

> **If the polarity of the meter leads are not known at first, the polarity of the meter leads can be determined by using a voltmeter across the ohm meter terminals.**

If the positive lead of the ohmmeter, lead A in the Fig 7 is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

Fig 7



While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

Polarity marking on the diodes: The cathode end of a diode is usually marked by a circular band or by a dot or by plus (+) sign. In some diodes the symbol of the diode, which itself indicates the polarities, is printed on the body of the diode.

Special diodes: All diodes are basically PN junction diodes and are made according to the application. There are many special purpose diodes are in use in which zener diodes widely used for voltage regulation.

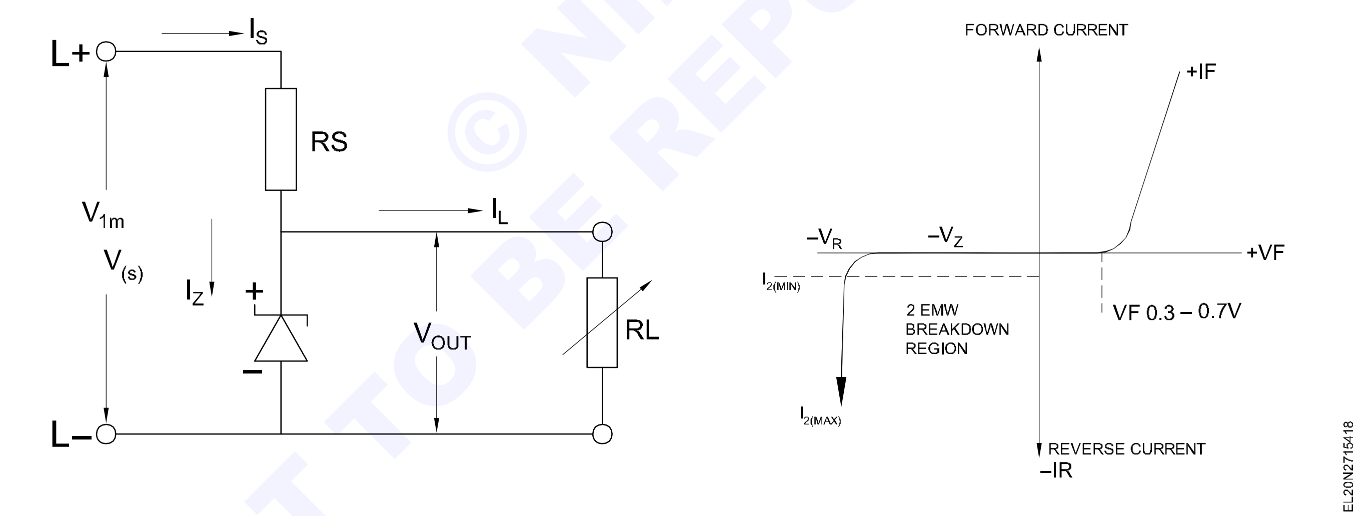
Zener diode: This diode specially designed for voltage regulation. A wide range of voltage regulated zener diodes are available.

It is a PN junction diode doped heavily for regulation purpose. It has a normal VI characteristic when it is forward biased. But the characteristic are changed abruptly when it is connected in reverse bias.

In the reverse bias condition a leakage current in the order of Microamps will flow. When the reverse voltage reaches to a particular designed voltage a sudden breakdown known as avalanche breakdown happens.

When a heavy current flows at constant voltage, the voltage continue to remain constant. Further increase in voltage, the current suddenly increases. Fig 8 shows the reverse characterises of zener diode.

Fig 8



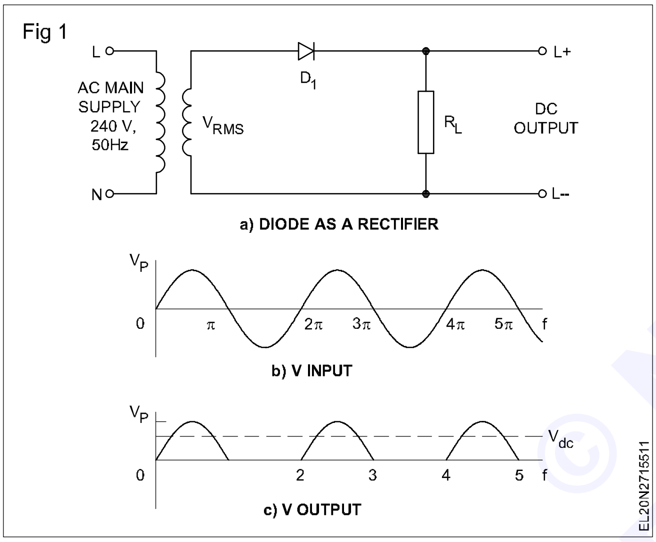
Rectifiers

Objectives: At the end of this lesson you shall be able to

- **state the purpose of rectifier in power supply circuit**
- **explain the working of half-wave, full-wave and bridge rectifier circuit**
- **state the need of filter circuit to rectifier circuits**
- **state the different types filter circuit for rectifiers.**

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to DC converter is by using one diode such an AC to DC converter is known as half-wave rectifier as in Fig 1.



A diode D_1 and a load resistance R_L in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D_1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D_1 and R_L to the negative terminal of the input. During this period of time, a voltage is developed across R_L. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load R_L and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops 0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$V_{rms} = 0.707\ V_p$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$$V_{dc} = 0.318\ V_p$$

$$= 0.318 \times \frac{V_{rms}}{0.707}$$

$$= 0.45\ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be V_{dc} = 0.45 x 24= 10.8 V

The DC load current is $I_{dc} = \dfrac{V_{dc}}{R_L}$

Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

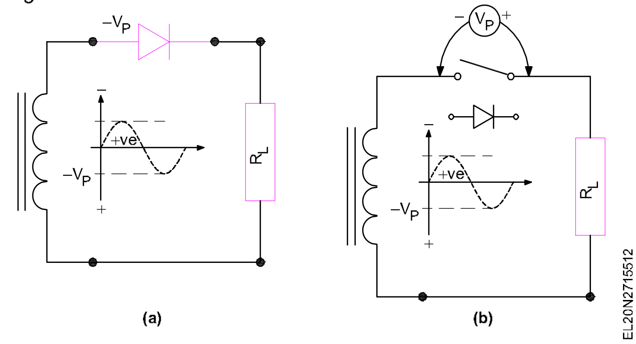
Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load R_L. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

Fig 2

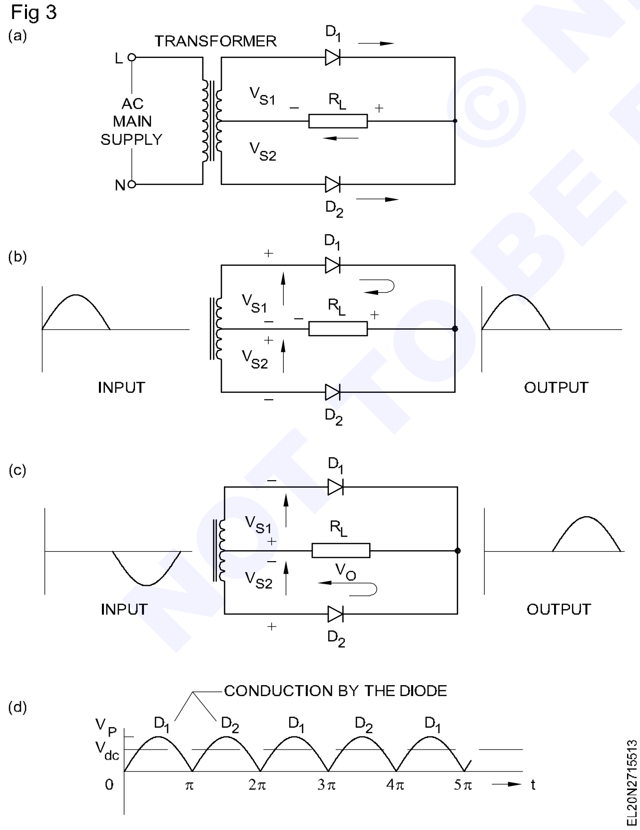


To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load R_L is connected to the centre tap and the other end of R_L to the diodes.

Fig 3



It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

During the positive half cycle of the secondary voltage, diode D_1 is forward-biased and diode D_2 is reverse-biased. (Fig 3b) The current flows through the load resistor R_L, diode D_1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D_2 is forward-biased and diode D_1 is reverse-biased. Therefore, current flows through the load resistor RL diode D_2 and the lower half of the secondary winding. (Fig 3c)

The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of a half wave rectifier driven by the same secondary voltage.

From Fig 3 it i s evident that the average of DC value of a full wave rectified output is

$V_{dc} = 0.318\ V_{s(peak)} + 0.318\ V_{s(peak)}$

$V_{dc} = 0.636\ V_{s(peak)}$

where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$Vs_{(rms)} = 0.707\ V_{s(peak)}$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s\,(rms)}}{0.707} = 0.9\ V_{s\,(rms)}$$

Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

$V_{dc} = 0.9\ V_{s(rms)}$

Therefore, in the given example

$V_{dc} = 0.9 \times V_{s(rms)} = 0.9 \times 24 = 21.6$ volts

Ripple frequency in a full wave rectifier: From Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.

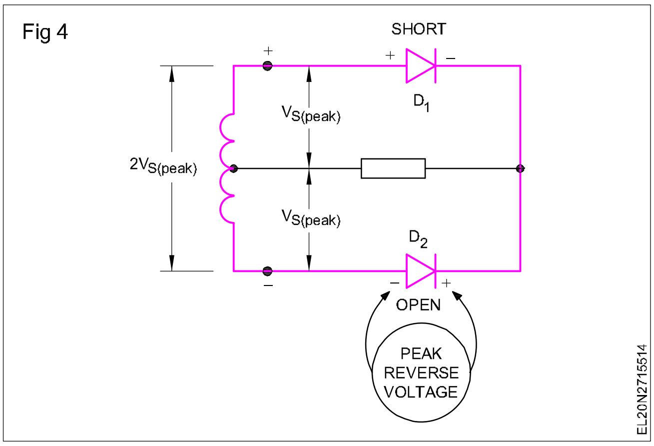
Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

Applying Kirchhoff's law around the outside loop, we get, $2V_{s(peak)}$ - Reverse voltage(PIV)

across D_2 + Forward voltage across D_1 = 0

Neglecting the small forward voltage across D_1 we have, $2V_{s(peak)}$ = PIV across D_2 + 0 = 0

or PIV across $D_2 = 2V_{s(peak)}$



From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be $2\,V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \quad = \quad 2\,V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, R_L connected in the fullwave rectifier is, say 10Ω the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10\,\Omega}$$

In the example considered above, V_{dc} = 21.6 volts

$$\text{Therefore,}\quad I_{dc} = \frac{21.6}{10} = 2.16 \text{ amps.}$$

It is interesting to note this current I_{dc} is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

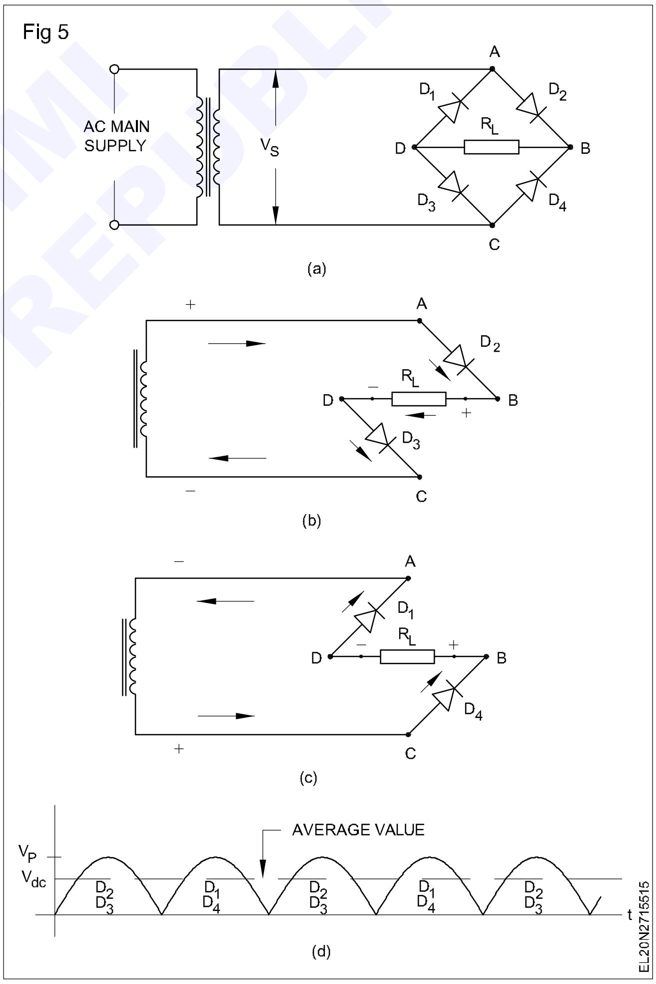
Therefore I_f(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.



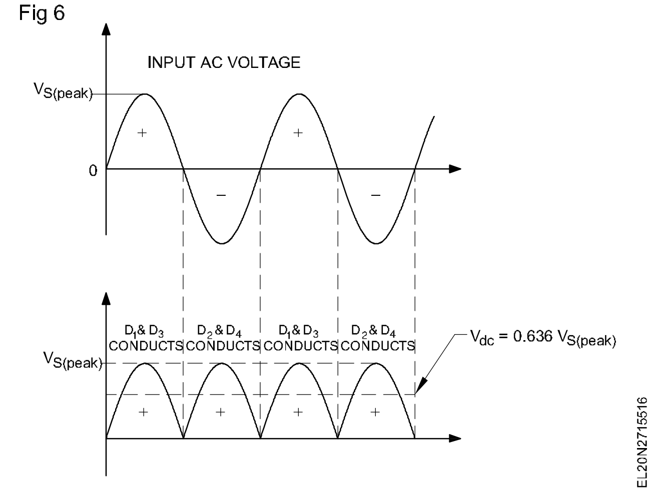
During the positive half of the secondary voltage, diodes D_2 and D_3 are forward-biased. Hence current flows through diode D_2 load resistance R_L and D_3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D_1 and D_4 are conducting . The current flows through diode D_4, resistor

R_L and diode D_1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

Fig 6



This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

V_{dc} = 0,636 $V_{s(peak)}$

or V_{dc} = 0.9 $V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

> **NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.**

Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, V_{dc} = 0.9 $V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

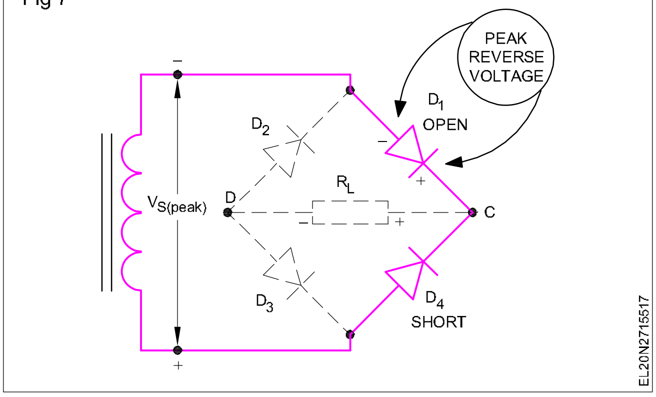
Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

> **NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.**

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 7



Diode D_4 is ideally short (as it is conducting) and D_1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or PIV across D_1 = $V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.

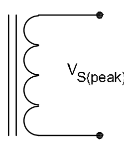
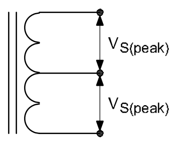
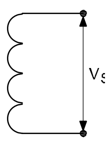
The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM\ (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, $T_A = 75°C$)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	$T_j T_{stg}$			-65 to 175					

Other diode specifications can be obtained from the data book).

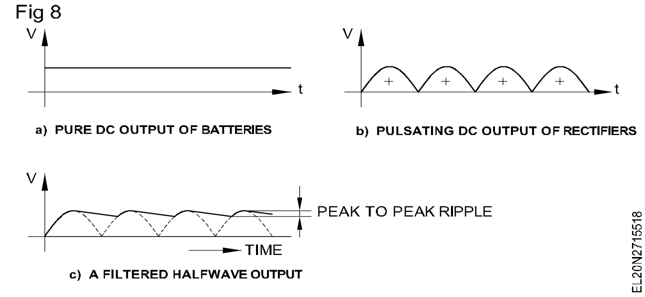
A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

	Half wave	Full wave	Bridge
Number of diodes required	1	2	4
Transformers peak output voltage			
DC output voltage in terms of $V_{s(peak)}$	$0.318\ Y_{s(peak)}$	$0.636V\ V_{s(peak)}$	$0.636V\ V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	$0.45\ V_{s(rms)}$	$0.9\ V_{s(rms)}$	$0.9V_{s(rms)}$
Diode current rating	$I_{L(max)}$	$0.5\ I_{L(max)}$	$0.5I_{L(max)}$

Peak inverse voltage	$V_{s(peak)}$	$2V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	$2f_{input}$	2_{finput}

Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.

Fig 8



Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1 Capacitor input filter.
2 RC filter
3 Series inductor filter
4 Choke input LC filter
5 π filter.

The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant R_LC. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Method 1

Knowing the required load current, I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

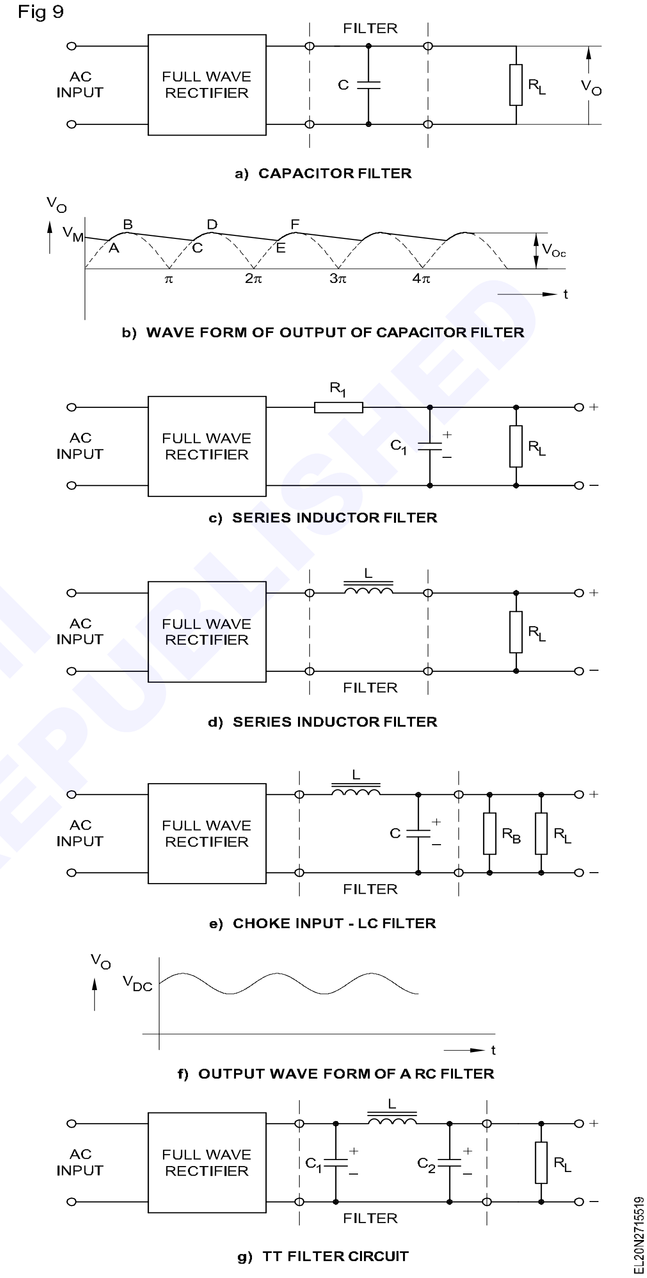
$$V_{rip(p-p)} = \frac{I_L}{F_r C} \text{ .... (2)}$$

Where

$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts
I_L = required Dc load current, in Amps
F_r = ripple frequency, in Hz
C = capacitance in Farads

Fixing the permissible $V_{r(p-p)}$ and knowing f and I_L the required value for C can also be found using this formula

Fig 9



Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

$$\text{Ripple factor, } r = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor (dimension less)

$V_{r\,(rms)}$ = rms value for ripple voltages.

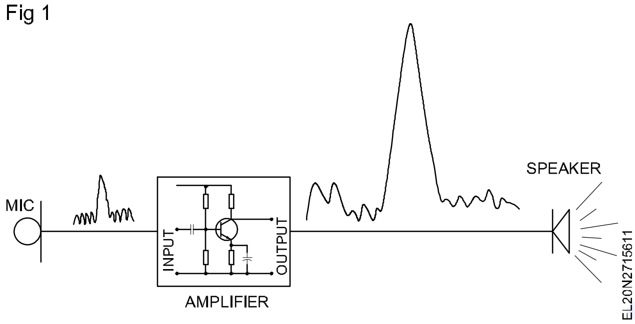
V_{dc} is the measured dc voltage at the output.

Transistors

Objectives: At the end of this lesson you shall be able to
- **explain the construction of bipolar transistors**
- **explain the classification and working of PNP and NPN transistors**
- **state the important packages and type number systems of transistor**
- **explain the methods of testing transistor.**

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum power loss in the form of heat
- Low operating voltage
- Rugged in construction
- Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

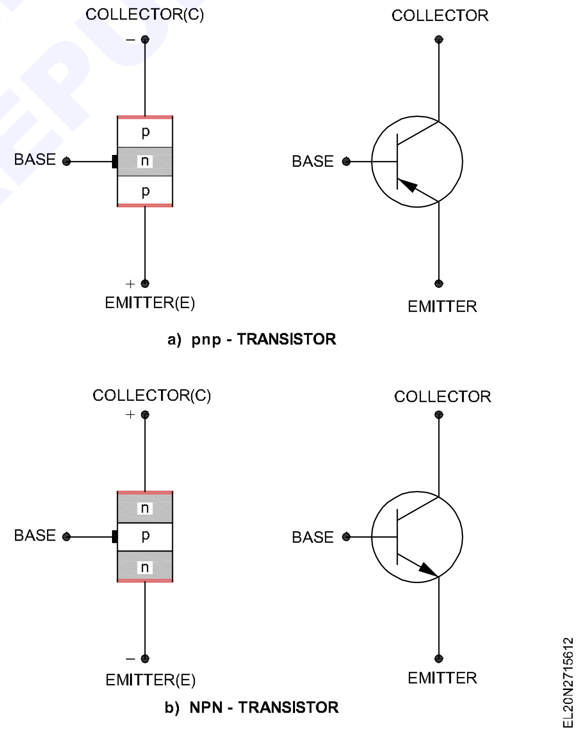
A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. 'N' type and 'P' type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of 'P' and 'N' type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used

- Germanium transistors
- Silicon transistors

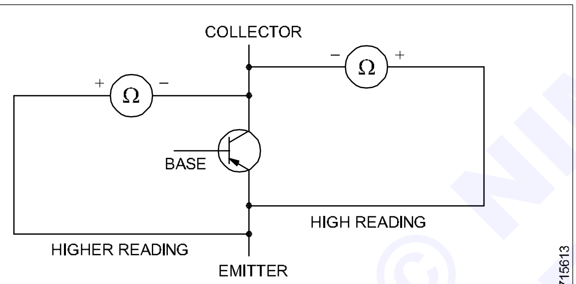
Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Fig 3



OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as in Fig 4

- NPN transistor
- PNP transistor

Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Operation of NPN transistor : During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

Fig 4

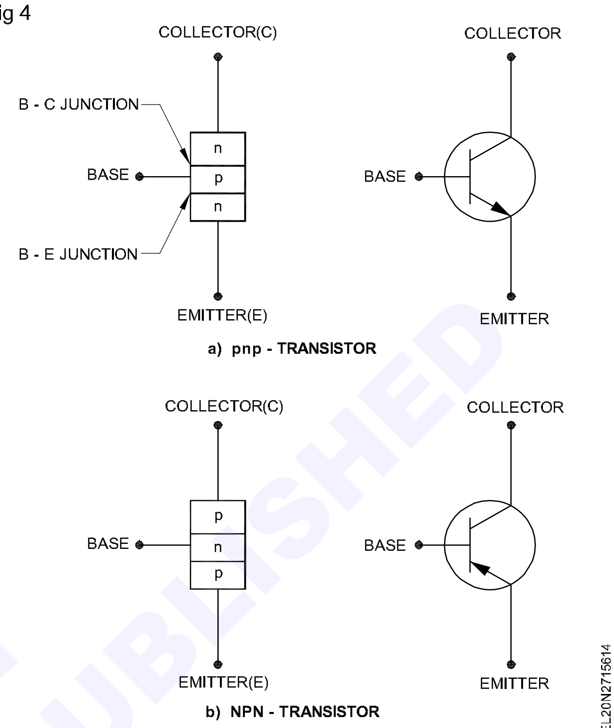
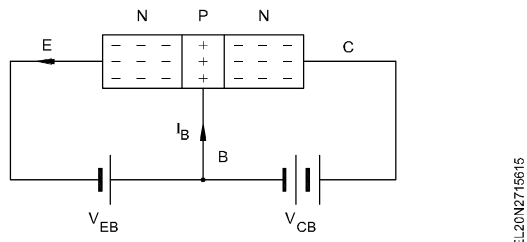


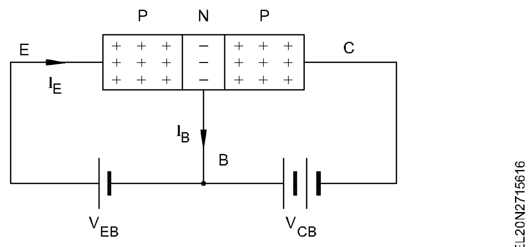
Fig 5



$I_E = I_B + I_c$

Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Fig 6



Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

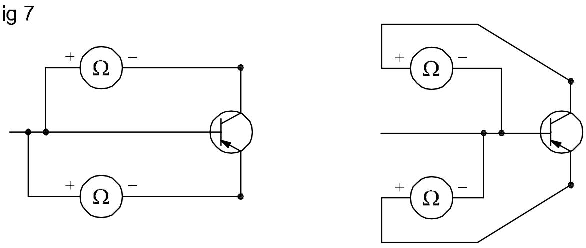
In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

Fig 7



BOTH READINGS ARE HIGH   BOTH READINGS ARE LOW

RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE PNP TYPE

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2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

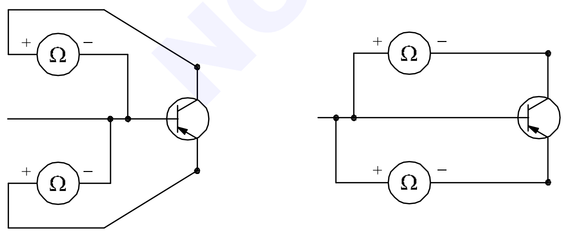
3 If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

5 If both readings show low resistance, then it is a PNP transistor.

NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8



BOTH READINGS ARE HIGH   BOTH READINGS ARE LOW

RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE NPN TYPE

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Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts

2 Medium power transistors is 2 to 10 watts

3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low frequency transistor (Audio Frequency of A/F transistors)
- High frequency transistor (Radio frequency of R/F transistors)

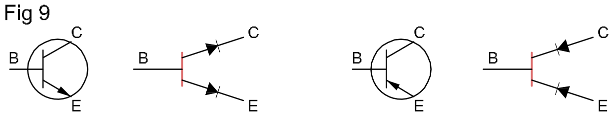
Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

Fig 9



a) NPN   b) PNP

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An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings.

Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/ multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.

2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3 When both the forward and reverse R are very high, close to infinity, the junction is open.

4 When both junctions are good transistor is good.

5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

> **Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.**

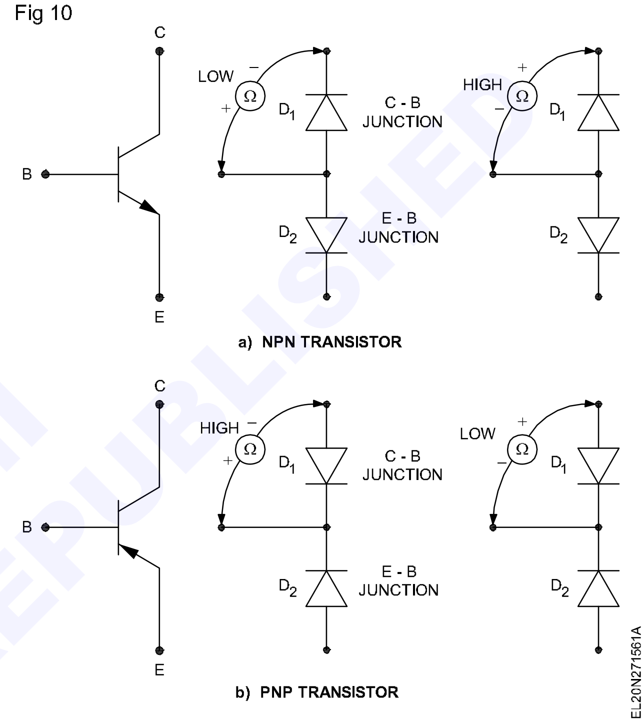
6 With a high voltage multimeter (MOTWANE multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Fig 10



Transistor biasing and characteristics

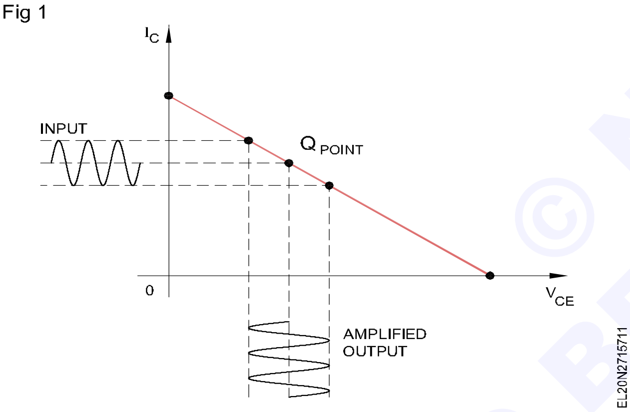
Objectives: At the end of this lesson you shall be able to
- **state the need and type of transistors biasing**
- **state the reason for shifting Q point due to temperature and β_{dc} changes**
- **state the necessity and importance of transistor characteristics**
- **state the importance of DC load line and meaning of Q point in transistors characteristics.**

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming AC signals can produce fluctuations above and below this Q point as in Fig 1.

Fig 1



For the normal operation of a transistor amplifier circuit, it is essential that there should be

a) a forward bias on the emitter-base junction and

b) reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1) work inefficiently and

2) produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in β (V_{BE}) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor β value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Further , the collector current I_C depends both on I_B and β of the transistor. If I_B changes, I_c also changes, and hence, the Q point changes. If β changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to β_{dc} changes: Practically two transistors of the same type number may have different value of β. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different β of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the β of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

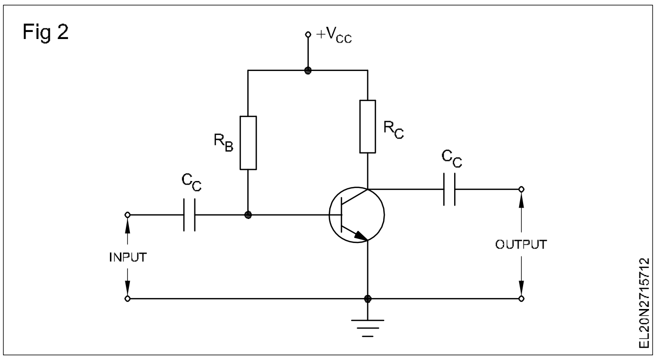
The methods used for providing a bias for transistors are 1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source V_{cc} and the base resistor R_B

Fig 2



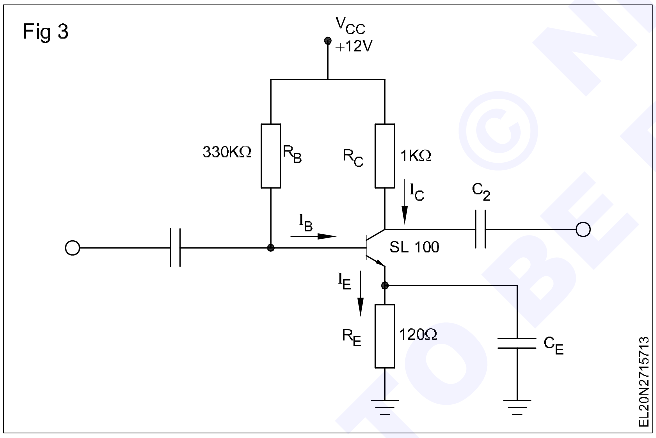
Self-bias arrangements are not practicable for small values of current because the DC Q point changes due to

– poor Beta sensitivity
– bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 SELF BIAS or EMITTER BIAS or emitter feedback bias: Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Fig 3



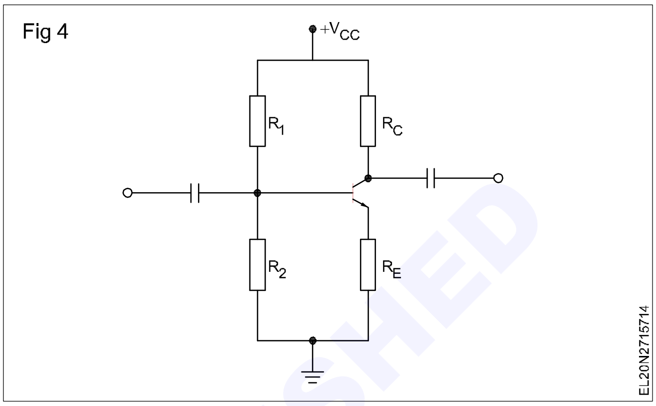
Let the temperature rise-causing rise in I_c and consequently rise in I_c. Then the current in R_E increases. The increased current in R_E increases the DC voltage drop across R_E, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the presence of the self-biasing resistor R_E reduces the increase in Ic and improves the operating point stability.

However if β_{dc} increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increase β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

3 **VOLTAGE-DIVIDER bias: Collector to base bias**: Fig 4 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 4



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

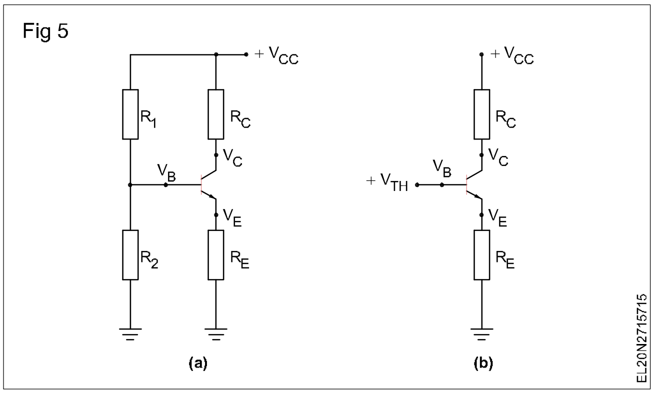
Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 5b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

NOTE: V_{TH} is known as the Thevenin's voltage. Refer reference books for Thevinin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 5a. then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 5a and the transistor acts like the controlled current source.

Fig 5



Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

The collector current I_c will be approximately equal to I_E.

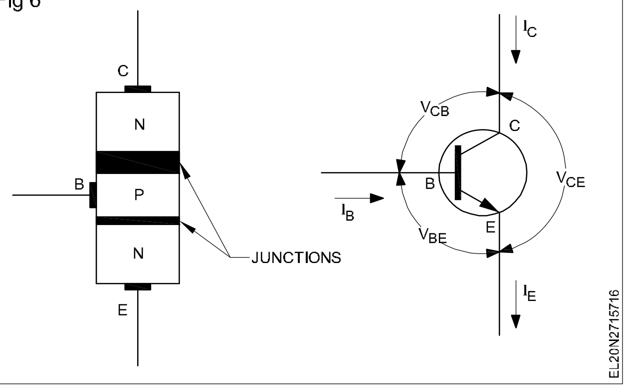
Notice that β_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in β_{dc}. This means that the divider-biased transistor has a stable Q point.

Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 6.

Fig 6

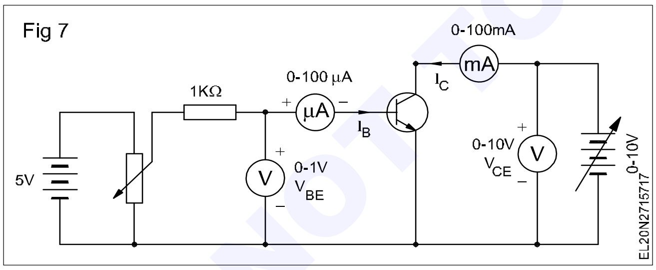


Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

- Input characteristics
- Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 7). The two characteristics graphs are in Fig 8.

Fig 7

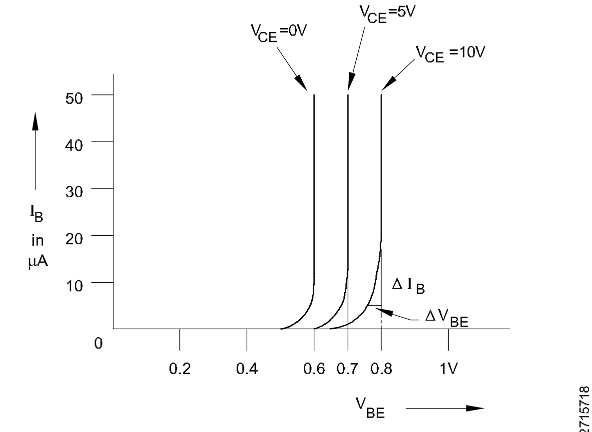


The graph at Fig 8 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

To find the input characteristics from the circuit as in Fig 7 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

Fig 8



INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER

The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu A - 10\,\mu A} = \frac{0.02}{10\,\mu A} = 2k\Omega$$

$(\mu = \text{micro})$

The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu A - 0.65\,\mu A} = \frac{5\,V}{0.1\,\mu A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 9.

It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B = 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\text{ m A} - 2\text{m A}} = \frac{6}{0.15\text{m A}} = 40 \text{ k ohms.}$$

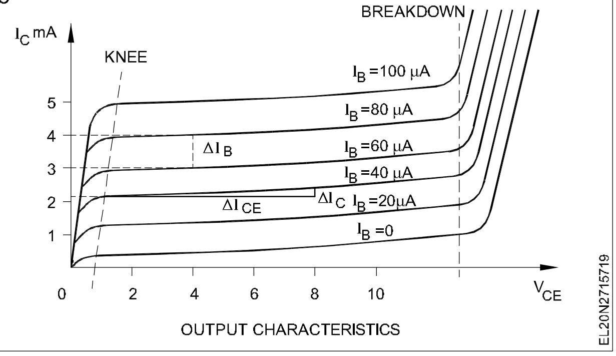
Current gain can be calculated by the formula

$$\text{Beta } \beta = \frac{I_C}{I_B} = \frac{4\text{mA} - 3\text{ mA}}{80\ \mu\text{ A} - 60\ \mu\text{ A}} = \frac{1\text{mA}}{20\ \mu\text{ A}} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha } \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Fig 9

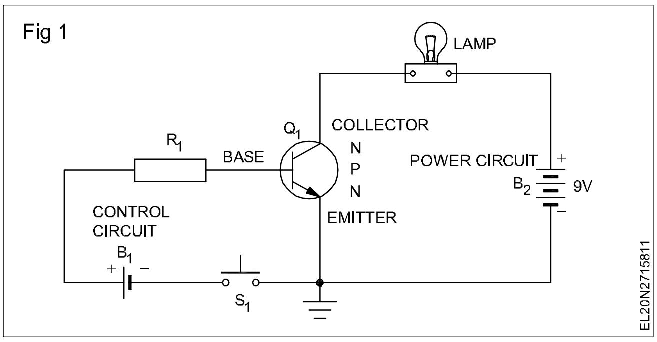


Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to
- **explain the function of the transistor at cut-off and saturation condition**
- **explain the operation of a transistor as a switch and its application**
- **state the working of series voltage regulator using transistor**
- **state the classification of amplifiers.**

The operation of transistor as switch: The switching action for Q_1 in Fig 1 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

Fig 1



- The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.
- The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q_1. This type requires positive V_{BE} forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.

The base emitter junction of Q_1, in Fig 1 can be forward biased by the battery B_1. Switch S_1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q_1 is supplied by B_2. The reverse polarity means that the N collector is more positive than the base. With switch S_1 open, no current flows in the base-emitter (or control) circuit.

The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S_1 is closed. This causes a small current to flow in the control circuit. R_1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops. Consequently, a large current flows in the power circuit, causing the lamp to light.

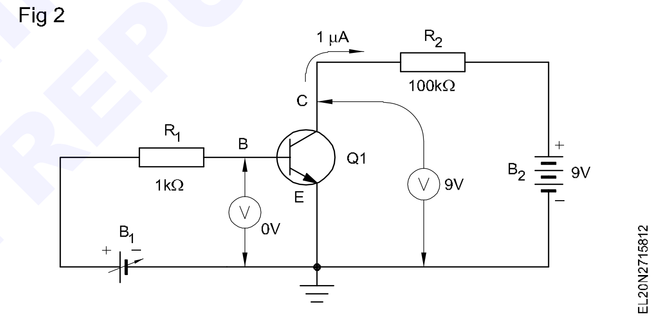
Finally, the opening of the switch S_1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q_1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit: The schematic circuit in Fig 2 shows the measured voltages and collector current I_c in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

$$R = \frac{V}{I} = \frac{9\ V}{0.000001\ A} = 9\ \text{megohm}$$

Fig 2



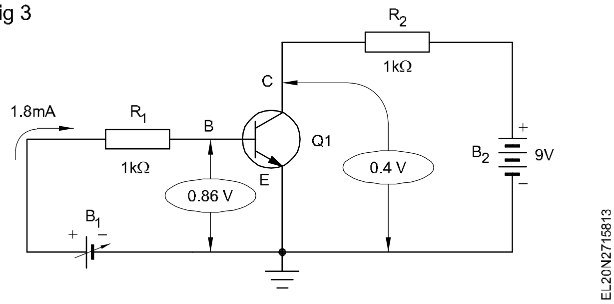
The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 3, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B_1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\ V}{0.085A} = 4.7\ \text{ohm}$$

The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

Fig 3



The transistor in Fig 2 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 3 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in Fig 4a, driven by the pulse wave-form in Fig 4b. This wave-form makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut off, and at V_1 is applied between the base and the emitter through a resistor R_1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 4b.

The response of the collector current I_c to the input wave-form, together with its time relationship to that waveform, is in Fig 4c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value $I_{CS} = V_{cc}/R_L$, is called the delay time t_d. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of I_{CS}. The total turn-on time t_{ON} is the sum of the delay and rise time,

$$t_{ON} = t_d + t_r$$

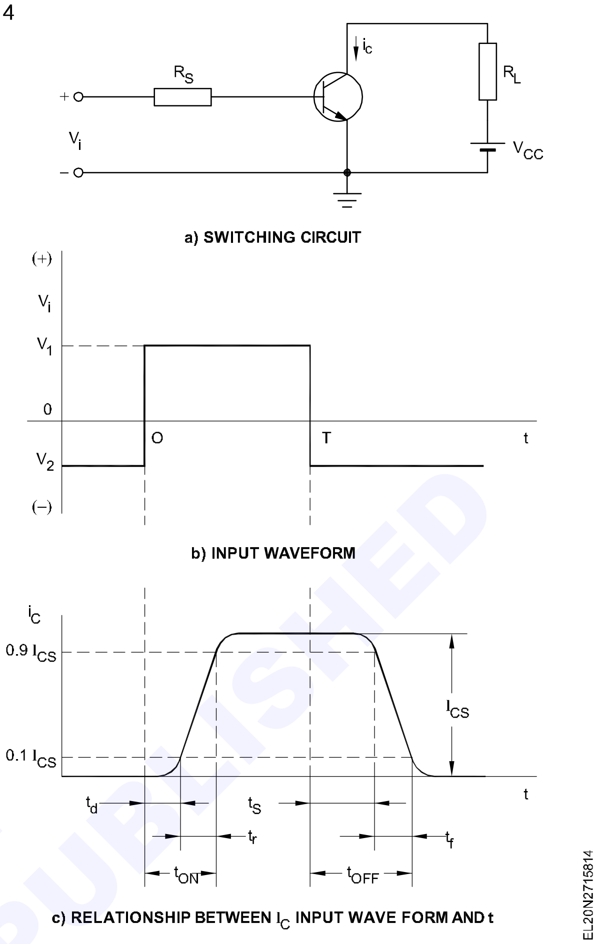
When the input signal returns to its initial state at t = T (Fig 4b), the current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when i_c has dropped to 90 percent of ICS is called the storage time t_s. The storage interval is followed by the fall time tt, which is the time required for i_c to fall from 90 to 10 percent of I_{CS}. The turn off time to t_{OFF} is defined as the sum of the storage and fall times,

$$t_{OFF} = t_s + t_F$$

The application of transistor switch: The transistor switch is used

- as an electronic ON and OFF switch

Fig 4



- in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits
- in the counter and pulse generator circuit
- in the clipping circuits
- as a sweep starting switch in the cathode ray oscilloscope equipment
- as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Series voltage regulator

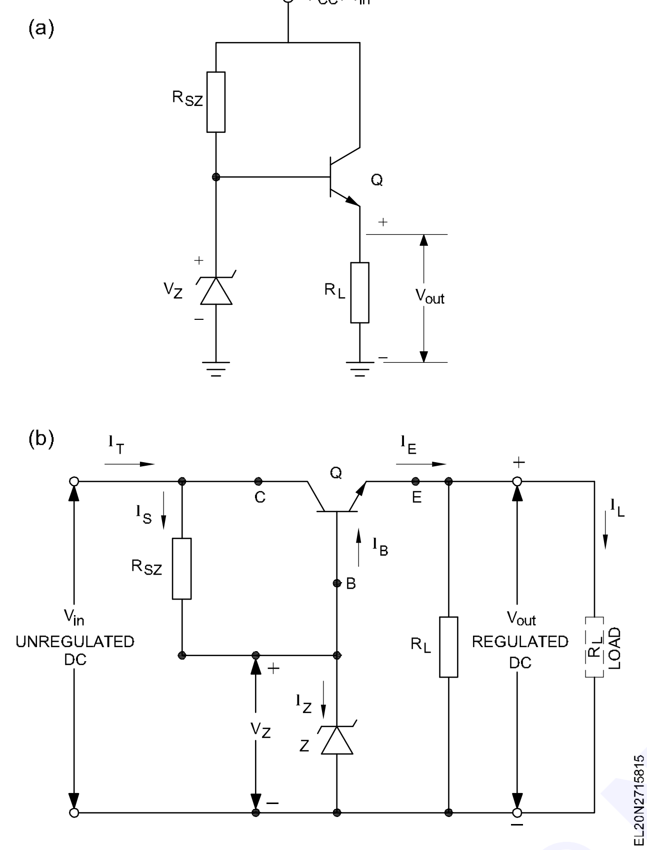
Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

1. When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.
2. In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, R_Z which ranges from a few ohms to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 5.

The simple series regulator is in Fig 5a, redrawn in Fig 5b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

Fig 5



Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifiers the weak signals received by its antenna.

Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1 Based on the transistor configuration

 a common emitter (CE) amplifier

 b common collector (CC) amplifier

 c common Base (CB) amplifier

2 Based on the output

 a voltage amplifier

 b current amplifier

 c power amplifier

3 Based on the input

 a small signal amplifier

 b large signal amplifier

4 Based on the coupling

 a RC coupled amplifier

 b transformer coupled amplifier

 c impedance coupled amplifier

 d direct coupled amplifier

5 Based on the frequency response

 a audio frequency (AF) amplifier

 b intermediate frequency (IF) amplifier

 c radio frequency (RF) amplifier

 d VHF and UHF amplifiers

6 Based on the feedback

 a current series feedback amplifier

 b current parallel feedback amplifier

 c voltage series feedback amplifier

 d voltage parallel feedback amplifier

7 Based on the biasing conditions

 a Class A power amplifier

 b Class B power amplifier

 c Class AB power amplifier

 d Class C power amplifier

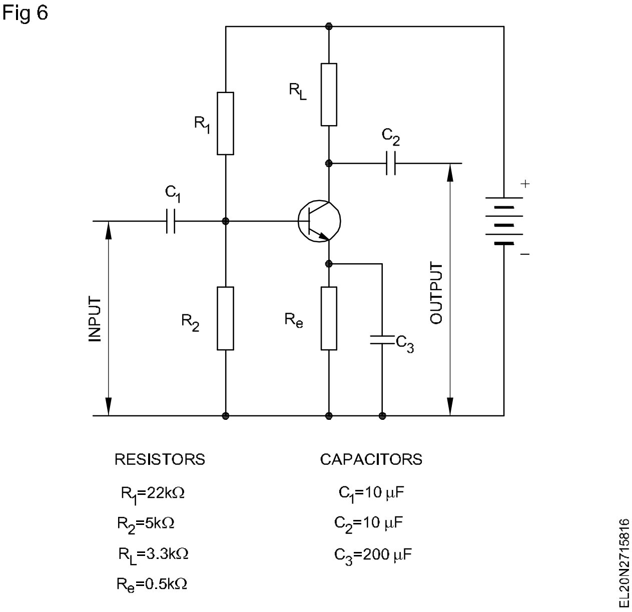
Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Fig 6.

The A.C. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

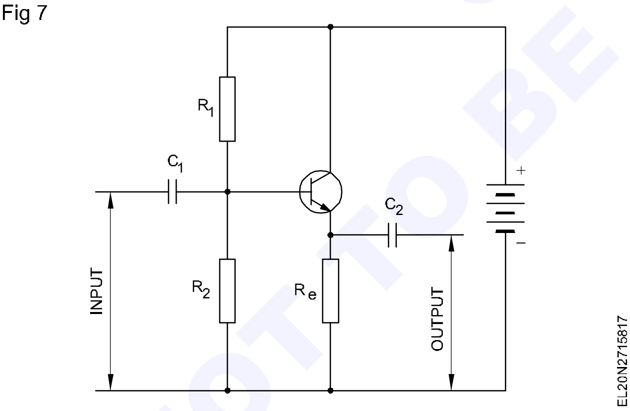
Fig 6



Resistor R_e is included to minimise the effect of temperature changes in the collector current. To prevent R_e from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

Common-collector amplifier : In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 7. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

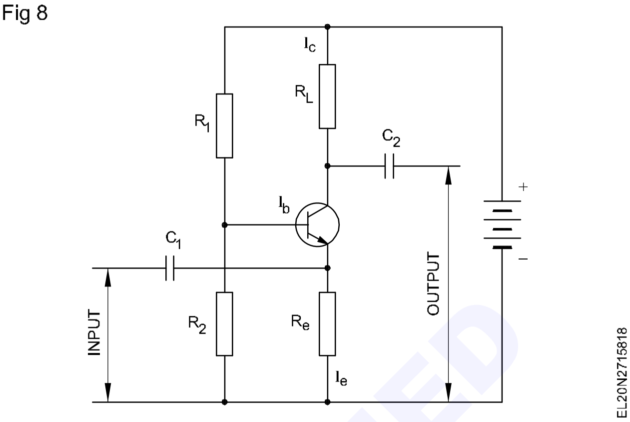
Fig 7



The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_c is the input current and the collector current I_c is the output current. (Fig 8) Since $I_e = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of I_b, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

Fig 8



For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

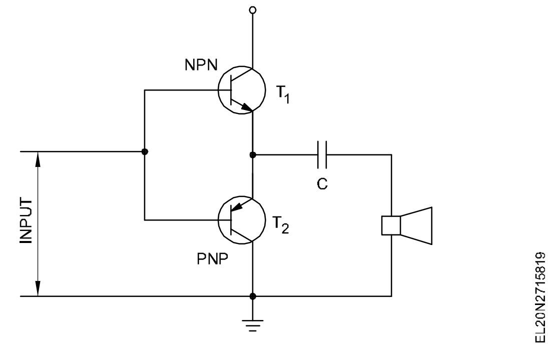
The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 9 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T_1 conducts and the PNP transistor T_2 is cut off. When the signal is negative going, T_1 is tuned of while T_2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 9



Function generator and cathode ray oscilloscope (CRO)

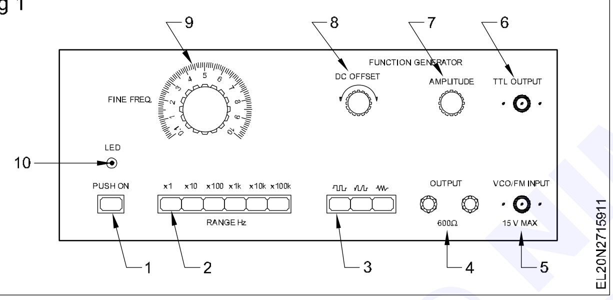
Objectives: At the end of this lesson you shall be able to
- **explain the use and control of function and AF (audio frequency) generator**
- **explain the function of CRO with block diagram**
- **state the functions of various controls in CRO**
- **state the use of CRO in electronic circuits.**

Introduction: A function generator is an equipment capable of providing sine, square and triangular wave outputs at different frequencies and amplitude. It has a maximum of 20 volts peak to peak single amplitude. A function generator finds applications in frequency modulations, tone control, Audio electronic, other laboratory and research work.

Panel controls and features of function generator

The front panel controls of function generator. (Fig 1)

Fig 1



1 **Power ON-OFF switch:** To turn on the function generator this button should be depressed. To turn off the same button should be pressed to release.

2 **Range selectors:** The range selection is of decade frequency type. The output frequency is given by the product of range selected and frequency dial indication. For example if the 10 K range button in depressed and frequency dial is at 2, then the output frequency is 20 KHz.

3 **Function selectors:** These selectors select the desired output waveform. (square, sine or Triangle)

4 **Output jack:** The wave forms selected by the function switches are available at this jack.

5 **VCO input jack:** An external voltage (not exceeding ± 20V peak) input will vary the output frequency. The change in frequency is directly proportional to the input voltages.

6 **TTL JACK:** A TTL (Transistor, Transistor logic) square wave is available at this jack. This output is independent of the Amplitude.

7 **Amplitude control:** This controls the amplitudes of the output signal.

8 **Offset control:** This controls the DC offset of the output.

9 **Fine frequency dial:** The output frequency of the wave forms is given by the product of the setting of this dial and the range selected.

Operating information: The function generator is powered by 240V. AC mains. When the power ON switch is depressed the LED will glow.

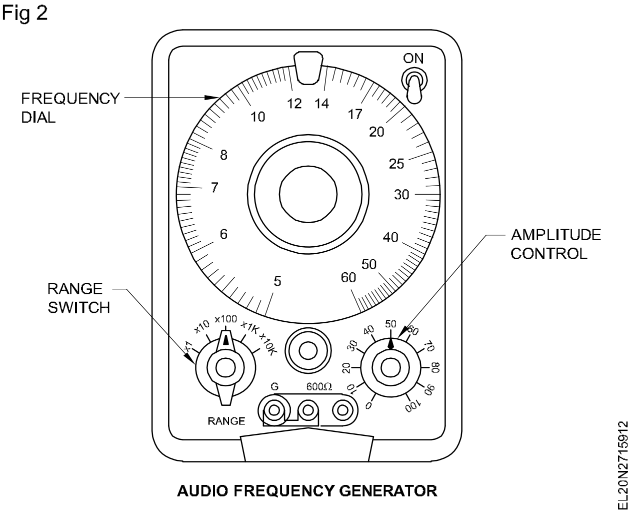
The desired frequency is set by depressing the frequency range switch an positioning the fine frequency dial.

The desired wave from is selected by depressing the appropriate function button from sine, square or triangle.

The amplitude of the selected output signal is adjusted by Amplitude control knob. A variation of the display amplitude from 0-20 V peak is possible. The TTL output is not affected by the amplitude control.

Audio Frequency (AF) Generator (Fig 2): Audio frequency generators produce sine wave signals from 20 Hz to 20 kHZ. Certain type of AF generators produce sine wave upto 100 kHZ. In addition to sine wave there may be provision to produce square waves too.

Fig 2



These generators contain a variable amplitude control which changes the signal amplitude from 10 mv to 20V. With the help of this generator the audio amplifier stages in radio, TV recorders and audio amplifier could be tested.

While the frequency range switch selects the desired frequency range switch selects the desired frequency range, the frequency dial is used to select the frequency within the desired range.

Cathode ray oscilloscope (CRO)

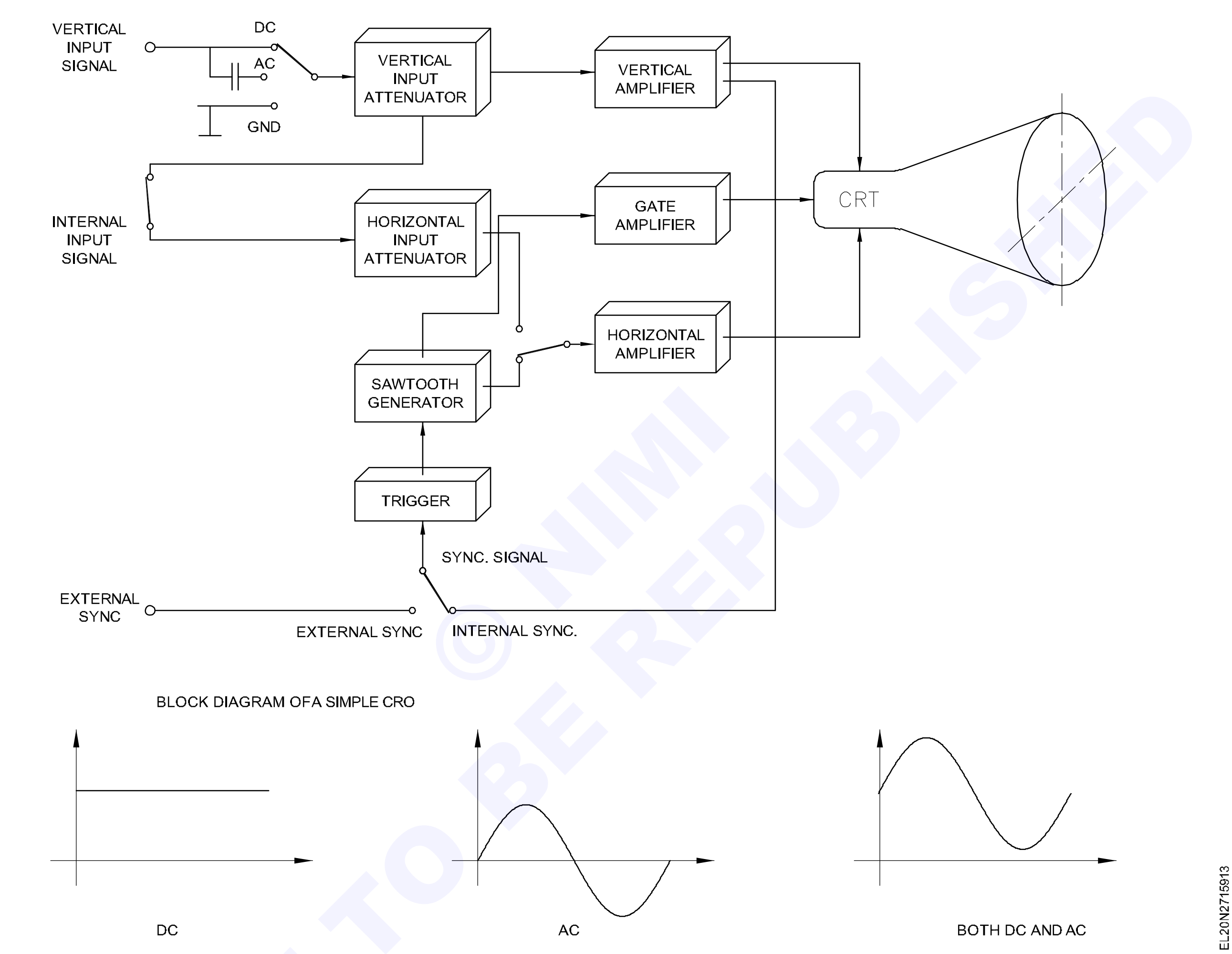
Introduction: The oscilloscope is an electronic measuring device which provides a visual presentation of any wave form applied to the input terminals. Cathode ray tube (CRT) like a television tube provides the visual display of the signal applied as a wave form on the front screen. An electron beam is deflected as it sweeps across the tube face, leaving a display of the input signal.

An oscilloscope usually consists of:

- Attenuator
- amplifiers
- saw-tooth generator
- gate amplifiers or Z-amplifier
- Trigger
- CRT (cathode ray tube)
- power supply

The block diagram of a simple cathode ray oscilloscope is shown in Fig 3.

Fig 3



BLOCK DIAGRAM OF A SIMPLE CRO

Attenuator : The input signal should be attenuated to a suitable magnitude before it is applied to the amplifier. The attenuators are employed at the input of both vertical and horizontal amplifiers.

Amplifier : The amplifiers of an oscilloscope consist of a vertical amplifier and a horizontal amplifier. The vertical amplifiers amplify the vertical input signal before it is applied to the Y-plates. The horizontal amplifier amplifies the signal, before it is connected to the X-plates.

Saw-tooth generator: The measuring signal of any shape is connected to the Y-input(plates) and then it appears on the screen. The signal on X-plates should be such that the image on the screen is similar to that on the Y-plates. Hence a saw-tooth signal is required to be connected to the X-plates which makes the image on the screen like the signal connected at the vertical plate. The saw-tooth signal is called the time base signal, and is produced by the saw-tooth generator. The shape of the saw-tooth signal is shown in Fig 4. The time-base signal consists of trace, retrace and hold off period.

Gate amplifier or Z-amplifier: It is desirable that the image seen on the screen of the CRT must be continuous, that is, the electron beam is desired to appear only in the trace period of the time-base signal. The retrace period of the electron beam must not be visible on the screen. Therefore, the gate amplifier is required to control the electron beam in order that it appears only in the trace period.

The signal from the gate amplifier is a square wave and is related to the time-base signal. This is illustrated in Fig 5.

Fig 4

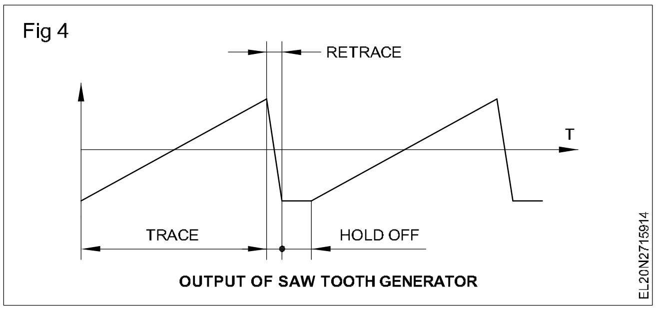
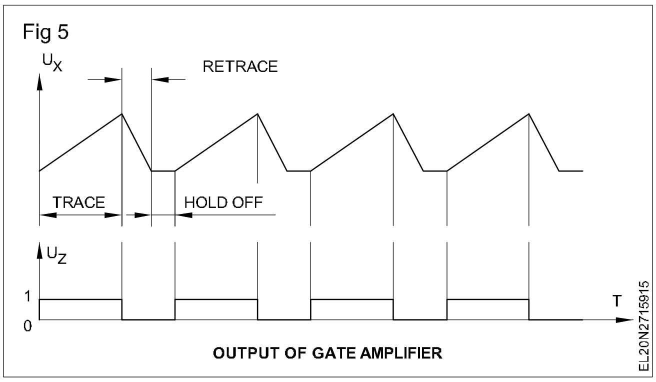


Fig 5



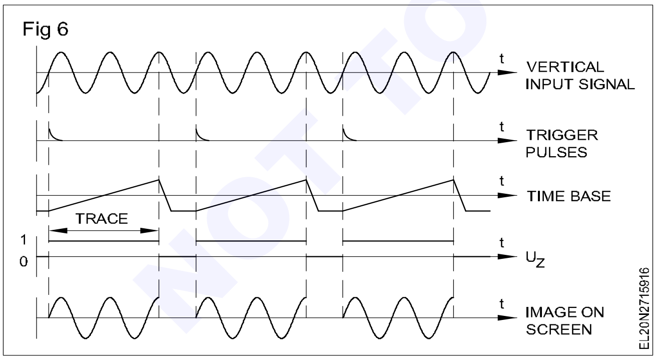
Trigger (Gate amplifier output) : As mentioned earlier, the measuring signal-wave form is connected to Y-input, which appears on the screen. In order to make the wave-form stationary on the screen, it is required that the starting point of the time base signal has to be fixed related to the signal connected to the Y-input. This is known s 'synchronization'. The functional stage which performs synchronization is the trigger.

The trigger will produce a pulse or impulse for triggering the time-base. Every time the time-base is triggered, one saw-tooth wave-form is produced.

There are three forms of triggering in an oscilloscope.

Internal triggering : The signal which is supplied to the trigger is the internal signal of the CRO produced by using the signal from the vertical input signal. The sequence of signal processing is shown in Fig 6.

Fig 6



External triggering : The signal which is supplied to the trigger is the external signal, produced by using the signal from the external, sync.

Line triggering : The signal which is supplied to the trigger is the signal from the power supply of CRO. (Not shown in the block diagram)

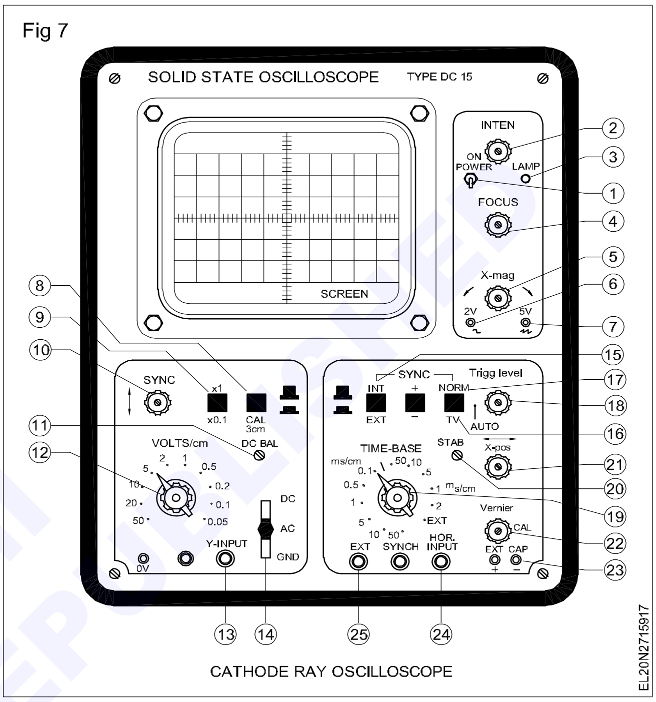
Switches are provided to select the form of triggers as required. In a CRO, suitable timing can be selected that causes the image on the screen to be stationary.

CRO (The Cathode ray tube): The constructional features are explained later in this text.

Power supply: Low voltage and high voltage DC supplies which are required for the oscilloscope function are produced by rectifier filters and switch mode power supply circuits.

Controls and their functions in a CRO: The operating controls on the front panel of a general purpose oscilloscope is shown in Fig 7. The names of the controls and their functions are listed below.

Fig 7



CATHODE RAY OSCILLOSCOPE

General

Power-on (1): It is toggle switch meant for switching on power. In the ON position, power is supplied to the instrument and the neon lamp (3) glows.

Intensity (2): It controls the trace intensity from zero to maximum.

It controls the sharpness of the trace. A slight readjustment of this control may be necessary after changing the intensity of the trace.

X-Magnification (5): It expands length of the time-based from 1 to 5 times continuously, and makes the maximum time-base to 40ns/cm.

Square wave (6): This provides a square wave of 2 V (p-p) amplitude to enable the user of the scope to check the Y-calibration of the scope.

Saw-tooth wave (7): This provides a saw-tooth, wave-form output coincident to the sweep-speed switch with an output of 5V (p-p). The load resistance should not be less than 10 k ohms.

Vertical section

Y (10) : This control enables the movement of the display along the y-axis.

Y (13) : It connects the input signal to the vertical amplifier through the AC-DC-GND coupling switch (14)

AC-DC-GND coupling switch (14): It selects coupling to the vertical amplifier, in DC mode, it directly couples the signal to the input; in AC mode, it couples the signal to the input through a 0.1 MF, 400-V capacitor. In GND position, the input to the attenuator (12) is grounded, whereas the Y-input is isolated.

Volts/cm (Attenuator) (12): It is a 10-position attenuator switch. It adjusts the sensitivity of the vertical amplifier from 50 m V/cm to 50 V/cm in 1,2,5,10 sequence. The attenuator accuracy is ±3%.

x1 or x 0.1 switch (9)

When switched in x 0.1 or position, it magnifies the basic sensitivity to 5 m V/cm from 50 m V/ cm

CAL switch (8): When pressed, a DC signal of 15 m V or 150 m V is applied to a vertical amplifier depending upon the position of x1-x0.1 switch (9) position.

DC bal (11): It is a preset control on the panel. It is adjusted for no movement of the trace when either x1 - x0.1 switch (9) is pressed, or the position of AC-DC-GND coupling switch (14) is changed.

X-Position (21): This control enables the movement of display along the X-axis.

Trigger level (18): It selects the mode of triggering. In AUTO position, the time-base line is displayed in the absence of the input signal. When the input signal is present, the display is automatically triggered. The span of the control enables the trigger point to be manually selected.

Time-base (19): This sector switch selects sweep speeds from 50 ms/cm to 0.2Ms/cm in 11 steps. The position marked EXT is used when an external signal to be applied to the horizontal input (24)

Vernier (22): This control is a fine adjustment associated with the time-based sweep-selector switch (19). It extends the range of sweep by a factor of 5. It should be turned fully clockwise to the CAL position for calibrated sweep speeds.

Sync. selector (15, 16, 17): The INT/EXT switch (15) selects internal or external trigger signal. The +ve or -ve switch (16) selects whether the wave-form is to be triggered on +ve or -ve step. NORM/TV switch (17) permits normal or TV (line frequency) frame.

Stab (20): It is a preset control on the panel. It should be adjusted so that you just get the base line in the AUTO position of the trigger level control (18). In any other position of the trigger level control, you should not get the base line.

Ext. Cap (23): This pair of connectors enables the time-base range to be extended beyond 50 ms/cm by connecting a capacitor at these connectors.

Hor. input (24): In connects the external signal to the horizontal amplifier.

Ext. sync. (25): It connects the external signal to the trigger circuit for synchronization.

Application of CRO

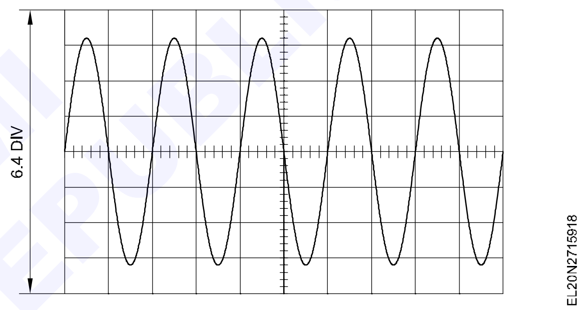
AC voltage measurement: The screen of the cathode ray oscilloscope usually has a plastic gratitude overlay, marked in centimeter divisions. The vertical amplitude of any wave form indicates peak-to-peak voltage.

To measure unknown AC voltages the main supply AC should be isolated through a isolation transformer and the attenuator is set to 50 V/ div. The AC-DC switch is set to AC position (out). Voltage to be measured is connected to the input and common terminal. Set the time base switch to display several cycles of the wave form. Adjust the V/div switch to get a wave form at a convenient height such that the positive and negative peaks appears with-in the screen.

Measure the vertical amplitude (no. of divisions peak-to-peak) of the voltage on the screen. Now multiply the amplitude by the volts/div setting to find the peak-to-peak voltage value.

Example : Assume a vertical deflection of 6.4 divisions as in Fig 8 and a volt/div setting of 5 volts.

Fig 8



Peak-to-peak voltage = 6.4 x 5 = 32 V

therefore peak voltage = 16 V

therefore RMS voltage = 16 x 0.707 = 11.31 V

$$\text{or RMS voltage} = \frac{\text{Peak to peak voltage}}{2.83} = \frac{V_{PP}}{2 \times \sqrt{2}}$$

$$= \frac{32}{2 \times \sqrt{2}} = 11.31\text{v}$$

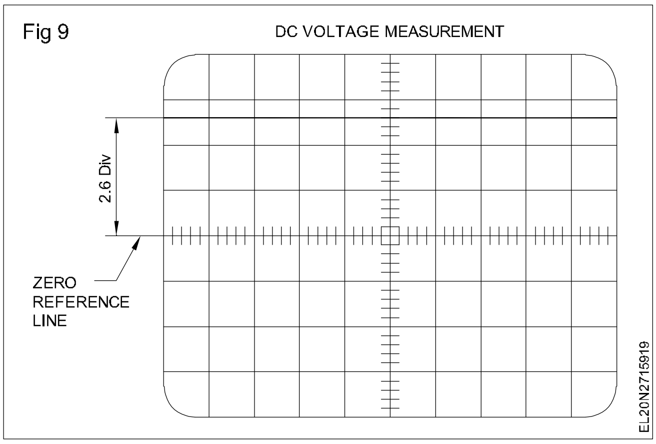
DC voltage measurement : The input selector switch is set to DC position. Adjust the Y shift position to get the trace at the centre of the screen. This line represents zero DC volts. Connect the +ve of the DC voltage to be measured to input terminal and the -ve to the common terminal. Now the horizontal line will move up. (Down for reverse polarity) the volts/div switch is set as required.

Now measure the vertical distance in divisions form the zero reference line.

The DC voltage can be found by multiplying the vertical distance (division) with VOLT/DIV setting.

An example is worked out with reference to Fig 9

Assume a vertical deflection of 2.6 division and a Volts/Div setting of 20 V.



DC voltage = 2.6 x 20 = 52V.

Measurement of time and frequency : The wave-form to be measured is connected to the V input. The volts/Div switch is set to display a suitable vertical amplitude of the wave-form. The Time/Div switch is set to display approximately two cycles of the wave-form to be measured. Adjust the Y-SHIFT control to move the trace so that the measurement points are on the horizontal centre line. The X-SHIFT control is adjusted to move the start of the measurement points to a convenient reference line.

The distance (divisions) between the points of one cycle is measured as in Fig 10.

The product of the divisions of one cycle and the setting of time/div switch gives the period of one cycle.

The frequency can be determined by the formula

$$\text{Frequency} = \frac{1}{\text{Time period}}$$

where frequency is in hertz and time in seconds.

Example

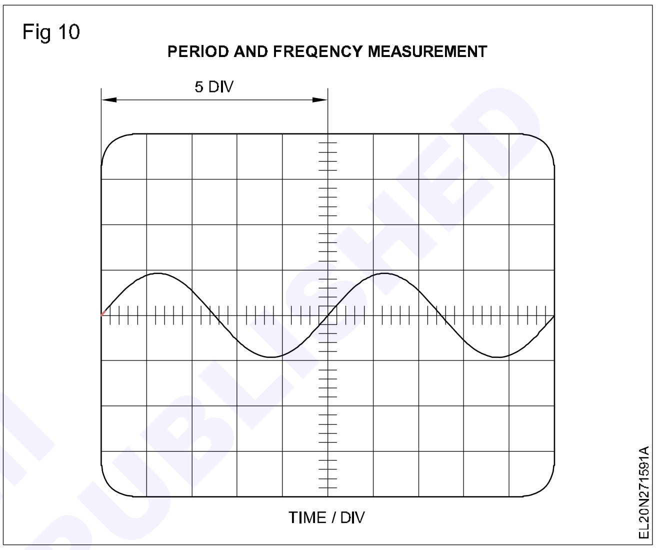
Time = Div x time base setting

= 5 x 0.2 ms

= 1 ms

$$\text{therefore frequency} = \frac{1}{T} = \frac{1}{1 \times 10^{-3}} = 1000\,\text{Hz}$$

Frequency = 1 kHz.



Printed circuit boards (PCB)

Objectives : At the end of this lesson you shall be able to
- **state the types of etchants used for etching and preparation of etchant solution**
- **state the reasons for agitating the etchant solution while etching**
- **list the important points while drilling holes on PCBs**
- **list the advantages of marking component positions on PCBs.**

Introduction

Printed circuit board in which the connecting wires are replaced by a thin conducting path called copper or silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phonetic, paper or fibre glass or epoxy.

The moulded conducting path generally known as tracks size depend on the power of the circuit. The width of tracks are varied few millimeters to less than one millimeter depend on the circuit.

The thin tracks less than one millimeter made up with silver tracks where IC circuits and micro controller circuits are to be made. Several process moulded to make PCB and it is explained below.

Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

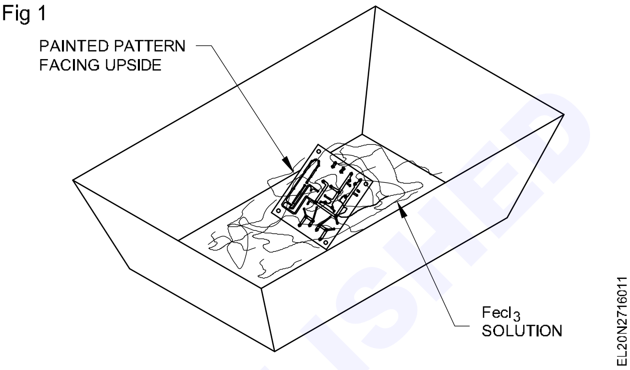
- Alkaline ammonia
- Sulpuric-hydrogen peroxide
- Ferric chloride
- Cupric chloride

The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This $Fecl_3$ is prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

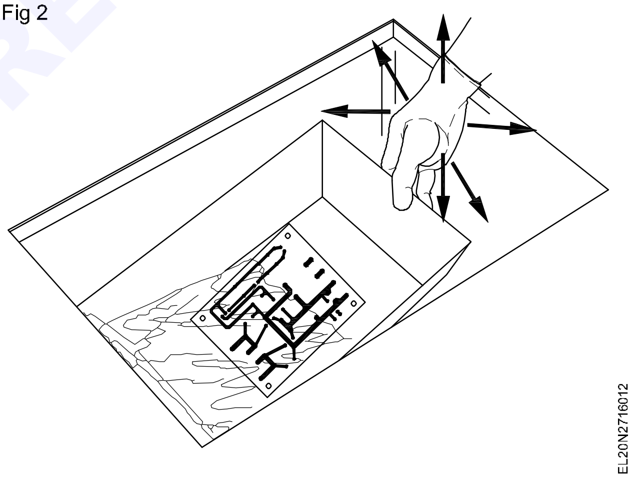
The painted laminate to be etched is slid into the $Fecl_3$ solution of required quantity, with the painted surface of the laminate facing the top as in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.

Fig 1



To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

Fig 2

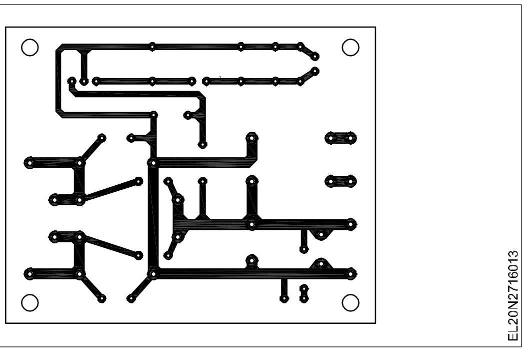


As the etching progresses, the copper in the unwanted portion is gradually removed. When the etching is complete, all the copper in the unwanted portion disappears and the etched portion will have the colour of the insulator of the laminate board.

Once the unwanted portions of copper are completely etched, the board is taken out of the solution and is cleaned using fresh water to remove the remaining $Fecl_3$ solution. This stops any further etching process.

After cleaning the board using water and drying, the etch-resistant ink/paint on the lay out pattern is removed using solvents, such as, thinner or petrol. The cleaned board will then have bright copper stripes and pads, only in the required portions representing the circuit as in Fig 3.

Fig 3



Drilling holes on PCBs

The next step after etching and removing the mask/paint is to drill holes of required diameter at the pad centers for inserting the components, input/output and V_{cc} & ground(Gnd) connections. Extra care is to be taken while drilling holes because carelessness while drilling may peel off the pad area of the copper. Some hints for drilling on PCB's are given below;

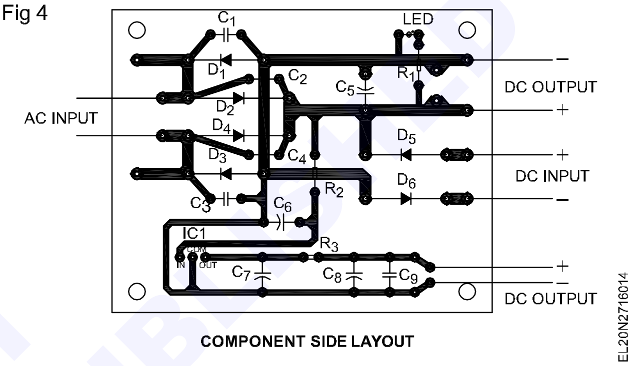
- If the point where drilling is to be made is not clear, punch the point again such that the drill bit sits at the punched point before starting the drilling.
- Use a high speed drill gun/machine.
- Use drill bits of the required size. If an exact size drill bit is not available, use a drill bit one size smaller but never one size larger.
- Fix the PCB firmly on a vice using a wooden block so that the PCB does not become loose while drilling and peel of the pad area copper.
- Ensure that all the points required are drilled because, once the components are mounted, drilling holes on the PCB may damage the mounted components due to vibration.

After drilling holes, clean the PCB such that it is free from burr and dust. Apply varnish on the layout pattern, to protect the copper pattern from corrosion.

Preparing and marking component lay out

A typical component side of a PCB with the components marked on it is in Fig 4.

Fig 4

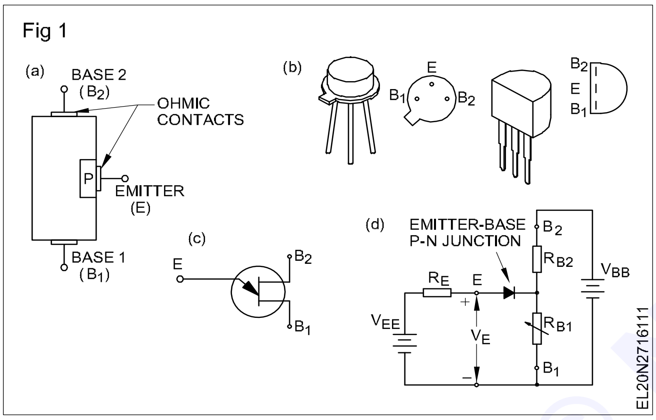


Unijunction transistor (UJT) and FET and its application

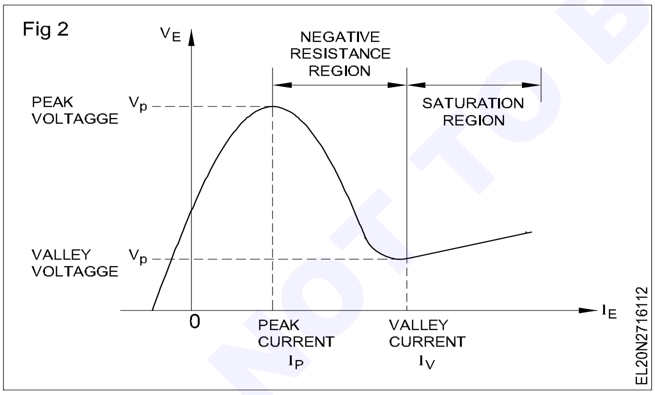
Objectives: At the end of this lesson you shall be able to
- **explain the construction and working principle of UJT**
- **make a quick test of UJT**
- **state the FET, JEFT principle, working biasing application as an amplifier**
- **list and explain the application of UJTs**

Unijunction transistor(UJT) is a three terminal semiconductor device as shown in fig 1a. In its appearance it looks like a transistor as shown in Fig 1b. As shown in Fig 1a, it consists of two layers(a P-layer and a N-layer) and therefore it has only one junction(hence its name, uni-junction).

The symbol of UJT and its electrical equivalent circuit is shown in Fig 1c and 1d.



UJT is a special semiconductor device because it exhibits negative resistance characteristics as shown in Fig 2. The details of the characteristics are discussed in subsequent paragraphs.



Construction of UJT

2646 and 2N 2647 UJT's are available in the modified TO-18 case style as shown in Fig 1b.

Equivalent circuit of UJT

The electrical equivalent circuit of UJT is shown in fig 1d. The resistance between the B_1 and B_2 terminals is called the inter-base resistance R_{BB}. The N-type silicon bar serves as a resistance divided into two parts R_{B1} and R_{B2} by the PN junction. The total of the internal R_{B1} and R_{B2} is the interbase resistance R_{BB}. Value of R_{BB} is typically in the range of 4 to 10 K ohms. Also r_{B1} usually a little greater than r_{B2} because the emitter is a little closer to B_2.

The interbase resistance R_{BB} is measured with the emitter open.

$$R_{BB} = R_{B1} + R_{B2} \text{ at } I_E=0.$$

Operation of UJT

The DC supply polarities for a UJT to function is shown in Fig 3. As can be seen from fig 3, B_2 is connected to +ve and B_1 to ground. As a result current(conventional) flows from B_2 to B_1. This conduction results in a voltage gradient along the N-type silicon bar. Therefore there is a voltage in the region of the emitter junction(V_E) which is positive with respect to ground. The magnitude of this voltage is given by the simple voltage divider action between R_{B1} and R_{B2}.

$$V_E \text{ or } (V_{RB!}) = \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB} = \eta V_{BB} \quad ....[1]$$

The Greek letter η (eta) is called the intrinsic stand-off ratio. This is an important data of any UJT and is invariably mentioned in all UJT data sheets. From the above equation, intrinsic stand-off ration η (eta) is given by,

$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} \quad ....[2]$$

UJT and its applications of triggering circuits

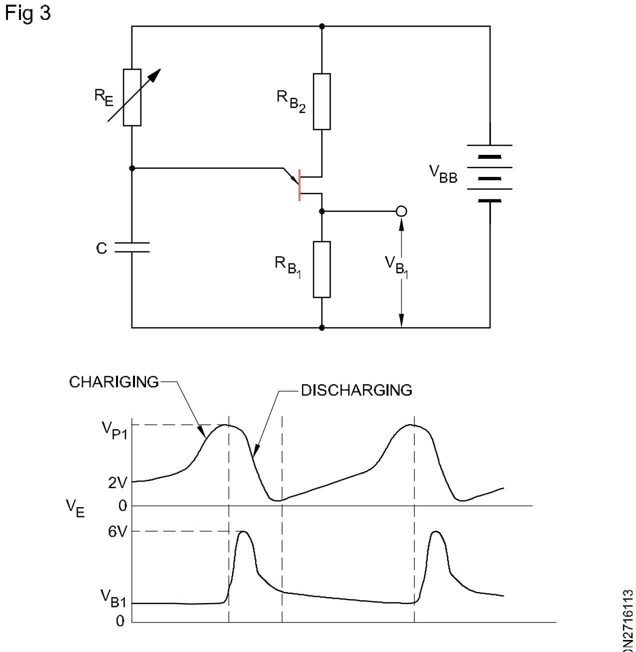
UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

- triggers for thyristors
- as oscillators
- as pulse and saw tooth generators
- timing circuits
- regulated power supplies
- bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R_1 with respect to the relaxation oscillator or free running oscillator as in Fig 3.

The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 3 to develop a relaxation oscillator.

Fig 3



UJT AS RELAXATION OSCILLATOR

The wave form developed across the capacitor is shown in Fig 3 as V_E, whereas the waveform produced across the resistor R_{B1} is shown as a pulse V_{B1}.

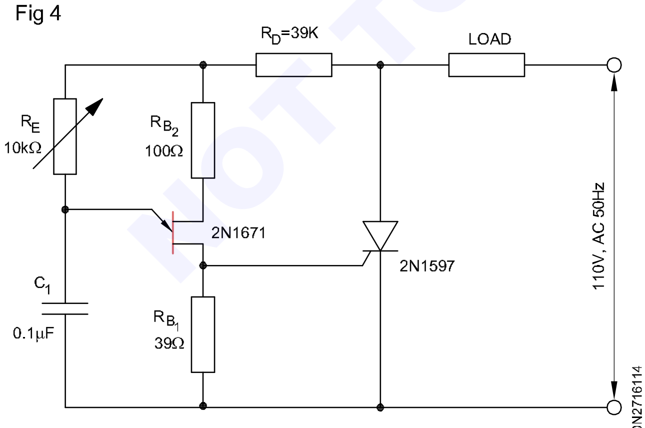
The frequency of oscillation

$$f = \frac{1}{R_E C}$$

Where R_E is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of R_E, the frequency of the oscillator can be varied. Although such an oscillator using a DC supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current. Fig 4 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

Fig 4



UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR

Field-effect transistor (FET)

The main difference between a Bi-polar transistor and a field effect transistor is that,

Bi-polar transistor is a current controlled device

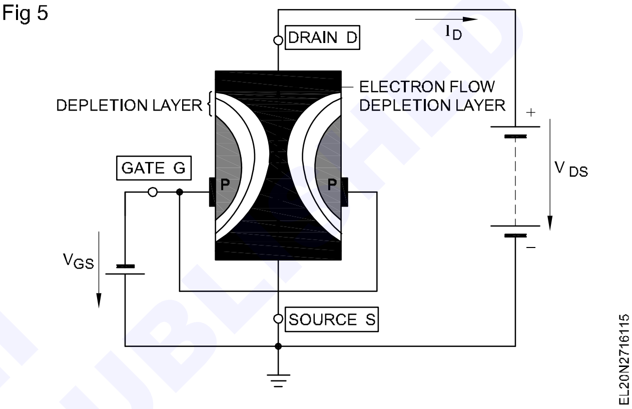
In simple terms, this means that the main current in a bi-polar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device

This means that the voltage at the gate(similar to base of a bi-polar transistor) controls the main current.

In addition to the above, in a bi-polar trasistor (NPN or PNP), the main current always flows through N-doped and P-doped semiconductor materials. Whereas, in a Field effect transistor the main current flows either only through the N-doped semiconductor or only through the P-doped semiconductor as in Fig 5.

Fig 5



If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N-type FET. The current through the N-doped material in the N-type FET is only by electrons.

If the main current flow is only through the P-doped material, then such a FET is referred as a P-channel or P-type FET. The current through the P-doped material in the P-type FET is only by Holes.

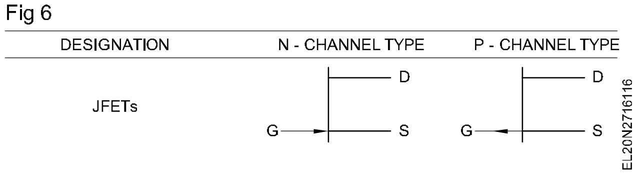
Unlike in bipolar transistors in which the main current is both by electrons and holes, in contrast in FETs depending on the type(P or N type) the main current is either by electrons or by holes and never both. For this reason FETs are also known as Unipolar transistors or Unipolar device.

There are a wide variety of FETs. In this lesson one of the fundamental types called as Junction Field Effect Trasistor (JFET) is discussed.

Junction Field effect Transistor(JFET)

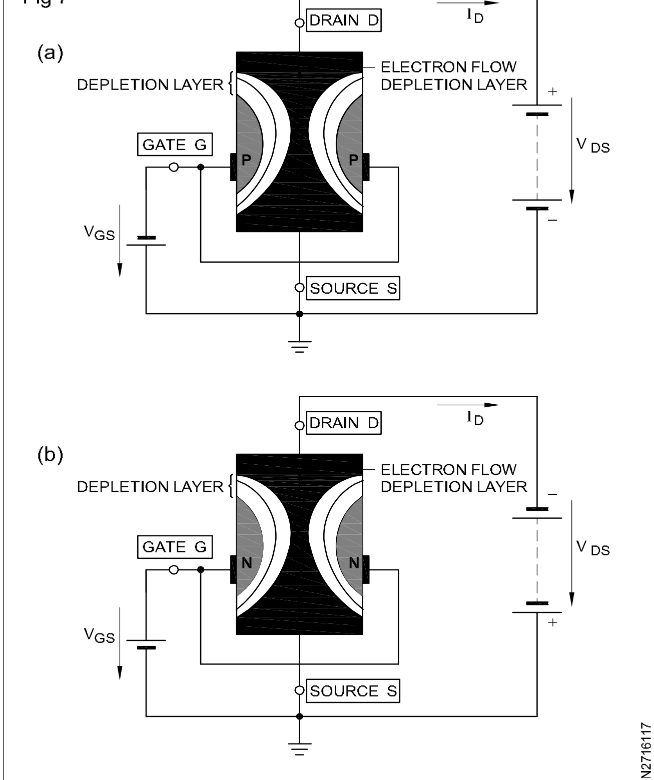
It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 6.

Fig 6



The internal diagram of a N-channel FET is shown in Fig 7.

Fig 7



N-CHANNEL FET

FET notation listed below are essential and worth memorizing,

1 **Source terminal:** It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).

2 **Drain terminal:** It is the terminal through which majority carriers come out of the bar.

3 **Gate terminal:** These are two internally connected heavily doped regions which form two P-N junctions.

4 **Channel:** It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

Working of FET

Similar to Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

Biasing a JFET

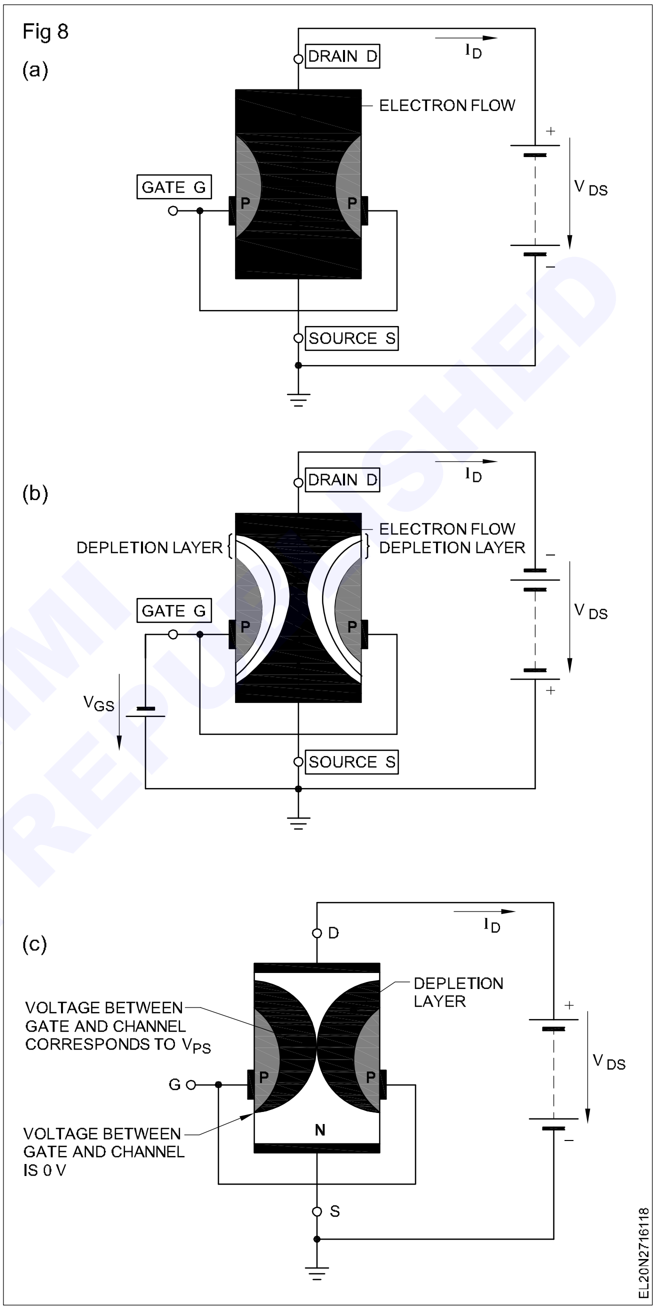
– Gates are always reverse biased. Therefore the gate current I_G is practically zero.

– The source terminal is always connected to that end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the posive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply for the drain to get the holes from the P-channel where the holes are the charge carriers.

Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage V_{DS} as shown in Fig 8a. When gate to source voltage V_{GS} is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current, I_D.

Fig 8



When gate is reverse biased with a negative voltage(V_{GS} negative) as shown in Fig 8b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 8b.

This depletion region decreases the width of the channel causing the drain current to decrease.

If V_{GS} is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel cutting off the flow of drain current as in Fig 8c. This voltage at which this effect occurs is referred to as the Pinch off voltage, V_P.

Thus, by varying the reverse bias voltage between gate and source($-V_{GS}$), the drain current can be varied between maximum current (with $-V_{GS}=0$) and zero current(with $-V_{GS}$=pinch off voltage). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explained above except that bias voltages are reversed and the majority carrier of channel are holes.

Advantages of FET

1 Since they are voltage controlled amplifier this makes their input impedence very high

2 They have a low noise output. This makes them useful as preamplifiers where the noise must be very low because of high gain in the following stages.

3 They have better linearity

4 they have low inter electrode capacity.

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence of the order of 10^9 ohms. This characteristic of FET, has made it very popular at the input stage of a majority of electronic circuits.

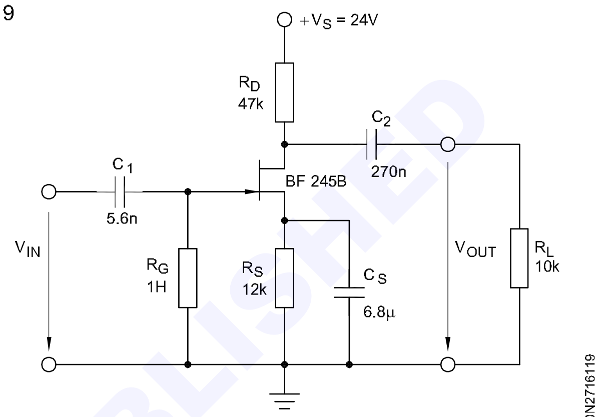
As discrete components FETS are mainly used in,

- DC voltage amplifiers
- AC voltage amplifiers(input stage amplifiers in HF and LF ranges)
- Constant current sources
- Integrated circuits of both analog and especially in Digital technology.

1 FET AC voltage amplifier

In the circuit at Fig 9, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometer can be connected in series for this purpose.

Fig 9



CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER

Power supplies-troubleshooting

Objectives: At the end of this lesson you shall be able to
- **list the initial activities involved in troubleshooting**
- **list the three general steps involved in troubleshooting**
- **list and explain the two popular methods of troubleshooting**
- **list the possible defects in a power supply.**

Introduction

Troubleshooting in any equipment or in a circuit involves the following activities:

- To identify the exact nature of the problem.
- To identify the section causing the problem.
- To isolate and arrive at the exact cause(s).
- To confirm the causes by necessary tests.
- To replace the problem-causing parts.
- To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting.

i Physical and sensory tests

- Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt out components.
- Smell for hot or burning components.
- Feel with the fingers for unduly hot components.

ii Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

iii Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fall in most cases.

- **Active high power components:** For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.
- **Active low power components:** These are the same as in (a) but are physically small and can handle smaller amounts of power.
- **High voltage/power passive components:** Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/ power. They are found in power supplies and output circuits.
- **Low power passive components:** These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohm, microfarad, microhenry, etc.)

Note: This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting: This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

Although this approach may take more time, this is the most suited approach for the beginners.

Shortcut or logical approach method of troubleshooting: This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. Divide and conquer procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting power supplies: All electronic systems can be broken down into blocks, generally based on their function. Fig 1 shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the Fig 2.

Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

Step-by-step approach to troubleshoot power supply: In the step-by-step approach of troubleshooting, the various blocks of the power supply is in Fig 1 and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Fig 1

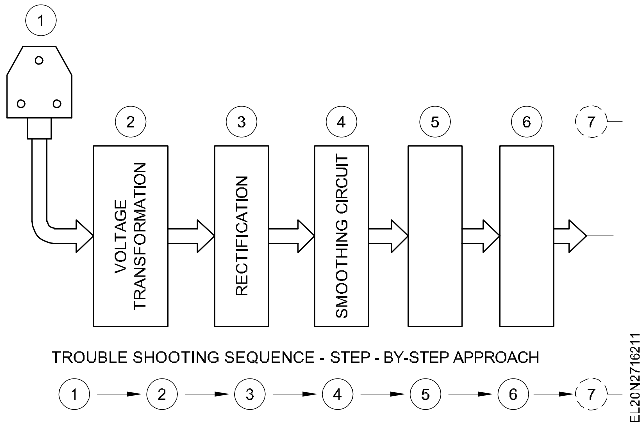
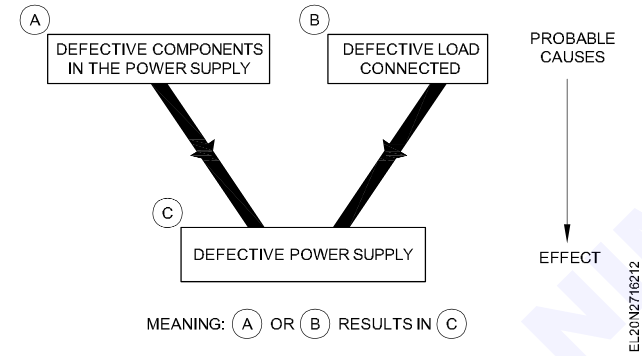


Fig 2



Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

Power control circuit using SCR,DIAC,TRIAC & IGBT

Objectives : At the end of this lesson you shall be able to
- **explain the construction and working of SCR,DIAC,TRIAC & IGBT**
- **explain power control circuits using SCR**
- **explain power control circuit using DIAC & TRIAC**
- **explain the construction and using of IGBT.**

Introduction to power electronics devices

Industrial electronics is concerned primarily with electronics applied to industries such as industrial equipments, controls and processes. An important application of electronics in industries is in controlling of machinery.

In communication electronics, domestic & entertainment electronics, generally, the electronic devices operate with currents in the order of Microampere to Milliampere. For industrial applications, most frequently, devices are required to handle currents in the range of ampere to several thousands of ampere. This, therefore calls for high power electronic devices. One such high power electronic device frequently used in industrial electronic application is the SCR,TRIAC,IGBT and DIAC for associate triggering circuits.

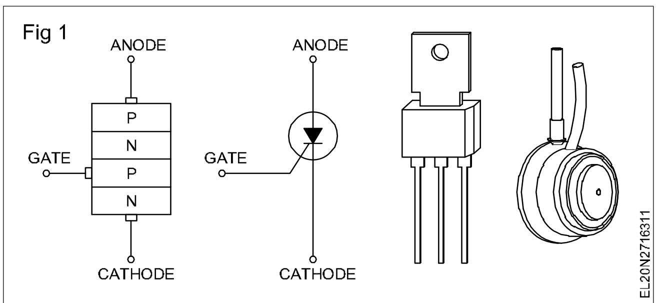
This devices can be used to run, dc motors from an ac power source, control power tool speed,also to control motor speeds of small appliances like, mixers and food blenders, illumination control, temperature control and so on.

Silicon Controlled Rectifier (SCR)

Before Silicon controlled rectifiers were invented(1956), a glass tube device called Thyratron was used for high power applications. Silicon Controlled Rectifier (SCR) is the first device of the thyristor family. The term thyristor is coined from the expression Thyratron-transistor. SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig 1 shows the electrical symbol, basic construction and a typical SCR packages.

Fig 1



Basic operation of SCR

When a gate direct current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR **does not cut-off**. This means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current**.

Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

In Fig 2b, when S_1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load R_L.

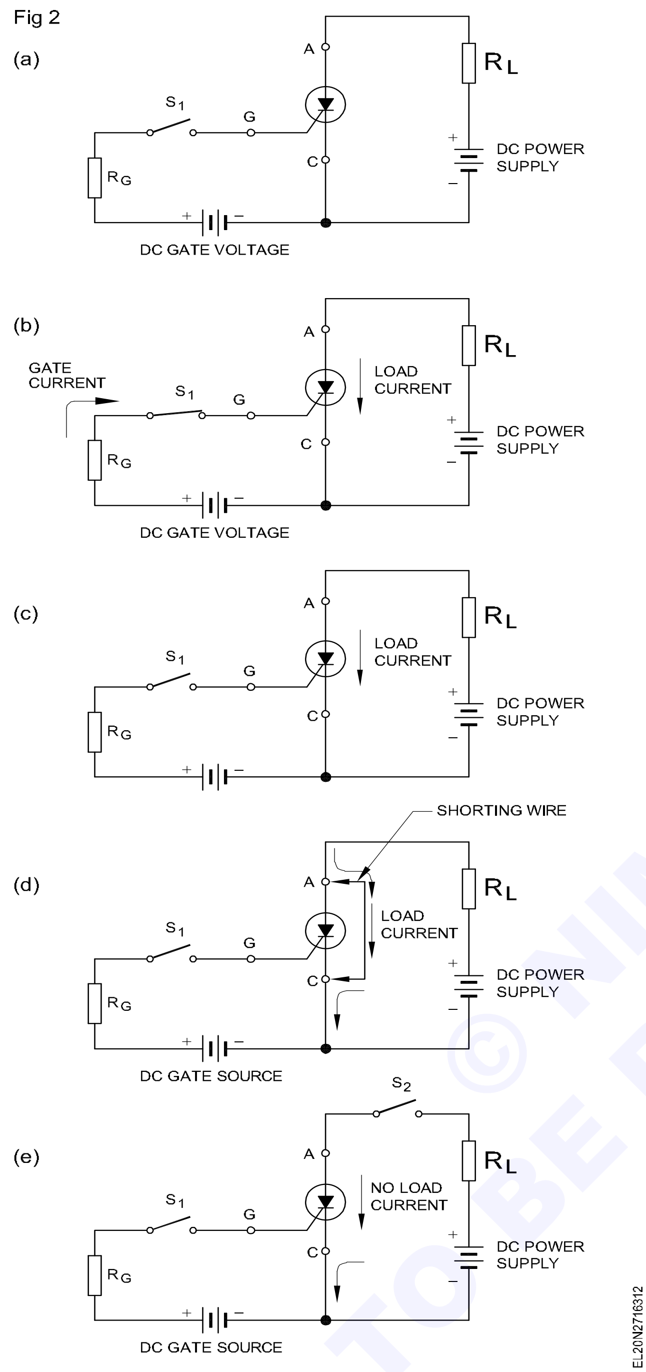
In Fig 2c, when S_1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR in the DC gate supply.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S_2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S_2 is closed. To make the SCR fire again, with the switch S_2 closed, the gate current should be made to flow by closing the switch S_1.

Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.

Fig 2



Important features of SCR,

- A very small gate current will control the switching OFF a large load current.

SCR operation with AC supply

Operation of SCR with AC circuit is similar to SCR operation . Fig 3 illustrates working of SCR in AC control circuits.

The SCR gate circuit consists of resistor R_1, potentiometer R_2 and silicon diode D_1. Resistors R_1 and R_2 act as a variable voltage divider. By adjusting the value of R_2 the gate current I_G can be suitably modified. Diode D_1 prevents negative voltage being applied to the gate when the ac supply is in the negative half cycle.

[X] During the +ve half cycle of the AC power source, as the positive half cycle voltage increases, the gate current I_G increases. When I_G reaches the trigger level, SCR fires and allows current I_L to flow through the load.

From this point onwards the SCR impedance is low and current I_L continues to flow throughout the +ve half cycle even though the gate current reduces below the trigger value(recall: once SCR is fired it continues to conduct even if the gate trigger is decreased or removed).

[Y] At the end of the +ve half cycle of AC power source, the +ve voltage drops to zero and SCR ceases to conduct(recall: one method of turning off SCR is to reduce the current through the SCR to below the holding current. This can be done by either opening the load circuit or reducing the supply to zero). Thus the SCR remains in off state throughout the negative half cycle.

Cycle [X] and [Y] repeats and current through the load flows in pulses as in Fig 3d.

Fig 3b,3c shows the voltage wave forms of source and gate voltage.

If the value of R_2 is varied, the point at which SCR triggers also varies changing the firing point shown in Fig 3d. In the circuit shown in Fig 3a, the firing of SCR can be adjusted any where between almost 180 degrees(maximum) to 90 degrees(minimum).

This simple AC control circuit shown in Fig 3a using SCR can be used to control the current through the load during the +ve half cycle of AC. During the -ve half cycle the SCR remains turned off. Thus, SCR can be used as an excellent switching device in AC control circuits.

The circuit in Fig 3 is useful only in limited applications such as temperature control of soldering iron etc.,

Power control using SCR

- DC Motor speed control
- AC Motor speed control
- Regulated DC power supplies
- Power control
- Circuit breakers
- Time delay circuits
- Soft start circuits
- Pulse, logic and digital circuits and so on.

Speed control of DC motors: In this Related Theory information only brief outline of power circuits is discussed. Due variation of motor load currents, inductance effect in winding, the practical circuit should be modified to suit the requirement. DC motors consists of field winding and armature winding. The speed of DC motors can be varied by two methods,

1 controlling the field current

2 controlling the armature voltage

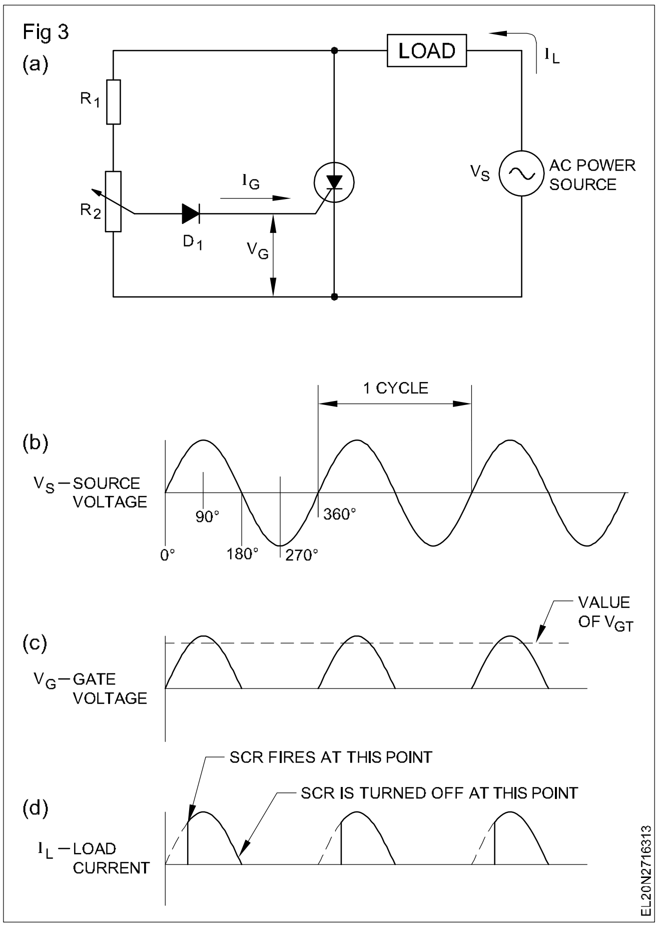


Fig 3

The first method is used for controlling the motor speed above the rated speed of the motor. The second method is used for controlling the motor speed below the rated speed of the motor.

Power circuit using TRIAC and DIAC

TRIAC or SCR for speed control of AC motors: Compared to SCR, Triac is most popular and works satisfactorily for lamp dimmer circuits and speed control of universal motors. Although both SCR and TRIAC can be used to phase control and vary the current through the lamp or motor, TRIAC being a full wave device, symmetrically controls the phase of both half cycles of the applied AC.

The resultant full wave current format then produces smooth lamp or motor operation that can be attained from the half wave rectification using SCRs. This is particularly noticeable during low/dim light requirement or low speed for motors.

The circuit at Fig 4 shows a TRIAC phase control circuit for controlling the brightness of the lamp or speed of universal motors.

The load shown in circuit at Fig 4 is a general load rather than a motor symbol because, this circuit can also be used for light dimmers and for the control of heaters.

This circuit features a double time constant phase-shift network. This reduces hysteresis in firing of the triac, thereby making the manual adjustment of dimmer operation or control off speed more repeatable.

The DIAC used as trigger device, adds to the reliability of the circuit. The elemental low-pass filter comprising L_F and C_F attenuates much of the radio-frequency interference (RFI) that gets generated and tries to get into the power line. This high frequency RF1 energy is generated by the extremely rapid turn-on time of the TRIAC. Which should be eliminated to avoid radio interference due to higher frequency content of the rectified wave form Otherwise, the frequency may interfere with reception at nearby places or in the main line circuit elsewhere.

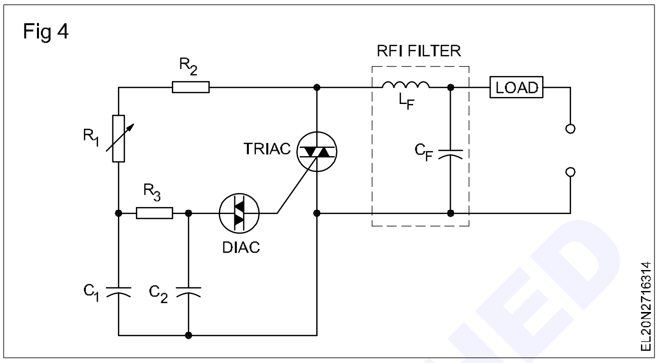


Fig 4

Lamp dimmers: Lamp dimmer is a circuit which controls as AC power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights: Advantage of semi-conductor based light dimmers over the auto transformer connected light dimmers

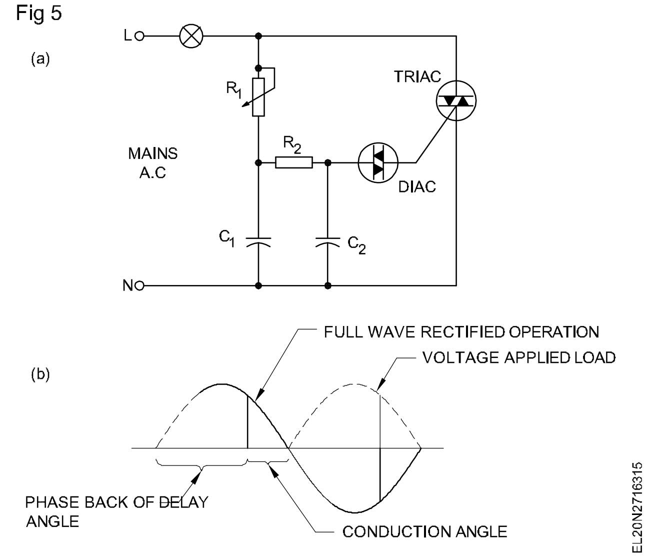
Old technology light dimmers used high wattage rheostats adjustable auto-transformers or saturable reactors, which were large, expensive generated considerable heat and power loss. Present day semi-conductor light dimmers have overcome these difficiencies and have therefore become very popular for many applications.

Modern semi-conductor dimmers are inexpensive, reliable, small generate little heat, and are easy to control remotely. These properties have not only permitted semi-conductor dimmers to supersede older types in theatres and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

Semi-conductor based light dimmers: Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low in rush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive lights with short lives, such as projection lamps and photographic bulbs.

Simple light dimmer: The circuit shown in Fig 5 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source (240V, 50Hz) by choosing appropriate value of circuit components. The circuit can control upto 1000watts of power to incandescent bulbs.

Fig 5

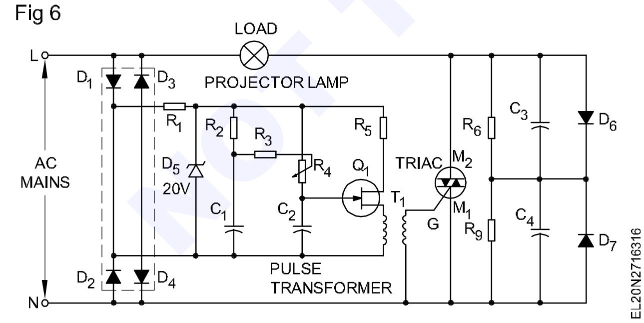


The power to the bulbs is varied by controlling the conduction angle of Triac. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

The control circuit for this Triac must function as shown in Fig 5b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The Triac is triggered after this delay and conducts current through the load for the remaining part of each alteration. This circuit can control the conduction angle from 0° to about 170° and provides better than 97% of full power control.

Light dimmer with soft-start option: The circuit at Fig 6 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching ON, the low resistance of the lamp causes very high inrush currents which leads to short filament/lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to eliminate high surges.

Fig 6



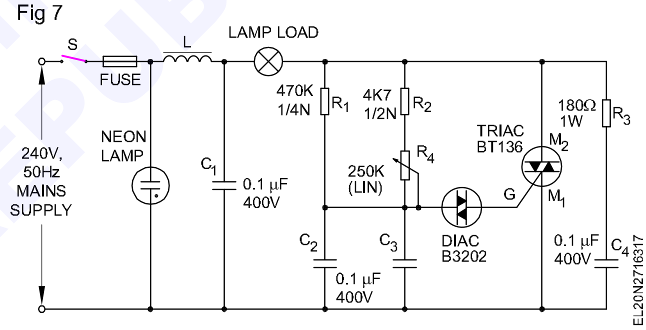
Operation of the circuit at Fig 6 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a DC voltage to resistor R_1 and zener diode D_5. The zener provides a constant voltage of 20volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero. Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger Q_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the inrush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle.

At the same time the lamp is being heated by slowly increasing applied voltage and by the time the peak voltage applied to the lamp has its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value.

Resistor R_4 controls the charging rate of C_2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R_4. T1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit from the low power triggering circuit (gate isolation methods for Triac is discussed in further paragraphs).

A simple lamp dimmer cum Universal motor speed controller: In the lamp dimmer cum universal speed controller circuit is in Fig 7, a Triac is used as control device. Phase control technique is used to control conduction angle of the triac which inturn control the power fed to the lamp.

Fig 7



A lamp L is connected in series with AC mains supply to the Triac. The trigger pulses to Triac gate is given through Diac. The Diac is triggered at the same breakover voltage level (30V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubber circuit: One problem with the Triac control is the sudden application of reverse voltage across the triac immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit R_4 and C_4 as shown in Fig 7. This RC network slows down the rate of rise of voltage applied across the Triac. This RC circuit connected across the Triac circuit is called snubber circuit.

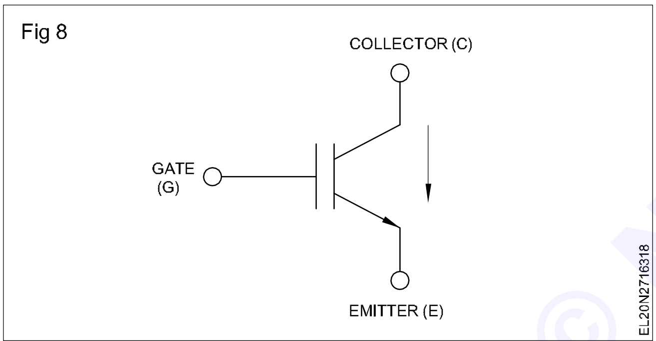
The inductance L and capacitor C_1 forms a low pass filter to substantially reduce the radio frequency interference (RF) generated by the rapid turn-on and turn-off the triac.

Fan speed regulator: The lamp dimmer circuit at Fig 7 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 7. The speed can be varied from almost zero to full speed by just rotating POT R_3.

IGBT (Insulated Gate Bipolar Transistor)

The insulated Gate Bipolar Transistor (IGBT) is the latest device is power electronics. It is obtained by combining the properties of BJT and MOSFET. We know that BJT has lower on - state losses for high values of collector current. But the drive requirement of BJT is little complicated. The drive of MOSFET is very simple (i.e only voltage is to be applied between gate and source). But MOSFET has high on - state losses.

The gate circuit of MOSFET and collector emitter circuits of BJT are combined together to form a new device. This device is called IGBT. Thus IGBT has advantages of both the BJT and MOSFETs. Fig 8 shows the symbol of IGBT. Observer that the symbol clearly indicates combination of MOSFET and BJT.



The IGBT has three terminals : Gate (G), collector (C) and emitter (E), Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to have turned 'ON'. When gate emitter voltage is removed, IGBT turns - off. Thus gate has full control over the conduction of IGBT. When the gate to emitter voltage is applied, very small (negligible) current flows. This is similar to the gate circuit of MOSFET. The on - state collector to emitter drop is very small like BJT.

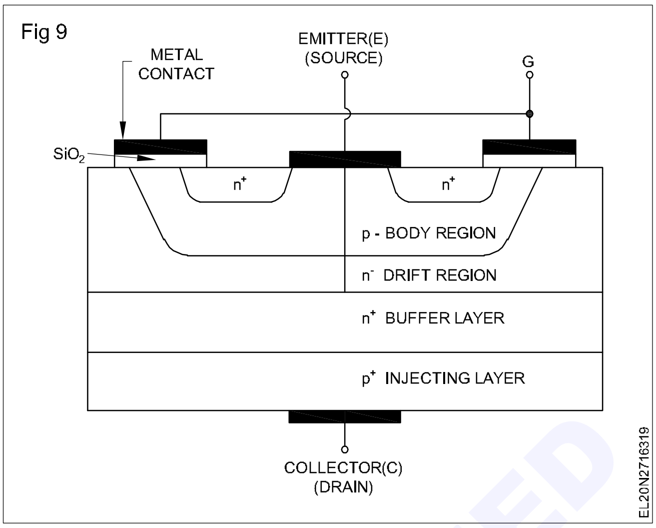
Structure of IGBT

The structure of IGBT is similar to that of MOSFET. Fig 9 show the vertical cross section of IGBT . In this structure observe that there is additional P+ layer. This layer is collector (Drain) of IGBT.

This P+ injection layer is heavily doped. It has the doping intensity of 10^{19} per cm^3. The doping of other layer is similar to that of MOSFET. n+ layers have 10^{19} per cm^3. P-type body region has doping level of 10^{16} per cm^3. The n- drift region is lightly doped (10^{14} per cm^3).

Punch through IGBT

The n+ buffer layer is not necessary for the operation of IGBT. The IGBTs which have n+ buffer layer are called punch through IGBTs. Such IGBTs have asymmetric voltage blocking capabilities. Punch through IGBTs have faster turn-off times. Hence they are used for inverter and chopper circuits.



Non - punch through IGBT

The IGBTs without n+ buffer layer are called non-punch through IGBTs. These IGBTs have symmetric voltage blocking capabilities. These IGBTs are used for rectifier type applications.

Operation of IGBT

When $V_{GS} > V_{GS}$(threshold), then the channel of electrons is formed beneath the gate as in Fig 10. These electrons attract holes from p+ layer. Hence, holes are injected from p+ layer into n- drift region. Thus hole / electron current starts flowing from collector to emitter. When holes enter p-type body region, they attract more electrons from n+ layer. This action is exactly similar to MOSFET.

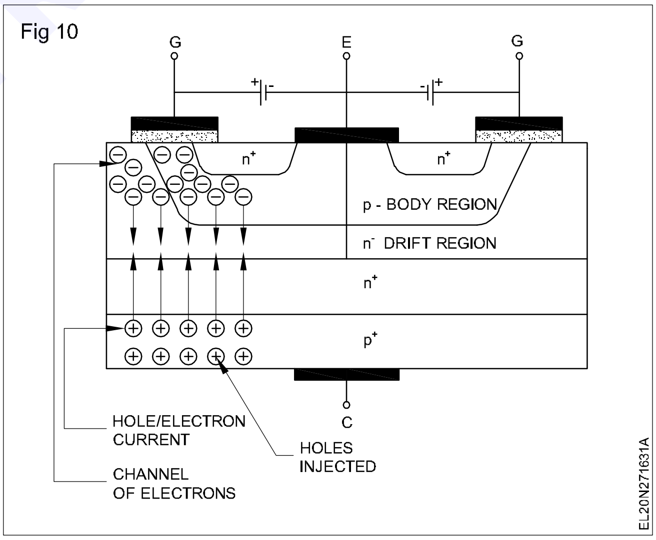
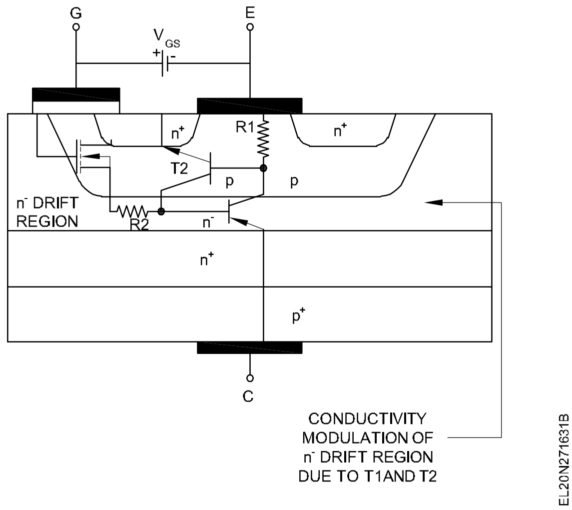


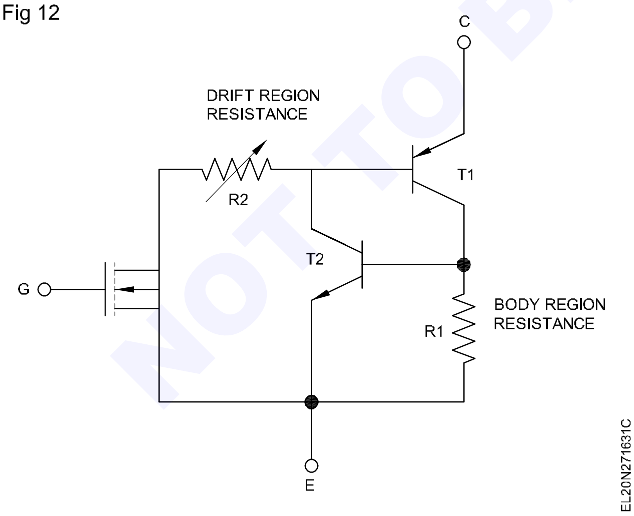
Fig 11 shows the structure of IGBT showing how internal MOSFETs and transistors are formed. The MOSFET is formed with input gate, emitter as source and n- drift region as drain. The two transistors T_1 and T_2 are formed as in Fig 11. The holes injected by the P+ injecting layer go to the n- drift region. This n- drift region is base of T_1 and collector of T_2. The holes in the n- drift region further go to the p - type body region, which is connected to the emitter. The electrons from n+ region (which is emitter) pass through the transistor T_2 and further in the n- drift region. Thus holes and electrons are injected in large amounts in n- drift region. This reduces the resistance of the n- drift region. This is called conductivity modulation of n- drift region. Note that such conductivity modulation does not exist in MOSFET. The connection of T_1 and T_2 is such that large amount of hole/electrons are injected in n- drift region.

Fig 11



The action of T_1 and T_2 is like SCR which is regenerative. The gate serves as trigger for T_1 through internally formed MOSFET. Fig 12 shows the equivalent circuit. In this figure observe that when gate is applied ($V_{GS} > V_{GS}(th)$), the internal equivalent MOSFET turns ON. This gives base drive to T_1. Hence T_1 starts conducting. The collector of T_1 is base of T_2. Therefore T_2 also turns ON. The collector of T_2 is base of T_1. Thus the regenerative loop begins and large number of carriers are injected in n- drift region. This reduces the on- state loss of the IGBT just like BJT. This happens due to conductivity modulation of n- drift region.

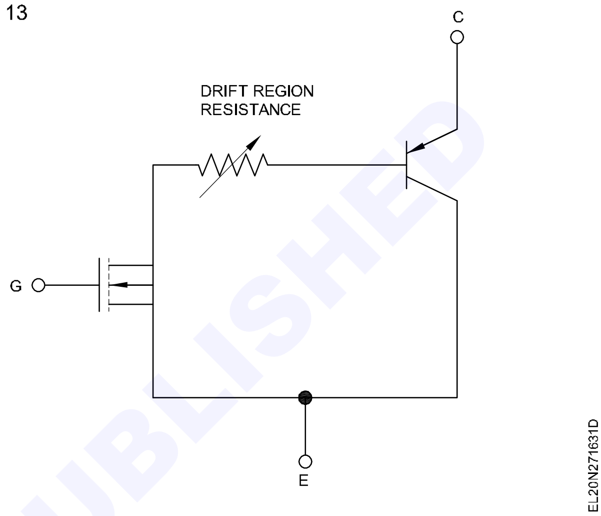
Fig 12



When the gate drive is removed, the IGBT should turn-OFF. When gate is removed, the induced channel will be vanished and internal equivalent MOSFET will turn-OFF. Hence T_1 will turn -OFF if T_2 turns-OFF T_2 will turn - OFF if the p- type body region resistance R_1 is very very small. Under such situation, its base and emitter will be virtually shorted. Hence T_2 turns - OFF. Therefore T_1 will also turn - OFF. Hence structure of IGBT is organizes such that body region resistance (R_1) is very very small.

If R_1 is very very small, than T_2 will never conduct and the equivalent circuit of IGBT will be as in Fig 13. IGBTs are thus different than MOSFETs because of conduction of current from collector to emitter. For MOSFETs, on state losses are high since resistance of drift region remains same. But in IGBTs, resistance of drift region reduces when gate drive is applied. This resistance reduces because of P+ injecting region. Hence, on state loss of IGBT is very small.

Fig 13



Merits, Demerits and Applications of IGBT

Merits of IGBT

1 Voltage controlled device. Hence drive circuit is very simple.

2 On - state losses are reduced.

3 Switching frequencies are higher than thyristors.

4 No commutation circuits are required.

5 Gate have full control over the operation of IGBT

6 IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1 IGBTs have static charge problems.

2 IGBTs are costlier than BJTs and MOSFETs.

Applications of IGBTs

1 AC motor drives, i.e. inverters.

2 DC to DC power supplies, i.e choppers

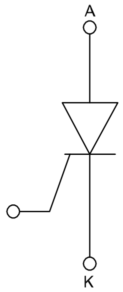
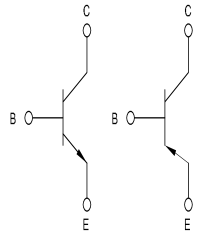
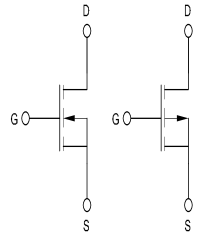
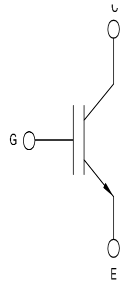
3 UPS systems.

4 Harmonic compensators.

Comparison of Power Devices

The power devices can be compared on the basis of switching frequency, gate drive circuit, power handling capacity etc. Table 1 shows the comparison of SCR, BJT, MOSFET and IGBT.

Table 1

S.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on	Base has full control control	Gate has full control	Gate has full control
5	On-state drop	< 2 Volts	< 2 Volts	< 4-6 Volts	< 3.3 Volts
6	Switching frequency	500 Hz	10 kHz	up to 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/4kA	2 kV/4kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and	Asymmetric	Asymmetric	Asymmetric
12	Application	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers, UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drivers, UPS choppers, SMPS etc,.

Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
- **explain integrated circuit**
- **state the classification of integrated circuit**
- **state the types of IC voltage regulators**
- **design voltage regulator for a required output voltage**
- **modify fixed voltage regulator to variable output regulator, circuit.**

IC introduction

Integrated circuit

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as Integrated circuits or ICs. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC

i Small scale integration (SSI) - consists of 1 to 10 transistors.

ii Medium scale integration (MSI) - consists of 10 to 100 transistors.

iii Large scale integration (LSI) - 100 to 1000 transistors.

iv Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

i Bipolar - carries both electron and hole current.

ii Metal oxide semiconductor (MOS) - electron or hole current.

iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

> **Note: The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.**

ICs are available in different packages and shapes. The usual packages are:

– dual in the packages DIP

– single in line package SIP and

– metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

Table 1

Integrated circuits	Discrete circuits
1 All in a single chip	All are separate discrete components
2 Requires less space due to smaller size	Requires more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

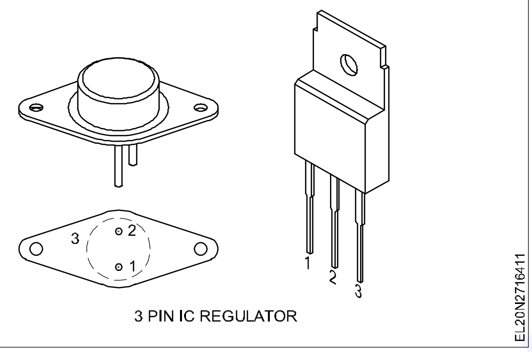
There are two types of voltage regulator ICs. They are,

– Fixed output voltage regulator ICs

– Adjustable output voltage regulator ICs.

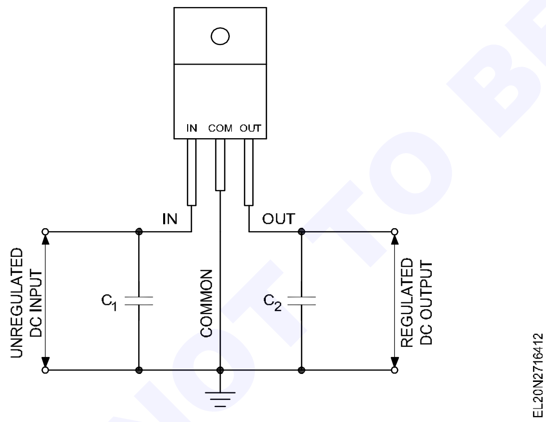
Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

Fig 1



These ICs consist of all those components and even more in the small packages in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as in Fig 2.

Fig 2



The reason behind using capacitor C_1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220µF to 1µF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1µF to 10µF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

The most popular three terminal IC regulators are,

1 LMXXX-X series

Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series

Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC µA7812. The table 2 given below lists the specifications of µA7812.

Table 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Identification of output voltage and rated maximum load current from IC type number

– 78XX and 79XX series are 3 Terminal voltage regulators.

– All 78XX series are positive output voltage regulators

– All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

Example

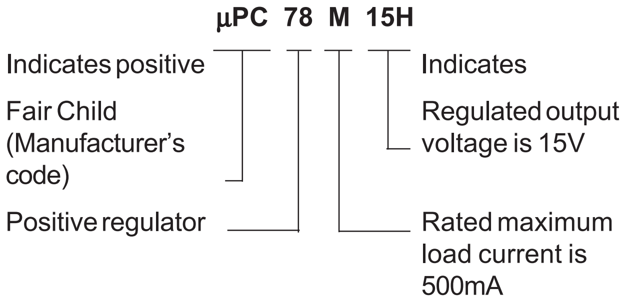
	7805	
Indicates positive output regulator		Indicates output voltage is +5V
	7912	
Indicates negative output regulator		Indicates output voltage is –12V

It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX - L indicates rated maximum load current as 100mA.

78MXX	-	M indicates rated a maximum load current as 500mA
78XX	-	Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.
78SXX	-	S indicates rated maximum load current is 2amp.

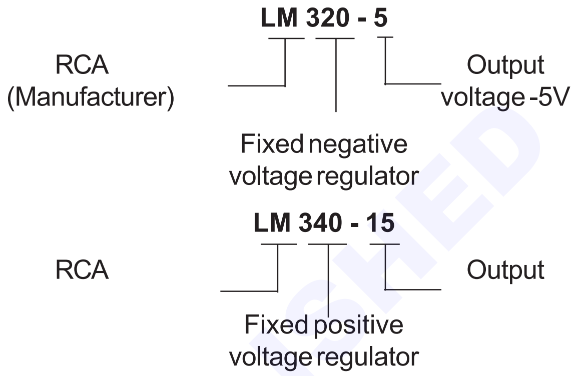
Example



LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX	→	Fixed –ve voltage regulators.
LM340-X or LM340-XX	→	Fixed +ve voltage regulators.

Examples



Binary numbers, logic gates and combinational circuits

Objectives : At the end this lesson you shall be able to
- **explain the digital electronics principle and positional notation and weightage**
- **explain decimal to binary conversion, binary odometer**
- **explain hexadecimal number system**
- **convert decimal to hexa, hexa to decimal and BCD system**
- **explain logic gates principle - NOT, OR and AND gates with truth table**
- **explain combinational gates - NAND, NOR with truth table and logic pulser.**

Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Digital circuits do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as 1967 = 1000 + 900 + 60 + 7. In powers of 10, this becomes.

10^3	10^2	10^1	10^0	
				$1 \times 10^3 = 1000$
				$9 \times 10^2 = 900$
				$6 \times 10^1 = 60$
1	9	6	7	$7 \times 10^0 = 7$
				1967

i.e. $[1967]_{10} = 1(10^3) + 9(10^2) + 6(10^1) + 7(10^0)$

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence 10^0, 10^1, 10^2, 10^3 etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$$

$$= 8 + 0 + 2 + 0$$

$$[1010]_2 = [10]_{10}$$

Any binary number can be converted into decimal number by the above said positional weightage method.

Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

Example

	0		
2	1	1	⟶ MSB
2	2	0	
2	4	0	
2	8	0	
2	17	1	
2	34	0	⟶ LSB

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore, $[34]_{10} = [100010]_2$

Counting binary number

To understand how to count with binary numbers, let us see how an odometer (KM indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1KM , reading becomes 0001.

Successive KM produces 0002, 0003 and so on upto 0009

At the end of 10th KM , the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010.

That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999KM , the odometer shows 0999.

After the next KM , the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Addition of binary numbers

Sum	Carry
0 + 0 = 0	0
1 + 0 = 1	0
0 + 1 = 1	0
1 + 1 = 0	1 (one plus one is equal to zero with carry one)

Ex: 1

```
   1 0
+  1 1
 1 0 1
```

Ex: 2

```
1 + 1 + 1 =  1
            + 1   (One plus one plus one is equal to one with carry one)
             10
            + 1
             11
```

Hexadecimal number system: In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

For Example

$[23]_{16} = [35]_{10}$; $16^1 \times 2 + 16^0 \times 3 = 32 + 3 = 35$;

$[2C]_{16} = [44]_{10}$; $16^1 \times 2 + 16^0 \times 12 = 32 + 12 = 44$;

Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

```
        0
16 |    1     1   ⟶ MSB
16 |   27     11  or  B
16 |  432     0   ⟶ LSB
```

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16} = 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$= 8192 + 512 + 48 + 10$

$= 8762_{10}$

BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

8421 code

The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers is the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in the Table.

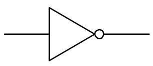
Decimal digit	0	1	2	3	4
BCD	0000	0001	0010	0011	0100
Decimal digit	5	6	7	8	9
BCD	0101	0110	0111	1000	1001

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.

Fig 1



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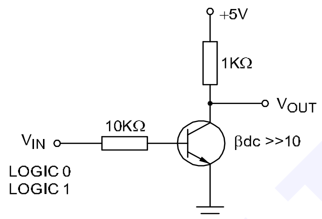
Transistor inverter

The Fig 2 shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When V_{in} is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore, V_{out} = +5V which is taken as high logic level. On the other hand, when V_{in} is in high level, the transistor saturates and V_{out} = V_{sat} = 0.3V i.e low level.

Fig 2



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The table summarizes the operation

V_{in}	V_{out}
Low(0)	High(1)
High(1)	Low(0)

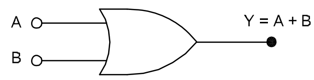
The logic expression for the inverter is as follows: Let the input variable be 'A' and the output variable be Y, then the

output Y = .

OR and AND gate circuits

OR Gate : The output of an OR will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 3 shows the schematic Symbol of an OR Gate :

Fig 3



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The boolean expression for OR gate is Y=A+B.

The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

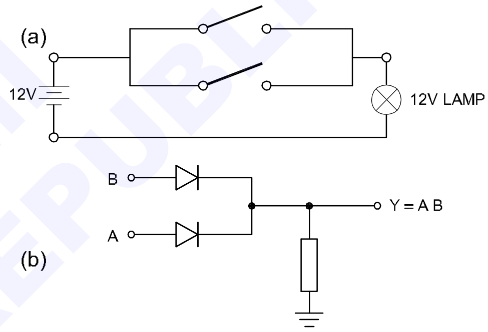
Truth table for OR gate

A	B	Y=A + B
0	0	0
1	0	1
0	1	1
1	1	1

Electrical equivalent circuit

The Fig 4a shows the electrical equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.

Fig 4



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2 in-put OR gate using diode

The Fig 4b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Assume logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

Case 1: A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

Case 2: A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

Case 3: A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

Case 4: A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y-is in high level.

OR gates are available in the IC form. IC7432 is a T.T.L OR gate IC having 4 OR gates inside it.

Simple application of OR gate

Intrusion detection

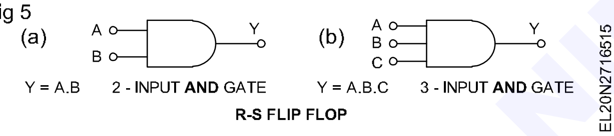
Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activities an alarm circuit to warn of the intrusion.

AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output. Even if one of the inputs is low, the output becomes low.

AND gate symbols for 2 input and 3 input gates are shown in Fig 5a and 5b.

Fig 5



Truth table

Two input AND gate

A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

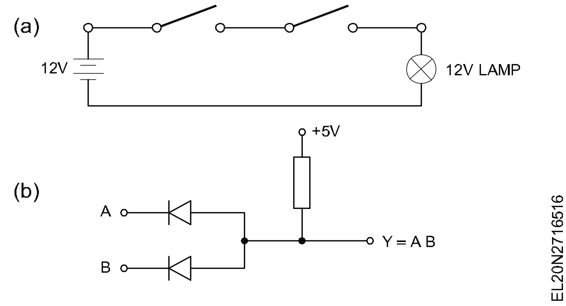
Three input AND GATE

A	B	C	Y=ABC
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Electrical equivalent circuit of an AND gate

The output is available only when both the switches are closed. IC7408 is a T.T.L quad AND gate IC. (Refer data book for pin diagram). The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 6a and 6b.

Fig 6

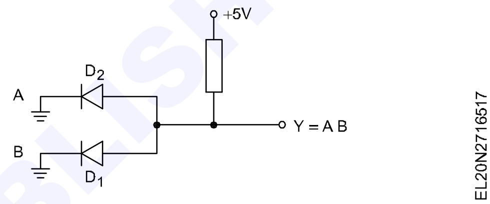


Two input AND gate using diode

I condition

A=0, B=0, Y=0 as in Fig 7.

Fig 7

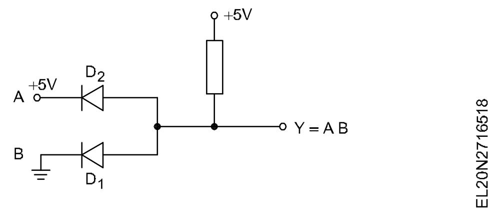


During the above condition I/P A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the O/P Y to logic-0.

II condition

A=0, B=1, Y=0 as in Fig 8.

Fig 8

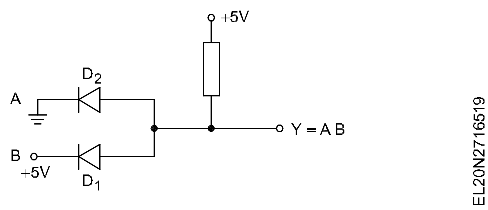


In the II condition shown in the figure above, diode D_1 is connected logic-0 input and diode D_2 is connected to +5V [Logic high]. Diode D_1 is in forward bias and conducts. Diode D_2 is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode D2 does not conduct. The output Y is pulled down to logic zero, since D_1 is conducting.

III condition

A=1, B=0, Y=0 as in Fig 9.

Fig 9

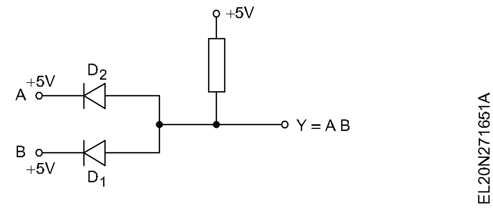


The III condition is similar to the II condition. D_2 is forward biased. D_1 is reverse biased. Hence output Y is pulled to logic-0.

IV condition

A=1, B=1, Y=1 as in Fig 10.

Fig 10



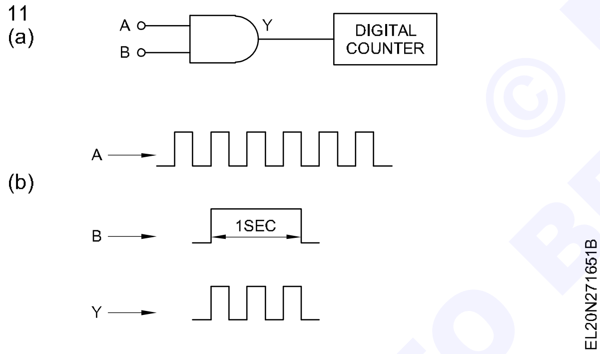
In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore output y is +5V i.e y is in logic-1 condition.

AND gate as an Enable/Inhibit device

A common application of the AND gate is to enable (i.e to allow) the passage of a signal (pulse waveform) from one point to another at certain times and to inhibit (prevent) the passage at other times.

In Fig 11a AND gate controls the passage of a signal (waveform A) to a digital counter. The purpose of this circuit is to measure the frequency of waveform 'A'. The enable pulse has a width of precisely 1 second. When the enable pulse applied at B is high, waveform A passes through the gate to the counter, and when the enabled pulse is low, the signal is prevented (inhibited) from passing through. Refer Fig 11b for the waveforms of the above process.

Fig 11



During the 1 second interval of the enabled pulse, a certain number of pulses in waveform A pass through the AND gate to the counter. The number of pulses counted by the counter is equal to the frequency of the waveform A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

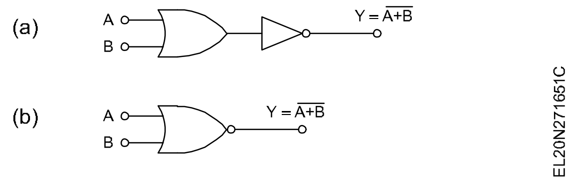
Combinational gate circuits - NOR and NAND

NOR Gate

In Fig 12a the output y of the circuit equals to the complement of A OR B, because the circuit is an OR gate followed by a NOT gate. To obtain high output [Logic-1], both the inputs should be tied to low input [Logic-0]. For the rest of the other three possibilities, output will be zero, the combination of this OR and NOT gate is called as NOR gate.

Symbol (Fig 12b) :

Fig 12



We can define a NOR gate as follows:

The output of a NOR gate is 0, even if one of the inputs is in logic-1. Only when both the inputs are in logic-0, the output is in logic-1.

Truth table

A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

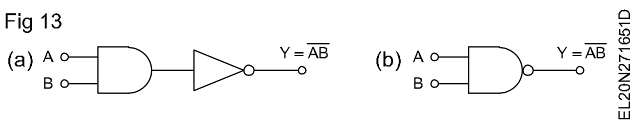
IC7402 is a T.T.L NOR gate IC. It contains 4 NOR gates. For pin details, refer data book.

NAND gate

An AND gate followed by a NOT gate forms the NAND gate as in Fig 13a. In this gate to get a low output (logic=0), all the inputs must be in high state and to get high output state, any one of the inputs or both inputs must be in low state.

Fig 13b is the standard symbol for a NAND gate. The inverter triangle has been deleted and the bubble is moved to the AND-gate output.

Fig 13



Truth table for NAND gate

A	B	
0	0	1
0	1	1
1	0	1
1	1	0

Pulsed operation

Output waveform Y is low only for the time intervals when both inputs A and B are high as shown in the timing diagram Fig 14.

Logic pulser

Fig 15 shows the circuit diagram of logic pulser, the circuit essentially consists of NAND gates connected debouncer circuit and its output is Double inverted. The LED indicates, pulses ON or OFF status.

Fig 14

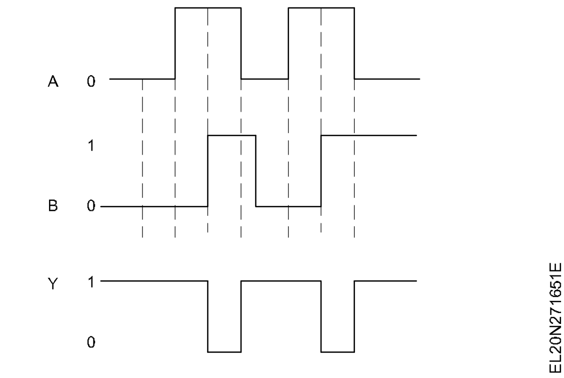
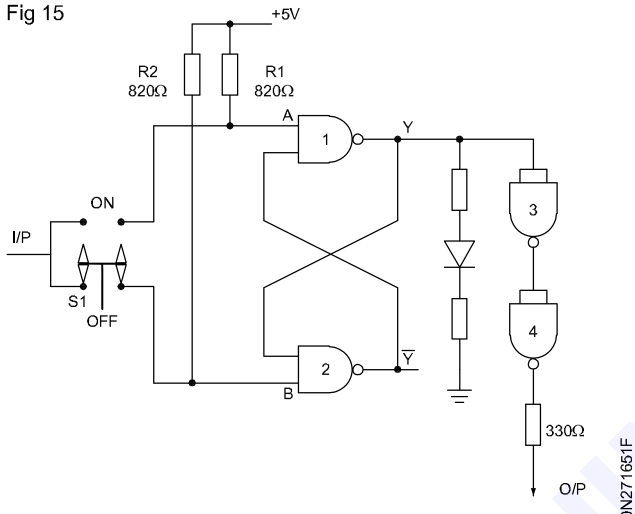


Fig 15



LOGIC PULSER

When switch S_1 is not pressed, (OFF position) B input of NAND gate No.2 is grounded, hence its output $\overline{Y}$ is forced to go logic HIGH. This HIGH output is feedback to NAND gate 1, A input of NAND gate 1 is also held HIGH through R_1 resistor (820Ω) and thus the output of NAND gate-1 'Y' is at low. This logic low output keeps LED in OFF condition and this logic low is again double inverted at the logic pulser tip through NAND gate 3 and 4 to get logic low level at pulser tip.

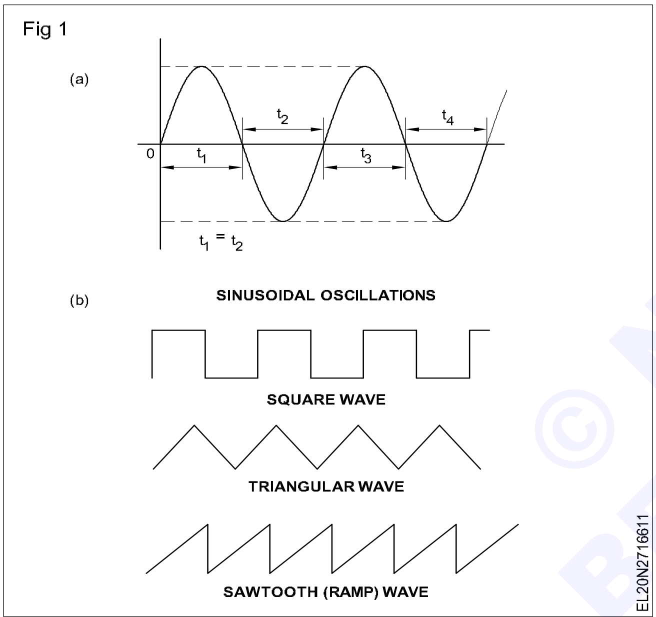
When S_1 is pressed to ON, A input of NAND gate is forced to go logic-low. Hence the output of this NAND gate is forced to go logic-HIGH. Therefore the 'Y' output is at logic-1, so LED glows and a logic-HIGH appears at probe tip. Also note that with HIGH at Y output, the inputs of NAND gate 2 are also at logic-HIGH and the output of NAND gate-2 is forced to go low. As long as switch S_1 is at ON position the probe tip is HIGH. When it is released it springs back to OFF position, and the output returns to a logic-LOW condition.

Wave shapes - Oscillators

Objectives: At the end of this lesson you shall be able to
- **state the working principle and gain of oscillator**
- **explain the RC phase-shift oscillator and frequency calculation**
- **state the features, gain and frequency of Hartley, colpitts and crystal oscillators**
- **state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.**

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.



The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

– An amplifier

– A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than A_v (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i k = 0.01

ii k = 0.02

iii k = 0.025

Solution

i $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.01 \times 40} = \frac{40}{0.6} = 66.7$

ii $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.02 \times 40} = \frac{40}{0.2} = 200$

iii $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.025 \times 40} = \frac{40}{0} = \infty$ (Infinity)

In (iii) the gain of the amplifier become infinite when the loop gain $kA_v = +1$. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of $kA_v = 1$ can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

There are 3 types of oscillators.

1 Hartley oscillator

2 Colpitts oscillator

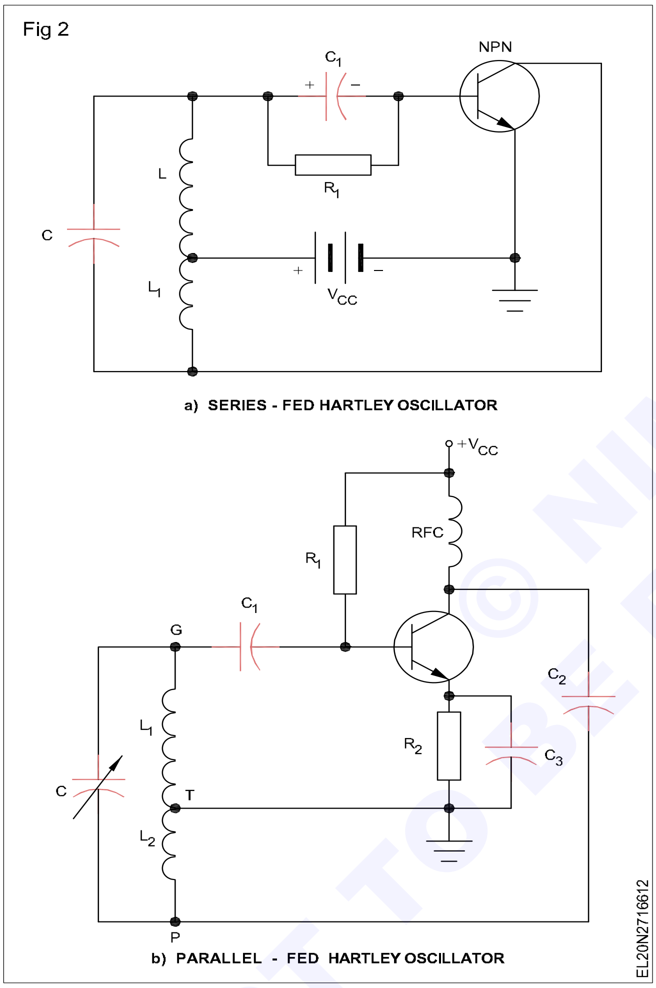
3 Crystal oscillator

Out of three Hartley oscillator only discussed.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 2a and 2b.

As in Fig 2a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator, but the tickler circuit coil L_1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 2b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.



The circuit at Fig 2b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations.

The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

RF current through L_2 induces a voltage in L_1 in proper phase and amplitude to sustain oscillations.

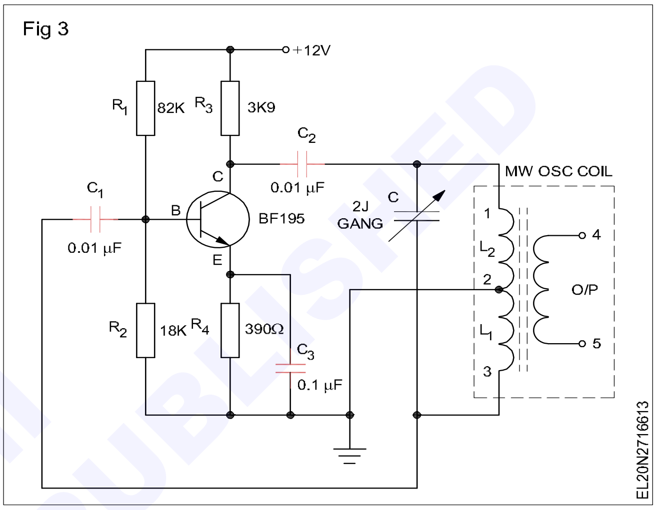
The position of the tap at the junction of L_1 and L_2 determines how much signal is fed back to the base circuit.

The capacitor C and the inductors $L_1 + L_2$ forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C_1 and R_1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the V_{cc} supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor R_2 connected in the emitter provides DC stabilization. R_2 is by-passed by C_3 to prevent AC degeneration.

The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 3, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.



Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L ($L = L_1 + L_2$) and C are known using the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.

- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

$$f = \frac{1}{T}$$

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical Hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 3.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

Control elements, accessories - layout of control cabinet

Objectives: At the end of this lesson you shall be able to
- **explain the layout marking methods and necessity**
- **state the methods of marking, cutting, drilling, fixing of accessories and components**
- **explain the methods of mounting and wiring the accessories**
- **state the various control elements used for control panel board**
- **list the different wiring accessories used in control panel wiring.**

Introduction

Preparation of layout drawing and marking on control cabinet is very much essential, we must have a clear vision of mounting components and their location on panel board/ control cabinet.

There is no such important method inpratice to make the layout on control cabinet. However a neat layout on control cabinet is very much required.

The display and indicating instruments should be selected on the top position of the cabinet. Heavy and rare operated devices such as fuse breaker etc; are to be fixed on the bottom of the cabinet.

The components and fixtures should have sufficient space in between to carryout future repair (or) replace requirements. But too much space should not be provided, that will increase the size of the cabinet unnecessarily. While finalising the layout plan the relevant IE rulers to be followed for better result.

Layout marking

Wiring diagrams for power and control circuit should be developed for sequence of operation of automatic star - delta starter with forward and reverse. Types of protection, control, indication and measuring accessories needed should be finalized.

To wire up the above starter in a control panel the well designed and easily understandable layout should be finalized. Layout of the finalized wiring diagram should developed keeping important features of the control panel in mind. While designing the control panel the outside dimensions, the swing area of cabinet doors and area required for maintenance and tools kit have to be considered.

Control panel may be often used near the process area with high temperature, humidity and dust hence the arrangement for cooling fan and dehumidifier along with filters and intake and exhaust vents should be needed.

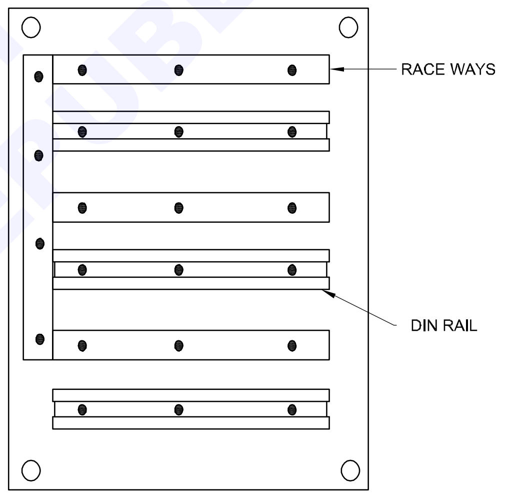
Suitable size of control panel which can accommodate all the controlling, protective, measuring, indicating and wiring accessories required for said wiring should be obtained or fabricated.

While selecting the control and protective accessories of the control panel the full load current of the individual load, total load and duty cycle, simultaneous operation of the load and 25% additional load capacity of the motors have to be considered.

The over load and short circuit protection may be given either ahead of the control panel by calculating the highest rating of the branch circuit or individual motors depends on space available, cost factor and sensitiveness of the operation.

The finalized layout may vary depends the individual design and mind application. However a sample layout marking for the above starter is given in the Fig 1.

Fig 1



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TYPICAL LAYOUT MARKINGS

Once the panel layout is designed we must find out where and how to fit the accessories.

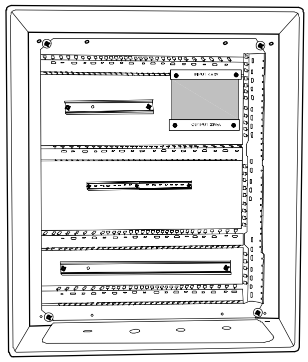
The finalized layout of accessories can be marked in the control panel using suitable marking device.

Cutting and drilling

The mounting or fixing holes along with necessary tap or die in suitable size (if any) can be prepared in the front door and inside of the control panel as in Fig 2.

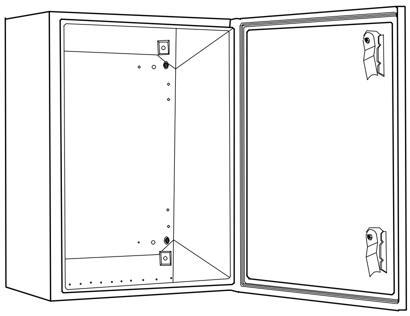
Din rail is a metal rail made from cold rolled carbon steel sheet with zinc plated or chromate bright surface finish used to mount the circuit breakers and control accessories without using screws as in Fig 2. DIN rail being fixed to the chassis before fitted the contactors and other accessories as in Fig 3.

Fig 2



CONTROL PANEL WITH RACEWAYS / DIN RAILS

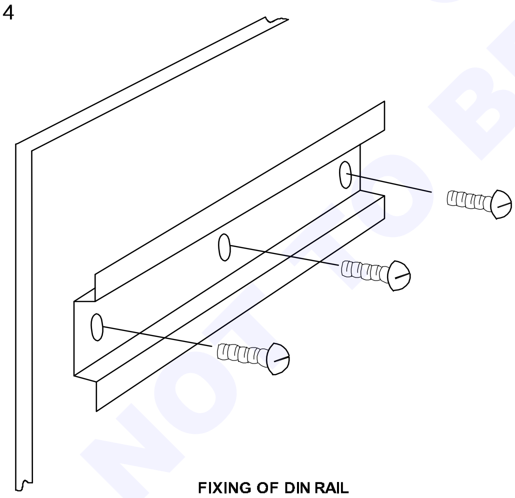
Fig 3



CONTROL PANEL WITH MOUNTING AND FIXING HOLES

The standard specification of widely available DIN rail is top hat rail EN 50022 which dimension is 35 mm width and a 15 mm or 7.5 mm depth. They can be cut in to the required length and then screwed or bolted inside the panel before mounting any accessories and wiring begins as in Fig 4.

Fig 4



FIXING OF DIN RAIL

Race way is one form of cable ducting used to carry the wiring between components and keeping the wires neat. The leads wires and cables are laid inside the raceways brought out through the holes / slots in the sides and can be inspected by removing the cover of the raceways.

The minimum spacing between components and raceways should be 100 mm for 415V systems and 50 to 75 mm for less than 415V system. The next stage is to clip the accessories to the rail and wire them.

Mounting and wiring the accessories in control panel

The accessories can be mounted on the DIN rails allowing sufficient space for easy maintenance, wiring and troubleshooting. The mounting should not move or lean in the DIN rail due to vibration or strain due to cables.

Contactor can be either flush mounted to the chassis or DIN rail - mounted . Contactor mounting type over load relay which have three pin connectors engage into the contactor terminals may be used to reduce the mounting and wiring time and labour.

To mount the contactor on rail first place the back top groove on the top of rail and turn it downwards against the lower rail which will cause the spring of the contactor to retract and snap into place behind the rail. There is a slot in the spring clip of the contactor so that the clip can be retracted using small screw driver or connector to remove the contactor if required. To avoid fouling the underneath of the accessories use screws with low profile heads.

The contactor arrangements and terminals are usually labeled which conforms to BS 5583. For example 1 and 2 for NC contacts, 3 and 4 for NO contacts, odd numbers like 1, 3 and 5 for incoming terminals and even numbers like 2, 4 and 6 for outgoing terminals of the main contacts of contactors and OLR.

The conductor should be trimmed OFF to that the conductor does not insert more than the half way through the connectors. Single strand wire should be folded back to give additional thickness. The over tightening of screw have to be avoided otherwise this can crush the strand and give a weak connection.

All the internal wiring should be terminated in the top and external wiring in the bottom of the connectors to avoid the crossover of both wirings. Flexible conduit and cables have to be installed in such a way that the liquid or water if any can drain away from the fitting and grommets.

An earth terminal usually green or green yellow to be clamped to the rail and ensure the cabinet and door are earthed properly.

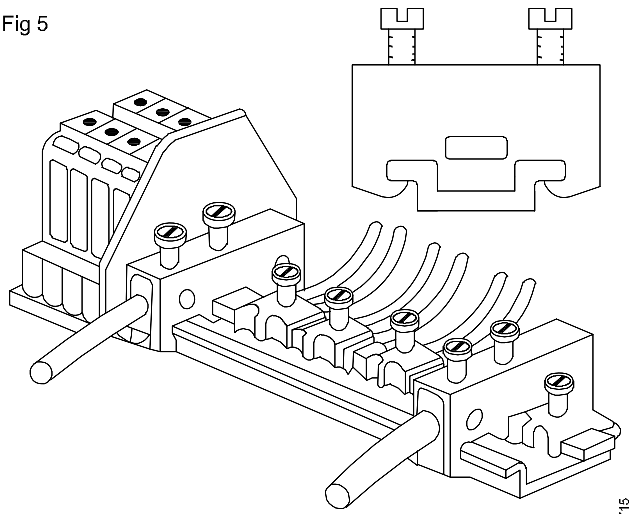
An insulated separator can be used to isolate the high voltage connections from others. End stops are used to clamps the connectors together and close the open terminals on one end, sometimes the earth terminal will do the same job as in Fig 5.

The control panel should be grounded properly so that control panel should have proper earthing bolts / nuts. If more ground points are used a common earth plate should be fixed inside the cabinet as in Fig 5.

U loops of the cables as long as possible facing down and anchored on each side of the hinged doors and panel with screws or bolts and do not use adhesive. Place the sleeve and spiral flexible conduits of suitable size over the cables running between the hinged doors and panel as in Fig 6.

The care to be given to the bundle of wires which is mounted on the hinged doors should not restrict the opening and closing of the door or the doors should not damage the wires.

Fig 5



TERMINAL CONNECTORS / EARTH TERMINAL WITH SEPERATOR

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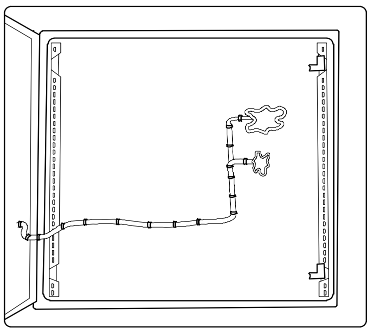
Fig 6



U LOOP OF CABLES

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Minimize the use of cable ties if the raceways are used. They may be cut OFF during troubleshooting and rarely replaced.

Routing and bunching

Routing : Conductors and cables should run from terminal to terminal without any intervening joins and cross over. Extra length should be left at connector / terminals where assembly needs to be disconnected for maintenance and servicing. Multi core cable terminations have to be adequately supported to avoid undue strain on the terminals.

Different colour may be used to aid identification of group of controls and functions.

The associated earth and neutral conductor should be routed close to the respective live conductors to avoid undue loop resistance.

Select the race ways to leave some slacks or looping of the cable inside it. The wires inside the race way should not more than the half fill.

Bunching and tying

Run the wires in horizontal and vertical lines avoid diagonal runs as possible. Do not run the wire over the other devices or race ways. Uses of spring cage terminals instead of standard screw terminals can reduce the termination error, the wiring and maintenance time which in turn reduce the cost and labour.

To connect the accessories, cut the individual control wires to the proper lengths, strips the insulation, mark wire identification, insert ferrules at the ends of wires, use suitable lugs or thimbles.

The wires should be neatly bundled, run in the race ways and routed with smooth radius bends.

All the terminals, wires and components should have identification marks and labels. A good labelling and identification will reduce the errors in termination, testing, maintenance and repairs. A legible and durable label in an efficient and cost effective manner may be chosen.

To the possible extent the power and control wiring should be run in separate race way or cable management which will reduce the radio interference, trouble shooting time and make the future alteration if any is easier.

By taking some extra cares like pest control, dust control, adequate terminal pressure, selection of proper wires and accessories, it can be ensured that the control panel has no failure time and with moderate maintenance it will be trouble free panel for entire life.

Where the multiple earths are used it is necessary to use a common earth terminal or connectors as in Fig 5.

Tests

Before energizing the control panel all necessary tests should be carried out like open, short, earth continuity and earth soundness etc. The supply voltage and frequency are also to be checked.

Control elements

Difference between control panel and switch board

A panel board contains a single panel or a group of panel units as single panel that includes bus-bars, protective devices and control switches, instruments and more starters etc.

For wiring of control panel board the following control elements / components and accessories are required.

They are

- Isolating switch
- Push button switch
- Indicating lamp
- MCB (Miniature Circuit Breaker)
- Contactors
- Electro mechanical relays
- Thermal over load relays
- Time delay relay (timers)
- Rectifiers
- Limit switches
- Control transformers etc.

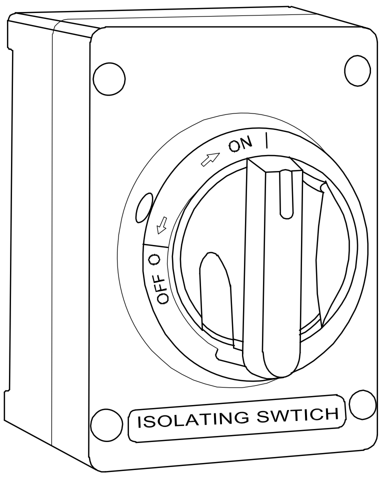
Control elements for control panel

1 Isolating switch (Fig 7)

Isolating switch (Isolator) is a manually operated mechanical switch which isolates/disconnects the circuit which are connected with it from the supply system as and when required. It should be normally operated at "OFF" load condition.

It is available in different current, voltage rating and size.

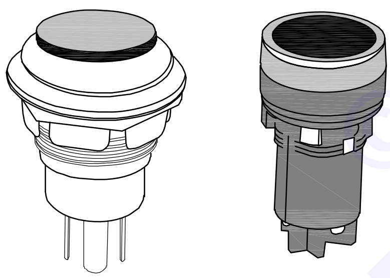
Fig 7



2 Push button switch (Fig 8)

Push button is a simple push switch mechanism for making or breaking the circuit as and when required. It is made out of hard plastic or metal. An indicating lamp is incorporated with the push button switch to indicate start or stop is also available.

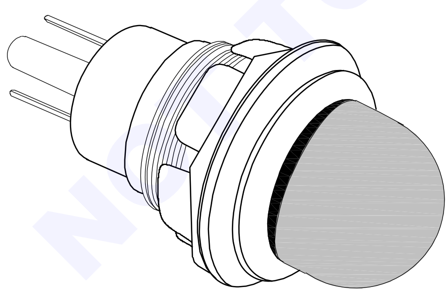
Fig 8



PUSH BUTTON SWTICHES

3 Indicating lamp (Fig 9)

Fig 9



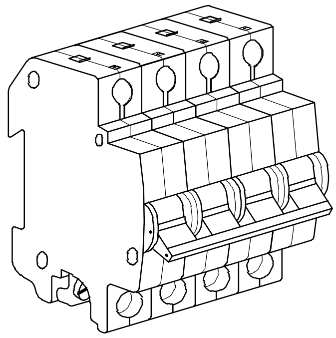
INDICATING LAMP WITH HOLDER

It is a low voltage, low wattage filament or neon or LED lamps used to indicate the various indication like availability of supply or motor **ON/OFF,** mains/motors fails or trip etc.

It is available in different size, colour and wattage. It should be generally fitted in the front side of the control panel with suitable holder.

4 MCB (Fig 10)

Fig 10



MINIATURE CIRCUIT BREAKER

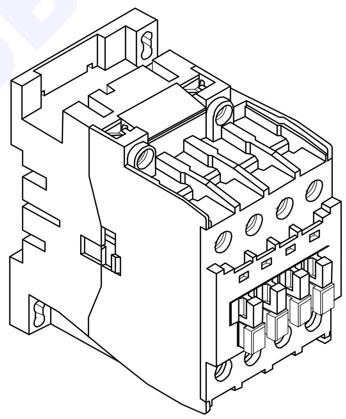
Miniature circuit breaker (MCB) is an electro mechanical protective device which protect an electrical circuit from short circuit and over load . It automatically turns off, when the current flowing through it exceeds the maximum allowable limit.

5 Fuses

It is a protective device which is connected is series with the live wire to protect the circuit from short circuit and earth fault.

6 Contactors (Fig 11)

Fig 11



A contactor is an electrically controlled double break switch used for switching ON / switching OFF the electrical circuit, similar to a relay with higher current ratings. It is controlled by a circuit which has a much lower power level than the switched circuit.

7 Electro mechanical relays (Fig 12)

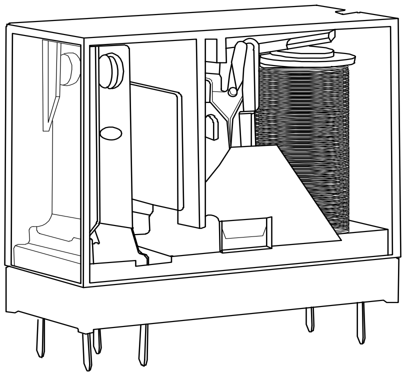
Electromechanical relays are electrically operated switches used to control a high powered circuit accessories using low power signal. When an electric current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

8 Thermal overload relays (Fig 13)

It is a thermally operated electromechanical device that protects motors from over heating and loading.

Fig 12



ELECTRO MECHANICAL RELAY

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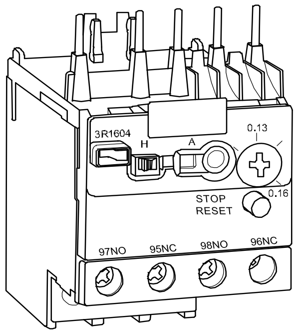
Fig 13



THERMAL OVERLOADED RELAYS

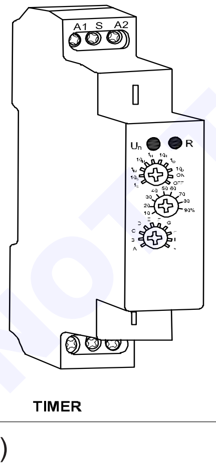
EL20N281671D

9 Time delay relay (timers) (Fig 14)

Time delay relays are simply the control relays in - built with a time delay mechanism to control the circuit based an time delay.

In time delay relays its contact will open or close after the pre-determined time delay either on energising or on de-energising its no volt coil. It can be classified into two types as ON delay timer and OFF delay timer.

Fig 14



TIMER

EL20N281671E

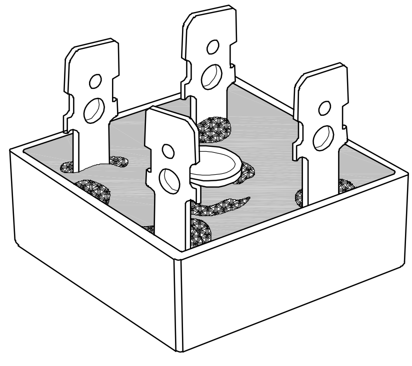
10 Rectifiers (Fig 15)

A rectifier is a static device consists of one or more diodes that converts alternating current (AC) to direct current (DC). A diode is like a one -way valve that allows an electrical current to flow in only one direction.

11 Limit switches (Fig 16)

Limit switch is a switch with an actuator which is operated by the motion of a machine part or an object.

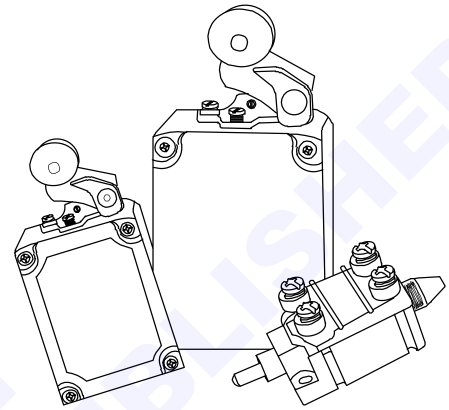
Fig 15



RECTIFIER

EL20N281671F

Fig 16



LIMIT SWITCHES

EL20N281671G

When an object or parts comes into contact with actuator, it operates the contacts of the switch to make or break an electrical connection. They are used to control the distance or angles of movement of any machine parts or axis or objects.

12 Control transformer

It is a transformer which is used to supply the power to the control or auxiliary circuit or equipment which does not intend for direct connection to the main supply.

13 Panel meter (voltmeter and ammeter)

They are the measuring instruments used to measure the various electrical parameter of the circuits such as voltage and current etc.

Wiring accessories for control panel wiring

1 PVC channel / Race ways (Fig 17)

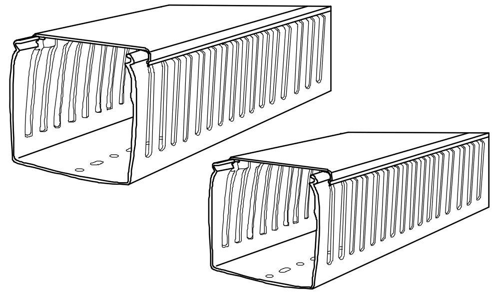
It is an inspection type PVC enclosed channel which provides a pathway for electrical wiring inside the control panel. It has the opening slots on both sides to facilitate the good ventilation and visual inspection.

It protects the wires from dust, humidity, corrosion, water intrusion, heat, mechanical damage and physical threats.

2 DIN rail (Fig 18)

It is a zinc - plated or chromated metal rail which is used for mounting the control accessories like MCB, contactors and OLR etc, with out using screws inside the control panel.

Fig 17



PVC CHANNEL

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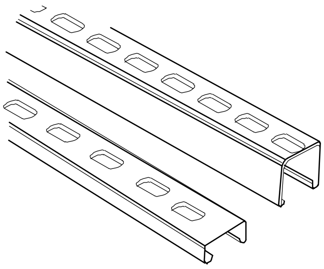
Fig 18



DIN RAILS

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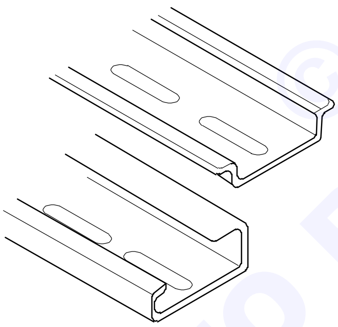
3 G Channel (Fig 19)

It is a zinc - coated metal channel which is especially used for mounting the feed through or spring load or double deck terminal connectors without using screw inside the control panel.

Fig 19



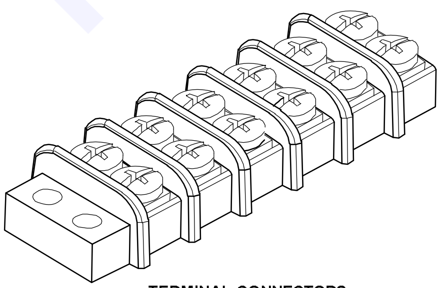
'C' CHANNEL

EL20N281671J

4 Terminal connectors (Fig 20)

It is the set of insulated screw terminals at both sides used to connect the accessories of the control panel with external control switches, limit switches, input supply and motor terminals etc.

Fig 20



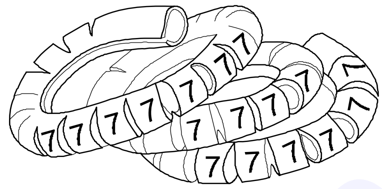
TERMINAL CONNECTORS

EL20N281671K

Terminal connectors with barrier strips and clamping plates provide a tight and electrically sound termination. It is available in various size, current and voltage ratings.

5 Wire ferrules (Fig 21) : It is a small circular ring made up of polymer plastics or rubber or fibre, used to easily identify the ends of wires which are to be connected into a particular terminals or accessories. It should be inserted on the both ends of a wire as collar or bracelet.

Fig 21



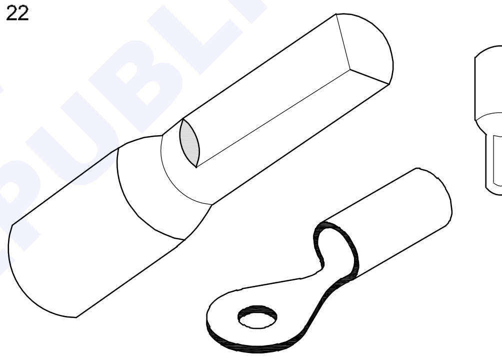
WIRE FERRULES

EL20N281671L

It is available is different size like 1 sq.mm, 1.5 sq.mm and 2.5 sq.mm etc generally in yellow colour printed with either numerical or alphabet letters on it.

6 Lugs and thimbles (Fig 22)

Fig 22



LUGS AND THIMBLES

EL20N281671M

It is a cylindrical barrel along with circular rings or cylindrical rod or U shape or flat surface made up of aluminum or copper or brass, used to ensure the sound electric connection of the cable / wire on to the terminals. It prevent flare out of stripped and stranded cable, increase the conductivity of the connection, support the cable / wire and avoid the loose connection and sparking. Suitable crimping tool has to be used to connects them with cables / wires. It is available in different size like 1 sq.mm, 4 sq.mm, 25 sq.mm, 70 sq.mm, 125 sq.mm and so on.

- Thimbles may also be referred as sockets.

7 Cable binding straps and button (Fig 23)

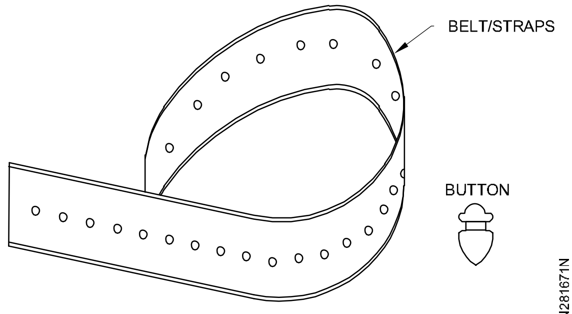
It is made up of PVC or polymer belt with a small holes at regular intervals, used to tie up, bunching, binding and dressing the cable / wires with help of buttons.

It is reusable and good insulator to the heat and electricity. It is generally available 8mm, 10 mm and 12 mm width.

8 Nylon cable ties (Fig 24)

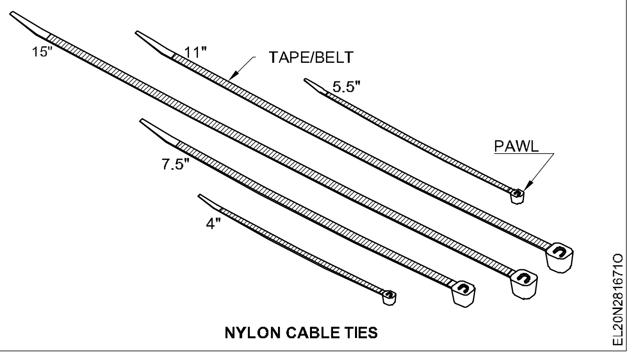
- It is a type of fastener used to hold or tie or bunch the wires / cable or group of cables.

Fig 23



CABLE BINDING STRAPS AND BUTTON

Fig 24

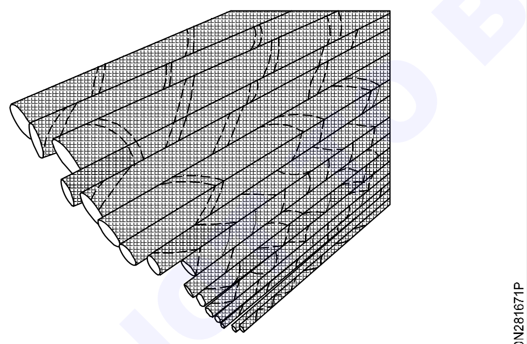


NYLON CABLE TIES

- It is made of nylon tape or belt which has teeth that will engage with head of the pawl to form a ratchet and tightens the wires.
- In general the tie can not be loosened, or removed or reused. However some reusable ties are also available.
- it is available in different colour, length and width.
- Because of its low cost and easy to use, it is widely used in general purpose application also.

9 Sleeves (Fig 25)

Fig 25

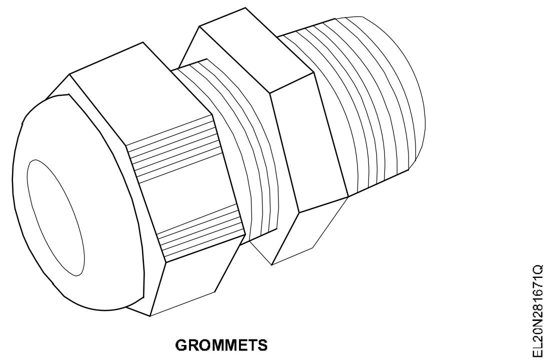


WIRE SLEEVES

- It is flexible tubular / cylindrical insulator into which the electric wire or cable or group of cables can be inserted.
- Apart from the electrical insulation and easy identification of wires, it also protect the wires from abrasion, heat, chemical, physical damage and radio interference.
- It is available is different colour, style, materials like carbon fibre, fabrics, Teflon, fibre glass, nylon, poly ethylene (PET) wrap, braided metal and heat shrink sleeves.

10 Grommets (Fig 26)

Fig 26

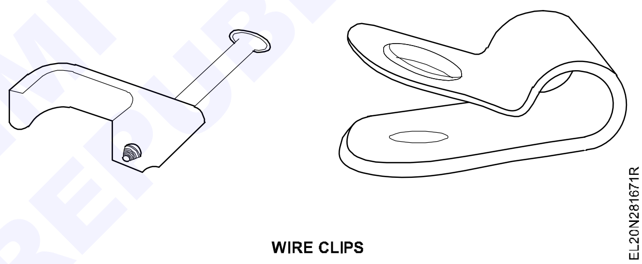


GROMMETS

It is a type of bushing which is used to insulate and hold the cables when they pass through a punched / drilled holes of panels or enclosures. It is generally made of rubber, plastic, plastic coated metal and protect the cable from twist, tug, cut, break, strain, vibration etc and prevent the entry of dirt, dust, water, insects and rats into the panel. It may also called as glands.

11 Wire clips (Fig 27)

Fig 27

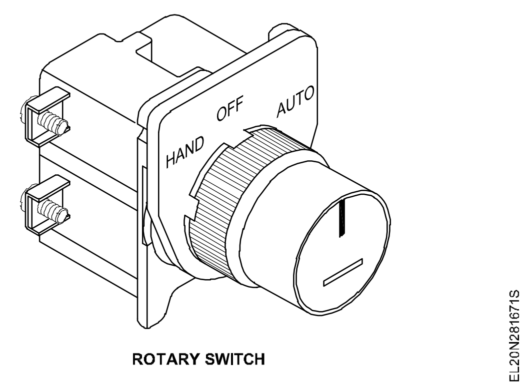


WIRE CLIPS

It is a type of fixing or fastening device which is used to fix and hold the cables or punch of cables in a secure manner.

Rotary type switches (Fig 28)

Fig 28



ROTARY SWITCH

Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs. Fig 28 shows 250V AC 15 Amps 2-pole three position flush mounting coin-slot operator.

Function: This switches can do a number of functions, depending upon the cover and contact block combinations. According they can be used for ON/ OFF switch, manual Forward / Reverse operation, Manual star delta switches, Pole changing switches, Selection switch for meaning instrument etc..

Power and control circuits for three phase motors

Objectives: At the end of this lesson you shall be able to

- **state the necessity of starters for a 3-phase induction motor to start and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of DOL starter, semi and fully automatic start - delta starter**
- **explain the remote station control circuit**
- **explain the sequential control of motors.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For motors, up to 3 Hp, full normal voltage can be applied for starting. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter - semi and fully automatic
- Step-down transformer starter
- Auto-transformer starter.

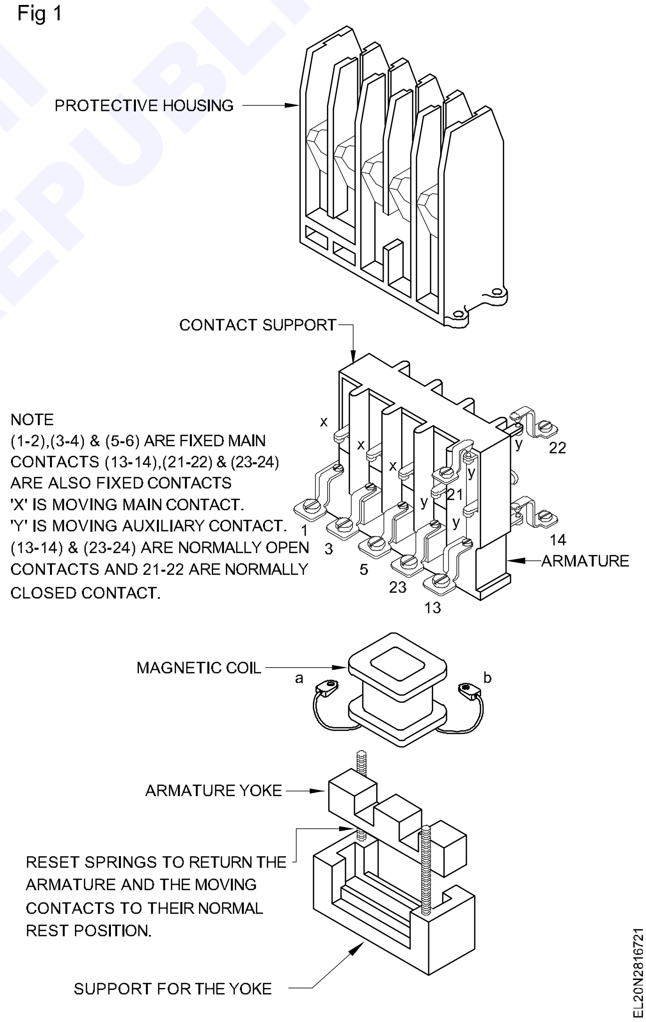
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the rated speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 50 cycles per second or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22.

Fig 1

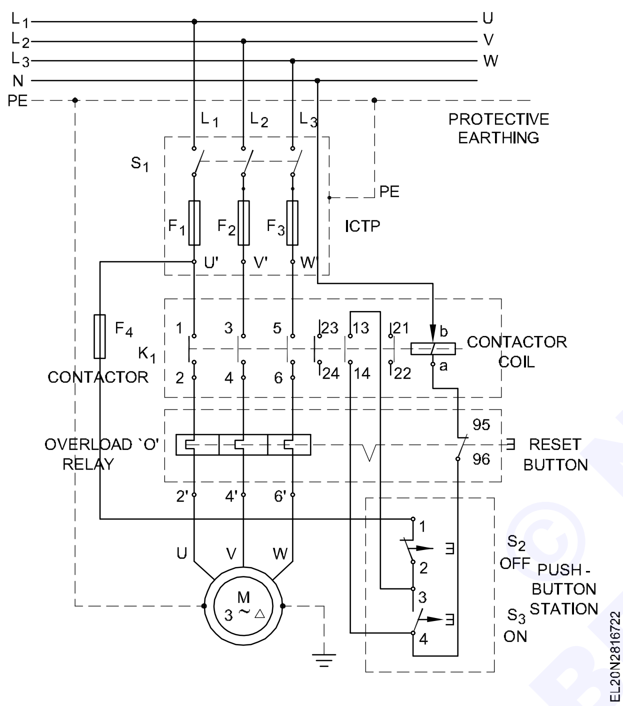


Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function. The main parts of a magnetic contactor are in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2



The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

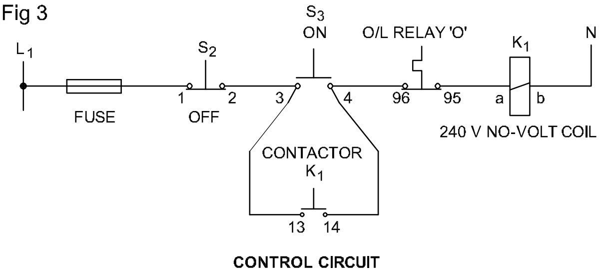
Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

After S_3 is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit.

Fig 3



Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

Push-button actuation from two operating locations (remote control): If it is desired to switch a contactor OFF and ON from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as in the complete diagram Fig 4 and the control diagram Fig 5.

Fig 4

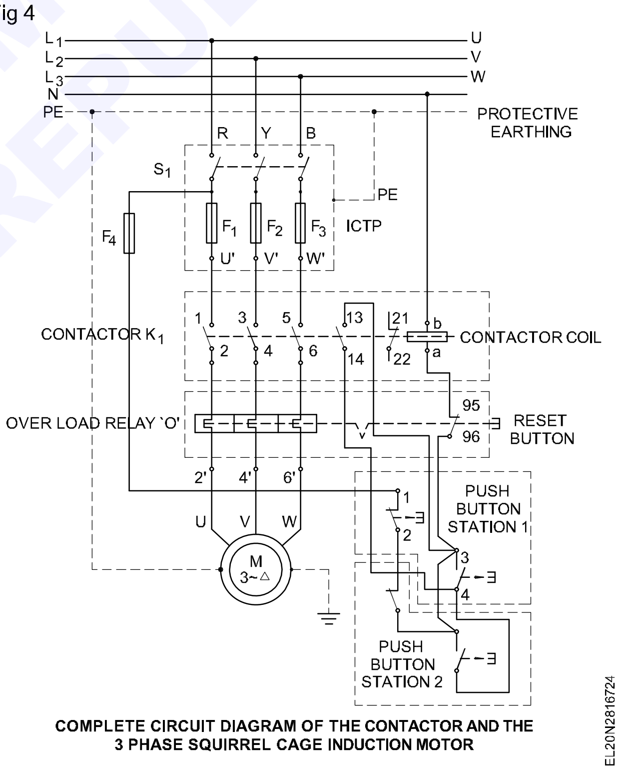
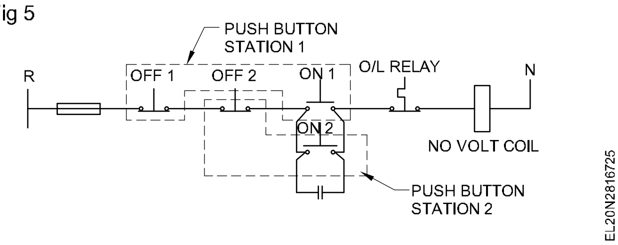


Fig 5



If either of the two ON push-buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1. If either of the two OFF push -buttons is actuated, the contactor opens.

Tripping of starters: A starter may trip due to the following reasons.

- Low voltage or failure of power supply
- Persistent overload on the motor

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V 230/250 V, 380V 400/440V AC or DC are available as standard for contactors and starters.

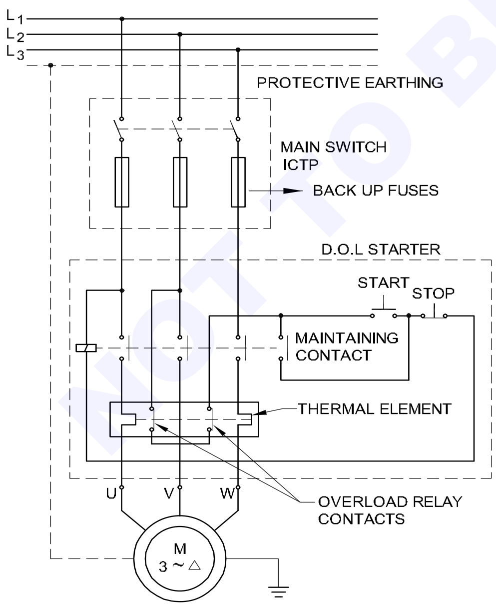
D.O.L. starter

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is in Fig 6. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as in Fig 6. Further the overload relay can be situated between ICTP switch and contactor or between the contactor and motor as in Fig 6, depending upon the starter design.

Fig 6



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

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Forward and reversing of 3 phase induction motors

In many machines like large milling machine, it is essential to run the motor in both directions in forward & reverse. In lift also the forward & reverse operation is essential.

By changing the phase sequence of any two phases the direction of rotation of a 3 phase motor can be changed but it is not practically possible of interchanging any two phases of 3 phase supply when even needed. It consumes time and also damages the equipments.

So it is necessary to have a circuit for forward and reversing of 3 phase induction motors. (Fig 7)

The supply terminal L_1 is connected with motor terminal A_1 in both direction of runing (Fig 7)

Supply terminal L_2 & L_3 are connected with motor terminal B_1 & C_1 in forward direction. While the reverse contact energiser supply terminal L_2 connected with motor terminal C_1 and L_3 terminal connected with B_1 thus the sequence of phase changed the direction of rotation also changed.

The inter locking protection is in corporated by normally closed (NC) contacts of forward and reverse contactors (Fig 7b) By this when forward contactor is working, if reverse push button is wrongly pressed, without any break the motor run in same direction continuously.

The direction only can be changed by switch OFF and press the reverse direction push button.

Automatic star-delta starter

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding are used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Automatic star - delta starter with forward and reverse control : It is a starter which is used to start the three phase motor in star and after some pre-determined time it automatically runs in delta either in forward or reverse direction depends upon the requirement. Like all other starters it reduces the starting current, protects the motor from over load and disconnects the motor from supply during power failure.

The Fig 8 and 9 shows the power and control circuit of the automatic star-delta starter with forward and reverse operation.

Fig 7

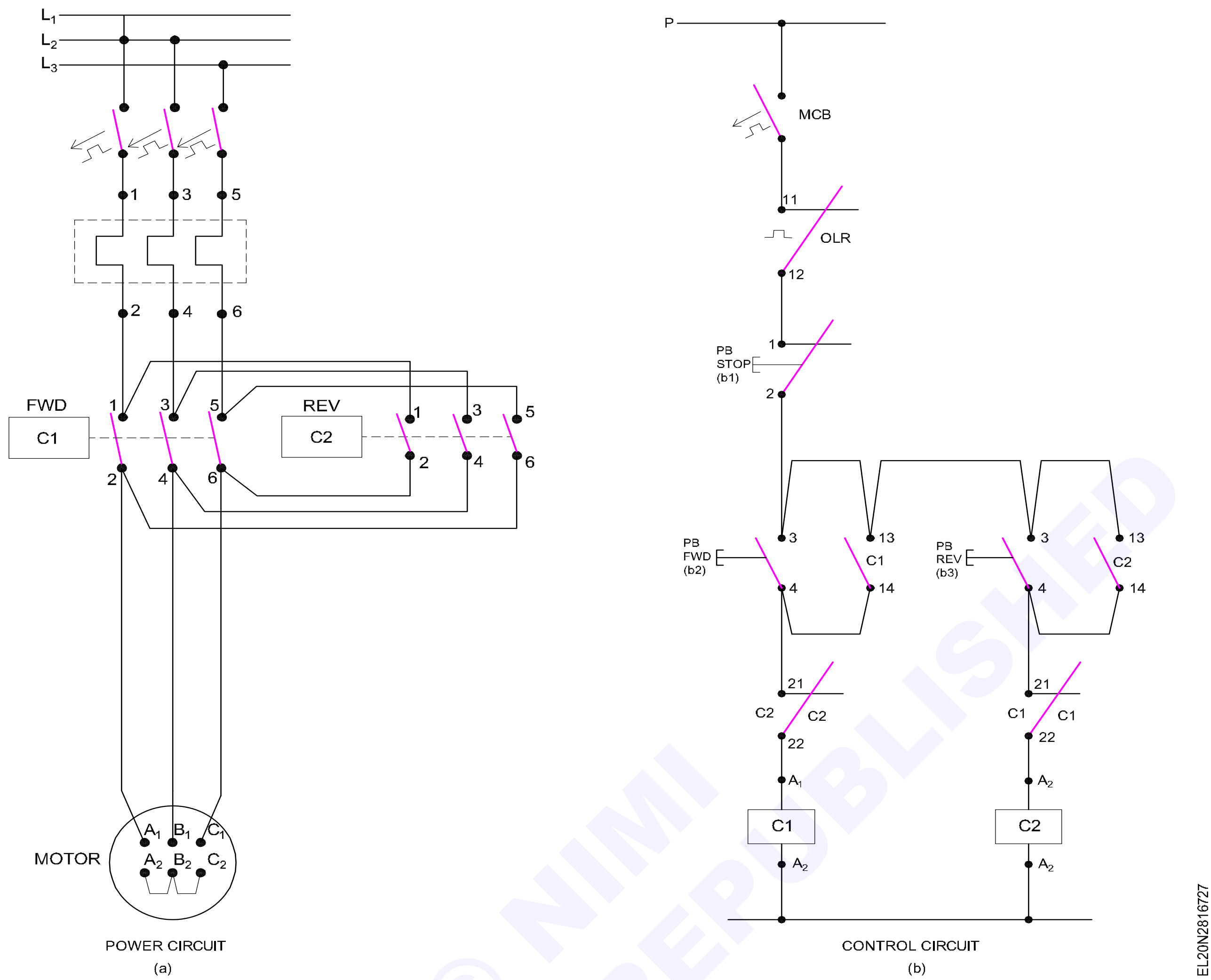
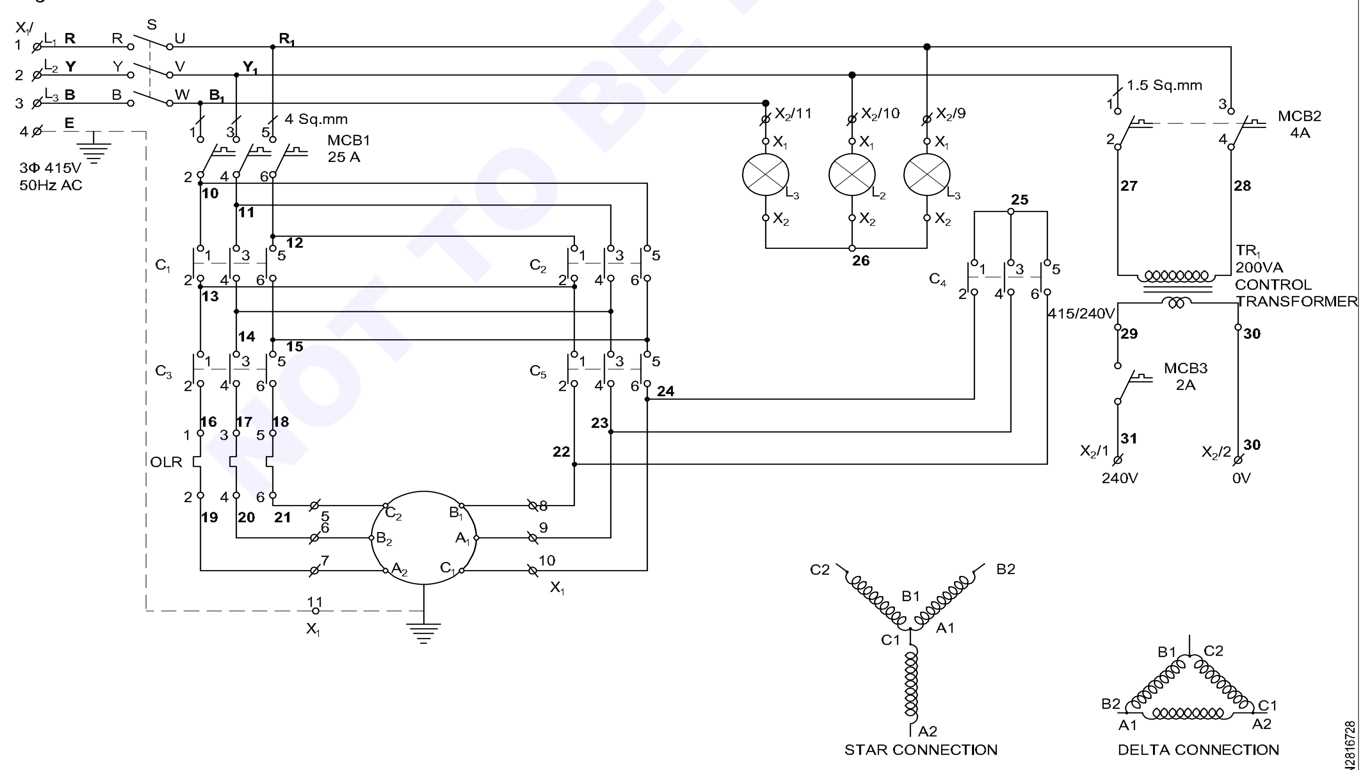
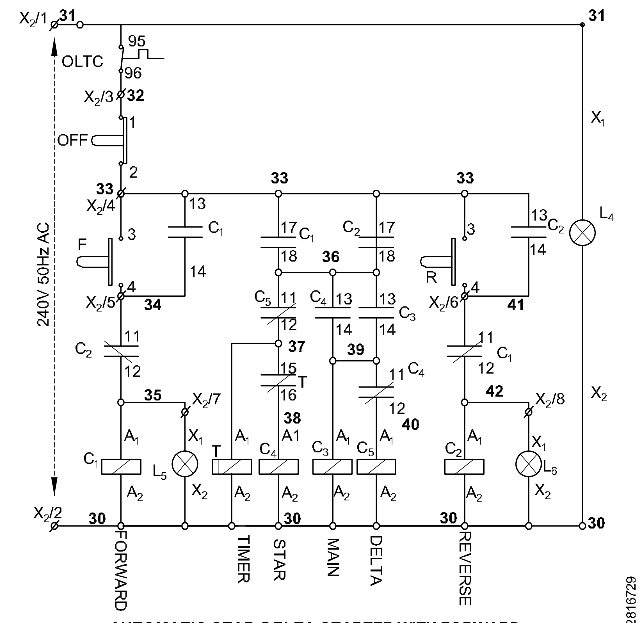


Fig 8



AUTOMATIC STAR-DELTA STRATER WITH FORWARD AND REVERSE-POWER CIRCUIT

Fig 9



AUTOMATIC STAR-DELTA STARTER WITH FORWARD & REVERSE-CONTROL CIRUIT

Its main components are, five numbers of power contactors, one ON-delay timer, three numbers of push buttons and one thermal over load relay (OLR). The five power contactors are intended one each for forward direction (C_1), reverse direction (C_2), main contactor (C_3), star contactor (C_4) and delta contactor (C_5).

Six numbers of indicator lamps are also used to indicate the availability of the three supplies, availability control voltage and to indicate whether the motor is running either in forward or reverse direction. These neon indicators lamps are to be mounted in the front door of the control panel along with three push buttons.

Three push buttons are intended one each for stop push button with one NC (Normally Closed) contact, for forward and for reverse operation with one NO (Normally Opened) contact.

The choosing of control circuit voltage and power depends on the no volt coil rating of the contactor, whether it needs AC or DC. Here a separate 415/240V, 200 VA control transformer is used for control circuits.

The choice of contactor depends upon the type of supply voltage, load power, load characteristics and duty cycles. The standed duty cycles of the contactors is given below.

Sequential control of motors

It is a kind of multiple motor's control in a specified manner by means of timer or limit switches or sensor depend the requirements of industries or application.

In this method generally the operation of two or more individual motors are controlled with respect to the specified time lapse or reaching of the specified level or completion of the specified operation. The operation of first motor will control the operation of the second or other motors and operation of second motor will control the operation of other motors and so on.

This type of the control system reduce the error due to human and man power, increase the accuracy of the operation cycle, minimize the ideal time of the machines and increase the efficiency and production of the industries.

The example of such sequential control system might be found in some of the industrial agitator system which explained in details below.

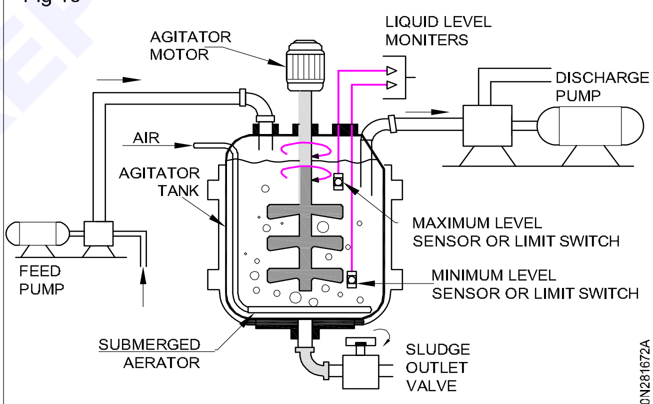
Industrial agitator

It is the machine consists of an electric motor along with impeller in its long shaft and fitted in the agitator tank which used in the chemical, food and pharmaceutical process industries to

- Mix the different type of liquid or chemical homogeneously.
- Improve the chemical properties of the liquid or substance.
- Keep and stir the stored liquid in the specified heat and properties.

Fig 10 show a typical industrial agitator used to remove the sludge and improve the chemical properties of the liquid or chemical before feeding to the process reactor. It has the feeding pump, agitator and discharge pump. The liquid to be treated is fed into the agitator tank through the feed pump which is started manually.

Fig 10



INDUSTRIAL AGITATOR SYSTEM

After some time lapse the agitator motor starts by means of timer and stir the liquid continuously till the level of the liquid reaches the minimum level. When the liquid level in agitator reaches the maximum level, the sensor or limit switch installed in the tank is switched off the feed pump.

After specified time lapse of starting the agitator motor the discharge motor is started by means of one more timer and discharge the liquid to further process. When the liquid level in agitator reaches the minimum level, the sensor or limit switch installed in the tank is switched OFF the discharge pump.

The agitator also have the submerged aerator through which the air is fed, a sludge discharge line with valve to discharge unwanted sludge, minimum and maximum level sensor or limit switches to maintain the liquid level in the tank.

A control panel with necessary wiring and protection are designed and installed to control the sequential control of all the three motors. The Fig 11 and 12 show the power and control circuit of the sequential control of the typical agitator system with three motors.

All the three motors have individual power circuit of DOL starter with over load and short circuit protection. The total control panel has an isolation switch to ON and OFF the supply. It has indicator lamps to indicate the availability of the power supply and control supply and also indicates the running status of feed pump, agitator motor and discharge pump.

Sequence of operations of the sequential control of the agitator system having three motors

When the start push button is pressed the NVC of the feed pump motor contactor (C_1) and timer 1 (T_1) is getting the control voltage through the stop push button, OLTC of OLR1 and NC contact of the maximum level limit switch.

Now the C_1 and T_1 energized and get self holding through the NO contact C_1. So even after releasing the 'start' push button the C_1 and T_1 will continuously be in energized condition.

After some pre-determined time lapse the NO contact of the timer 1 closes and the NVC of the agitator motor contactor (C_2) and timer 2 (T_2) get control voltage through the minimum level limit switch and OLTC of OLR 2. Now the C_2 energized and get self holding through its own NO contact. So even if the C_1 if get de-energized due to maximum level limit switch, the C_2 will continuously be in energized condition.

After the some time lapse the NO contact of the timer 2 closes and the NVC of the discharge pump motor contactor (C_3) is getting the control voltage and get energized.

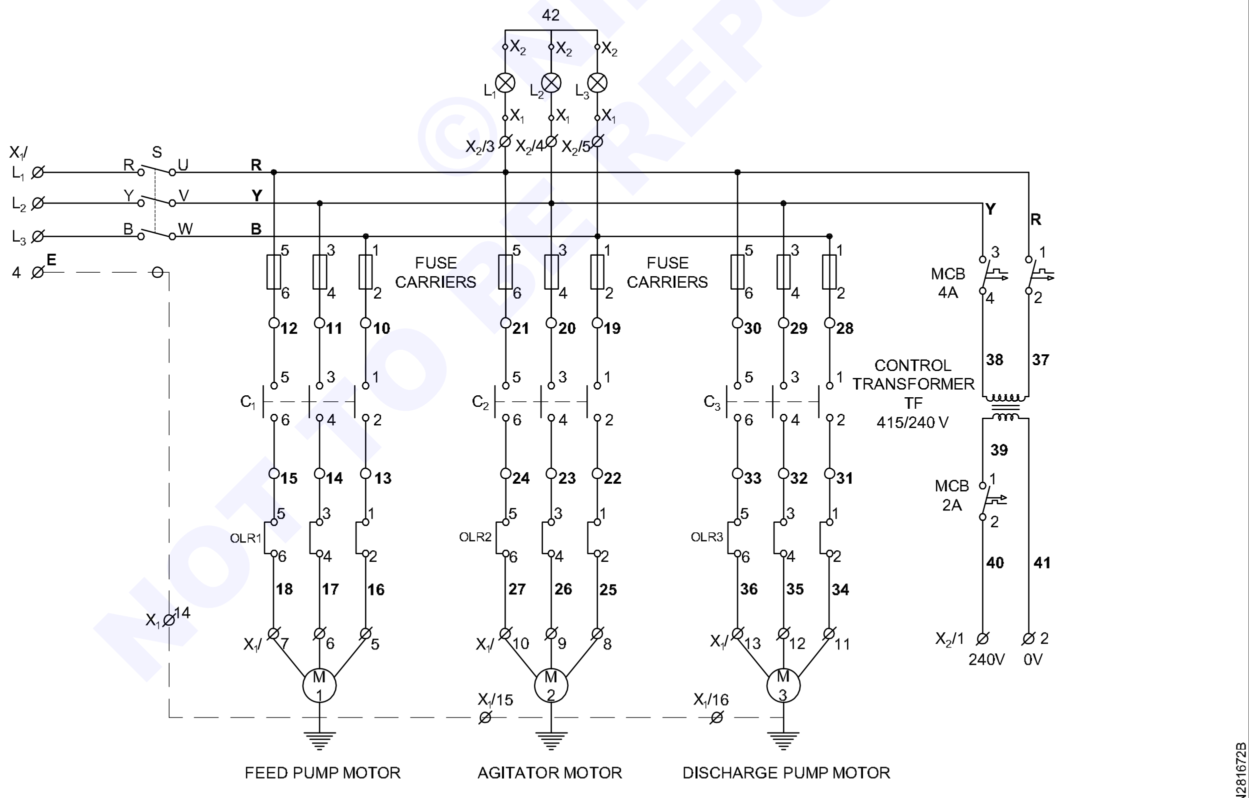
If the liquid level of the agitator reduces to the minimum, the NO contact of the minimum level limit switch open causes C_2 and C_3 get de-energized.

When the all the three motors are working, in case if the OLTC of OLR1 opens the C_1 will only get de-energized and C2 and C3 continuously in energized condition through the self holding contact of C_2.

In case if the OLTC of OLR 2 opens due to over load the C_2 will only get de-energized if the C_1 is in energized condition. In other hand if the C_1 is already of OFF condition due to activation of maximum level limit switch, the C_3 also will get de-energized.

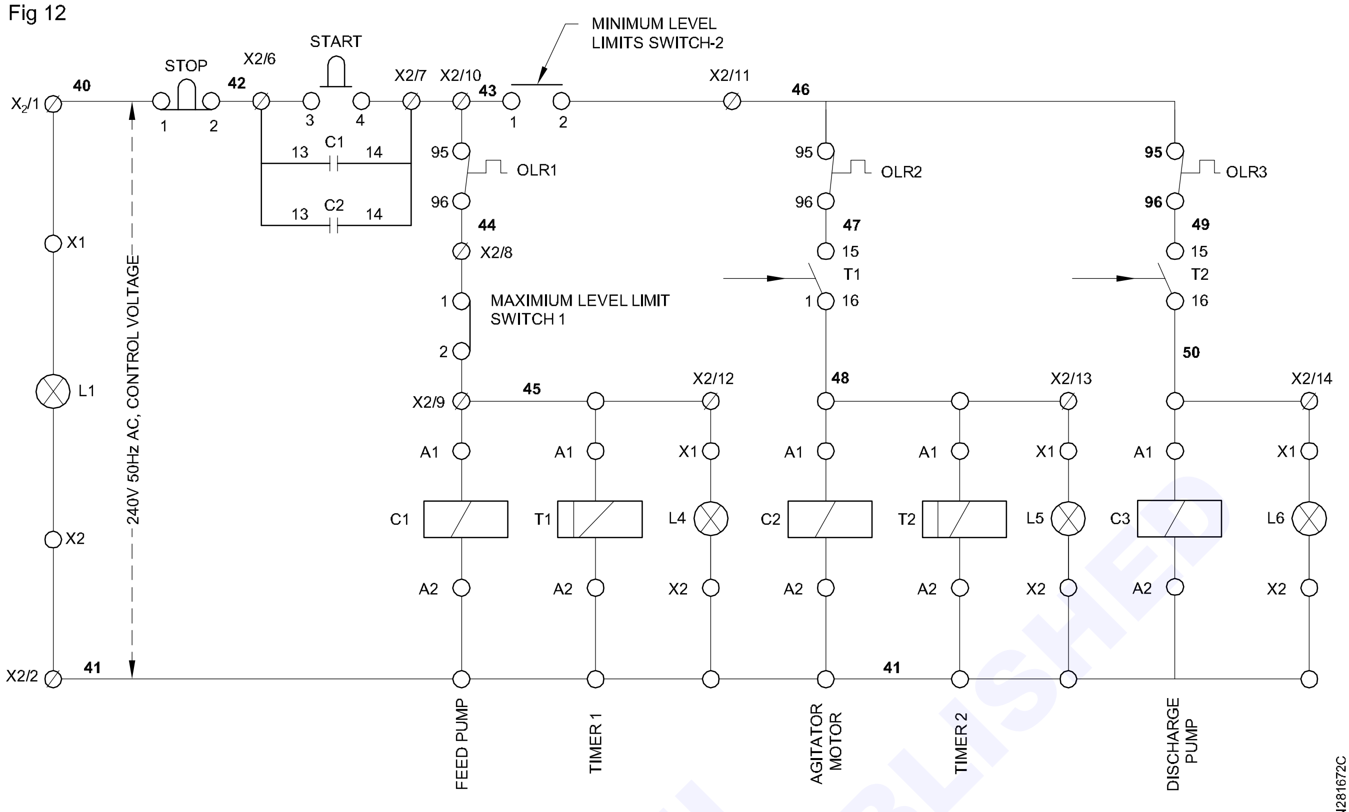
In case if the OLTC of the OLR3 opens due to over load the C_3 alone will get de-energized.

Fig 11



POWER CIRCUIT FOR SEQUENTIAL CONTROL OF THREE MOTORS

Fig 12



CONTROL CIRCUIT OF SEQUENTIAL CONTROL OF AGITATOR SYSTEM WITH THREE MOTORS

Installation of instruments and sensors in control panel and its performance testing

Objectives: At the end of this lesson you shall be able to
- **state the sensor main specification, application necessity and types**
- **state the specification and types of sensors required in panel board**
- **explain the performance testing of panel control board.**

Instruments in panel board

Industrial operation for any process requires many machines, apparatus for usual supply and maintain continuous production. Some machines requires operator always to operate many control on process for example a lathe machine is required always its operator assistance to do different job, turning, shaping etc, but in some cases the machine not required continuous manual operator for single job operations.

In a workshop AC motor or DC motor is to operate for many of its intended job. Once the machine starts it will continue to work for its assigned job and requires only ON and OFF operation. This operation may need many job completion in different places located in the work shop. This operation has to be controlled and monitored in time intervals and a constant watch also may require.

The instruments are used to measure the electrical quantities, which in turn gives the feed back of load conditions and performance. A motor draws a constant current, which can monitor by a ammeter connected to them similarly the rated voltage, frequency, power factor etc, are also to be checked through the meters. If number of machines and meters are more it is difficult to watch the parameters individual places. A panel board having this meters are installed helps to collect the data at one place where different machines are working.

Selection of meters are in accordance with the machine ratings and working voltage limits. A low range meter cannot be connected in a heavy load machine for its readings it may damage the meter and its wiring.

Sensors types, classification and its application

Sensors is a device that detects/measures a physical quantity. A motor is running with its rated rpm but some cases load variations on motor affects the rpm. The quality of the product may depend on the machine accuracy, then it is very important to run the motor at its rated rpm. Automatic rpm correction is possible with relevant circuits but a sensor has to feed back the working rpm to the control circuit. In this case a Tacho generator is the device to produce the feed back of rpm of motor. Tacho generator can be fixed on the shaft of the motor and the resultant feed back quantity(V or I) can be brought to the control panel board.

Similarly, the temperature measurement also can be done by suitable sensors. Since the temperature is the big problem for all electrical applications, a constant watch on the temperature helps to increase the life of the machine and a uniform production with specified quality. In this way temperature can be controlled by installing suitable sensor preferably with a thermistor-PTC or NTC will help to control the temperature within safe limits. The sensor element will kept in the winding and the cable is brought up in the control panel, to connect the temperature indicating unit for indication.

A sensor is a special kind of transducer which is used to generate an input single to a measurement, instrumentation or control system. The signal produced by a sensor in an electrical analogy of a physical quantity, like acceleration, temperature, pressure, distance, velocity, light, level etc.

Types of sensors: There are two types of sensors

a Passive sensor

b Active sensor.

a Active sensor: Self generating sensor is that one can generate a signal without any external power source. Eg. photovoltaic cell, thermo couple, piezoelectric device .

b Passive sensor: It requires external power supply to generate the signal. Eg. Diaphragm used to convert pressure or velocity, oscillations, or sound wave's into movements of a solid sheet.

Classification of sensors: It is classified into many categories according to the output, application etc. It is mainly divided into two groups, they are; a) Digital sensor and b) Analog sensor.

Digital sensor: The resolution of this sensor is most accurate and maximum speed. Its ability to detect a change in the sensed quantity is excellent. The output is always taken as 180, high and low, or yes or no.

Analog sensor: The resolution of this sensor in less accurate corporate to digital and it records very small changes or variations resulting more error. It is usually used to record very small changes, or variations.

Further, the sensors are mainly used to measure temperature and RPM in the electrical circuits. The following sensors are used to measure temperature. They are;

a Thermo couple

b RTD (Resistance Temperature Detector)

c Thermistor

d IR sensors (Infra Red)

e Semi conductor sensors - VDR, LDR, Photo diode etc.,

The sensors used to measure RPM of motor; are in different types; they are

a Shaft encoders (rotary type) 1-5000 pulses

b Photoelectric (optical type)

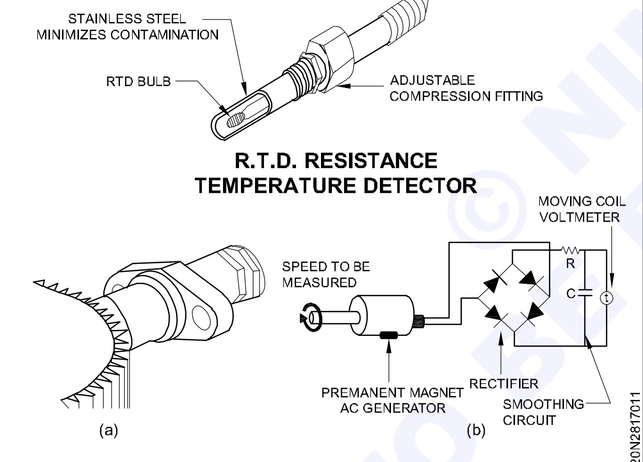
c Magnetic rotational speed (proximity type) - medium or low RPM.

d Photo sensor reflection target- Tachometer - 20-20,000 range

Sensor assembly and measurements

Temperature measurement using resistance temperature detector (RTD) and $\sqrt{1}$ assembly with position adjustment, tachometer sensor assembly and a AC tachometer generator is in Fig 1. The AC is rectified by a bridge circuit. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft. Thus either amplitude or frequency is used for measuring the angular velocity.

Fig 1



A.C TACHOMETER GENERATOR

Performance testing of panel board

It is important to see that the panel board is to install carefully as it carries a number of connection and controls. Any loose connection or wrong connection to any device will affect the performance and it may cost more.

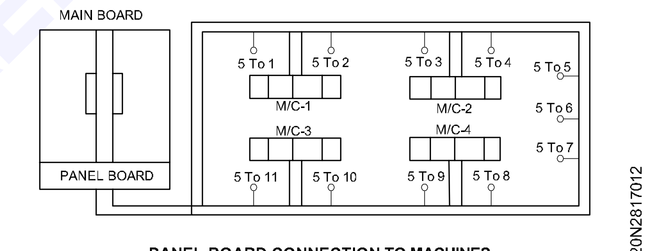
While testing the performance make sure that all connections and wiring are correct and as per IE rules. Wrong connection and substandard materials will cause heavy damage to the panel board. The continuity of cable, earth resistance values are to be kept in the safe level as per IE rule normal.

The panel board should be earthed properly and all metal parts have to be connected to earth. If the current in the panel board is heavy; a separate earthing has to be provided and maintained within the standard.

Connection to machine from panel board has to be made on short as possible. If the machine draws less current, line drop will be minimum and resultant power is low hence in cable is also low and even negligible. If the connecting cable length is much more than line loss will be too high and it will turn shorten the life of machine and cables connected. Running of cable can be made as per the situation and facilities. Keep away from direct sun light wet condition, and near fire or any other polluted areas.

A simple model panel board to the load power is given for your guidance in Fig 2.

Fig 2



PANEL BOARD CONNECTION TO MACHINES

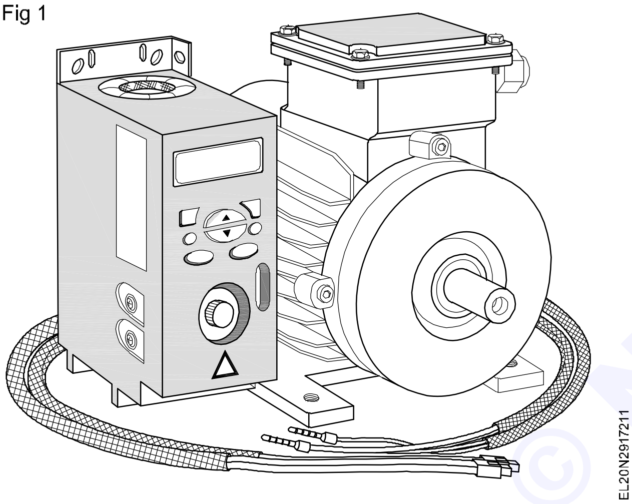
AC/DC drives

Objectives: At the end of this lesson you shall be able to
- **state the classification types and working of AC & DC drives**
- **state the applications of AC & DC drives**
- **describe the block diagram, parts of DC drive and advantages and disadvantages of DC drives.**

Electrical drives

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to feed motion to different machines and mechanisms for various kinds of process control. (Fig 1)

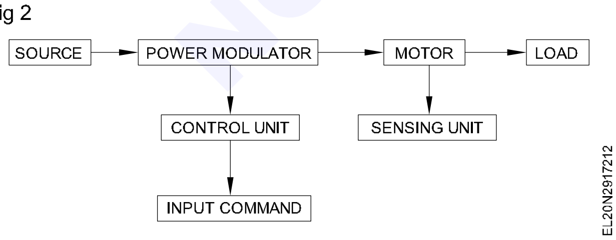
Fig 1



Motion control is required in large number of industrial and domestic applications like transportation, systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called Drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors; Supplying mechanical energy for motion control Drives employing electric motors are known as Electrical drives. The block diagram of an electric drive is shown in Fig 2.

Fig 2



Types of electric drives

i According to mode of operation
- Continuous duty drives
- Short time duty drives
- Intermittent duty drives

ii According to means of control
- Manual
- Semi automatic
- Automatic

iii According to number of machines
- Individual drive
- Group drive
- Multi - motor drive

iv According to dynamics and transients
- Uncontrolled transient period
- Controlled transient period

V According to methods of speed control
- Reversible and non - reversible uncontrolled constant speed
- Variable position control
- Reversible and non - reversible smooth speed control

Advantage of electrical drives

1 They have flexible control characteristics.

2 Drives can be provided with automatic fault detection systems. Programmable logic controller (PLC) and computers can be employed to automatically control the drive operation in a desired sequence.

3 They are available in wide range of torque, speed and power.

4 They are suitable to almost any operating conditions such as explosive and radioactive environments.

5 It can operate in all the four quadrants of speed - torque plane.

6 They can be started instantly and can immediately be fully loaded.

7 Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

The requirement of refuel is not necessary.

Choice (or) selection of electrical drives: Choice of an electric drive depends on the important factors are.

1 Steady state operating conditions requirements. Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, rating etc.

2 Transient operation requirements

3 Values of acceleration and deceleration, starting, braking and reversing performance.

4 Requirements related to the source. Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.

5 Space and weight restriction if any.

6 Environment and location.

7 Reliability

Group electric drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also some times called as **shaft drives.**

Advantages: The advantages of electrical drives include the following:

- These drives are obtainable with an extensive range of speed, power & torque.
- Not like other main movers, the requirement of refuel otherwise heat up the motor is not necessary.
- They do not contaminate the atmosphere.
- Previously the motors like synchronous as well as induction were used within stable speed drives. Changeable speed drives utilize a DC motor.
- They have flexible manage characteristics due to the utilization of electric braking.
- At present, the AC motors motor is used within variable speed drives because of semiconductor converters development.

Disadvantages

The disadvantages of electrical drives include the following.

- This drive cannot be used where the power supply is not accessible.
- The power breakdown totally stops the entire system.
- The primary price of the system is expensive.
- The dynamic response of this drive is poor.
- The drive output power which is obtained is low.
- By using this drive noise pollution can occur.

Applications of Electrical Drives: The applications of electrical drives include the following.

- The main application of this drive is electric traction which means transportation of materials from one location to another location. The different types of electric tractions mainly include electric trains, buses, trolleys, trams, and solar-powered vehicles inbuilt with battery.
- Electrical drives are extensively used in the huge number of domestic as well as industrial applications which includes motors, transportation systems, factories, textile mills, pumps, fans, robots, etc.
- These are used as main movers for petrol or diesel engines, turbines like gas otherwise steam, motors like hydraulic & electric.

Thus, this is all about the fundamentals of electrical drives. From the above information, finally, we can conclude that a drive is one kind of electrical device used to control the energy which is sent to the electrical motor. The drive supplies energy to the motor in unstable amounts & at unstable frequencies, thus ultimately controls the speed and torque of the motor. Here is a question for you, what are the main parts of the electric drive.

Individual electric drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

Multi motor electric drive : In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

e.g: Complicated metal cutting machine tools

Paper making industries.

Rolling machines etc.

A modern variable speed electrical drive system has the following components

- Electrical machines and loads
- Power modulator
- Sources
- Control unit
- Sensing unit

Electrical machine

Most commonly used electrical machines for speed control applications are the following.

DC machines

Shunt, series, compound, DC motors and switched reluctance machines.

AC machines

Induction, wound rotor, synchronous, permanent magnet synchronous and synchronous reluctance machines.

Special machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators (Controller)

Functions

- It modulates flow or power from the source to the motor is imparted speed - torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it reduces the motor current with in permissible limits.
- It converts electrical energy of the source in the from of suitable to the motor.
- It selects the mode of operation of the motor (i.e) motoring and braking.

Types of power modulators (Controllers)

- In the electric drive system, the power modulators can be any one of the following.
- Controlled rectifiers (AC to DC converter)
- Inverters (DC to AC converters)
- AC voltage controllers (AC to DC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Electrical sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3-phase source. Low and medium power motors are fed from a 415V supply. For higher ratings, motors may be rated at 3.3KV, 6.6 KV and 11 KV. Some drives are powered from battery.

Sensing unit

- Speed sensing (from motor)
- Torque sensing
- Position sensing
- Current sensing and voltage sensing (from lines or from motor terminals from load)
- Temperature sensing

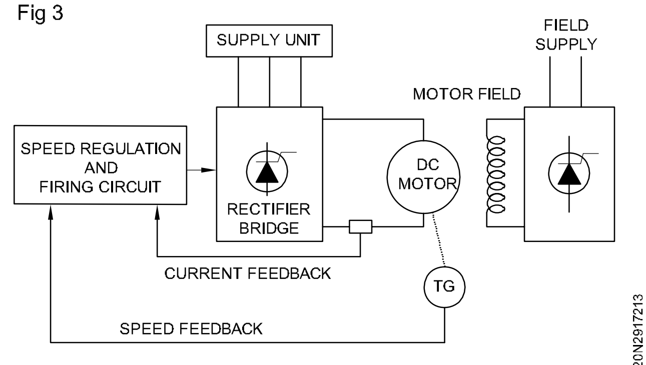
Control unit :Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Block diagram of DC drive : The block diagram of a DC drive system is in Fig 3

DC drive input : Some thyristor based DC drives operate on a single phase supply and use four thyristors for full wave rectification. For larger motors 3 phase power supply is needed because the waveforms are much smoother. In such cases, six thyristors are needed for full wave rectification.

Rectifier Bridge : The power component of a controlled DC drive is a full wave bridge rectifier which can be driven by three phase or single phase supply. As mentioned above the number of thyristor may vary depends on the supply voltage.

Fig 3



COMPONENTS OF A DC DRIVE SYSTEM

A six - thyristor bridge (in case of three phase converter) rectifies the incoming AC supply to DC supply to the motor armature. The firing angle control of these thyristors varies the voltage to the motor.

Field Supply Unit (FSU) : The power is to be applied to the field winding is much lower than the armature power.

In many cases a two - phase supply is drawn from the three phase input (that supplies power to the armature) and hence the field exciter is included in the armature supply unit.

The function of the field supply unit is to provide a constant voltage to the field winding to create a constant field or flux in the motor. In some cases, this unit is supplied with thyristors to reduce the voltage applied to the field so as to control the speed of the motor above the base speed incase of permanent magnet DC motors, the field supply unit is not included in the drive.

Speed Regulation unit : It compares the operator instruction (desired speed) with feedback signals and sends appropriate signals to the firing circuit. In analog drives, this regulator unit consists of both voltage and current regulators. The voltage regulator accepts the speed error as input and produces the voltage output which is then applied to the current regulator.

The current regulator then produces required firing current to the firing circuit. If more speed is required, additional current is drawn from the voltage regulator and hence thyristors conduct for more periods. Generally, this regulation (both voltage and current) is accomplished with proportional -integral- derivative controllers.

The field current regulator is also provided where speed greater than the base speed is required.

Parts of DC drive : DC drives of various brands with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power terminals, control terminals, keypad for controlling the drive etc. It has provision for connecting to PC for programming the drive.

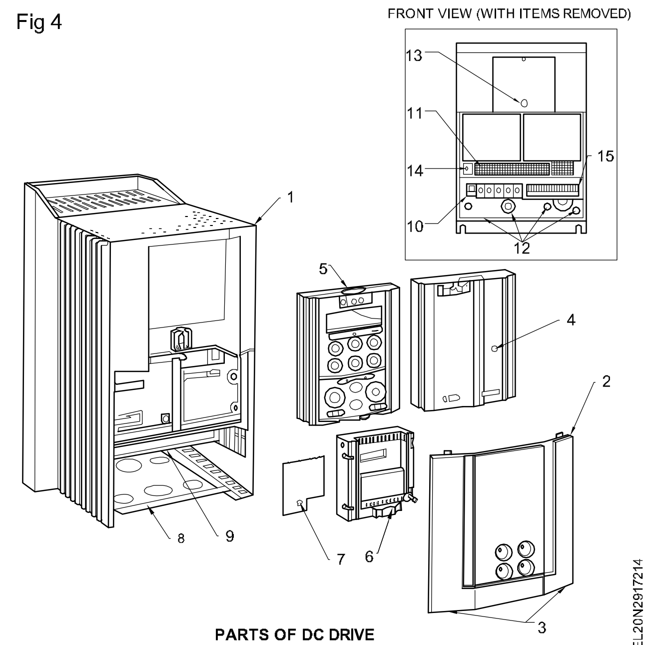
The main parts of DC drive are given below. (Fig 4)

1 Main drive assembly

2 Terminal cover

3 Terminal cover retaining screw

Fig 4



PARTS OF DC DRIVE

4 Blank cover

5 Keypad

6 COMMS technology box (optional)

7 Speed feedback technology card (optional)

8 Gland plate

9 Power terminal shield

10 Power terminals

11 Control terminals

12 Earthing / grounding points

13 Keypad part

14 Programming part

15 Auxiliary power, external contactor, blower and isolated thermistor terminals

Power and control terminals

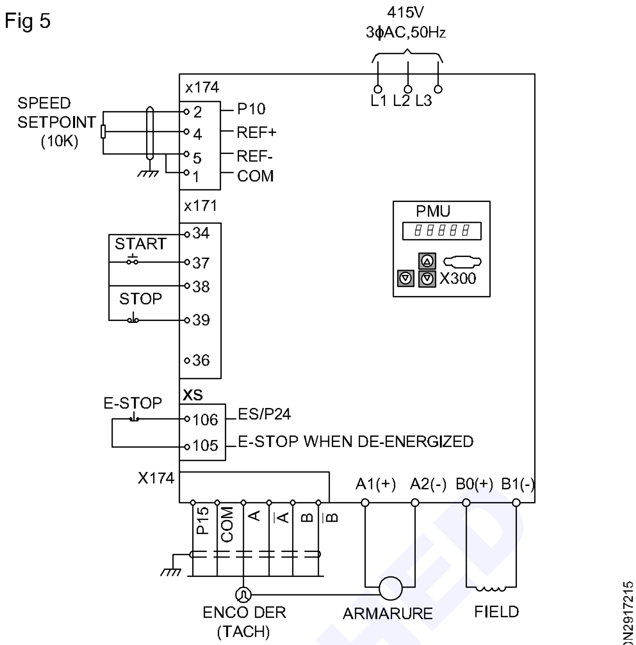
In DC drive, the front panel has the power terminals L1, L2 and L3 where 3 phase input supply of 415V can be connected.

There are control terminals given for speed adjust potentiometer, Torque adjust potentiometer, START/RUN/ STOP switch, JOG/RUN/ switch, AUTO/MAN switch, FORWARD/REVERSE switch etc. Terminal A1 & A2 and B_0 & B_1 are meant for armature and field connections respectively. Names and locations are illustrated in Fig 5.

Advantages of DC drive

- DC drives are less complex with a single power conversion from AC to DC.

Fig 5



CONTROL TERMINALS OF DC DRIVE

- DC drives are normally less expensive for most horsepower ratings.
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.
- Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.
- Accessory mounting flanges and kits for mounting feedback tachometers and encoders.
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.
- Properly applied brush and commutator maintenance is minimum.
- DC motors are capable of providing starting and accelerating torques in excess of 400% of rated value.
- Some AC drives may produce audible motor noise which is undesirable in some applications.

Disadvantages of DC drive

- More complicated because of commutators and brushes.
- Heavier than AC motors.
- High maintenance is required.
- Large and more expensive than AC drive.
- Not suitable for high speed operation.

Speed control of 3 phase induction motor by VVVF/AC drive

Objectives: At the end of this lesson you shall be able to
- **state about AC drives (VFD/VVFD) and changing of speed of AC motor by AC drive**
- **explain the operation of AC drive with block diagram**
- **list out the advantages and disadvantages of AC drive**
- **explain the components / parts and power and control terminals of AC drive**
- **state the parameter setting - speed control changes of direction of AC & DC drives / VFD/VVVFD (variable frequency drive/ variable voltage variable frequency drive)**
- **state the speed control of universal motor.**

Variable Voltage Variable Frequency Drive (VVVFD)

The AC drive industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep AC drive installations running smoothly. AC drives change the speed of AC motor by changing voltage and frequency of the power supplied to the AC motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts / hertz ratio must be maintained. This is the main task of VFD (Variable frequency drive).

Applications of AC drives

1 AC drives are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.

2 AC drives control the speed of AC motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.

3 AC drive consists of rectifier and inverter units. Rectifier converts AC to DC voltage and inverter converts DC voltage back to AC voltage.

Changing of speed of AC motors by using AC drive

From the AC motor working principle, that the synchronous speed of motor N_s in rpm, is dependent upon frequency. Therefore by varying the frequency of the power supply through AC drive, it can control the synchronous speed.

Speed (rpm) = Frequency (Hertz) x 120 / No. of poles.

Where

Frequency = Electrical frequency of the power supply in Hz., No. of poles = Number of electrical poles in the motor stator. Thus the speed of AC motor can conveniently be adjusted by changing the frequency applied to the motor. There is also another way to make the AC motor work on different speed by changing the no. of poles, but this change would be a physical change of the motor. The VFD provides the controls over frequency and voltage of motor input to change the speed of a motor. Since the frequency is easily variable as compared with the poles variation of the motor. AC drives are frequently used.

Constant V/F ratio operation

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the ϕ_m constant.

All AC drives maintain the voltage -to- frequency (V/F) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency F and the magnetic flux ϕ of motor are related by the equation.

$V = 4.444\ f\ N\ \phi_m$

or

$V/f = 4.444 x\ N\ \phi_m$

Where N = number of turns per phase

ϕ_m = magnetic flux

Moreover, the AC motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage - to - frequency (V/f) ratio constant.

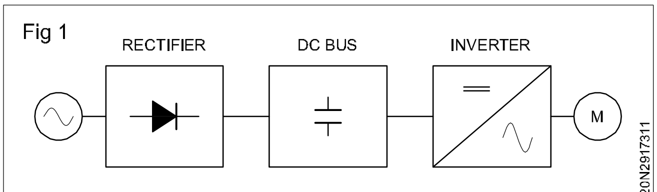
Block diagram of AC drive

The Insulated - Gate - Bipolar- Transistor (IGBT) is in the past two decades come to dominate VFD as an inverter switching device.

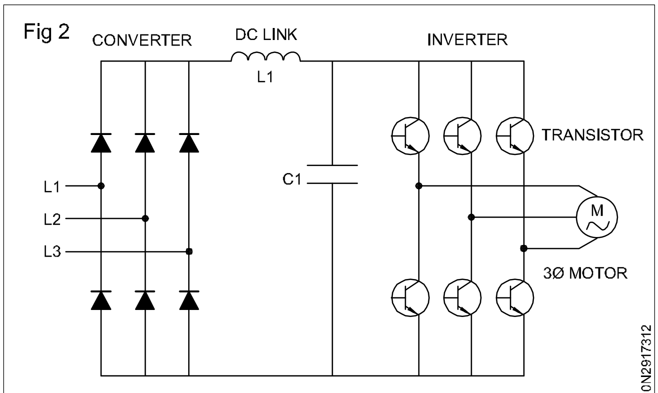
IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM (Pulse width Modulation) inverter operation. IGBTs are capable of switching ON and OFF several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter.

An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on. So the gate can control the switching on/off operation of an IGBT.

Fig 1 shows the block diagram of AC drive and Fig 2 shows the internal connection diagram. There are three basic sections of the AC drive; the rectifier, DC bus, and inverter.



BLOCK DIAGRAM OF AC DRIVE



INTERNAL CONNECTION OF AC DRIVE

The rectifier in an AC drive is used to convert incoming AC power into direct current (DC) power. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power . An AC drive using transistors in the rectifier section is said to have an "active front end.

After the power flows through the rectifiers it is stored on a DC bus. The DC bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The DC bus may also contain inductors, DC links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the DC bus.

Inverter : An inverter is a device which converts DC into AC. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common selection in modern AC drives. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "Pulse Width Modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

Advantages and disadvantages of AC drive

Advantages

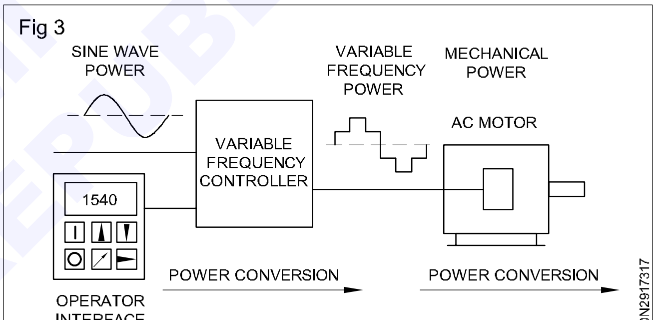
- They use conventional low cost 3 phase AC induction motors for most applications
- AC motors require virtually no maintenance and are preferred for application where the motor is mounted in an area not easily reached for servicing or replacement.
- AC motors are smaller, lighter, more commonly available and less expensive than DC motors.
- AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.
- Whenever the operating environment is wet, corrosive or explosive, special motor enclosures are required. Special AC motor enclosure types are more readily available at lower prices.
- Multiple motors in a system must operate simultaneously at a common frequency/speed.

Disadvantages

- A standard motor can not adequately cool its winding at slow speed or handle the irregular electrical waveform from the AC drive.
- An AC drive requires installation of motor with heavier windings.
- AC drive has complicated electronics circuit, so fault rectification is costly.
- AC drives produce a simulated waveform, not a perfect sine wave. That degrade the power equality.

Components of AC drive

A variable frequency drive is a device used in a drive system consisting of the following three main sub-systems. AC motor, main drive controller assembly, and drive / operator interface as in Fig 3.



COMPONENTS OF A.C DRIVE

AC motor

The AC electric motor used in a VFD system is usually three - phase induction motor. Some types of single - phase motors can be used, but three - phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three - phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed - speed operation are often used. Elevated - voltage stresses imposed on induction motors that are supplied by VFDs require that such motors are designed for definite - purpose inverter-fed duty.

Controller :The VFD controller is a solid - state power electronics conversion, system consisting of three distinct sub-systems, a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage - source inverter (VSI) drives are the most common type of drives. Most drives are AC to AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three -phase, six -pulse, full-wave diode bridge.

In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase- controlled current - source inverter (CSI) and load - commutated inverter (LCI) drives.

In variable -torque applications suited for volts - per- Hertz (V/Hz) drive control. AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, 415V, 50Hz motors, this linear V/Hz relationship is 415/50=8.3V/Hz.

Although space vector pulse- width modulation (SVPWM) is becoming increasingly popular, sinusoidal PWM (SPWM) is the most straight forward method used to vary drives motor voltage (or current) and frequency. With SPWM control quasi- sinusoidal, variable - pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current).

An embedded microprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user - inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment.

Operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and /or indication lights and meters to provide information about the operation of the drive.

An operator interface keypad and display unit is often provided on the front of the VFD controller shown in the Fig 3. The keypad display unit can often be cable - connected and mounted a short distance from the VFD controller. They are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

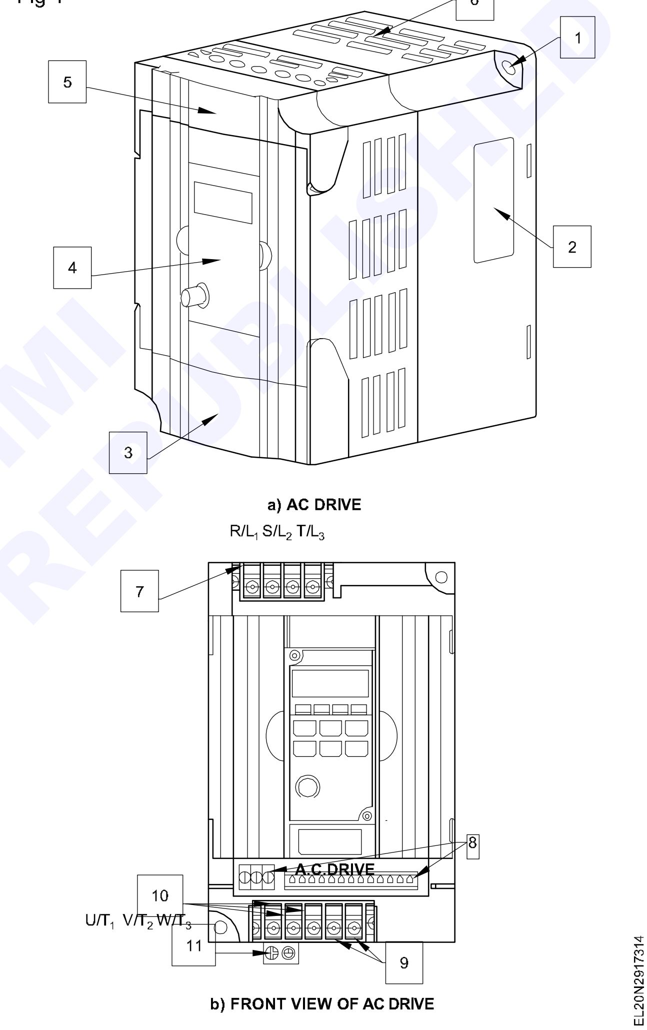
Operation of AC drive

When the VFD is started the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low - speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low -speed operation with significant torque is not usually possible without separately motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy.

Part of AC drive (Fig 4a & 4b)

Fig 4



AC drives of various brand with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power input and output terminals, control terminals, keypad (operator interface) for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts are given below and shown in Fig 4a and 4b.

1 Mounting screw holes

2 Name plate label

3 Bottom cover

4 Digital keypad

5 Upper cover

6 Ventilation hole

7 Input terminals

8 Control Input/Output terminals

9 External brake resistor terminal

10 Output terminals

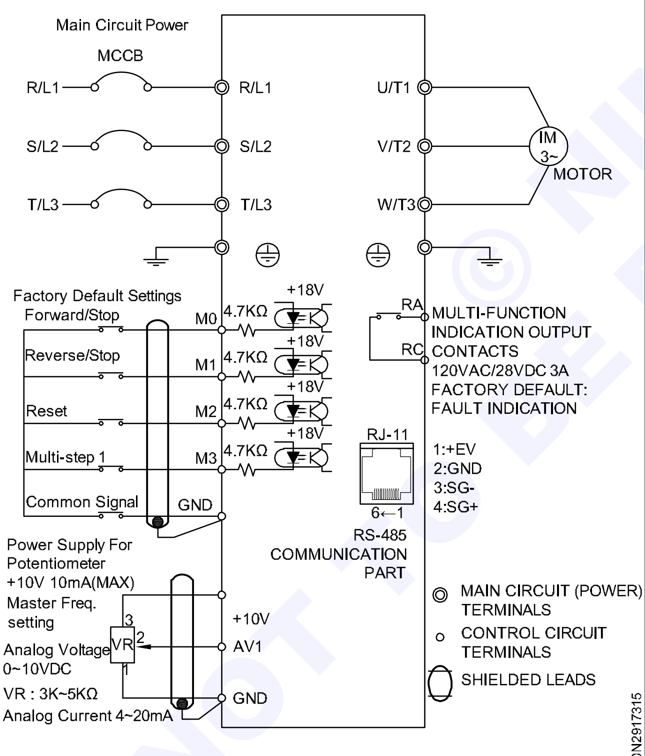
11 Grounding

Power and control terminals

In AC drive, the front panel has the input power terminals viz R/L_1, S/L_2 and T/L_3 where 3 phase AC 415V, 50Hz supply is connected. The 3 phase induction motor is connected of output power terminals viz. U/T1, V/T2 and W/T3.

There are control terminals viz M0, M1, M2, M3, GND, +10V, AV1 etc. for starting/stopping/ reversing and speed control actions. Names and locations are given in Fig 5

Fig 5



CONNECTION DIAGRAM OF AC DRIVE & MOTOR

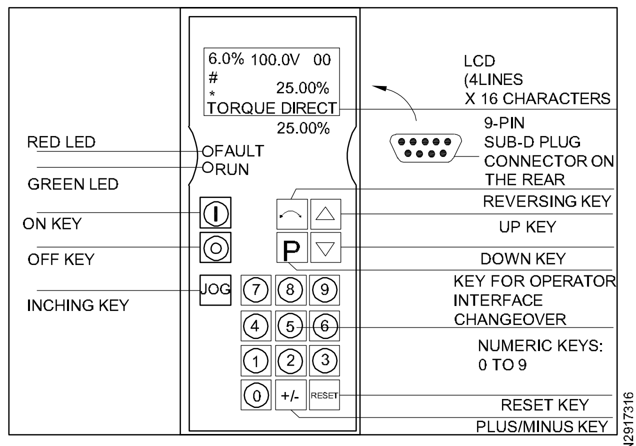
Parameter settings of DC drive

As discussed in previous chapter, the speed of DC motor is directly proportional to the armature voltage (E_b) and inversely proportional to the field current(I_f) and also the armature current (Ia) is proportional motor torque.

In armature controlled DC drives, the drive unit provides a rated current and torque at any speed up to rated speed.

The Fig 6 shows **Basic Operator Panel (BOP)** keypad provided on the front panel meant for controlling the drive.

Fig 6



BASIC OPERATOR PANEL (BOP) KEY PAD

The LCD is used to monitor the parameter. To start the motor, 'ON' key is to be pressed, and to stop the motor 'OFF' key is to be pressed. There is 'JOG' key provided for inching operation.

There is a key 'P' given for operator interface, changing over the parameter setting can be done by using this key in association with (Δ) key and key (∇). Parameters like, voltage current, Torque etc will be displayed turn by turn on each pressing of 'P' key /button.

The (Δ) or (∇) keys are used to increase or decrease the values. Numeric keys are also can be used to enter the values directly.

LED indicators are provided to indicate the status of drive. Green LED indicates the system running where as Red LED indicates when fault is occurred.

Programming of DC drive is possible through, personal computer (PC) also. For this purpose a connector for connecting PC through interfacing cable is provided at the rear panel.

There may be variations in terms of names of key, display setting etc for different brands.

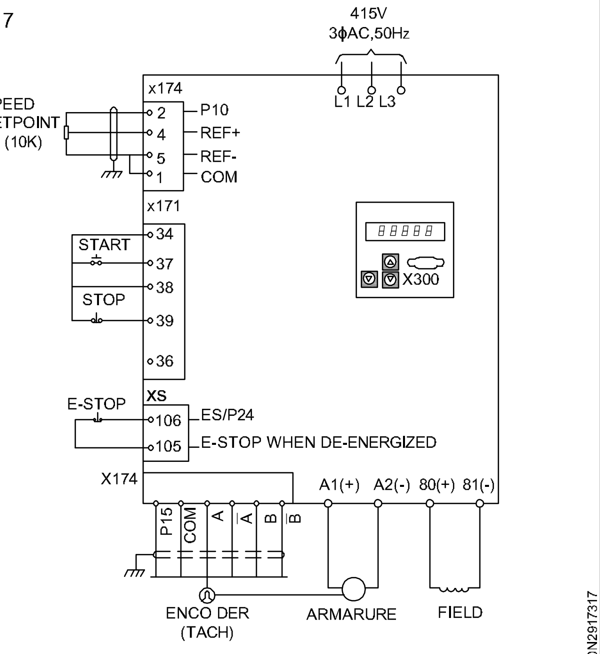
Operation of motor through DC drive

Fig 7 shows the operation of controls arrangement which is called as basic operator panel (BOP) .

The input supply connections and armature and field connections are well illustrated in Fig 7. Input 3 phase AC, 415V, 50Hz supply can be connected L_1, L_2 and L_3. The armature is connected across A_1 and A_2 where as the field is connected across B_0 and B_1 (The terminal names may vary depends on the type and make) an equipment ground conductor (Ground wire) must be connected to the controller mounting panel. Separate equipment grounding conductors from other major components Viz, motor, drive enclosure isolation transformer case (if used) in the system must also be connected continuously to a control connection point.

The AC input supply is provided should match the voltage and frequency given on the controller's name plate. Improper voltage may damage the equipment and insufficient current will cause erratic operation of the drive.

Fig 7



CONTROL ARRANGEMENT OF BOP

The shielded cable is recommended for the tachometer and all low level signal circuit to eliminate the possibility of electrical interference.

In some DC drives a speed adjusting potentiometer is provided to vary motor speed by controlling armature input voltage after the controller has been started. Some time a torque adjusting potential meter is used in place of speed adjusting potentiometer. It controls motor torque by controlling the DC current in the motor armature.

Starting and controlling the speed of DC motor

When the 'ON' button in BOP is pressed, the motor will start running. The desired speed can be attained by using 'P' button and Δ & ∇ buttons.

When the "OFF" button is pressed the motor will stop but AC line voltage remains connected to the controller and full field voltage is present. Armature voltage is reduced to zero. When pressing the "ON" button again the motor will accelerate to the preset speed.

Inching operation

For inching operation the 'JOG' position should be selected. Then the controller will operate only as long as the "ON" button is held pressed.

Changing the direction of rotation

In some model a 'reversing switch' is provided to change the direction of rotation of the motor. This switch is responsible for changing the polarity at the motor armature connection. First start the motor by pressing 'ON' button. The motor will run in forward direction. To change the direction of rotation, press "OFF" button and ensure that the motor is completely stopped. Now press the reversing button and then press the "ON" button. The motor will now run in the reverse direction. The reversing key has a provision which prevents direct transfer from one direction to the other.

Precautions during installation, connection and operation of DC drive

- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that appropriate protective devices (circuit breaker MCB or fuses) are connected between the power supply and DC drive.
- Make sure that the drive is properly earthed.
- Do not attach or remove wiring when power is applied to the DC drive.

Parameter setting of AC drive

As explained earlier the speed (N) of AC induction motor is directly proportional to the voltage (V) and frequency (f) of the applied power supply. Within the base speed limit, the torque (T) can be kept constant by maintaining a constant voltage / frequency (V/F) ratio. By increasing of speed to above base speed limit is also possible but at the cost of the torque.

(VFD /VVVFD (Variable Voltage Variable Frequency Drive) drives are used for efficient speed control of AC motors. The advantages of using drives to control the speed is already explained.

The AC drive has a front panel which includes two parts. Display panel and keypad. The display panel is provided with the parameter display and shows operation status of the AC drive. Keypad provides programming interface between users and AC drives. The Fig 8. shows the location of buttons and display unit on the front panel of AC drive.

Mode /Reset button

By pressing this button repeatedly the display will show status at the AC drive such as the reference frequency and output current. If the drive stops due to a fault, correct the fault first, then press this button to reset the drive.

Prog/Data button

By pressing this button will store the entered data or can show factory stored data.

Run/Stop button

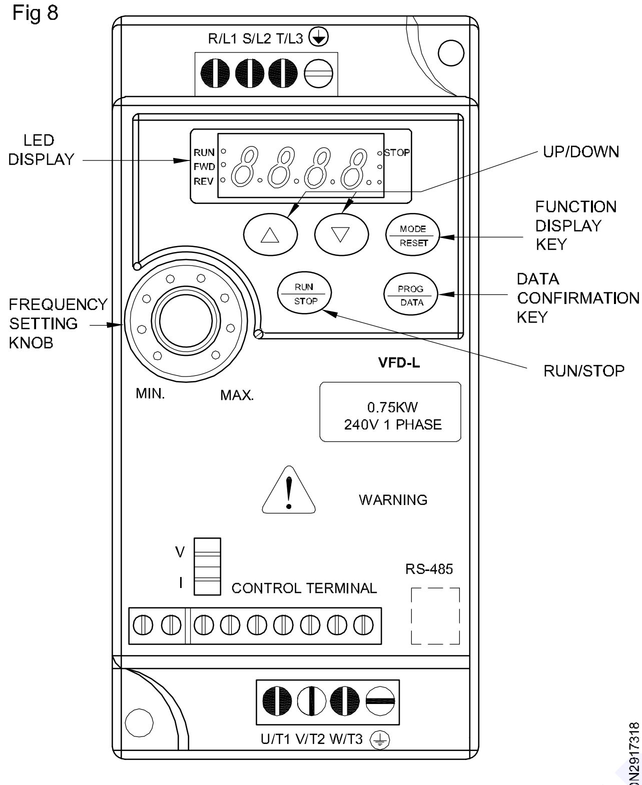
To 'start' or 'stop' the AC drive operation this button is to be pressed.

This button can only be used to 'stop' the AC drive, when it is controlled by the external control terminals.

UPΔ / down ∇ button

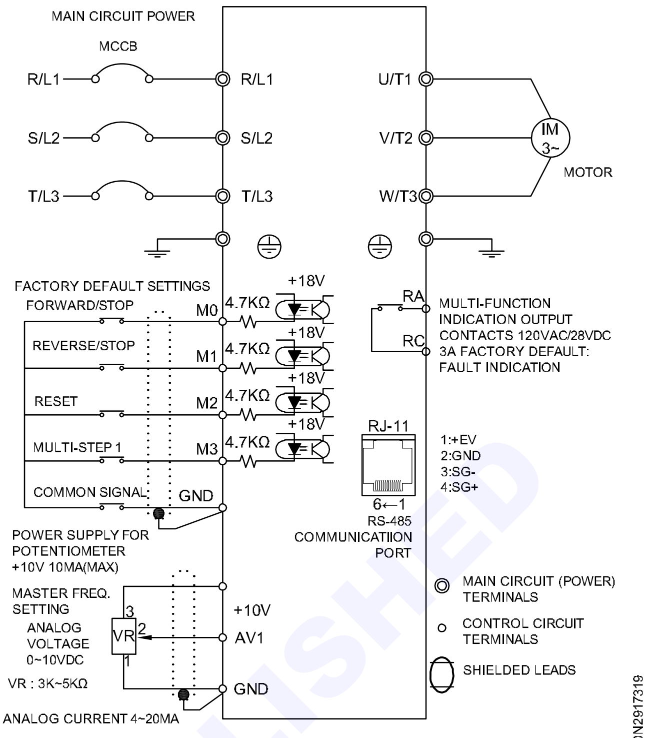
By pressing the 'Up' or 'Down' button momentarily parameter setting can be changed. These key may also be used to scroll through different operating values or parameters. Pressing the 'Up' or 'Down' button momentarily it will change the parameter setting in single unit increments. To quickly run through the range of settings, press 'Down' and hold the button.

Fig 8



DISPLAY UNIT OF AC DRIVE

Fig 9



CONNECTION DIAGRAM OF AC DRIVE AND MOTOR

Frequency setting knob

By using this knob, the frequency variation can be done.

'RS 485' communication port

Programming of AC drive can be done through personal computer (PC) also. For this, the drive should be interfaced with PC through 'RS 485' port.

LED displays are also given in the display unit to indicate the status of drive like 'RUN', 'FWD' and 'REV'.

Operation of AC motor through drive

The motor and drive connections are well illustrated in Fig 9. A 3∅ , 415V, 50Hz AC supply is connected to the drive input terminals R/L_1, S/L_2 & T/L_3. Similarly output terminals of this drive is such as U/T_1, V/T_2 & W/T_3 are connected to 3 phase induction motor. (The terminal names may vary depends on the type and make)

Both input end and output ends are earthed separately.

Changing of speed

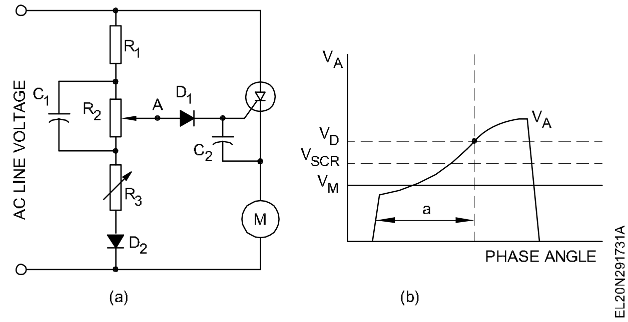
The AC input supply provided, should match the voltage and frequency given on the nameplate. Improper voltage may damage the drive.

Programming can be done through 'MOD/RESET' button in association with ∆ and ∇ button and the drives speed can be changed by using these buttons. The drive is started through 'RUN'/STOP' button.

The motor can be run at different speed by programming for the required speed.

Speed control of universal motors using SCR : Majority of domestic appliances like electric drilling machine, mixer etc., incorporate universal electric motors. Any of the half wave or full wave controls discussed earlier can be used to control speed of universal motors. Universal motors have some unique characteristics which allow their speed to be controlled very easily and efficiently with a feedback circuit is in Fig 10.

Fig 10



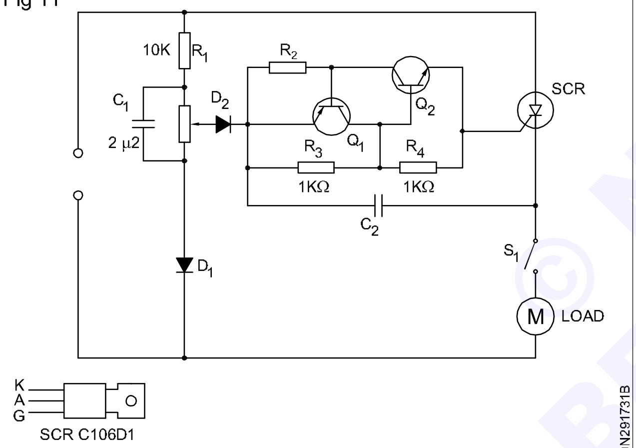
The circuit at Fig 10a provides phase controlled half wave power to the motor; that is, one the negative half cycle, the SCR blocks current flow in the negative half cycle, the SCR blocks current flow in the negative direction causing the motor to be driven by a pulsating direct current whose amplitude is dependent in the phase control of the SCR. The operation of the circuit shown in Fig 10 is as follows.

- Assuming that the motor is running, the voltage at point A in the circuit must be larger than the forward drop of diode D_1, the gate to cathode drop of the SCR, and the emf generated by the residual mmf in the motor, to get sufficient forward flow to trigger the SCR.

- The wave form at point A (V_A) for one positive half cycle is in Fig 10b and with V_{SCR}, V_D and motor generated emf V_M. The phase angle at which the SCR would trigger is shown by the vertical dotted line.
- For any reason if the motor speed increases, then V_M will increase, the trigger would move upwards and to the right along the curve so that the SCR would trigger later in the half - cycle thus providing less power to the motor, causing it to slow down. Similarly, if the motor speed decreases, the trigger point will move to the left and down the curve, causing the SCR to trigger earlier in the half cycle providing more power to the motor thereby speeding it up.
- Resistors R_1, R_2, R_3 along with diode D_1 and C_1 forms a ramp generator. Capacitor C_1 is charged by the voltage divider R_1, R_2 and R_3 during the positive half cycle. Diode D_2 prevents negative current flow during the negative half cycle, therefore C_1 discharges through R_2 and R_3 during negative half cycle. Varying the value of R_2 varies the trigger angle α.

A practical version of the circuit for controlling the speed of universal motors is in Fig 11.

Fig 11



CIRCUIT DIAGRAM OF UNIVERSAL MOTOR SPEED CONTROLLER

As can be seen, the circuit at Fig 11 is quite similar to that at Fig 10 but for the addition of two transistors and a few resistors.

In Fig 11, the action of Q_1 - Q_2 is to provide adequate gate current to trigger the SCR into conduction.

Q_1 - Q_2 and their associated resistors acts as a voltage sensitive switch. In each half cycle, C_2 is able to charge via R_1. As soon as voltage across C_2 rises to suitable value. Q_1 and Q_2 both switch- on and partially discharge C_2 into the gate of the SCR, thus delivering a pulse of high current to the SCR gate, independent of any current drive limitations of RV1. The Q_1 - Q_2 and C_2 network thus enables virtually any SCR to be used in the circuit almost irrespective of its sensitivity characteristics.

The universal motor speed control circuit is in Fig 11 enables the motor speed to be smoothly varied from zero to 75% of maximum via a single control. It also incorporates built - in feedback compensation to maintain the motor speed virtually constant at any given speed setting, regard-less of load changes.

Voltage stabilizer and UPS

Objectives: At the end of this lesson you shall be able to
- **state the basic concept of stabilizer**
- **draw the block diagram and explain the function of each blocks**
- **state the working various types of voltage stabilizers**
- **state the basics of UPS system**
- **explain the block diagram of OFF line UPS and its various controls and functions**
- **explain the block diagram ON line UPS and advantages and disadvantages.**

Voltage stabilizer

It is an electrical supply device controlled by electronic circuit which gives the constant output voltage irrespective of the variation in the high input supply voltage or disconnect the output circuit if the input voltage is very low or very high.

Every electrical device is designed to operate at a certain rated voltage for optimum efficiency and maximum length of service. Power supply voltages should not drop or rise by more than 5% of rated voltage as per IS.

The effect of voltage variations in commonly used electrical appliances are given below.

Sl.No.	Name of the equipment	Low voltage	High voltage
1	Incandescent lamp	Lamp efficiency decreases if the voltage is decreased.	Life of the lamp decreases or the lamp fuses in extreme cases.
2	Fluorescent lamp	If voltage is too low, lamp will not light up.	Life of the tube/choke decreases.
3	Electric stove, electric iron, water heaters, toasters etc.	Increases the heating time as heat produced is low.	Shortens the life of heating elements or heating elements burnt out.
4	Fans, vacuum cleaners	Efficiency decreases.	Life of the equipment is decreased
5	Washing machines, refrigerators and air-conditioners	Motor of the machine will draw more current from the line that results in overheating of the motor which may lead to burn out.	The motor insulation may fail and draw excess current which can lead to burn out.
6	Radios and television sets	Poor quality of reception, picture will not be clear in the television sets.	Life of the equipment is decreased

Some of the electronic equipment such as colour television sets are designed by the manufacturers with built in electronic stabilizers like Switch Mode Power Supplies (SMPS). Hence there is no need to provide an additional external stabilizers for these equipments.

Types of AC voltage stabilizers

1 Stepped voltage stabilizer

a) Manual

b) Automatic relay type

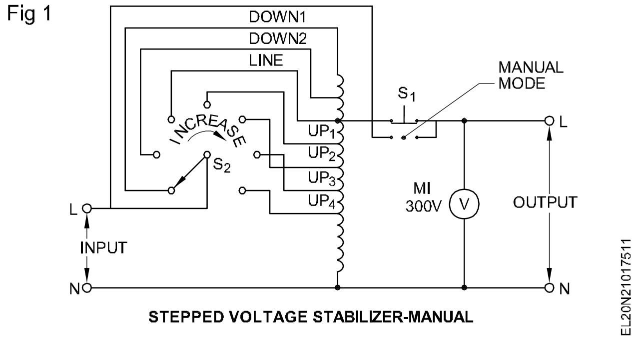
2 Servo voltage stabilizer

3 Constant voltage transformer

Stepped voltage stabilizer - manual type : Fig 1 shows an auto-transformer in which the output voltage increases as the tap changing switch S_1 is turned clockwise. The output voltage can be seen by connecting a voltmeter in the output side as in Fig 1. Increasing or decreasing the output voltage near to the set value is possible by rotating the tap changing switch S_2 in the appropriate direction within ±10% of the desired output voltage. A push-button switch S_1 enables to measure the incoming voltage.

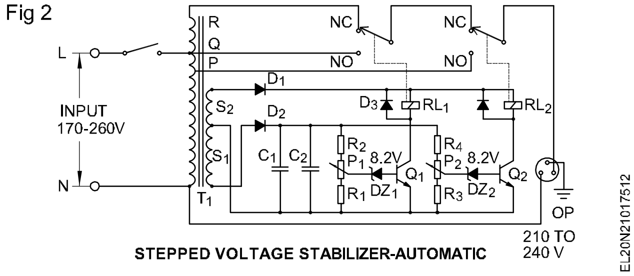
Stepped voltage stabilizer - automatic type : Fig 2 shows a stepped voltage stabilizer of the automatic type operated by relays. T_1 is an auto-transformer with multiple tappings. S_1 and S_2 are two secondaries for relay operation. The secondary voltage of S_1 is rectified and filtered for the use of the sensing circuit while voltage S_2 is rectified and filtered for the use of the relay operation. P_1 and P_2 are pre-set resistors (variable resistors) used for adjustment. R_1, P_1 and R_2 provide sensing voltage to the zener diode. DZ_1 and R_3P_2 and R_4 to the zener diode DZ_2. Q_1 and Q_2 are two transistors used as switches. RL_1 and RL_2 are two relays.

Fig 1



STEPPED VOLTAGE STABILIZER-MANUAL

Fig 2



STEPPED VOLTAGE STABILIZER-AUTOMATIC

When the input voltage is low, say less than 200V, both DZ_1 and DZ_2 do not conduct as the voltages at the preset tappings are less than their zener diode voltages. This causes both transistors to cut off and the relays are in the off position. At the off position of the relays, NO contacts of both the relays connect terminal R of the auto-transformer to output which results in booster output voltage.

When the input voltage increases above 210V, but below 240V voltage across S_1 increases proportionally. This increases the pre-set tap voltage, thereby the zener diode DZ_1 conducts and hence make the transistor Q_1 to ON. The relay RL_1 operates and connects the supply voltage directly to the output through NO. contact of RL_1 and NC contact of RL_2. By this operation the output voltage will be the same as the input voltage.

When the input supply voltage increases above 240V the zener diode DZ_2 gets voltage from P_2 and hence conducts which makes Q_2 to ON. This results relay RL_2 energise and output is taken from NO. point of RL_2. The output voltage reduces or bucks.

Usually 12V DC relays with the required current ratings of contacts are preferred for stabilizers. Diodes or capacitors are used across the relay coil to protect the transistors from reversed induced emf when the relays become OFF. LED indicators are sometimes used to indicate the mode of operation such as buck, normal, boost etc.

Stepped voltage stabilizers are available with different types of electronic circuits with one to three relays to provide an output voltage of 200-240V. They are specified for maximum input voltage variation and for their output, KVA ratings say 170 to 270 volts 1 KVA or 135 to 260 volts 0.5 KVA.

Some of the stabilizers are provided with over-voltage and under-voltage cut off to protect the connected equipment.

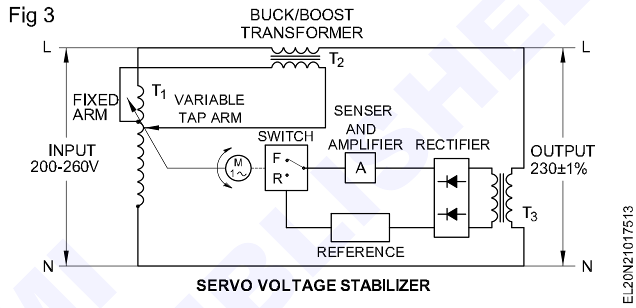
Applications : Stepped voltage stabilizers are used along with refrigerators, air conditioners, TVs, VCRs etc. Colour TVs with self-contained switch mode power supplies do not require voltage stabilizer as they are designed to operate from 130 to 260 volts.

Servo - voltage stabilizer

The servo voltage stabilizer employs a toroidal auto-transformer and a servo motor driven by a sensing circuit which senses the voltage. The difference between the output and nominal voltage is sensed by a sensing circuit which drives the servo motor. Any variations in mains cause the motor to move clockwise or anticlockwise thus correcting the voltage.

A servo voltage stabilizer is provided with three transformers function along with control circuits and a servo motor as in Fig 3. T_1 is a continuously variable toroidal auto-transformer (variac) driven by a servo motor M.

Fig 3



SERVO VOLTAGE STABILIZER

The output from the variac, drives a series buck/boost transformer T_2 so that boost takes place when the variable tap arm moves down and bucks the voltage when the arm moves up. The transformer T_3 provides the required reference voltage and sensing voltage for the electronic circuit which drives the motor.

When the output voltage is less than the reference voltage, the electronic circuit senses the difference, drives the motor in one direction which results in increase in the output voltage.

When the output voltage increases above the ratings, the motor is driven in the opposite direction so that the output voltage increases. When the voltage difference in output and the reference are equal, the servo motor is switched off by the circuit.

A servo stabilizer provides constant voltage to an accuracy around ±1% or ±0.5% and a correction range 10 to 30 volt/sec.

A servo stabilizer is more accurate and also costlier, and, therefore, used with costlier equipments such as computers, xerox machines, medical electrical equipments etc.

Constant voltage transformer

A constant voltage transformer works on ferro-resonant principle. The variation in the primary flux with an unsaturated iron core does not affect the secondary flux with saturated iron core. Thus, the secondary induced voltage remains relatively independent of the voltage impressed upon the primary winding.

Basics of UPS systems : Most people take the mains AC supply for granted and use it almost casually without giving the slightest thought to its inherent defects and the danger posed to sophisticated and sensitive electronic instruments. For ordinary household appliances such as incandescent lamps, tubes, fans, TV and fridge, the mains AC supply does not make much of a difference, but when used for computers, medical equipments and telecommunication systems, a clean, stable, interruption-free power supply is of utmost importance.

UPS (Uninterrupted Power Supply) is the only solution available to an individual customer faced with the problem of ensuring high quality of power for critical loads. All UPS designs contain a battery charger to keep the battery fully charged by the power from mains. Small UPS normally comes with a sealed maintenance free (SMF) batteries which can provide 10 to 15 minutes of power backup, the backup time increases with the capacity of the battery. Tubular batteries or automotive batteries are used in medium and large capacity UPSs.

UPS classification : There are two broad categories of UPS topologies - OFF line, and ON line . These topologies differ in the way they serve the load when the mains is present and is healthy. They vary in features & pricing.

OFF-Line and ON-Line : OFF-Line UPS filters the mains and feeds it directly to the load for most of the time. When the mains is unhealthy, perhaps due to a slight drop in voltage, the load is switched by a fast relay, in typically less than half a cycle, to an inverter deriving its power from a battery. The inverter generates a square or stepped waveform to emulate the mains-satisfactorily for most computers. This particular technique represents the lowest cost solution.

Online UPS converts AC mains into DC before inverting again to AC to power the load with a synthetic sine wave. A battery connected across the DC link acts as the backup power source.

This gives a supply for the computer that totally isolates the input mains from the load, removing all mains noise and with no break when the mains fails.

Standby/OFF Line block diagram (Fig 4) : In the off line UPS, the load is connected directly to the mains when the mains supply is available. When working over voltage/ under voltage conditions are detected on the mains, the off line UPS transfers the load to the inverter. When the line is present, the battery charger charges the battery and the inverter may either be shut down or will be idling. Thus in an off line UPS, there is a load transfer involved every time, the mains is interrupted and restored. This transfer is effected by change- over relays or static transfer switches. In any case there will be a brief period during which the load is not provided with voltage. If the load is a computer and the transfer time is more than 5ms, then there is a chance that the computer will reboot.

Some modified designs incorporate a limited range of voltage regulation by transformer tapping and a certain degree of transient protection by using RF filters and MOV's (Metal Oxide Varistor). Off line UPS is an economical and simple design and hence it is preferred for small rating, low cost units aimed at individual PC user's market. When the load is really a critical one an off line UPS is not acceptable. Usually square wave output off line UPS are available in market with lower loading capacities.

Advantages of OFF line UPS: High efficiency, small size, low cost.

Disadvantages: There can be change over complaint in offline UPS. Off line very much depends on battery. If battery fails entire system fails. Sometimes during change-over computer re-boots which causes loss of files. Another disadvantage is that output voltage will be a varying one. Usually in the range of 200V-240V and hence not suitable to all electronic gadgets.

Front panel indications and rear panel sockets/ switches used in UPS : All UPS systems have

- Fuse/Fuse holder
- Switches
- Sockets
- Panel indicator (LED and Neon lamp)
- Meters (Volt/Ampere)

Fig 4

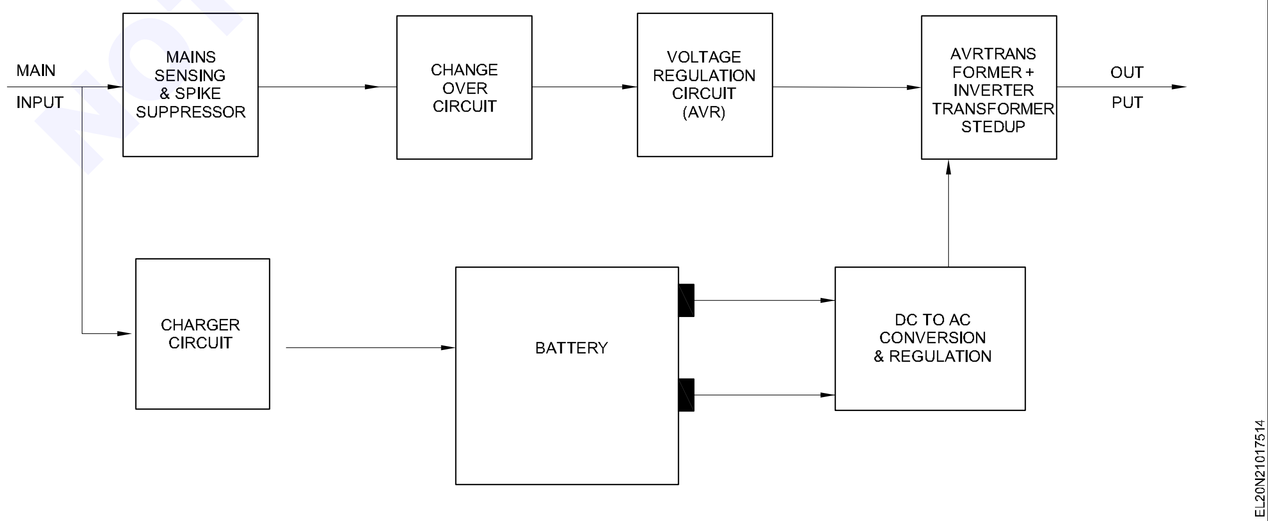
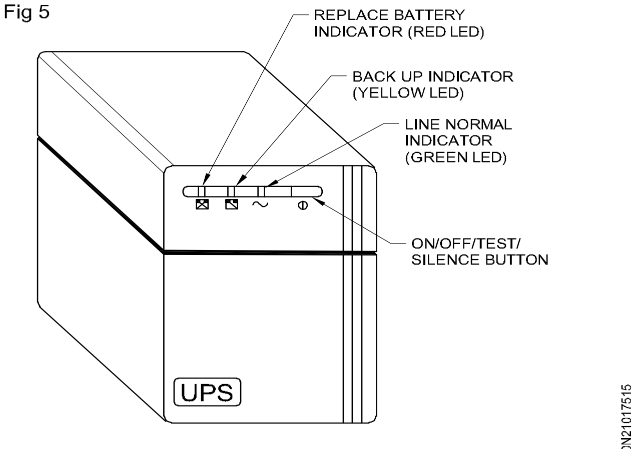


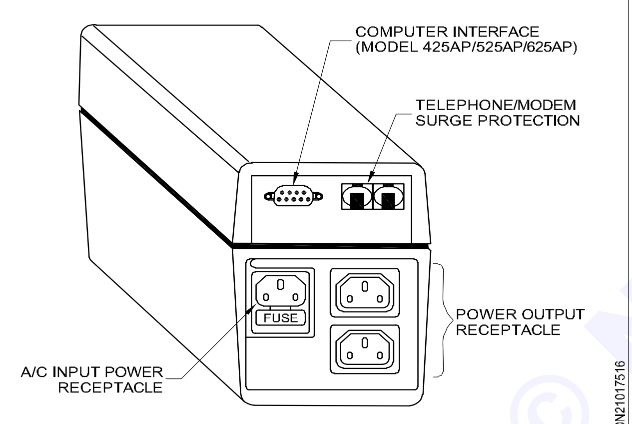
Fig 5 and 6 shows the front and rear panel controls/ sockets.

Fig 5



UPS FRONT PANEL

Fig 6



UPS REAR PANEL

ON line UPS

In an ON line UPS, the inverter always supplies the load irrespective of whether mains power is available or not. The load is always left connected to inverter and hence there is no transfer process involved. When the mains power is present, it is rectified and applied in parallel with the battery. Hence all the supply system transients are isolated at the battery and the inverter always delivers pure sine wave of constant amplitude to the load.

Fig 7 represents a basic block diagram of an ON Line UPS.

In the block diagram (Fig 7), the mains input is stepped down to a lower level and applied to a thyristor based phase controlled AC to DC converter, employing firing angle(α) control. The PWM inverter which usually employs pulse width modulation using triangular/square wave carrier runs in battery mode. The output is filtered and given to the load. The PWM inverter is switched in the frequency range (50Hz) depending on the power rating and hence the DC side current drawn by the inverter will contain switching frequency components.

Along with the charging current the second harmonic component of DC side current of the inverter also flows into the battery. This second harmonic is quite large in value and this represents unnecessary strain on the battery. This is one of the major disadvantages of this design since it affects the battery life adversely.

When the mains is present the load power flows though the converter, reaches the battery node and from there flows into the inverter i.e there is double conversion of power. The converter, Inverter and the two level shifting transformers incur power losses in this process. Hence the efficiency of this design is lower than the OFF line design.

In a properly designed control system the battery voltage is measured and compared with a set float voltage. The error is processed in a proportional controller and the processed error decides the charging current that should flow into the battery. Charging current will be a constant one for ON line UPS.

Often it is found that the battery is in discharge mode even when mains is present i.e the battery shares the load current with the mains. This happens when the mains voltage is low and/or the output is loaded to above 75%. The efficiency of ON line UPS can be increased by using boost type power factor correction circuit.

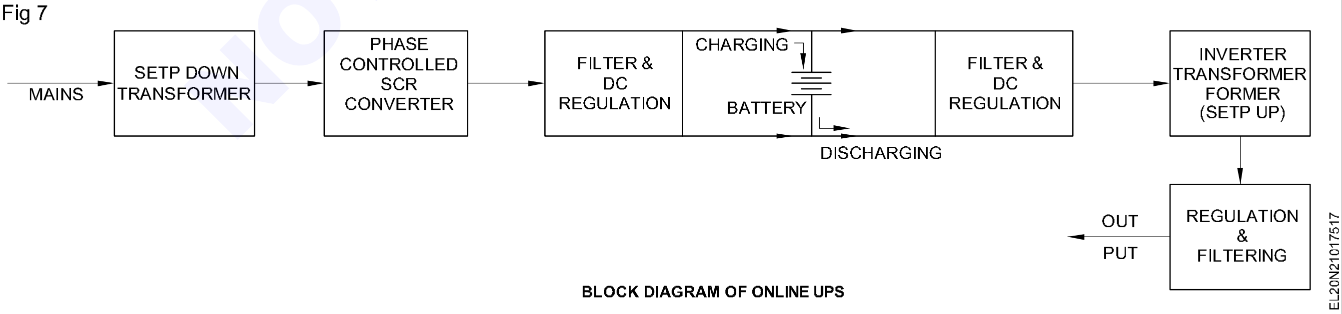
Advantages

- Constant output voltage (No AVR card) free from changeover problem.
- Constant charging current.

Disadvantages

- complex in design, lower efficiency, higher cost, bigger in size and strain on the battery.

Fig 7



BLOCK DIAGRAM OF ONLINE UPS

Emergency light

Objectives: At the end of this lesson you shall be able to
- **explain the block diagram of emergenccy light**
- **explain the emergency light circuit diagram and charging of battery.**

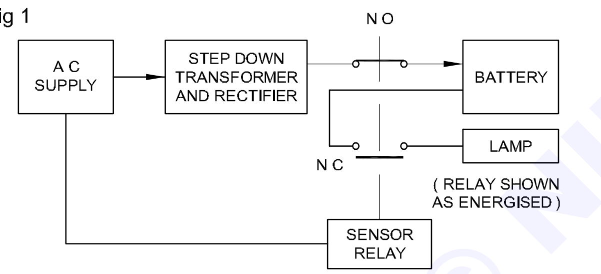
Emergency light

Emergency lighting system is commonly used in public building, work places, residences etc., The main function of the emergency lamp in the industry are

- to indicate ESCAPE routes
- to provide illumination to path ways and exit
- indicate the location of the fire fighting equipments.

The block diagram of an emergency light is in Fig 1. The circuit is discussed here are basic circuits without over charging protection for battery or trickle charging facility. Modern emergency lights have these facilities.

Fig 1



BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING INCANDESCENT LAMP

As shown in the block diagram AC main supply is fed to the step down transformer, then it is rectified to charge the battery through a sensor relay. A lamp is connected in the battery circuit through the relay. When AC supply fails the relay enables the battery to the connected lamp circuit through the normally closed contact and the lamp will glow.

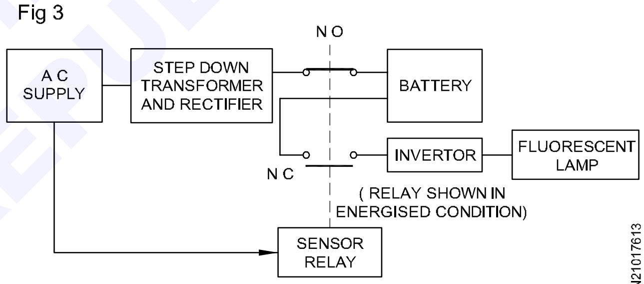
When the AC supply is restored, the battery will be getting charged through the normally open contact of the relay. The charging current is regulated by the series resistances of 2.2 ohm, 5 watt. as in Fig 2. The two LEDs, one is red and the other is green are provided in the circuit to indicate the presence of AC and the lighting of the lamp through the battery supply respectively.

One 1000 microfarad capacitor is used in the rectifier circuit to smoothen the output D.C. supply and one 10 microfarad capacitor is used across the relay to increase the efficiency of relay operation.

Emergency tube light circuit: The emergency light which is connected to an ordinary incandescent lamp will give less light. If the fluorescent tube is used in emergency light it will give about 3 times more light consuming same wattage. Hence most of the emergency lights are incorporated with fluorescent tube lights.

The inverter circuit is incorporated with the ordinary incandescent lamp could be replaced by a tube light as shown in the block diagram, (Fig 3). The tube light requires a high voltage for its operation. The inverter is used to convert DC supply to AC and then it is stepped up to light the fluorescent tube. The inverter circuit is made operative by the sensor (relay). When AC supply is not available, during power failure battery voltage operates the inverter, in which DC is converted to AC and then stepped up to high voltage to enable the fluorescent tube to light up.

Fig 3



BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING FLUORESCENT LAMP

Inverters are basically transistorised oscillators as in Fig 4. They can be made to oscillate at the frequency of about 6.6 kHz. The frequency of the circuit can be changed by changing the value of resistor and capacitor in the circuit which is connected in the base of the transistor.

When the AC supply is resumed the sensor relay connects the battery terminals to the rectified DC circuit for charging and the inverter circuit is disconnected from the circuit by the relay.

For keeping the temperature of the power transistor within its temperature range suitable heat sink should be mounted over the power transistor.

Fig 2

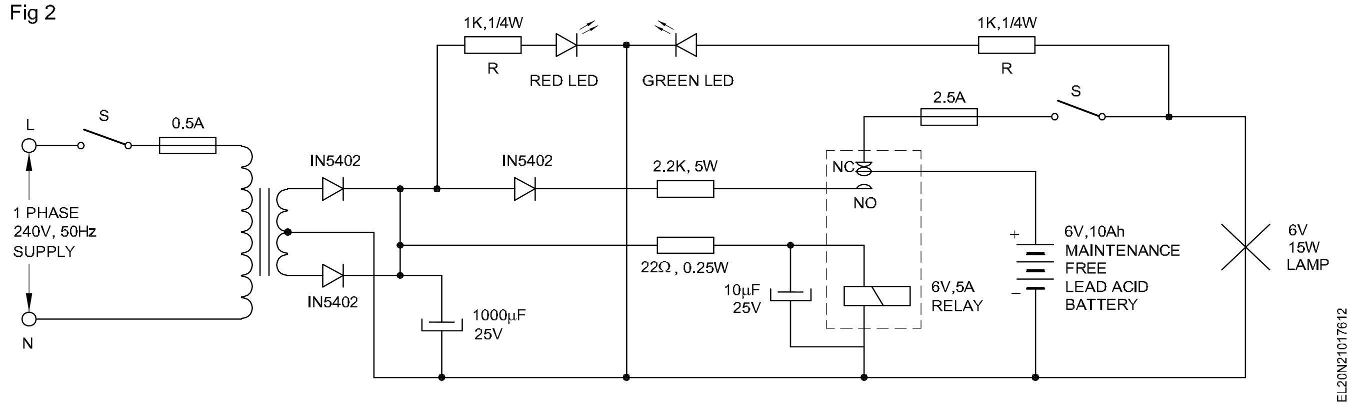
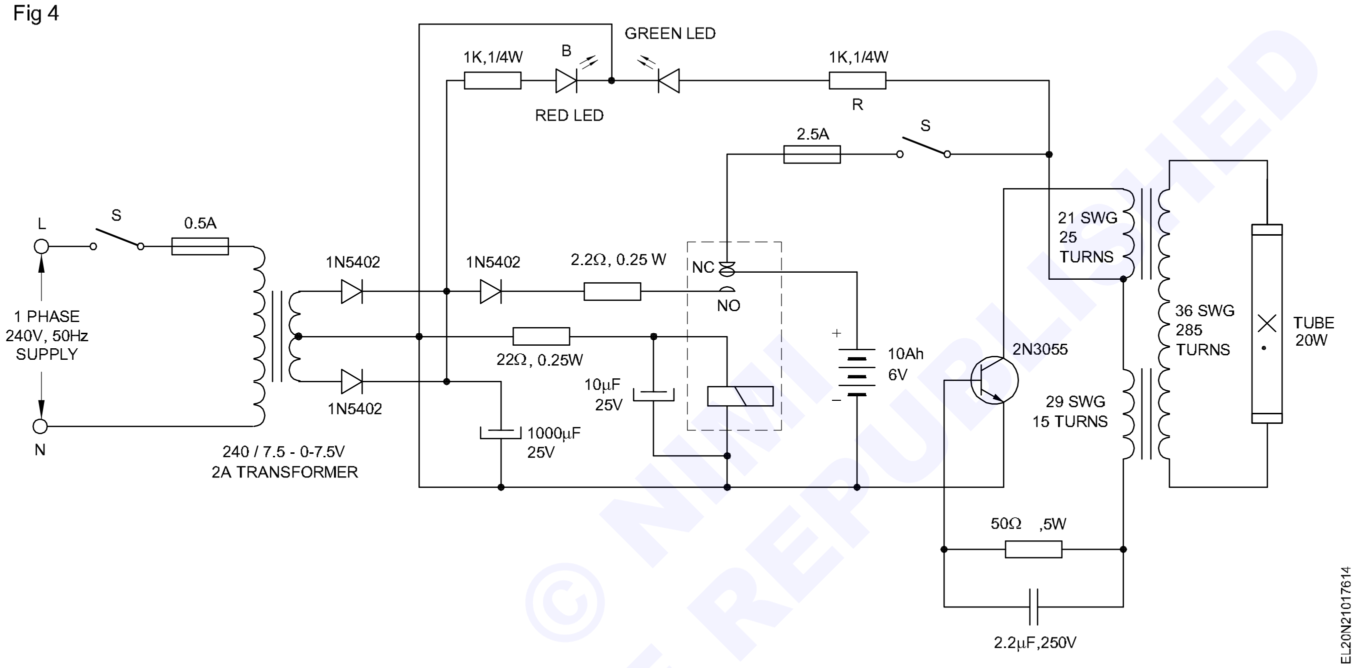

1K,1/4W
R
RED LED
GREEN LED
1K,1/4W
R
2.5A
S
L
S
0.5A
IN5402
IN5402
2.2K, 5W
NC
NO
1 PHASE
240V, 50Hz
SUPPLY
22Ω , 0.25W
6V,10Ah
MAINTENANCE
FREE
LEAD ACID
BATTERY
6V
15W
LAMP
IN5402
10µF
25V
6V,5A
RELAY
N
1000µF
25V
EL20N21017612

Fig 4


GREEN LED
1K,1/4W
B
1K,1/4W
RED LED
R
2.5A
S
L
S
0.5A
21 SWG
25
TURNS
1N5402
1N5402
2.2Ω, 0.25 W
NC
NO
36 SWG
285
TURNS
TUBE
20W
1 PHASE
240V, 50Hz
SUPPLY
22Ω, 0.25W
10Ah
6V
2N3055
1N5402
10µF
25V
29 SWG
15 TURNS
N
1000µF
25V
240 / 7.5 - 0-7.5V
2A TRANSFORMER
50Ω ,5W
2.2µF,250V
EL20N21017614

Battery charger and inverter

Objectives: At the end of this lesson you shall be able to
- **explain the working of battery charger with the help of block diagram**
- **state the principle of inverter with the help of block diagram.**

A Simple battery charger : The charger can charge 6V,12Vand 24V battery at Suitable current rate. This circuit has many protection built in it to protect the battery from overcharge and reverse polarity etc.

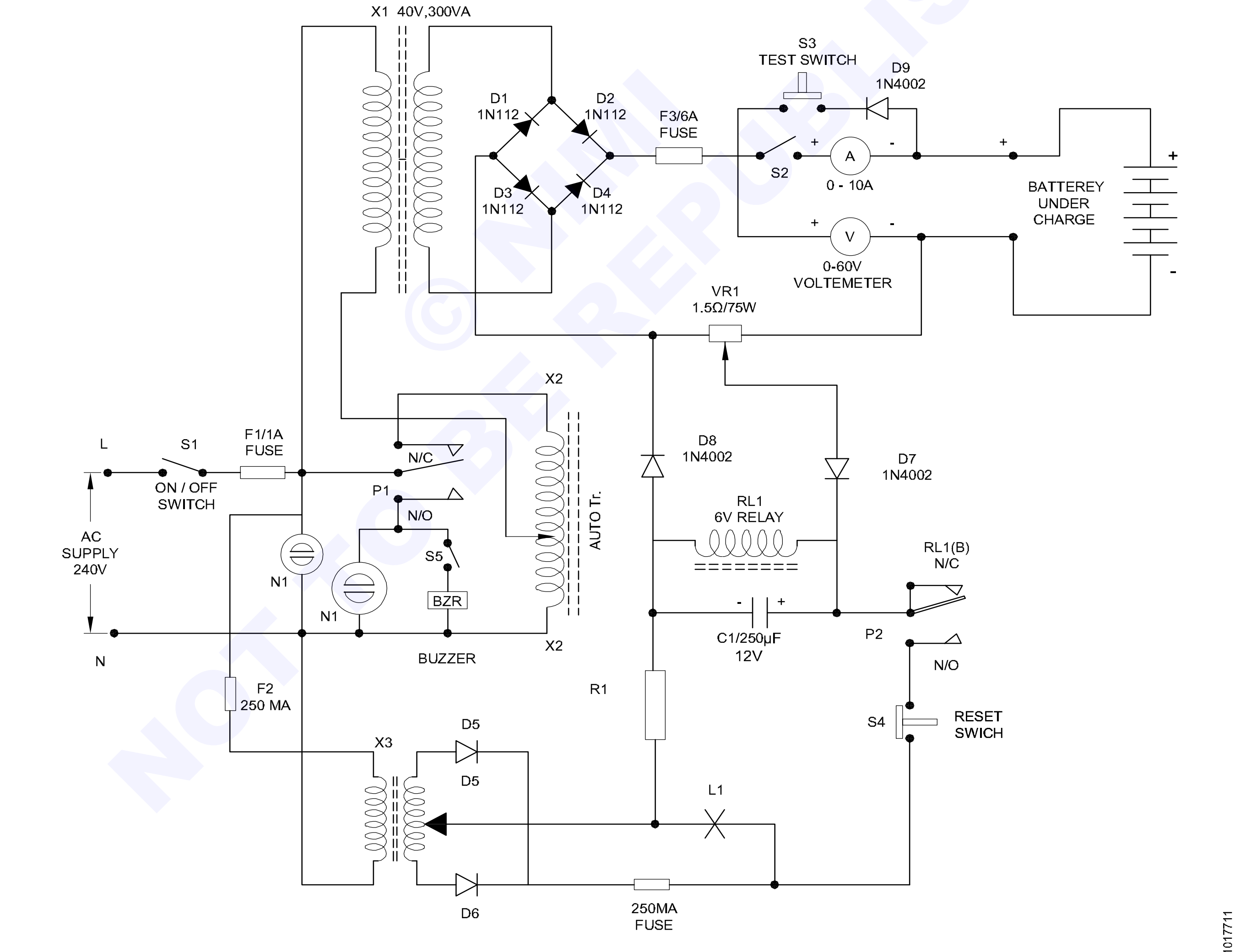
The charger consist of an auto transformer X_2 (Fig 1) for supplying constant current and voltage.

A charger transformer 'X_1' is connected to the auto transformer and the secondary of the X_1 (Fig 1) is rectified through full wave bridge rectifier and supplied to the battery under charger through. Ammeter voltmeter and a potentiometer (Fig 1)

A step down transformer X_3 is used to keep cut off relay is energised condition when the mains AC supply is cut off to the charger circuit. Relay RL_1 used to cut off the AC mains supply to the charger circuit. Pole P_1 of relay RL_1 is connected to AC mains supply and pole P_2 is connected to cut off circuit.

Relay is energised by the centre tapping of potentiometer, which is set such that, the current in the charger circuit exceeds then it is energised and poles P_1 & P_2 are connected to normally opened (NO)pin, switching 'Off' A/C mains supply to the circuit.

Fig 1



AUTOMATIC BATTERY CHARGER

The test switch S_3 is connected to check battery polarity, reset switch S_4 is used to reset the charger, when any fault occurs. Then the charger is cut off and the Switch 'S_1' is mains ON/OFF switch.

A fully charged lead acid battery must be 2.1 volt/cell during on charge. It will increase upto 2.7V/cell. The voltage of a battery is multiple of the number of cells.

In discharged condition the voltage is 1.8V/cell, it should not be further discharged in this condition as it may permanently damage the cell.

E.g A 100AH (ampere hour)battery requires (100 AH/ 10Hr=10 Amp) 10 Amp. Charging current for 10 hours for fully charged. To get complete discharge at the rate of 5Amps will require 20 Hrs.

The fully discharged battery requires about 11/2 times more to get charged .If the battery is in dead (or)not in use for long time even in normal changing current is passed. These dead batteries require higher charge voltage to start the charging current.

Checking of battery : Acid level and specific gravity of electrolyte, will indicate the condition of battery whether it requires charging or not.

The hydro meter is used for checking the acid level in a battery .The scale in marked in the hydrometer from 1100 to 1300.when it is inserted in the battery, the reading

i 1100-1150 -indicates battery is down

ii 1200-1250- indicates battery is o.k.

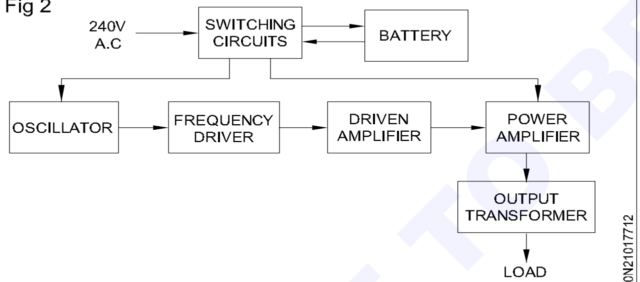
iii 1250-1300 indicates excess acid

Voltage testing : By using high rate discharge tester, the voltage the each cell must be 2.1V, If it indicates below than 1.8V, then it shows the battery is in fully discharged. It is still below 1.8V.Then the battery becomes dead condition.

Inverter : It is an electronic device, which converts a D.C potential (voltages) normally derived from a lead-acid battery into a stepped-up AC potential (voltage) which is similar to the domestic AC voltage.

Locating the fault and troubleshooting of an inverters which provide sine wave outputs or the use of PWM(Pulse Width Modulation) technology is very difficult. (Fig 2)

Fig 2



BLOCK DIAGRAM OF A DRIVEN INVERTER

Switching circuits : It is the input stage of a inverter. This circuits supplying the power to further stages and connected to battery. The DC supply of battery in this supplies to the switching circuits for various needs.

Oscillator

It is an electronic circuit which generates the oscillating pulses either through an IC circuit or a transistorized circuit. This oscillations are the production of alternate pulse of positive and negative (ground) voltage peaks of a battery and at a specified frequency (No.of positive peaks per second). These are generally in the form of square waves and the inverters are called square wave inverters.

The complete circuit diagram of a static 50Hz static inverter is in Fig 3.

The oscillator section of the inverter used a IC circuit to produce control signal frequency to the control and drianer section. The received oscillating frequency is amplified to a high current level using power transistor or MOSFET.IC 7473(JK Flip type) used to power amplification and control the frequency to the driver transistors T1 and T2 driving the power transistor to the required level as in the Fig 3.

The two parallel connected power transistor T5, T6 and T7, T8 are connected to the output transformer which is used to step up the low level AC from the amplifies stage into the specified level.

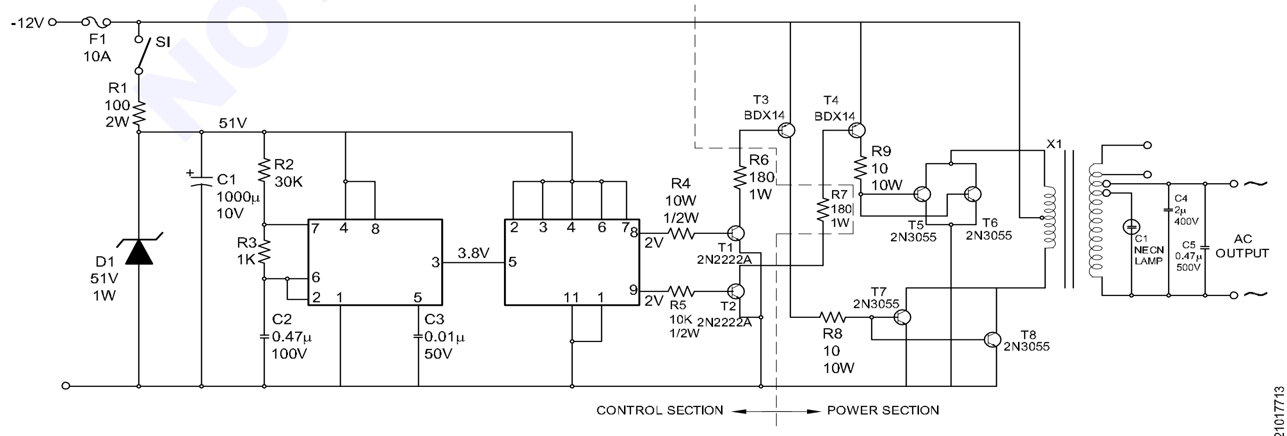
The transformer secondary is supplied the required level of AC 240V. The generation of the oscillations due to which the process of voltage induction is able to take place across the windings of the transformer.

The inverter does not produce any power and the power produced by DC source. The inverter requires a relatively stable power source capable of supplying of enough current for the intended power demands of the system.

An inverter can produce square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design.

The inverters more than three stages are more complex and expensive. Most of the electric devices are working with pure sine wave and AC motors directly operated on non-sinusoidal power may produce extra heat, and have different speed-torque characteristics.

Fig 3



COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER

Trouble shooting of voltage stabiliser, battery charger, emergency light, inverter and UPS

Objectives: At the end of this lesson you shall be able to
- **state the general precaution to carryout for preventive maintenance**
- **explain the steps to follow the break down maintenance**
- **service the voltage stabilizer, emergency light, battery charger, inverter and UPS**
- **analyse the trouble shooting chart and find the problem/ repair the equipment.**

Use of troubleshooting charts for fault location : The circuit diagram is in Fig 1 is given for your reference. The working of the mains cord, fuse, relay contacts, windings of the auto-transformer etc. can easily be ascertained by using a test lamp and/or a series lamp or by a voltmeter for checking the electronic circuit and relay coil winding. A multimeter in appropriate range is a must to localise the fault. A series lamp or test lamp should not be used to test these as they are liable to spoil while testing.

Troubleshooting chart given in Table 1 illustrates the problem, section to be suspected possible cause and action required for a stepped automatic voltage stabilizer.

General precautions for preventive maintenance

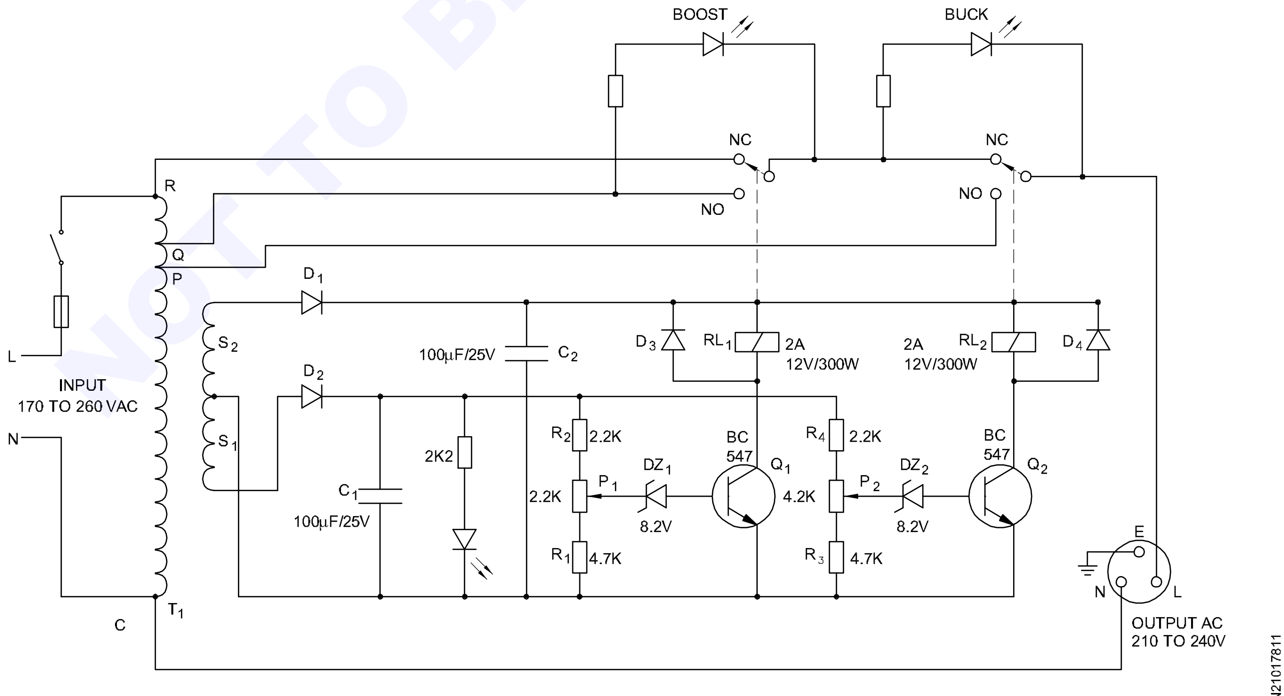
Maintenance for any equipment needs a working knowledge of that machine is very much essential to the person concerned. For example the volt ampere rating of voltage stabilizer is very important to carryout the preventive maintenance. Low quality, substandard components or materials never be used or recommended for use. Necessary steps to taken for safe temperature controlling and over loading conditions. Proper operating sequence or working steps to follow of all the equipments under maintenance.

Steps to follow break down maintenance

Break down can happen anytime, anywhere. Adequate protection might have provided to all equipments, for its smooth working. However continuous running or usage, lack of maintenance, human error and some unexpected reasons break down is happening.

Once break down maintenance or repair is required a detailed study of that equipment is essential. Always involve more persons pertain to the repair work or maintenance work for achieving a good result. A collective and competitive effort only will produce good results. Give value for everyone suggestion, expertise and workmanship. There must be a clean idea and vision to finalise the maintenance and repair. Ensure the services of experts, availability of spares, details of past records, diagrams and past history of the equipment such as its installation date, service records, number of break downs and its frequency etc; Servicing of voltage stabilizer by trouble shooting method.

Fig 1



TYPICAL CIRCUIT DIAGRAM OF A STABILZER

Table 1

Trouble shooting chart for stepped automatic stabilizer

Sl. No.	Problem	Section to be suspected	Possible cause for defective	Action
1	No output voltage at output socket.	Input buck/boost relays.	Mains cord, switch, fuse, transformer and relays	Locate and repair or replace
2	The output voltage is more, do not regulate.	Electronic circuit or relays.	Open/shorted rectifier / diodes, or open zener diodes	Locate the defective part and replace.
3	Output voltage is same as input. Do not regulate.	Transformer or Electronic circuit	Transistor or held up relay contacts or Partial open transformer / leads.	Test, repair or replace.
4	Output voltage is low. Do not regulate.	Electronic circuit	Shorted zener diode or transistor or open resistors	Test and replace.
5	Chattering in relays	Electronic circuit/relays	Leakage capacitors	Replace.

Trouble shooting of UPS

The trouble shooting and repair of UPS is difficult as this circuit is so complicated with so many functions. A step by step trouble shooting approach with a reasonable analysing is very important to carryout the troubleshooting in the UPS circuit.

A trouble shooting chart of UPS is given for your reference in table - 2.

Table 2

Troubleshooting chart of UPS

Sl.No.	Fault	Possible Reason	Troubleshooting
1	UPS works on 240V VAC mains but does not operate on battery	1 Battery fuse is blown out 2 Battery is discharged	1 Check the battery fuse. If fuse is blown, replace it, if it is loose, tighten 2 Recharge the battery, also check the polarity of battery
2	When UPS is switched on, charger does not turn on	1 Mains input fuse may be blown 2 Charger input fuse blown out	1 Change mains fuse, if fuse blown 2 Check the battery polarity and conditions, correct it if wrong, replace the fuse 3 Check the supply from mains, if OK, then check relay wiring, check relay coil.
3	240 VAC mains supply NOT available	1 Mains supply fails 2 Input AC mains is very low 3 Loose connection in input wiring	1 Check the supply of mains 2 Check the voltage 3 Tight the connection of wiring coming from distribution board
4	DC voltage is OK, but UPS shows DC under voltage and trips	1 Inverter fuse is blown 2 Rust/loose connection in battery	1 Replace fuse 2 Check the connection
5	When the UPS is switched ON with out load but DC under voltage indicator turns ON at load.	1 Load too high 2 Loose connection of battery terminal	1 Check the load, add loads gradually. 2 Tight the connections and check the polarity of battery

		3 Short or earth fault in load	3 Check the load circuit wiring
6	Where there is no AC mains supply and the UPS is operating on battery, DC under voltage indicator turns ON	1 Battery is discharged 2 Battery terminal dust or loose	1 Recharge the battery, use proper current capacity cable in the battery circuit. 2 Check the connection
7	DC fuse blows OFF	1 Overload or short circuit	1 Change DC fuse 2 Reduce the overload. If power transistors are short or leaky, replace them.
8	UPS does not switch ON	1 Supply fails due to blown out fuse or some break in cable 2 No DC supply in the control card due to dry soldering or desoldering	1 Replace fuse, check the cables 2 Check and correct dry soldering and de-soldering 3 Check control card wiring
9	UPS trips when full load is connected	1 Overload setting is wrong	1 Adjust the overload setting, check the power consumption of the load. Gradually increase the load.
10	UPS output is high	1 Some connection is broken in the feedback loop 2 Control card is not functioning properly 3 Over voltage sensing is faulty	1 Check feedback transformer wiring and adjust feedback voltage preset. 2 Check /Replace control card 3 Check overload sensing circuit
11	UPS does not switch on in battery mode	1 Mains earthing is not proper 2 Problem in inverter circuit	1 Check the earth connection 2 Check battery, MOSFET, oscillator section, driver section, output section
12	Battery wire getting burned	1 The relay points are joined together	1 Check / Replace relays
13	Change over time high, computer connected to the UPS reboots during change over.	1 Check oscillator circuit	1 Check /replace IC and other components of oscillator section
14	Low backup time	1 Main filter capacitor problem 2 Battery get short circuit/discharge	1 Check and replace capacitor 2 Check battery, replace if required

Trouble shooting of battery charger and emergency light

As you have seen that the battery charger is a simple circuit compare to UPS. The main function of the charger circuit is to feed the DC voltage to battery at a prescribed level we discuss only the trouble shooting of charger circuit and its repair. Battery maintenance is not discussed in the trouble shooting chart.

Analyse the fault in battery charging circuit (Fig 1) with the help of trouble shooting chart given in Table 3 and 4.

Table 3

Sl. No.	Problems	Section to be suspected	Possible cause for defects	Action
1	No DC voltage at charging terminal	1 Faulty Ammeter (open circuit)	Aged/over current	Replaced Ammeter
		2 Blown fuse	Over current	Replace fuse
		3 Faulty rectifies diode	Aging/over loading	Replace all diodes

		4 Defective transformer	Aging/over loading	Replace transformer
		5 Faulty Relay contacts	Repeated closed open	Replace contact
		6 Open Relay coil	Over voltage/current	Replace relay
		7 Main fuse blown	Over loading	Replace fuse
		8 No link between meter to battery	Loose connection	Tighten the connection
		9 Defective auto transformer	Over loading	Replace transformer
2	Low terminal voltage	Anyone pain diode open circuited	Ageing	Replace all four diodes
		Partial short in transformer	Over heat	Replace transformer
3	No automatic charging voltage cut off	Defective potentiometer	Long use	Replace new potentiometer
		Driver diode open	Ageing	Replaced 2 diodes(D7)
		Defective electrolytic capacitor	Ageing	Replace capacitor (C_1)
		Defective bleeder resistor	Over current	Replaced same value resistor(R_1)
		Control circuit rectifier diode open	Ageing Over current	Replace both diodes(D_5 & D_6)
		LT winding transformer open	Ageing / over current	Replace new transformer (x_3)
		LT fuse open	Over current	Replace fuses (F_2)
		Defective auxiliary relay terminal	Repeated operation	Replace contact RLI(B)
4	Irregular over voltage cut off	Defective potentiometer	Loose contact in the disc (track)	replace new potentiometer (VP1)
		Shorted driver diode	ageing/over current	replace new diode (d7)
		Loose in relay contacts leaky electrolytic capacitor	Repeated contacts ageing	replace contacts replace electrolytic capacitor

Table 4

Trouble shooting chart for emergency light

Sl No	Problems	Section to be suspected	Possible cause for defective	Action
1	Lamp dead in both condition lamp	Defective tube	Ageing	Replace tube lamp
		Defective inverter transformer	Over loading/ageing	Replace inverter transformer
		Defective driver	Over loading/ageing transistor	Replace transistor (213055)
2	Lamp out glowing if AC fails	Low/ dead battery	Ageing	Replace New battery

Servicing of equipment are discussed based on a sample circuits. When servicing of other equipments with different circuits may differ from the troubleshooting sequences. However the basic principle based on the block diagram may be taken for guidance to service/repair the equipment.

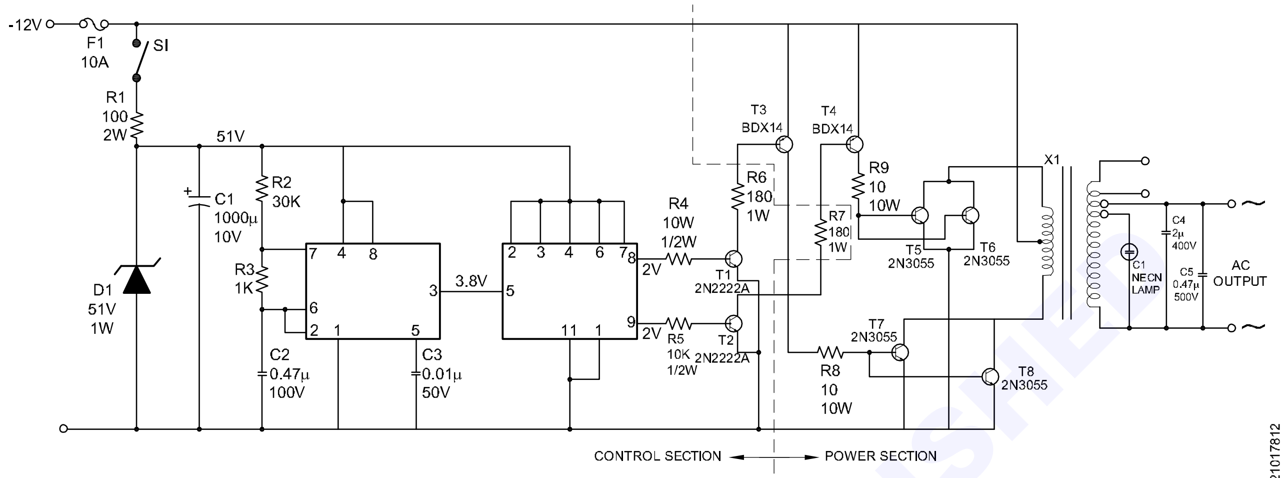
Trouble shooting of inverter

DC to AC inverter is quite complicated circuit, it consists of many functions. The switching circuit, oscillator circuit, control circuit power amplifier circuit, driver, finally the output circuit through the transformer. A feed back is also taken from the output transformer to regulate the output through the control circuits.

A constant DC source; either from a converter or battery is very much essential to keep the power output in a constant stage. DC to AC conversion with a specified frequency and a particular wave is difficult.

Analyse the fault in a inverter is explained (Fig 2) with the help of trouble shooting chart is given in Table 5. However the fault and problem are discussed while considering the 50Hz static inverter circuit is in Fig 2.

Fig 2



COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER

Table 5

Sl No	Problems	Section to be suspected	Possible cause for defects	Action
1	Output - Dead	- Output transformer - DC source	- Transformer open or short - CT & transformer open - No DC from battery - Battery dead	Rectify transformer Rectify the CT connection Replace battery
2	Low or high frequency	- Oscillator IC (555) - Control IC JK Flip-Flop	- Faulty IC - Faulty IC - No supply to IC (series resistor open) - Capacitor connected to IC 555 shorted	Replace IC Replace IC Replace resistor Charge faulty capacitor
3	Low voltage frequency ok	- Driver transistor - Power transistor (output transistor)	Fault in driver transistor Fault in power transistor Fault in output transformer Partial short in winding / cave	Charge the transistor Replace the power transistor Rectify the transformer fault or Replace the transformer
4	Frequent cut-off the output	- Battery - Fault in IC - Fault in power transistor	- Low A/H capacitor of battery - Over heat in IC - Over heat in power transistor	Replace Battery Provide heat Sink to IC Sink to transistor

Installation of inverter in domestic wiring

Objectives: At the end of this lesson you shall be able to
- **enumerate the important points to be kept in your mind to select the inverter to be installed**
- **state how to select the place to install the inverter and battery**
- **explain how to install the inverter with battery and load, and check for its performance**
- **state the rating of inverter and its sample calculation.**

Important points to be considered before installing an inverter : Many time when a new inverter is not giving proper service, the fault is due to improper installation only, not in inverter.

Another most important point is when connecting an inverter to the line is, the total load connected to the inverter should not exceed 80% of capacity of inverter.

Before providing points to connect the loads to the inverter, the total connected load must be considered.

If over load occur, then the overload protection will 'cut OFF' the output and reduce the load then the reset key must be pressed, and if the inverter is not provided with overload protection, it may get damaged at the time of over load than the capacity of the inverter.

Selection of place for installation of inverter : To connect inverter to the supply line, suitable place for the inverter is to be located. That place must be nearer to the service energy meter and ICDP switch and provide a 3 pin output socket from the mains supply line for the inverter and connect the inverter to the socket as in (Fig 1).

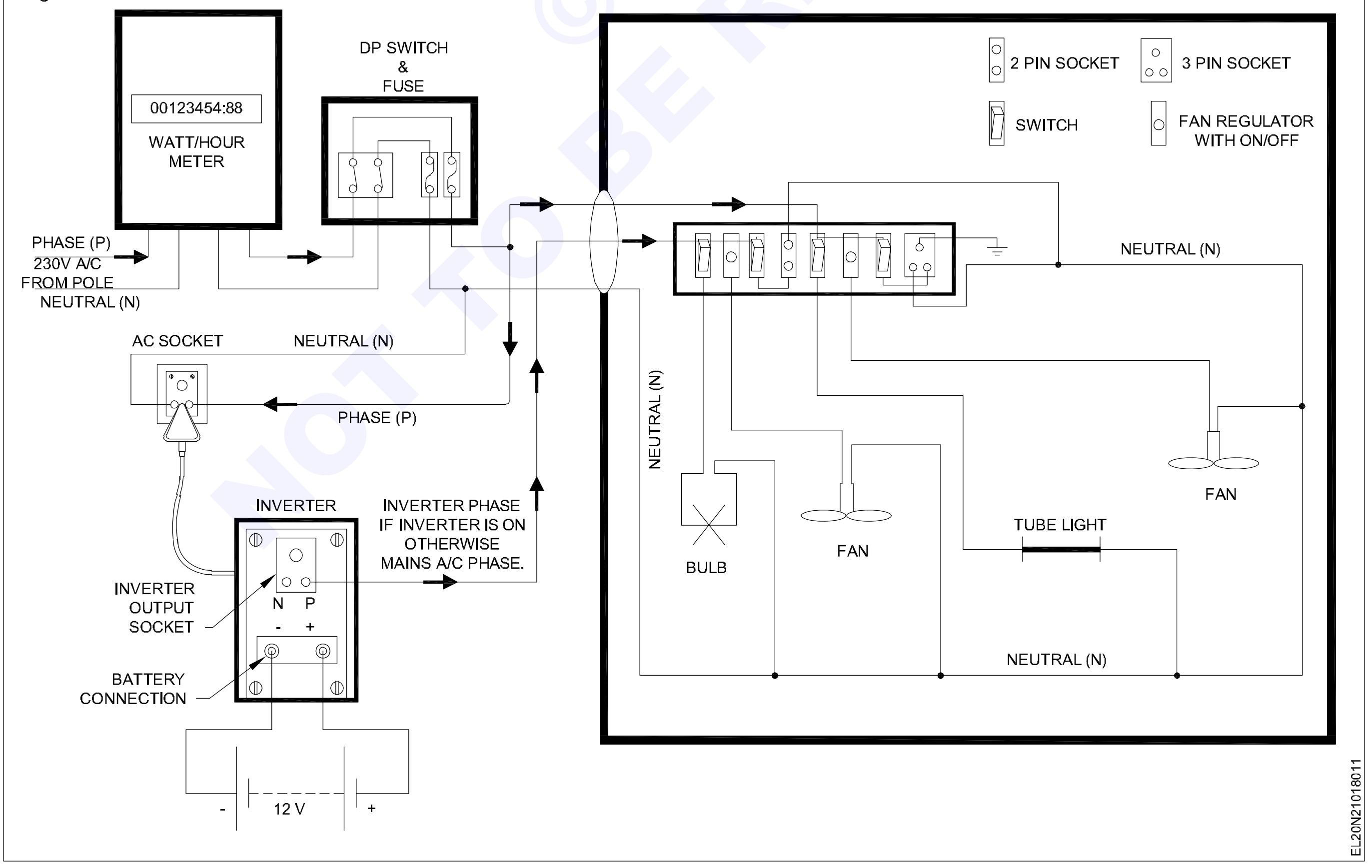
Installation of inverter : Collect the suitable inverter with sealed free maintenance battery to be installed, and check for their proper function

Place the inverter's battery to a suitable place near the inverter and connect the battery to the inverter.(Fig 1)

Keep the battery as close as possible to the inverter, so that the wire connecting the battery terminals to the inverter can be small and current loss is reduced. Make sure the battery is fully charged before installation.

The positive terminals of battery (red wire) is connected to the place provided for the positive terminal on the inverter and the negative terminal of the battery (blue or black wire), which is to be connected to the place provided for the negative terminal on the inverter.

Fig 1



When connecting battery terminals to the inverter, use special auto wires do not use common mains wiring with wires such as ‘3/20’ and 7/20 etc.connecting battery using these wires will not provide proper connection between the battery and the inverter.

After connecting the battery, put some grease (or) vaseline on the battery terminals, which reducing the terminal corrosion.

All the connection is completed take the output from the inverters output socket and use it to power the load. Use 1/18 copper wire to the output of the load. Do not use 3/20, 3/22 or 7/20 wires, commonly used in house wiring.

The output is taken from the phase out ‘pin of inverter’ output socket, and is provided to the ON/OFF switches on the wall pause.(Fig 1)

The neutral line is common for both the inverter output and the mains A/C line. So, only one wire for the phase line can be drawn from the inverter output socket to the switches.

In Fig 1, one bulb, one fan and a 2 pin output socket are connected to the inverter output and the other devices in the room. (ie) the tube light, fan (2) and a 3 pin output socket are directly connected to the mains A/C line.

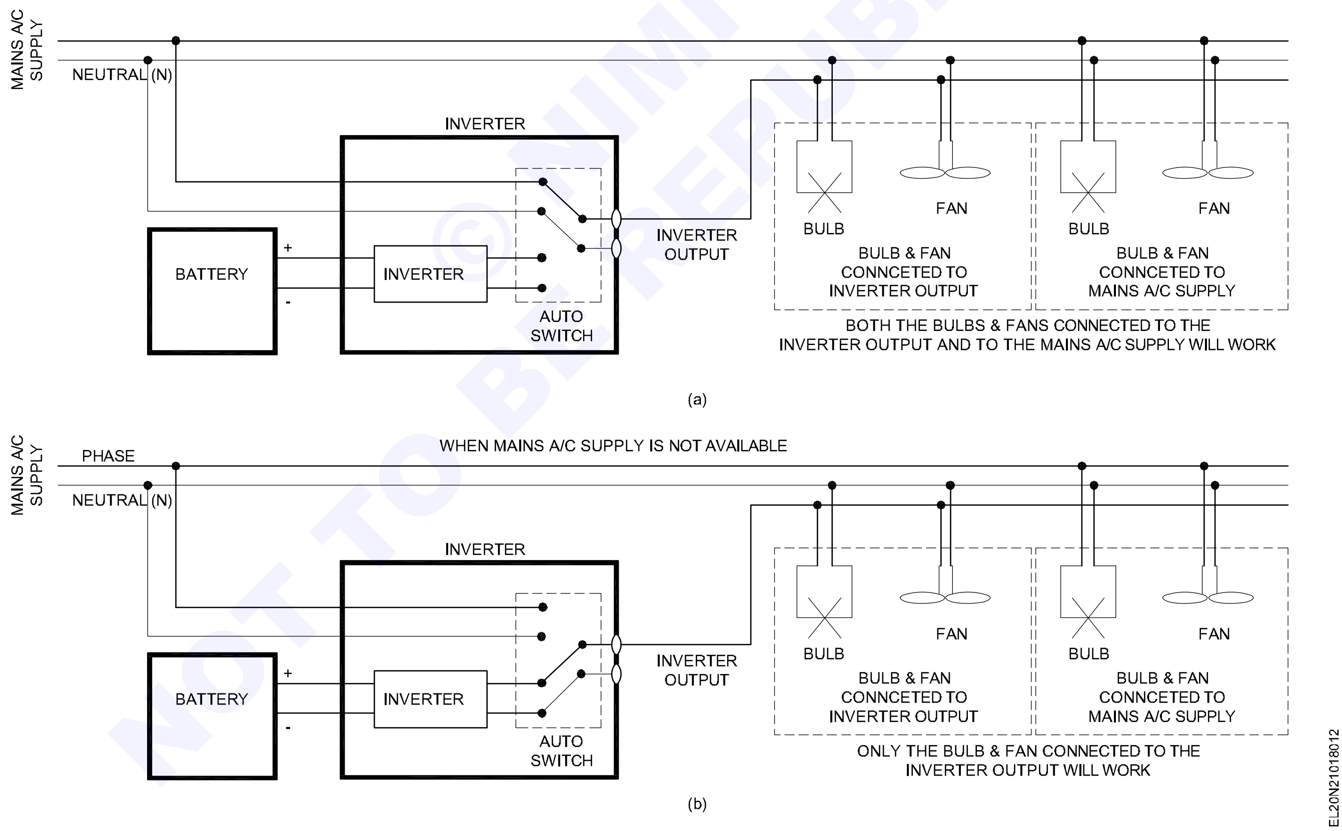
In the two pin socket, should not be connected with heavy load during power ‘OFF’ only small load like mosquito repeller can be connected.

As in (Fig 1) the load connected to the inverter will get the mains A.C supply. If the mains supply is ‘On’ at the same time, other devices will also work on the main supply, because they are connected directly to the mains A.C supply.

But at the time of power shut down, the devices directly are connected to the mains A.C will stop functioning and the devices, which are connected to the inverter output will keep on working on the inverter output.

Later, if the mains A.C supply returns, the inverter will once again connect the load, which are connected to its output to the main supply. This process is shown in Fig 2.

Fig 2



Sources of energy - Thermal power generation

Objectives: At the end of this lesson you shall be able to
- **explain conventional and energy source**
- **state the various source of energy**
- **explain the working principle of thermal power station.**

Introduction of power generation

Energy is the basic necessity for the economic development of a country and it exists in different forms in nature. But the most important form is the electrical energy . The modern society is fully depend on the electrical energy and it has close relationship with standard of living. The per capita consumption of energy is the measure of standard of living of people.

Sources of electrical energy

Since electrical energy is produced from energy available in various forms in nature, it is desirable to look into the various sources of energy. The natural sources of energy which are used to generate the electricity are :

i Sun

ii Wind

iii Water

iv Fuels

v Nuclear energy

vi Tidal

Types of electrical power generation

Basically power generation are of two types

a Conventional power generation

Power generations by using non- renewable sources of energy through various methods such as hydro, thermal and nuclear etc is called conventional power generation. It contributes to the major power requirement.

b Non conventional power generation

Power generation by using renewable energy sources such as wind, Tide and sun etc, is called non-conventional power generation. They are small scale power generation used for specific purpose.

Generating stations

Bulk electric power is produced by special plants known as generating station or power plants. A generating station employs a prime mover coupled with an alternator or generator for the production of electric power. The generated power is further transmitted and distributed to the customers.

Depending upon the form of energy converted into electrical energy the generating station are classified into,

1 Steam power stations /Thermal power stations

2 Hydro - electric power stations

3 Diesel power stations

4 Nuclear power stations

5 Gas - turbine power stations

1 Thermal /steam power station

A generating station which converts the heat energy of coal combustion into electrical energy is known as a steam power station.

The scheme of generation can be divided into two phases (i) Formation of steam in the boiler house (ii) Generation of electrical power in the generator room.

In the boiler the fuel is burnt and the water is converted into high pressure steam which is further super heated in a super - heater. The super - heated steam is passed in to the turbine to rotate the turbine blades, thus it converts the heat energy into electrical energy.

The turbine is the generation room acts as a prime mover of the alternator which generates electric energy. The alternator is connected through the circuit breaker to the bus bars.

This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

Choice of site for steam power stations

In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station.

i **Supply of fuel :** The steam power station should be located near the coal mines so that transportation costs of fuel is minimum.

ii **Availability of water :** As huge amount of water is required for the condenser, therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

iii **Transportation facilities :** A modern steam power station often requires the transportation of materials and machinery. Therefore, adequate transportation facilities must exist. i.e., the plant should be well connected to other parts of the country by rail, road etc.

iv **Cost and type of land :** The steam power station should be located at a place where land is cheap and further extension, if necessary is possible.

v **Nearness to load centers:** In order to reduce the transmission cost, the plant should be located near the center of the load.

vi **Distance from populated area :** As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding areas. This necessitates that the plant should be located at a considerable distance from the populated areas.

Schematic arrangement of steam power station

Although steam power station simply involves the conversion of heat of coal combustion into electrical energy, yet it embraces many arrangements for proper working and efficiency. The schematic arrangement of a modern steam power station is in Fig.1. The whole arrangement can be divided into the following stages for the sake of simplicity.

1 Coal and ash handling arrangement

2 Steam generating plant

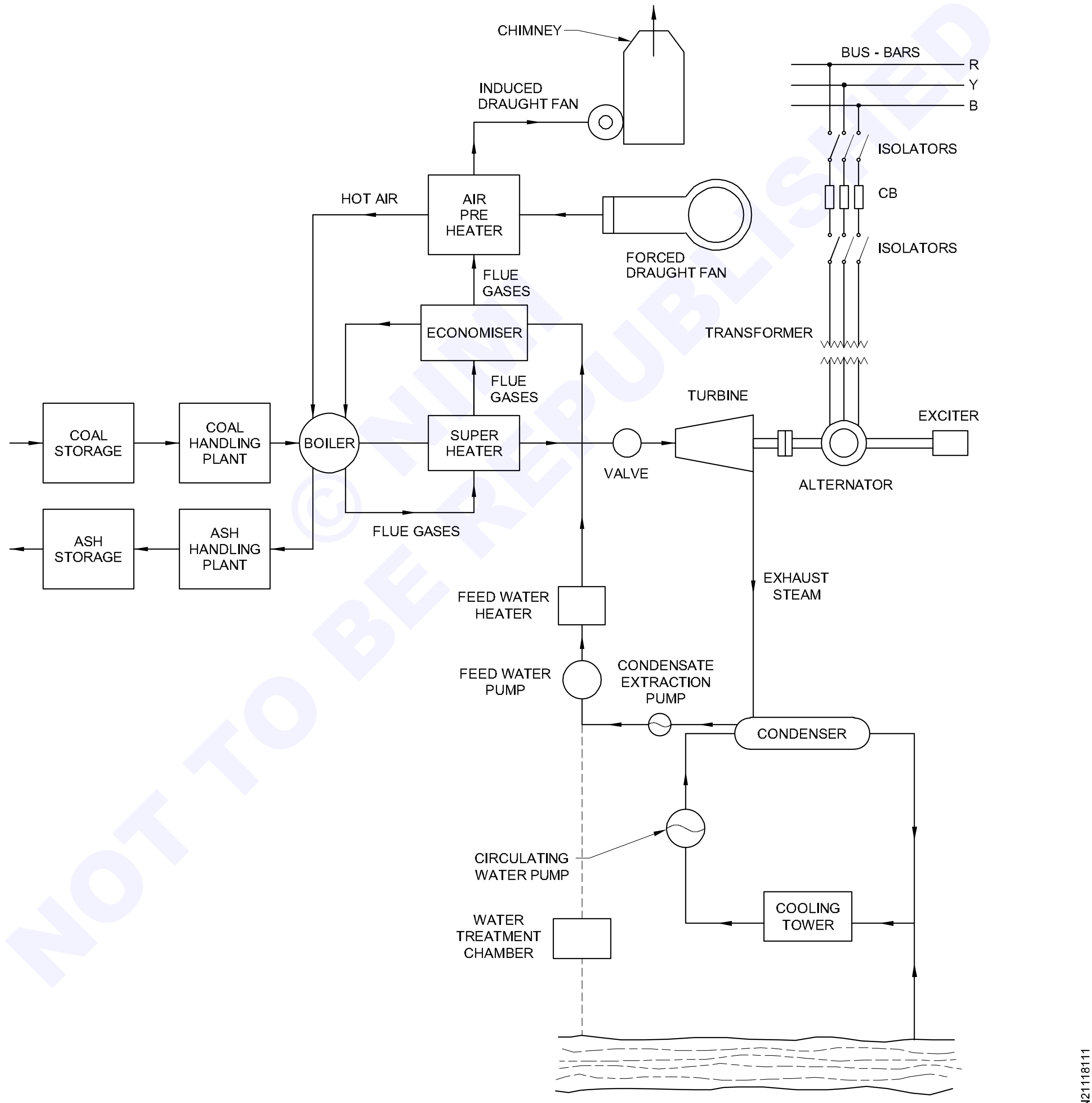
3 Steam turbine

4 Alternator

5 Feed water

6 Cooling arrangement

Fig 1



SCHEMATIC ARRANGEMENT OF STEAM POWER STATION

Constituents in steam power station *:* A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are :

1 Steam generating equipment

2 Condenser

3 Prime mover

4 Water treatment plant

5 Electrical equipment

1 Steam generating equipment

This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, super heater, economizer, air pre-heater and other heat reclaiming devices.

i **Boiler :** A boiler is closed vessel in which water is converted into steam by utilizing the heat of coal combustion. Steam boilers are broadly classified into the following two types.

ii **Boiler furnace :** A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy. In addition, it provides support and enclosure for the combustion equipment i.e burners. The boiler furnace walls are made of refractory materials such as fire clay, silica, kaolin etc. These materials have the property to resist change of shape, weight or physical properties at high temperatures.

iii **Super heater :** A super heater is a device which super heats the steam (i.e) it further raises the temperature of steam. This increases the overall efficiency of the plant.

iv **Economiser :** It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduces stresses in the boiler due to high temperature of feed water.

v **Air Pre-heater :** Super heaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre - heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion.

2 Condensers

A condenser is a device which condenses the steam and the exhaust of turbine. It serves two important functions. Firstly, it creates a very low pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in Converting heat energy of steam into mechanical energy in the prime mover. Secondly, the condensed steam can be used as feed water to the boiler.

3 Prime movers

The prime mover converts steam energy into mechanical energy. There are two types of steam prime mover viz., steam engines and steam turbines. A steam turbine has several advantages over a steam engine as a prime mover viz., high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. Therefore, all modern steam power stations employ steam turbines as prime movers.

Steam turbines are generally classified into two types according to the action of steam on moving blades viz.

a Impulse turbines

b Reaction turbines

4 Water treatment plant

Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler

Hydel power plants

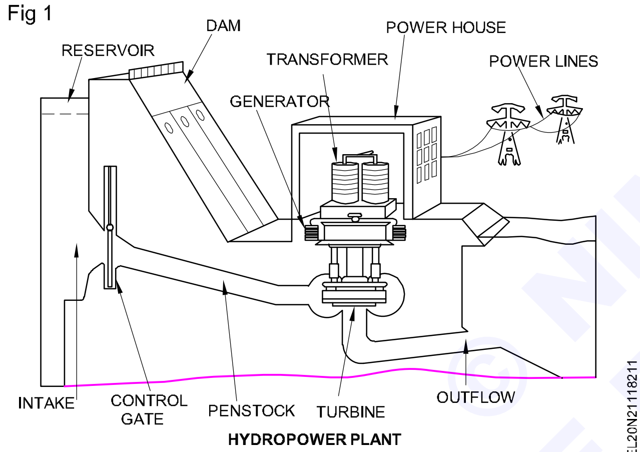
Objectives: At the end of this lesson you shall be able to
- **state the types of hydro- electric power station**
- **state the advantage & disadvantage of hydro electric power station over thermal power station**
- **list out the reason for selecting the site of a hydro electric power station**
- **explain the schematic arrangement of hydro electric power station**
- **state the turbines used in hydro electric power station with suitable reasons**
- **state the classification of hydro electric power station.**

Hydro - electric power stations

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as "Hydro-electric power station".

A basic model of a H.E.P generation is illustrated in Fig 1 is known as hydro - electric power station.

Fig 1



HYDROPOWER PLANT

Hydro - electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e product of head and flow of water) into mechanical energy at the turbine shaft.

The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro electric power stations are becoming very popular because the reserves of fuels (i.e coal and oil) are depleting day by day.

Advantages

i It requires no fuel as water is used for the generation of electrical energy

ii It is quite neat and clean as no smoke or ash is produced

iii It requires very small running charges because water is the source of energy which is available free cost.

iv It is comparatively simple in construction and requires less maintenance.

Disadvantages

i It involves high capital cost due to construction of dam

ii There is uncertainly about the availability of huge amount of water due to dependence on weather conditions.

iii Skilled and experienced hands are required to build the plant

iv It requires high cost of transmission lines as the plant is located in hilly areas which are away from the consumers.

Choice of site for hydro - electric power stations

The following points should be taken into account while selecting the site for a hydro - electric power station

i Availability of water : Since the primary requirement of a hydro - electric power stations is the availability of huge quantity of water, such plants should be built at a place (e.g. river, canal) where adequate water is available at the good head.

ii Storage of water : There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year.

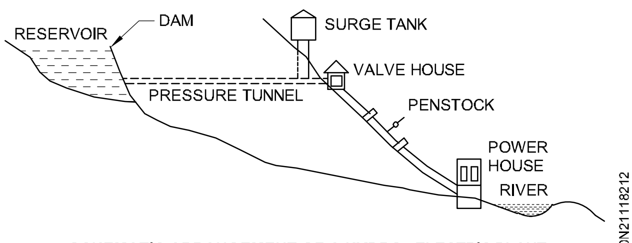
iii Cost and type of land : The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstands the weight of heavy equipment to be installed.

vi Transportation facilities : The site selected for hydro - electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported

Schematic arrangement of hydro - electric power station (Fig 2)

The schematic arrangement of a modern hydro - electric plant is shown in Fig. 2. The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir. A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the Penstock.

Fig 2



SCHEMATIC ARRANGEMENT OF A HYDRO - ELECTRIC PLANT

The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts of supply of water flow to the power house when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock . The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

Constituents of Hydro - Electric Plant

The constituents of hydro - electric plant are (1) hydraulic structures (2) water turbines and (3) electrical equipment.

1 Hydraulic Structures

Hydraulic structures in a hydro electric power station include dam, spillways, headworks, surge tank, penstock and accessory works.

i **Dam :** A dam is a higher barrier which stores water and creates water head. Dams are built of concrete or stone masonry, earth or rock fill.

ii **Spillways :** There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down - stream side of the dam, spillways are used.

iii **Headworks :** The headworks consists of the diversion structures at the head of an intake. They generally include booms and racks for diverting floating debris, sluices for by - passing the debris and sediments and valves for controlling the flow of water to the turbine. The flow of water into and through head works should be as smooth as possible to avoid the head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.

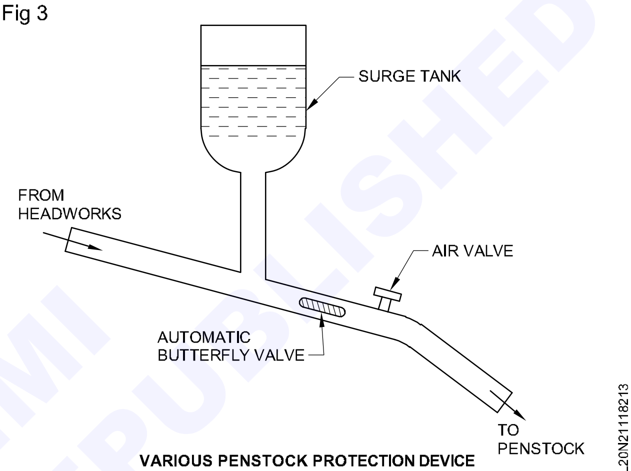
iv **Surge tank :** Open conduits which leading the water to the turbine require no protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank. a surge tank is a small reservoir or tank (open at the top) in which water level rises or fails to reduce the pressures swings in the conduit.

v **Pen stock :** Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel. The thickness of the Penstock increases with the head or working pressure

Various devices such as automatic butterfly valve, air valve and surge tank are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstocks promptly of its ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure.

When water run out of a penstock faster than it enters, a vacuum is created which may cause the penstocks to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure. A typical penstock protective device is in Fig 3.

Fig 3



VARIOUS PENSTOCK PROTECTION DEVICE

vi **Tail race** : The tail race is the channel which carries water (known as tail water) away from the power house after it has passed through the turbine.

vii **Draft tube :** In the case of a reaction turbine there is a pressure difference existing between water in the turbine and atmosphere. Therefore this type turbine must be completely enclosed. Accordingly it is necessary to connect the turbine outlet by means of a pipe or a passage of gradually increasing cross sectional area up to tail - race level.

A draft tube has two important purposes to serve.

1 It permits a negative or suction head to be established at the runner exit thus making it possible to install the turbine above the tail race level without loss of head.

2 It converts a large proportion of the velocity energy rejected from the runner into useful pressure head i.e it acts as a recuperator of pressure energy.

2 Water turbine

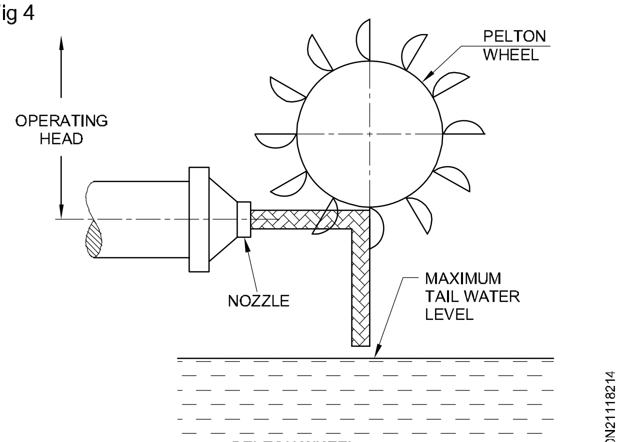
Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are :

i Impulse turbines

ii Reaction turbines

i **Impulse turbines :** Such turbines are used for high heads. In an impulse turbines, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel i.e, pelton wheel as in Fig 4. It consists of a wheel fitted with elliptical buckets along it periphery. The force of water jet striking the bucket on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of needle or spear (not shown in the figure) placed in the tip of the nozzle.

Fig 4



PELTON WHEEL

The movement of the needle is controlled by the governor. If the load on the turbine decreases the governor pushes the needle into the nozzle, there reducing the quantity of water striking the bucket. Reverse action takes place if the load on the turbine increases.

ii **Reaction turbines :** Reaction turbines are used for low and medium heads. In a reaction turbine water enters the runner partly with pressure energy and partly with velocity head. The important types of reaction turbine are.

a Francis turbines

b Kaplan turbines

A fancies turbine is used for low to medium heads. It consists of an outer ring of stationary guide blades for to the turbine casing and an inner ring of rotating blade forming the runner.

3 Electrical equipment

The electrical equipment of a hydro - electric power includes alternators, transformers, circuit breaker and switching and protective devices.

Types of hydro - electric plants

There are three different methods of classifying the electric plants. The classification may be based on,

a Quantity of water available

b Available head

c Nature of load

Classification of Hydro - electric plants according to quantity of water available

According to this classification, the plants may be divided into.

i Run - off river plants without pondage

ii Run - off river plants with pondage

iii Reservoir plants

i Run off river plants without pondage

As the name indicates this type of plant does not store water. The plant uses water as it comes. The plant can use water only as and when available.

ii Run- off river plants with pondage

Usefulness of a run - off river plant is increased by pondage. Pondage permits storage of water during the off - peak periods and use of this water during the peak periods.

iii Reservoir plants

Water is stored behind the dam and is available to the plant with control as required. Such a plant has better capacity and can be used efficiently throughout the year.

Classification of hydro - electric plants according to available head

Hydro - electric plants may be classified into high - head, medium - head and low head plants. A plant may be classified as high - head if operating on a head above 300 meters. Low - head plants work under heads below 30 metres. Medium - head plants are those lying between the above two classes.

Classification of Hydro- electric plants according to nature of load

Hydro - electric plants may be classified in to base load peak load and pumped storage plants for peak load.

Visiting to transmission and distribution sub station

Objectives: At the end of this lesson you shall be able to
- **state the initial preparatory work before commencing the visit**
- **explain the individual trainees main areas and its importance for preparation**
- **list out the supporting materials to carry for visit**
- **prepare a list of do's and dont's during visit.**

Introduction : A industrial visit is a very important step to tap actual working environments. During practical exercises practicing in the lab or workshop never provides actual working condition because it is a part of structure training planned to complete within a stipulated time and a assessment at later stage.

To understand the whole process from the concerned technician or operator, you must have a sound knowledge of that particular abject or process. You should prepare well to meet the challenge whenever you go industrial visit in a factory or sub station.

Preparation areas and its importance : If the process is complicated or multi level procedure involved; in that case trainees should be made small batches to interact or involve the whole process. In such cases each batch should be formed in advance and decided the section or part to be interacted. Finally all the batches together to make the end result.

When you visit a sub station collect the following:

1 Installed capacity of the sub station.

2 Maximum load demand.

3 Load factor .

4 Total number of transformers installed and its working conditions.

5 Location Map of the sub station and its surroundings.

6 Gather maximum information regarding transmission and distribution techniques other than guided or studied.

7 Maximum hazardous Area - PPE facility Emergency root in case of emergency.

Do's & Dont's

Do's

1 Wear uniform with name badge.

2 Ensure the protective gadgets are available otherwise carry them.

3 Follow the safety norms imposed in the particular areas, listen the instruction carefully.

4 Carry materials to record your findings and assessments to make then and their.

5 Follow strict discipline and punctuality .

6 Obey all the instructions and rules.

7 Walk in the prescribed areas only.

Dont's

1 Avoid wearing loose clothes and ornaments.

2 Not to carry any bag or attachments.

3 Do not cross-over any prohibited areas .

4 Do not operate, touch or play with any part or machine you pass over.

5 Do not sit or learn over any machine or place you come across.

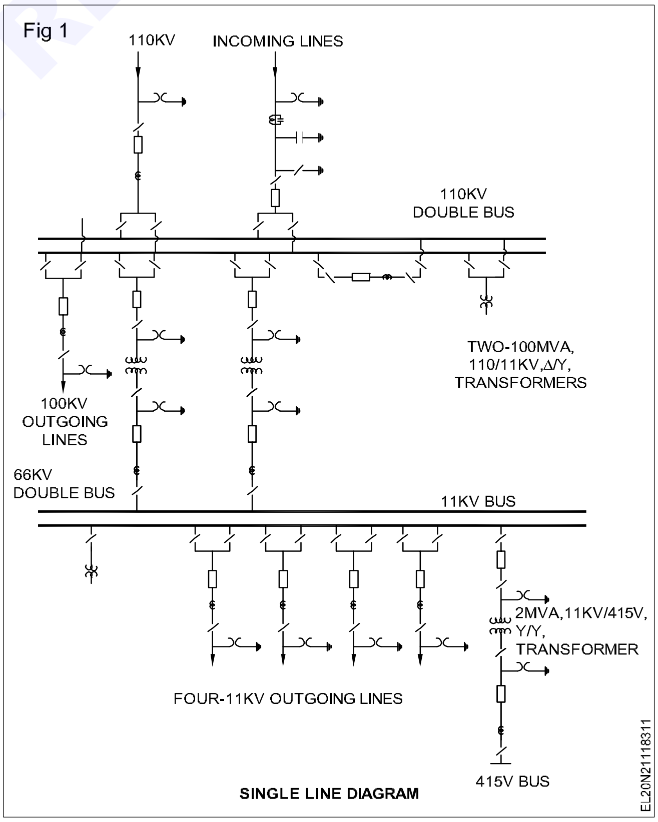
6 Do not shout or make any unusual noises when the visit is in progress or inside the factory.

7 Do not involve any kind of horse play at the time of visiting various sections, areas.

8 Do not avoid or neglect any instruction passed on you at any time.

Fig 1 shows a typical single line layout diagram of a transmission and distribution substation.

Fig 1



Electrical substations

Objectives: At the end of this lesson you shall be able to
- **state the functions and purpose of electrical substations**
- **classify the different types of substation**
- **list out the equipment and components used in substation.**

Substations

Electric power is produced at the power generating stations, which are generally located far away from the load centers. Between the power generating station and consumers a number of transformations and switching stations are required. These are generally known as substations.

Substations are important part of power system and form a link between generating stations, transmission systems and distribution systems. It is an assembly of electrical components such as bus-bars, switch gear apparatus, power transformers etc.

Function

Their main functions are to receive power transmitted at high voltage from the generating stations and reduce voltage for switching operations of transmission lines. Substations are provided with safety devices to disconnect equipment or circuit at the time of faults.

Classification of substation

The substations may be classified in according to service requirements and constructional features. According to service requirements they are classified in to transformer substations, switching substations and converting substations.

1 **Transformer substations :** Majority of the substations in the power system are in this type. They are used to transform the power from one voltage level to another voltage level. Transformer is the main component in such substations. Transformer substations are further classified into step-up substations, primary grid substations, secondary substations and distribution substations.

   a **Step - up substations :** These substations are usually located at the generating stations. Generating voltage of the order of 11KV needs to be stepped up to a primary transmission voltage level of the order of 220KV or 400KV.

   b **Primary grid substations :** These substations are located at the end of primary transmission lines and the primary voltage is stepped down to suitable secondary voltages of the order of 66KV or 33KV.

   c **Secondary substations :** The voltage is further stepped down to 11KV. Large consumers are supplied with power at 11KV.

   d **Distribution substations :** These substations are located near the consumer localities to supply power at 415V three phase or 240V single phase to the consumers.

The parts, equipment and components installed in substation (Fig 1)

Each substation has the following parts and equipment.

Fig 1

EL20N21118321

1 **Outdoor switchyard**
- Incoming lines
- Outgoing lines
- Busbar
- Transformers
- Bus post insulator & string insulators
- Substation equipment such as circuit-breakers, isolators, earthing switches, surge arresters, CTs, PTs neutral grounding equipment
- Station earthing system comprising ground mat, risers, auxiliary mat, earthing strips, earthing spikes & earth electrodes.
- Overhead earthwise shielding against lightning strokes.
- Galvanized steel structures for lower equipment supports.
- PLCC equipment including line trap, tuning unit, coupling capacitor, etc.
- Power cables
- Control cables for protection and control
- Road, cable trenches
- Station illumination system

2 **6.6/11/22/33/66/132 KV switch gear LV**
- Indoor switch gear

3 **Switchgear and control panel building**
- Low voltage AC switchgear
- Control panels, protection panels

4 Battery room and DC distribution system

- DC battery system and charging equipment
- DC distribution system

5 Mechanical, electrical and other auxiliaries

- Fire fighting system
- D.G (Diesel Generator) set
- Oil purification system

Transmission substation

The three phase power leaves the generator and enters a transmission substation at the power plant. This sub station uses large transformers to convert or “step up” the generators voltage to extremely high voltages for long distance transmission on transmission grid. Typical voltages for long distance transmission are in the range of 220 KV to 400 KV. The higher the voltage the less energy is lost due to resistance.

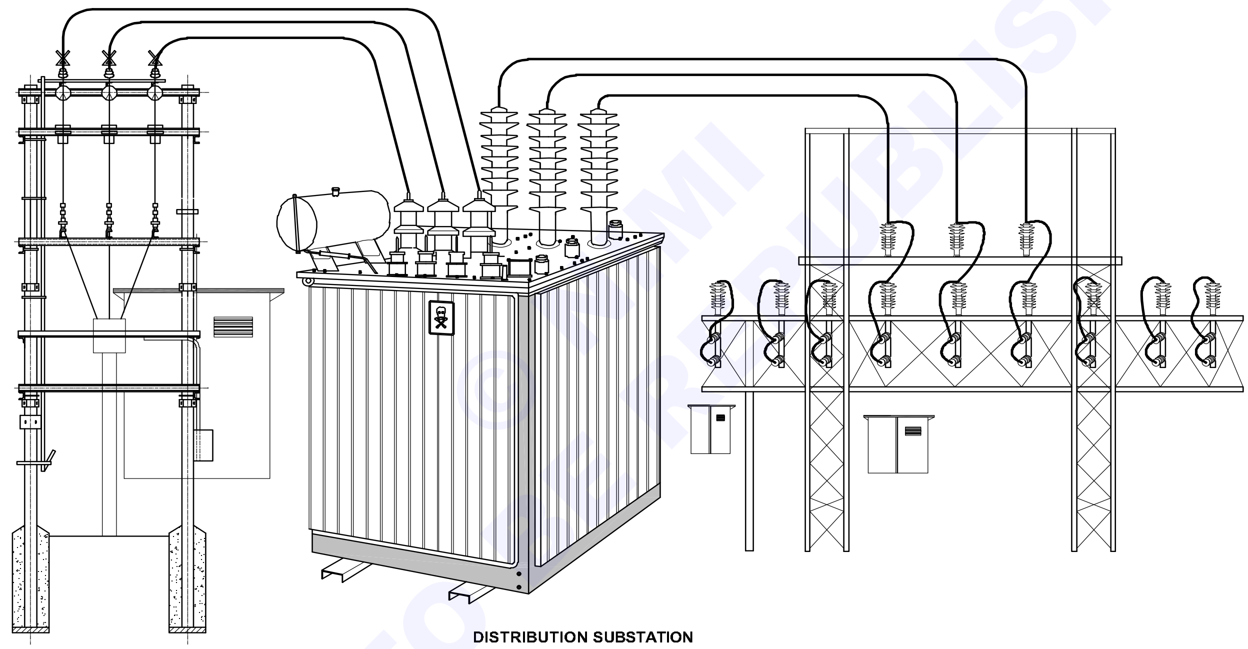
A typical maximum transmission distance is about 400 kilometres. High voltage transmission lines are quite obvious when you see them. They are huge steel towers string out in a line that stretches towards the horizon.

All high voltage towers have three wires for three phases. Many towers also have extra lines running along the top of the towers. These are ground wires and there are primarily in an attempt to attract lighting.

Distribution Substation (Fig 2)

Distribution substation typically operates at 11000 - 440V voltage levels, and deliver electric energy directly to industrial and residential consumers. Distribution feeders transport power from the distribution substations to the end consumers' premises. These feeders serve a large number of premises and usually contain many branches.

Fig 2



DISTRIBUTION SUBSTATION

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Distribution substation and its main components

At the consumers' premises, distribution transformers transform the distribution voltage to the service level voltage directly used in households and industrial plants, usually from 440 to 230 V.

Distribution substation is generally comprised of the following major components: (Fig 3)

1 Supply Line

2 Transformers

3 Busbars

4 Switchgear

5 Outcoming feeders

6 Switching apparatus

a Switches

b Fuses

c Circuit breakers

7 Surge voltage protection

8 Grounding

1 Supply Line : Distribution substation is connected to a sub-transmission system via at least one supply line, which is often called a primary feeder. However, it is typical for a distribution substation to be supplied by two or more supply lines to increase reliability of the power supply in case one supply line is disconnected.

A supply line can be an overhead line or an underground feeder, depending on the location of the substation, with underground cable lines mostly in urban areas and overhead lines in rural areas and suburbs.

2 **Transformers :** Transformers "step down" supply line voltage to distribution level voltage. Distribution substation usually employs three-phase transformers.

3 **Busbars :** Busbars (also called buses) can be found throughout the entire power system, from generation to industrial plants to electrical distribution boards. Busbars are used to carry large current and to distribute current to multiple circuits within switchgear or equipment

4 **Switchgear :** Switchgear is a general term covering primary switching and interrupting devices together with its control and regulating equipment. Power switchgear includes breakers, disconnect switches, main bus conductors, interconnecting wiring, support structures with insulators, enclosures, and secondary devices for monitoring and control.

5 **Switching Apparatus :** Switching apparatus is needed to connect or disconnect elements of the power system to or from other elements of the system. Switching apparatus includes switches, fuses, circuit breakers, and service protectors.

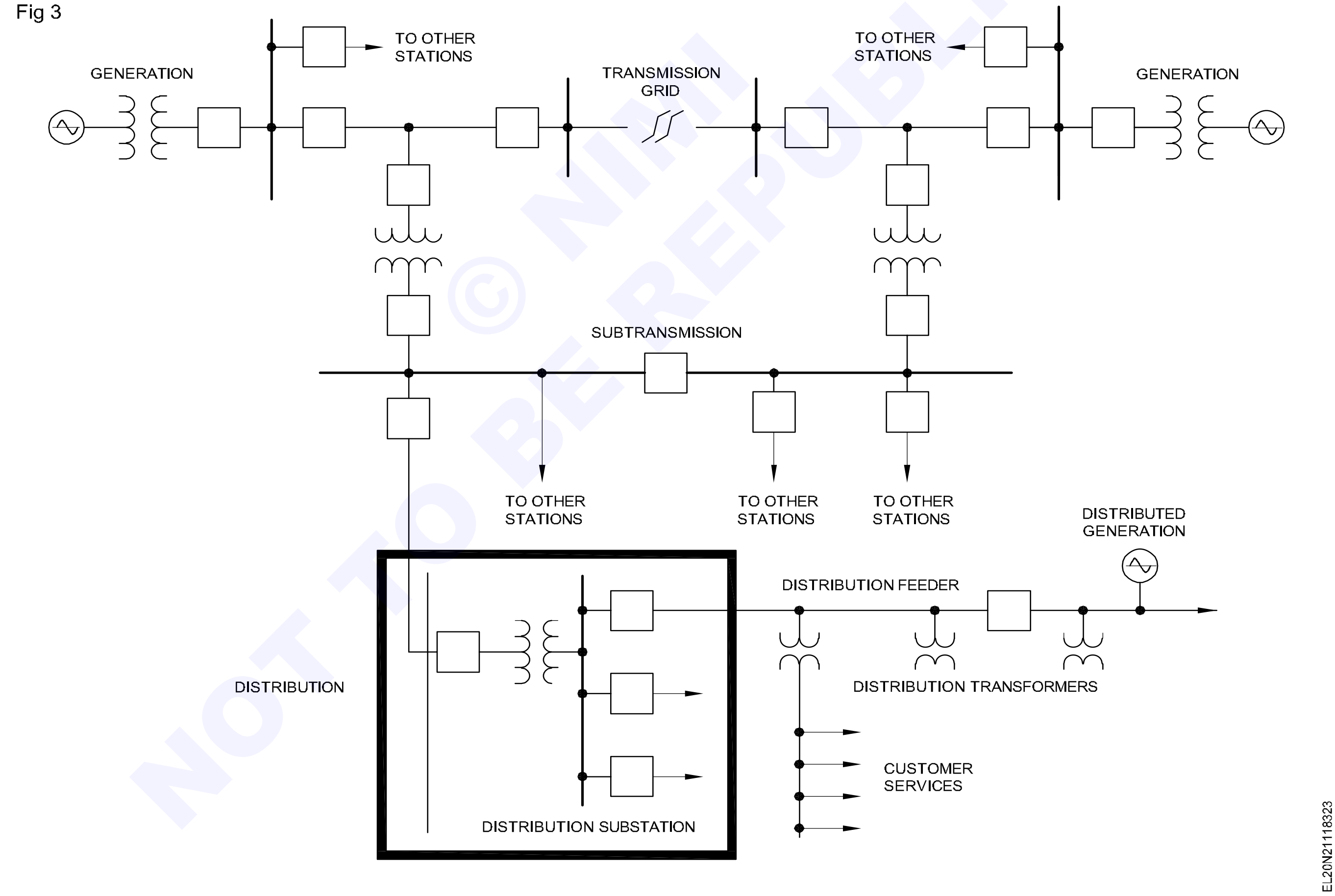
6 **Surge Voltage Protection :** Transient over voltages are due to natural and inherent characteristics of power systems. Over voltages may be caused by lightning or by a sudden change of system conditions (such as switching operations, faults, load rejection, etc.), or both. Generally, the overvoltage types can be classified as lightning generated and as switching generated.

7 **Grounding :** Grounding is divided into two categories: power system grounding and equipment grounding. electrical system grounding means that at some location in the system there are intentional electric connections between the electric system phase conductors and ground (earth).

Power system grounding

System grounding is needed to control overvoltages and to provide a path for ground-current flow in order to facilitate sensitive ground-fault protection based on detection of ground-current flow.

Fig 3



Circuit diagram of sub station and its components

Objectives: At the end of this lesson you shall be able to
- **explain the circuit diagram of a sub station**
- **explain components of sub station.**

Substation

The electrical substation can be defined as a network of electrical components comprising of power transformers, busbars, auxiliaries, and switchgear etc. The components are interconnected such that creating a sequence of a circuit capable to be switched OFF while running on normal operation through manual commands while in emergency situations it can be switched OFF automatically. The emergency situations may be an earthquake, floods, or short circuit etc.

The electrical substation does not have a single circuit but is composed of numerous outgoing and incoming circuits which are connected to a busbar i.e. common entity among circuits. The substation receives electrical energy directly from generating stations through incoming power supply lines while it delivers electricity to the consumers through outgoing transmission lines. A substation which is near to the electrical power generation is also known as grid substation.

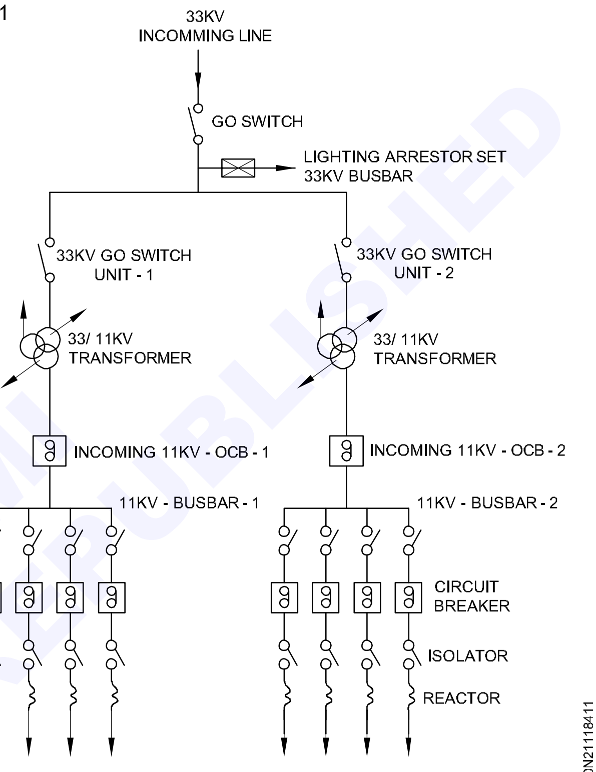
Major Tasks of Substations

There are numerous tasks associated with power substations in the distribution and transmission system. Some of the major tasks that substations perform are as follows.

- It serves as protection hub of the transmission system.
- It maintains the frequency of system confined in targeted limits and has to deal with load shedding.
- It controls the exchange of electrical energy amid consumers and generating stations.
- It is ensuring transient stability along with steady-state stability of the system.
- It delivers sufficient line capacity hence securing supply.
- It helps in reducing the flow of reactive power, hence gaining voltage control.
- Through line carrier, it performs data transmission to ensure monitoring of network, protection, and control.
- It helps in fault analysis and pinning cause for a failure, hence improving the performance of the electrical network.
- It ensures reliable supply through feeding network at numerous points.
- It assists in determining energy transfer with help of transmission lines.

Single Line Diagram of an Electrical Substation (Fig 1)

Fig 1



SINGLE LINE DIAGRAM OF SUBSTATION

The single line diagram of the 33kv substation is depicted in the figure below. The connection of the substation is divided as

- Incoming or power feeder connection (33kv Incoming Line)
- Power transformer connection via Lighting Arrestor & Busbar
- Voltage transformer connection for control and metering.
- Outgoing feeder for feeding the other subsequent substations or switchgear.
- Circuit Breaker & Isolator between the incoming and the outgoing lines.

On the incoming 33kv incoming feeder line side, the transformer is connected to the bus bar and the lightning or surge arresters are connected as a phase to the ground as the initial connection equipment. A circuit breaker is connected between the 11kv bus-bar and each incoming and outgoing circuit with the support of the isolator being provided on each side of the circuit breaker.

Electrical power generation by non conventional methods

Objectives: At the end of this lesson you shall be able to
- **state the non - conventional energy**
- **explain the methods of generation power from bio-gas and tidal**
- **list out the merits and demerits of non-conventional power generation.**

Non - conventional energy

Energy generated by using wind, tides, solar, geothermal heat and biomass including farm and animal waste is known as non-conventional energy. All these sources are renewable or inexhaustible and do not cause environmental pollution.

Merits of non - conventional over conventional sources of energy

1 Provide more energy
2 Reduce security risk associated with the use of nuclear energy.
3 Reduce pollutants
4 Less running and maintenance cost
5 Never destroyed
6 Despite the high initial investment and several limitations, use of solar energy to meet our ever increasing energy demand seems to be the only answer.
7 Green house effect and global warming is avoided
8 Less environment problems.

Demerits of non conventional over conventional sources of energy

1 Many non- conventional sources are still in their infant stages and required a lot of development efforts.
2 High initial cost
3 Less reliable and efficiency
4 Can not be used for base load demand.

Bio-gas power generation

The method of generating the electrical energy by using bio-gas is termed as bio-gas power generation.

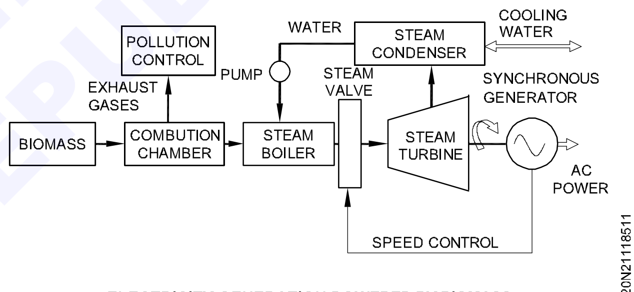
Bio-gas

Biogas is a good fuel. Bio mass like animal excreta, vegetable wastes and seeds undergo decomposition in the absence of oxygen in a biogas plant and form a mixture of gases. This mixture is the **biogas**. Its main constituent is methane. This is used as a fuel for cooking and lighting.

Electricity generating plant

Generating plant fuelled by biomass uses conventional steam turbine as used in thermal power stations with modifications to the combustion chamber and fuel handling systems to handle the bulkier fuel. The schematic arrangement is in Fig 1.

Fig 1



ELECTRICITY GENERATION POWERED BY BIOMASS

Co - generation

Because of the poor energy conversion efficiencies of biomass fuels, practical generating systems often employ a co-coal generation to achieve reasonable utilization of the generating plant.

Environmental issues

While biomass crops provide an environment friendly fuel source for generating electrical energy. The land used for disposing the slurry (waste) may be better employed for cultivation.

Tidal power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of tidal power generation**
- **state the system on which the tidal power generation works**
- **state the advantages and disadvantages of tidal power generation.**

The generation of electricity using tidal power is termed as tidal power generation. It is basically the transformation of tidal power found in tidal motion of water in seas and oceans into electrical energy.

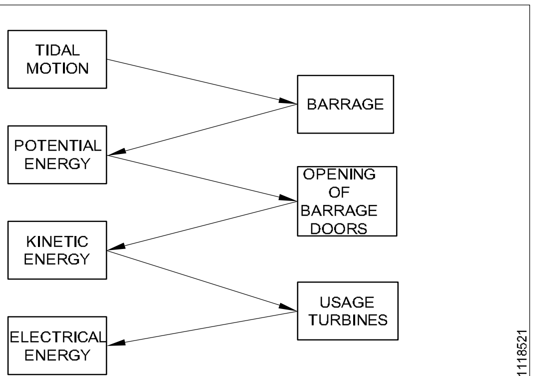
Tidal power

Tidal power is the power inherent in tides at sea or oceans, that is power of motion of water actuated by tides. Tides are defined as the increase and decrease in water levels due to the motion of water from one place to the other. Thus there is a renewable source of energy in the tidal motion of water at seas and oceans. This source of energy could be used to generate other types of energy that could be useful in industrial applications.

This is done using a very basic idea involving the use of a barrage or small dam built at the entrance of a bay where tides are known to reach very high levels of variation. This barrage will trap tidal water behind it creating a difference in water level, which will in turn create potential energy.

This potential energy will then be used in creating kinetic energy as doors in the barrage are opened and the water rush from the high level to the lower level. This kinetic energy will be converted into rotational kinetic energy that will rotate turbines giving electrical energy. Fig 1 shows the process in very simple terms.

Fig 1



A DIAGRAM SHOWING TRANSFORMATION OF TIDAL ENERGY TO ELETRICAL ENERGY

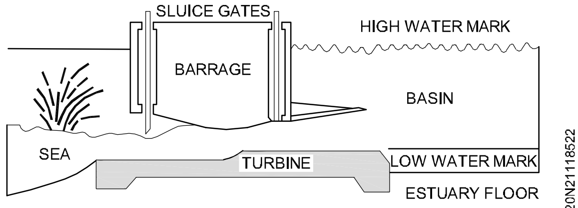
Working of tidal power generation system

In very simple terms a barrage is built at the entrance of a gulf and the water levels vary on both sides of the small dam. Passages are made inside the dam and water flows through these passage and turbines rotate due to this flow of water under head of water. Thus, electricity is created using the turbines. A general diagram of the system is in Fig 2.

The components of a tidal power station are :

1 **A barrage :** a barrage is a small wall built at the entrance of a gulf in order to trap water behind it. It will either trap it by keeping it from going into the gulf when water levels at the sea are high or it will keep water from going into the sea when water level at the sea is low.

Fig 2



GENERAL SCHEME OF THE TIDEL POWER STATION

2 **Turbines :** They are the components responsible for converting potential energy into kinetic energy. They are located in the passage ways that the water flows through when gates of barrage are opened.

3 **Sluices :** Sluice gates are the ones responsible for the flow of water through the barrage they could be seen Fig 2.

4 **Embankments :** They are caissons made out of concrete to prevent water from flowing at certain parts of the dam and to help maintenance work and electrical wiring to be connected or used to move equipment or cars over it.

Advantages of tidal power generation

There are many advantages of generating power from the tide; some of them are listed below.

- Tidal power is a renewable and sustainable energy resource.
- It reduces dependence upon fossil fuels.
- It produces no liquid or solid pollution.
- It has little visual impact.
- Tidal power exists on a world wide scale from deep ocean waters.

Disadvantages and constraint to tidal power generation

Unfortunately, there are also disadvantages and limitations to generating tidal power. Some of these are;

- At the present time both tide and wave energy are suffering from orientation problems, in the sense that neither method is strictly economical (except in few locations throughout the world) on a large scale in comparison with conventional power sources.

Power generation by solar energy

Objectives: At the end of this lesson you shall be able to
- **explain the basic principle and construction of the solar cell.**

Solar electricity

When sunlight strikes on photovoltaic (PV) solar panel, the electricity is produced. The method of generating the electrical energy from the solar panel (cells) is termed as solar energy generation.

Generation of electricity by using solar energy depends up on the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons.

When sunlight strikes on this layer, it absorbs the photons of sun light ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layer and resulting to a tiny potential difference between them.

The unit of such combination of two layers of semi conductor materials, for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as solar cell. For building cell, silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. Then both doped and undoped wafers are sandwiched together to build solar cell. A metallic strip is attached to two extreme layers to collect current.

A desired number of solar cell are connected together in both parallel and series to form a solar module for producing desired electricity.

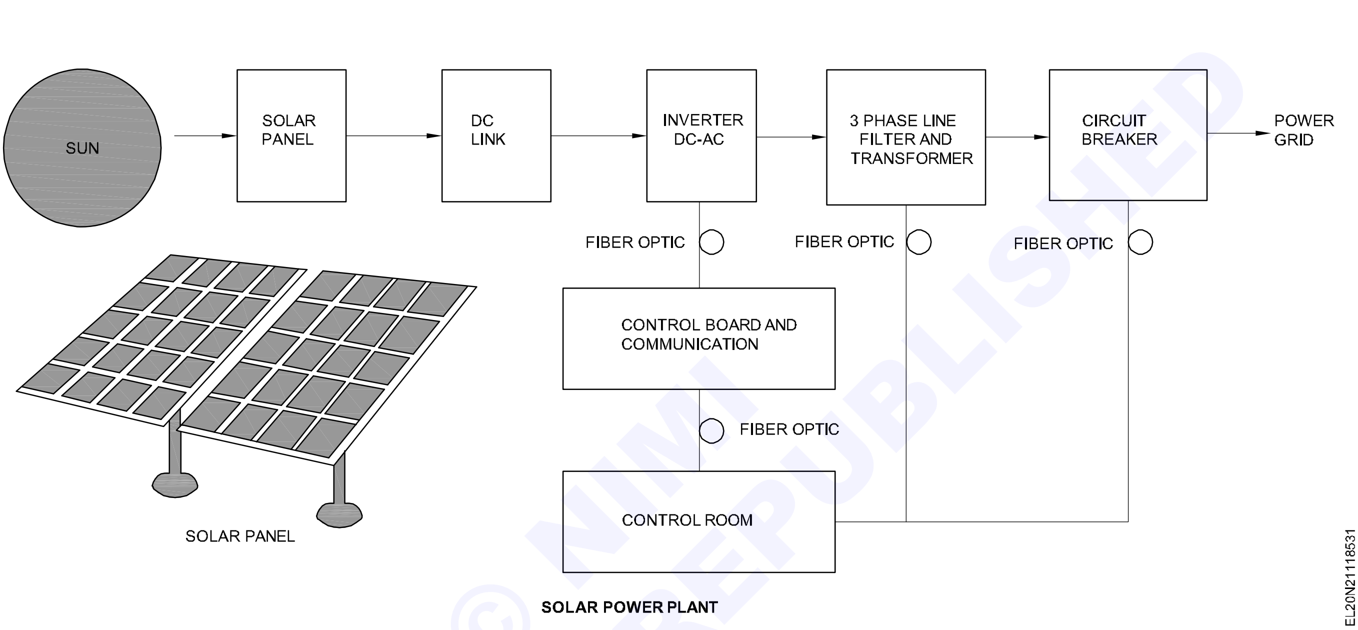
The solar cell can also work in cloudy weather as well as is moon light but the rate of production of electricity low as and it depends up on intensity of incident light ray.

Fig 1 describes the typical system of solar panels, controller, energy storage, inverter for converting DC into AC and how the system is connected to power grid.

Assembling and installation of solar panels

A solar panel is a able to function using the solar energy which is derived from the sun. The solar panel installed on the roof top absorb sun's light (photons) from the sun.

Fig 1



SOLAR POWER PLANT

Silicon and the conductors in use for solar panel converts the sunlight into direct current (DC) electricity flows into the inverter. It is an renewable energy. The process of converting sunlight to electrical energy and more efficient than other process.

Solar panel contains many different silicon cells (or) solar cells. The energy derived from the sun is connected into electricity with help of solar panels.

1 The solar panels installed on the roof top absorb sun's light from the sun.

2 The silicon and the conductor in the panel convert the sunlight into DC flows into inverter.

3 The inverter then converts DC to AC which can be used at home.

4 Excess electricity that is not used, can be feedback to the grid.

5 When the solar panels produce less power than required at home.

Process of connecting solar panel to electricity

Solar panels is used a special process of connecting photons to electrons to generate a current by making use of a special type of cell known as photovoltaic cell. These cells are commonly found on the front of calculation and small gadgets are connected together, called as solar panels (photovoltaic cells) are made up of semiconductor materials such as silicon, which absorb the light from the sun. The photons in the sunlight current the electron within the sunlight.

Basic idea of a solar module, array and balance of system (BOS)

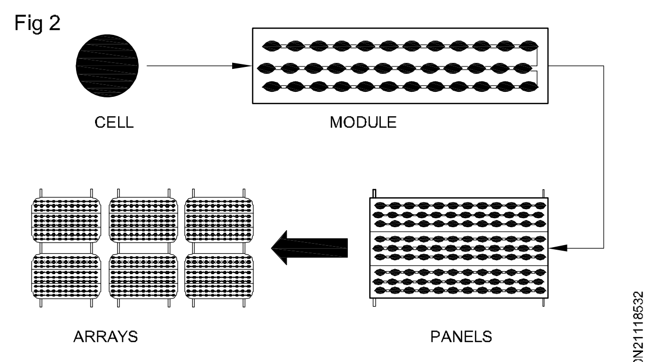
Module

Solar cells are made in various shapes and sizes. The smallest of the cells can be seen in devices like an ordinary calculator, these type of devices are very little amount of power used in home lighting system needs more power to run on. The number of cells are put together to produce more power. The group of cells is packaged together in an enclosed space is called as a **module**.

It helps to give higher voltage, high power and protects the panel from rain, snow and wind etc. voltage and power output of module depend on the size and number of cells used. So, more number of modules are to be connected in a simple assembly of modules is known as **array.** (Fig 2)

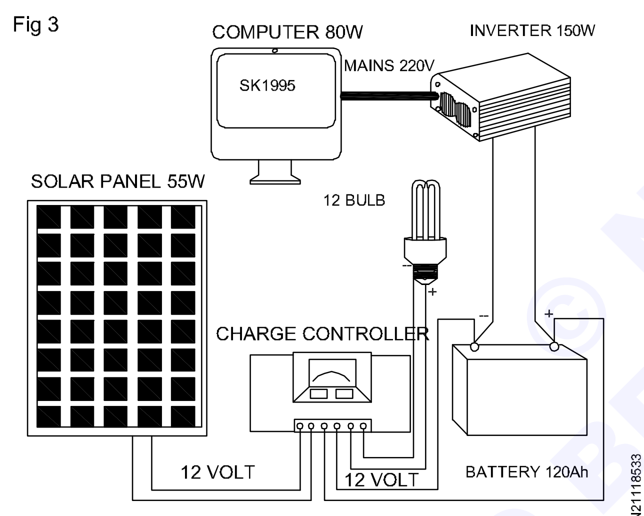
Balance of system (BOS)

The cells modules and arrays are the power producing part, a small devices like radio, needs a small amount of power, can be directly connected to a small module. But most of the devices appliances need more power at night. The assembly of module, battery and an appliance is simple form a P.V system.



CELL MODULE PANEL AND ARRAY SYSTEM

A module cannot be connected directly to a battery, so, a charge controller ON charge regulator is used in between module and battery and inverter are required to operate AC appliances. So, the whole system excepts the module is known as balance of system (BOS). (Fig 3)



BALANCE OF SYSTEM(BOS)

The main components is BOS assembly are:

- Storage battery
- Charge controller
- Inverter
- Support structure
- Junction boxes
- Wire, cables and fuses
- Connections and switches

The functions of the above components are explained briefly below:

Storage battery

The most small systems used for lightening needs only 12V battery for longer system like refrigerator, 24V is used. If helps to keep the wire size small and system losses to a minimum. It needs to be handled carefully. If must not be over charged or fully discharged to prevent from damage.

Charge controller

If the battery is not able to control charge on its own. This work is done by a simple automatic device known as a charge controller in the following way.

- It senses the battery charge and switches 'OFF' the charging current and avoid from damage.
- It disconnects the appliances when the battery charge goes below a set limit.
- Prevents reverse current and protects from short circuit.

Inverter

A solar system produces only DC power. But home appliances need AC power. The device (example CFL) is required for this purpose to convert DC into AC is called as inverter.

Support structure

The solar module cannot be simply placed either on ground or roof. It needs to collect the sunshine at an angle. To keep the module safe from any strong winds support structure is used for solar PV system.

Junction boxes

It is meeting point for many wires. These may be from a raw of modules are from modules to a battery bank. A junction box is made of an unbreakable material (ie) polycarbonate. It makes use of copper connectors for a high current flow. It protects the system from moisture.

Wires and fuses

This solar systems carry a low voltage but high current. So, the large diameter wire is needed. Fuses keep the solar equipment safe against the short circuit.

Mounting of charge controller

- Mount the controller to the wall into screws that fit to the wall material.
- Connect the battery cable assembly with fuse supplied along with the controller.
- Connect first controller and then battery and two modules
- Connect the wires to the load and only then to controller.

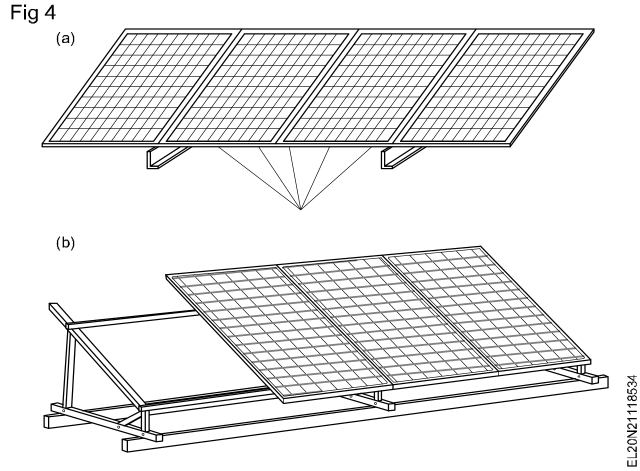
Electrical connection

- Connect the battery to the system only after getting fully charged.
- Do not switch 'ON' charged the loads for 2 - 3 days (when battery is 'ON' a full charged)
- Connect the array cable to charge controller with correct polarity.
- Keep the switch in 'OFF' position and connect the load cables and battery cables to charge controller.

- Switch 'ON' the load (ie) lamps for the normal operation.
- Test the solar panel installation for it's functioning.

(Fig 4a & b) shows the installed solar panel with mid clamp and with frame mounted installation are illustrated.

Fig 4



Functionality of solar panel

Sunlight is the basic fuel for a solar panel. Sunshine is the cause to keep the panel for normal functioning. But the environment around the modules will affect it's working.

The following few factors will affect it's normal working cause for power loss.

- Tilt angle
- Dust
- Shading
- Light intensity
- Temperature
- Charge controller
- Semiconductor energy loss
- Cabling losses
- Improper connections

Tilt angle : The solar module must be installed in the proper path of sun and it is tilted properly at an angle, equal to the latitude of the place. If any error in the tilt angle will lead to same amount of power loss.

Dust : If the modules is not cleaned properly, dust will form on the modules surface in the dry season, and it may cause for high energy loss 5-10%.

Shading

Solar module faces the sun all day. Their shade should not be present on it. In such a place only it must be put up. But due to extended free transformer, T.V antennas etc, may cause to present shades.

A solar modules are made of a string of individual solar cells and connected in series with one another. Suppose as an example one cell from 36 cells in a module is fully shaded, the power output from the module will become zero due to high resistance. But if one cell is 50% shaded then the power output is reduced to 50% only offers high resistance.

Light intensity

More power is produced from the panel in bright sunlight. For 1000W/M^2 of sunlight, the rated output power will be full. But, if it is 500W/M^2 only the rated power output will be half. The output power is directly proportional with the increasing of solar in isolation.

Temperature

The higher the temperature the output power is reduced from a module, due to power loss. It is tested at standard temperature at 25°C. During the bright sunlight, cell may reach 70°C also. If crystalline silicon decrease from 0.4 to 0.5% per°C temperature increases above 25°C. Amorphous silicon module temperature coefficient is 0.2 to 0.25 % per°C of temperature increase.

Charge controller

If the charger controller is in continuous operation and draws a small current of about 5mA to 25mA, then the power loss is around 1%.

Semiconductor energy loss

The charge controller is having the components as MOSFET and blocking diodes, which is cause for heat energy loss.

Cabling loss

The cables are also cause for power loss, It can be minimized by choosing a large diameter of wire size.

Improper connection

If the electrical connections are not made properly, it results in less power is fed to the battery. It can be reduced by keeping clean, and tight connections.

Wind power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of wind power generation**
- **state the advantages and disadvantages of wind power generation.**

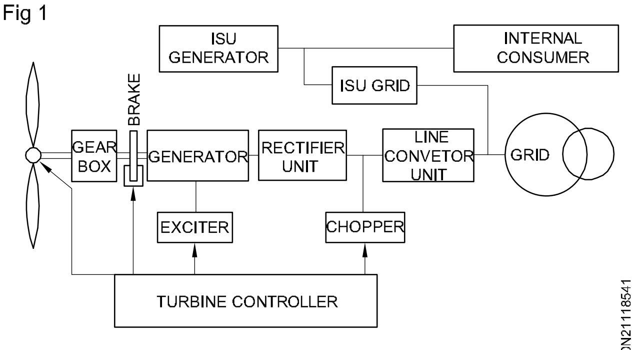
The method of generating the electrical energy by using the wind is termed as wind power generation. Since the wind has velocity and kinetic energy, it can be used to produce electricity. For that, we can use windmills. The important part of a windmill is a structure with large leaves, fixed at the top of a high tower. The speed of leaves changes with the speed of the wind. If the rotation of the windmill is given to the rotor of a generator, then the electricity will be obtained from the generator. If the windmill is connected to a water pump, the leaves of the windmill rotate the pump and pumping out the water.

Wind power can be usefully exploited for the generation of electricity as there are large, coastal, hill and desert areas. Wind turbines comprising of machines with blade diameter of 17 m, which can generate about 100 kilowatts. A strike of blowing wind on specially designed blades of a windmill's rotor causes both to rotate. This rotation, which is the mechanical energy, when coupled to a turbine, drive the power generator.

Operation

The schematic arrangement of wind power station is given in Fig 1.

Fig 1



WIND POWER GENERATION

When the wind strikes the rotor blades, blades start rotating. Rotor is directly connected to high speed gear box. Gear box converts the rotor rotation into high speed which rotates the electrical generator. An exciter is needed to give the required excitation to the coil so that it can generate required voltage. The exciter current is controlled by a turbine controller which senses the wind speed based on that it calculate the power what we can achieve at that particular wind speed.

The output voltage of electrical generator is given to a rectifier and rectifier output is given to line converter unit to stabilise the output AC that is fed to the grid by a high voltage transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc), this is called **internal supply unit**. ISU can take the power from grid as well as from wind. Chopper is used to dissipate extra energy from the Rectifier Unit (RU) for safety purpose.

Advantages

1 The wind energy is free, inexhaustible and does not need transportation.

2 Wind power plant on the other hand does not take long time to construct. Such wind mills will be highly desirable & economical to the rural areas which are far away from the existing grids.

3 There is a strong reason why wind power should be welcome by grids which have some hydroelectricity inputs in India. The water level in the hydel reservoir is at its lowest before the onset of the South West monsoon. If less water is drawn during the monsoon, a high level could be maintained for longer period. During the monsoon period wind energy can be used to feed the grid.

4 It is non polluting

5 It does not require high technology.

6 Electricity can be produced at a lower cost after installation.

Disadvantages

1 The major disadvantage associated in the wind power is that it is not constant and steady, which make the complications in designing the whole plant.

2 The rotor blades of wind turbine generators must sweep out large areas to produce worthwhile amount of power.

3 The wind is a very dangerous such storms can cause tremendous shear stresses which may spoil the whole plant within no time. To avoid this, special and costly designs and controls are always required.

4 Among all the disadvantages mentioned above, the cost factor is the major which has restricted the development of wind power on large scale for feeding to the existing grid. The estimated cost of wind electricity generation, storage & distribution system is over 1 lakh rupees which may be considered beyond the means of most Indian villages.

Modern wind machines are still wrestling with the problem of what to do when the wind is not blowing. Large turbines are connected to the utility power network some other type of generator picks up the load when there is no wind. Small turbines are often connected to diesel/electric generators or sometimes have a battery to store the extra energy they collect when the wind is blowing hard.

The wind energy is utilized by means of a wind mill or a series of wind mills. A wind mill consists of few vanes (normally 3 to 6) which rotate about their axis, when the wind blows against them. The rotational motion (i.e. mechanical energy) thus created is utilized for various applications, such as,

1 Lifting water from the well

2 Battery charging

3 Water pumping

4 Operating a simple machine

5 Wind energy is used for agricultural& rural applications such as grinding flour mills, wood cutting saw, stone crushers, mixers, water pumps and irrigation facility etc.

Electrical supply system - transmission and distribution network - line insulators

Objectives: At the end of this lesson you shall be able to
- **explain the electrical supply system and layout of AC power supply scheme**
- **list out the various power transmission**
- **compare AC and DC transmission.**

Electrical supply system

The electrical energy generated from the power plants has to be supplied to the consumers. This is large network, which can be broadly divided into two stages, (ie.) Transmission and distribution.

The conveyance of electric power from a power station to the consumers / premises is called is Electrical supply system.

The Electrical power supply system consists of 3 main components viz (i) The power station / plant (ii) The transmission lines and (iii) The distribution systems. The power is produced at power plant which is away from the consumers, It has to be transmitted over long distances to load centres by transmission and to consumers through distribution network.

This supply system can be classified into

- DC or AC system
- Over head lines (or) underground system

Now a days, 3 phase, 3 -wire AC system is universally adopted as an economical proposition. In some places 3 phase - 4 wire AC system is adopted.

The underground system is more expensive than the overhead system, therefore in our country O.H system is almost adopted.

Types of power transmission system

Universally, 3 - phase - 3 wire AC system is adopted in most of the places. However other systems can also be used for transmission under special circumstances.

1 AC single phase system

i Single-phase two wire

ii Single - phase two wire with mid point earthed

iii Single phase three wire

2 AC three phase system

i Three - phase - three wire

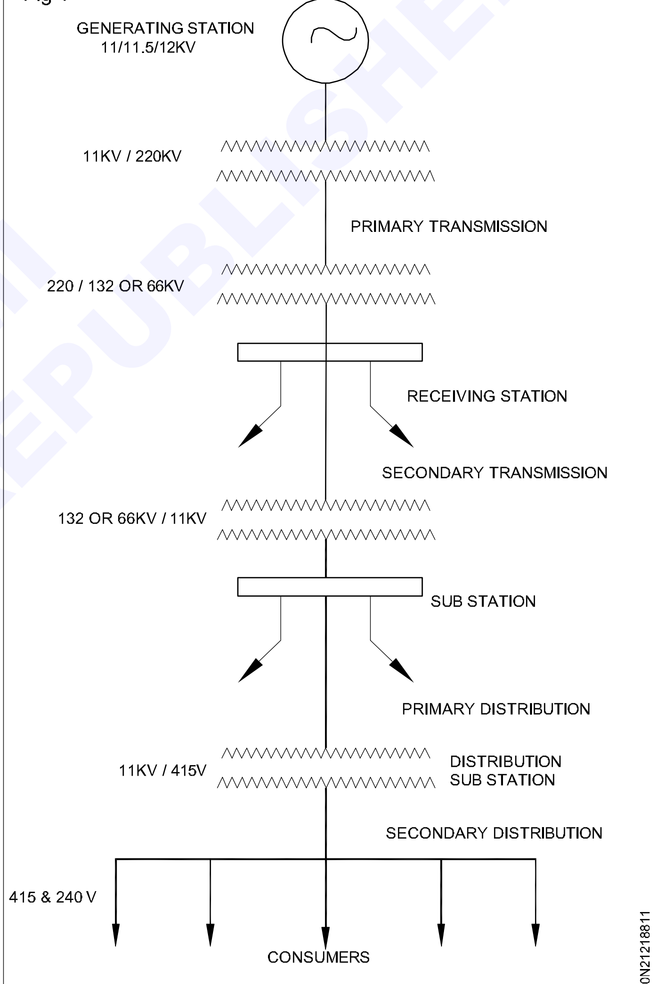
ii Three - phase - four wire

The line network between generating station (Power station) and consumer of electric power can be divided into two parts.

- Transmission system
- Distribution system

This system can be categorized as primary transmission and secondary transmission. Similarly primary distribution and secondary distribution. This is in Fig 1.

Fig 1



TYPICAL AC POWER SUPPLY SCHEME

It is not necessary that the entire steps which are shown in the diagram must be included in the other power schemes. There may be difference, there is no secondary transmission in many, schemes, in some (small) schemes there is no transmission, but only distribution.

Various stages of a typical electrical power supply system, are as follows

1 Generating station

2 Primary transmission

3 Secondary transmission

4 Primary distribution

5 Secondary distribution

Generating station

The place where electric power produced by the parallel connected three phase alternators / generators is called generating station (i.e power plant).

he ordinary power plant capacity and generating voltage may be 11KV, 11.5 KV, 12KV or 13KV. But economically. It is good to step up the produced voltage from (11KV, 11.5KV or 12KV) to 132KV, 220KV, 400KV or 500KV or greater (in some countries, up to 1500KV) by step up transformer (power transformer).

Primary transmission

The electric supply (132KV, 220 KV, 500KV or greater) is transmitted to load center by three phase three wire (3 phase - 3 wires) overhead transmission system.

Secondary transmission

Area far from city (outskirt) which have connected with receiving station by line is called secondary transmission. At receiving station, the level of voltage reduced by step-down transformers up to 132KV, 66 or 33KV and electric power is transmitted by three phase three wire (3 phase - 3 wires) overhead system to different sub stations. So this is a secondary transmission.

Primary distribution

At a sub station, the level of secondary transmission voltage (132KV, 66 or 33KV) is reduced to 11KV by step down transformers.

Generally, electric supply is given to heavy consumer whose demands is 11KV, from these lines which carries 11KV (in three phase three wire overhead system) and they make a separate sub station to control and utilize this power.

In other cases, for heavier consumer (at large scale) their demand is about 132 KV or 33KV they take electric supply from secondary transmission or primary distribution (in 132KV, 66KV or 33KV) and then step down to the level of voltage by step -down transformers in their own sub station for utilization (i.e for electric traction etc).

Secondary distribution

Electric power is given to (from primary distribution line (i.e.) 11KV) distribution sub station. This sub station is located near by consumers area where the level of voltage reduced by step down transformers is 415V. These transformers are called distribution transformers, in 3 phase four wire system (3 phase - 4 wires), there is 415 volts (Three phase supply system) between any two phases and 240 volts (single phase supply) between neutral and any one of the phase (lives) wire.

Residential load (i.e. Fans, light, and TV etc) may be connected between any one phase and neutral wires, while three phase load may be connected directly to the three phase lines.

Elements of distribution system

Secondary distribution may be divided into three parts.

1 Feeders

2 Distributors

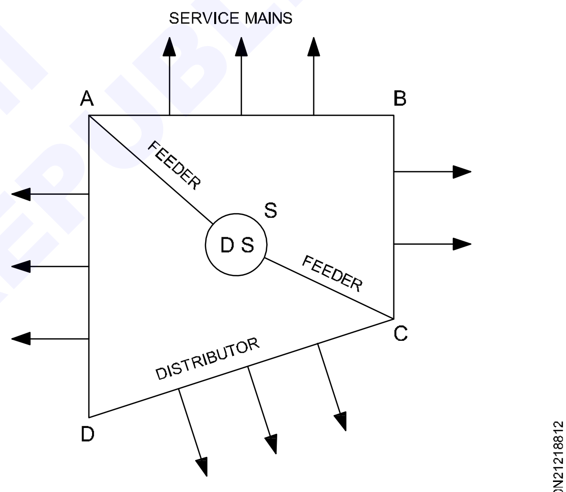
3 Service lines or service mains

Those electric lines which connect generating station (power station) or sub station to distributors are called **feeders.** Remember that current in feeders (in each point) is constant while the level of voltage may be different, the current flowing in the feeders depends on the size of conductor.

Distributors

Those tapings which extracted for supply of electric power to the consumers or those lines, from where consumers get electric supply is called **distributors** (Fig 2). Current is different in each section of the distributors while voltage may be same. The selection of distributors depends on voltage drop and may be designed according to voltage drop. It is because consumers get the rated voltage according to the rules.

Fig 2



DISTRIBUTION SYSTEM

Service lines or service mains

The normal cable which is connected between distributors and consumer load terminal are called **service line or service mains.** A complete typical AC power supply system scheme is in Fig 3.

Comparison of DC and AC transmission

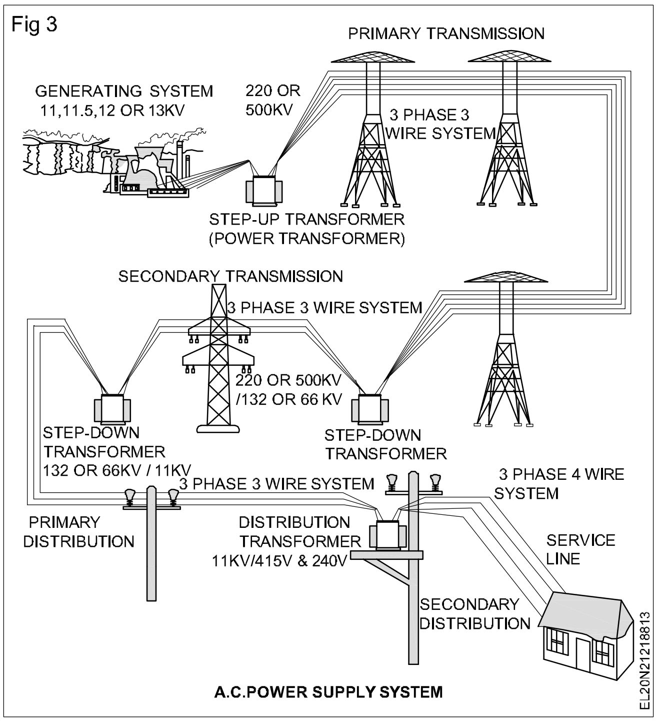
The electric power can be transmitted either by means of DC (or) AC. Each system has it's own merits and demerits. Some technical advantages and disadvantages of two systems are stated below.

AC transmission

Some years ago, the transmission of electric power by DC has been receiving of the active consideration of engineers due to it's appreciable advantages.

Advantages of DC electric power transmission

1 It requires only two conductors



A.C.POWER SUPPLY SYSTEM

2 There is no problem of inductance, capacitance and phase displacement which is common in AC transmission.

3 For the same load and sending end voltage, the voltage drop in DC transmission lines is less than that in AC transmission.

4 As there is no skin effect on conductors, therefore entire cross - section of conductor is usefully utilized thereby affecting saving in material.

5 For the same value of voltage insulating material on DC lines experience less stress as compared to those on AC transmission lines.

6 A DC line has less corona loss and reduced interference with communication circuits.

7 There is no problem of system instability which is so common in AC transmission.

Disadvantages of DC transmission

1 Generation of power at high DC voltages is difficult due to commutation problems and cannot be usefully utilized at consumer ends.

2 Step up or step -down transformation of DC voltages is not possible in equipment like transformer.

Advantages of AC electric power transmission

1 Power can be generated at high voltages as there is no commutation problems.

2 AC voltages can be conveniently stepped up or stepped down by using transformers.

3 High voltage transmission of AC power reduces losses.

Disadvantages of AC electric power transmission

1 Problems of inductances and capacitances exist in transmission lines.

2 Due to skin effect, more copper is required.

3 Construction of AC transmission lines is more complicated as well as costly.

4 Effective resistance of AC transmission lines is increased due to skin effect.

From the above comparison, it is clear that high voltage DC transmission is superior to high voltage AC transmission. At present, transmission of electric power is carried by AC and effort is making towards DC transmission also. The convertor and inverter have made it possible to convert AC into DC and vice versa easily. Such devices can operate upto 30MW at 400KV in single units. The present day trend is towards AC for generation and distribution at high voltage DC for transmission.

The AC power at high voltage is fed to the convertor which convert AC to DC. The transmission of electric power is carried at high DC voltage. At the receiving emf DC is converted into AC with the help of invertors. The AC supply is stepped down to low voltage by receiving end transformer (T_R) for distribution.

Line insulators

Objectives: At the end of this lesson you shall be able to
- **explain the types of insulators and their uses.**

Line insulators

The aim of using a line insulator in an overhead line is to hold the live conductor to prevent leakage of current from the conductor to the pole. These are made of porcelain clay and are thoroughly glazed to avoid the absorption of moisture from the atmosphere.

Properties of insulators

i High mechanical strength in order to withstand conductor load, wind load etc.

ii High electrical resistance of insulator material in order to avoid leakage currents to earth.

iii High relative permittivity of insulator material in order that dielectric strength is high.

iv The insulator material should be non - porous, free from impurities and cracks otherwise the permittivity will be lowered.

v High ratio of puncture strength to flash over.

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.

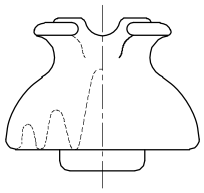
The following are the common types of insulators in use.

- Pin type insulator

- Shackle insulator
- Suspension insulator
- Strain insulator
- Post insulator
- Stay insulator
- Disc insulator

Pin Insulators : Pin insulators are used for holding the line conductors on straight running of poles. Pin insulators are three types. i.e single shed (Fig 1) double shed (Fig 2) and triple shed (Fig 3) The single -shed pin insulators are used for low and medium voltage lines. The double and triple shed pin insulators are used for over 3000V. These sheds are used to drip off the rain water.

Fig 1



SINGLE SHED TYPE OF PIN INSULATOR

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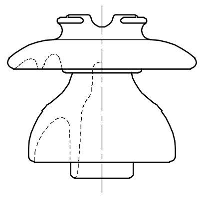
Fig 2



DOUBLE SHED TYPE OF PIN INSULATOR

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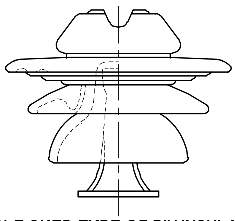
Fig 3



TRIPLE SHED TYPE OF PIN INSULATOR

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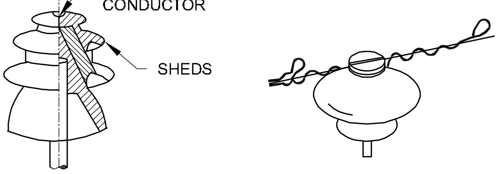
The part section of a pin type insulator is in Fig 4a & 4b As the name suggest, the pin type insulator is secured to the cross - arm on the pole. There is a groove on the top of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.

Fig 4



SECTION VIEW OF A PIN INSULATOR

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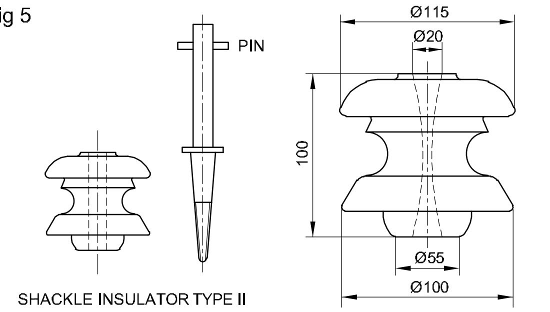
Shackle insulators : Shackle insulators are generally used for terminating on corner poles. These insulators are used for medium voltage line only. (Fig 5a & 5b)

Fig 5



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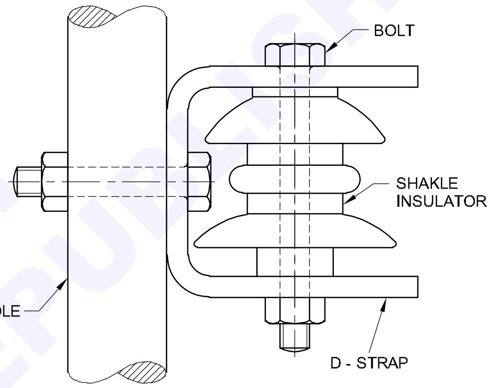
But now a days, they are frequency used for low voltage distribution lines. Such insulators can be used either in horizontal position or in a vertical position. They can be directly fix to the pole with a bolt or to the cross arm. Fig 6 shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

Fig 6



SHACKLE TYPE INSULATOR

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Suspension type insulators

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 KV. For high voltage (>33KV), it is a usual practice to use suspension type insulators as in Fig 7. They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross- arm of the tower. Each unit or disc is designed for low voltage, say 11KV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66KV, then six discs in series will be provided on the string.

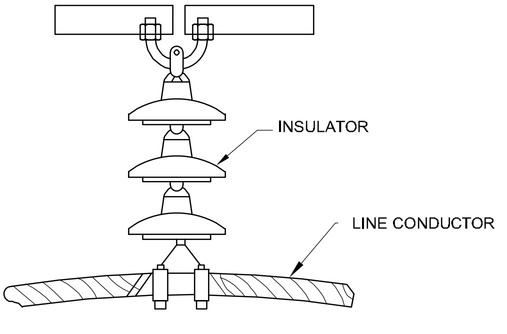
Advantages

1 Suspension type insulators are cheaper than pin type insulators for voltage beyond 33 KV.

2 Each unit or disc of suspension type insulator is designed for low voltage, usually 11KV. Depending upon the working voltage, the desired number of discs can be connected in series.

3 If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

Fig 7



SUSPENSION INSULATOR

4 The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

5 In case of increased demand on the transmission line it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

6 The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross arm of the tower, therefore, this arrangement provides partial protection from lighting.

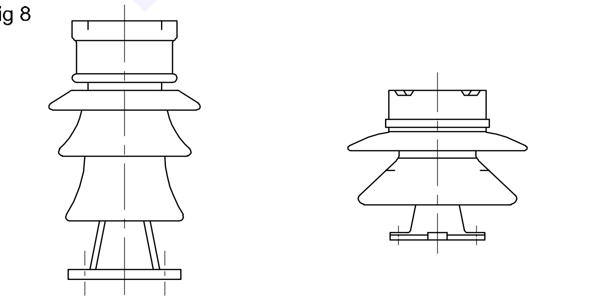
Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, the strain insulators are used. For low voltage lines (<11KV) shackle insulators are used as strain insulators. However for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators. The discs of strain insulators are used in the vertical plane. When the tension in the lines is excessively high, as at long river spans, two or more strings are used in parallel.

Post insulators

Cap and pin type (Fig 8a & 8b) : Such insulators can be used for mounting of buses, dropout fuses, line conductors, G.O.A.B (Gang Operated Air Break) switches. These are of outdoor type and are available in 11, 22 and 33KV ranges.

Fig 8

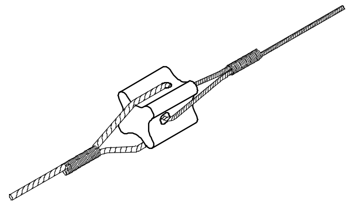


a) CAP AND PIN INSULATOR FOR GOAB SWITCH

b) ANOTHER DESIGN OF CAP AND PIN INSULATOR FOR GOAB SWITCH

Stay insulators (Fig 9) : Stay insulators are also known as strain insulators and are generally used up to 33 KV line. These insulators should not be fixed below three metres from the ground level. These insulators are also used where the lines are strained.

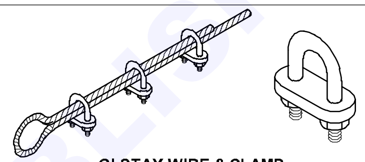
Fig 9



STAY INSULATOR

The supporting wire which is used in the opposite direction of tension on the pole due to overhead conductors is known as 'stay wire'. It prevents the bending of the pole due to tension of the conductor. These stay wires consist of 4 to 7 strands of GI wire is in Fig 10. The correct size to be used depends upon the tension on the pole.

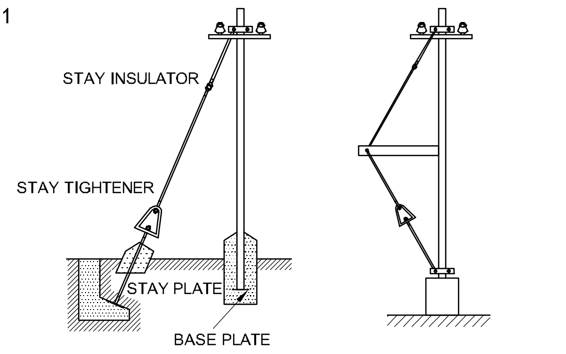
Fig 10



GI STAY WIRE & CLAMP

Stays and struts: Stays and struts are the different types of supporting wires for the pole. Stays are generally used for angle and terminating poles to prevent the bending of the pole whereas struts are used where space for stay is very limited. Fig 11 shows both the stay and the strut.

Fig 11



STAY TYPE SUPPORT

STRUT TYPE SUPPORT

One end of the stay is fixed at the top of the pole and its other end is grouted in the concrete foundation.

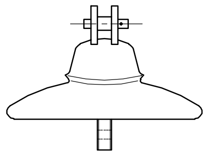
Disc insulators : Disc insulators are made of glazed porcelain or tough glass and are used as insulators at dead ends, or on straight lines as suspension type for voltages 3.3 kV and above. (Figs 12, 13 and 14)

These are available in four designs:

Tongue and clevis type (Fig 12): A round pin with a cotter pin is used to hold the tongue of one unit in the clevis of the other.

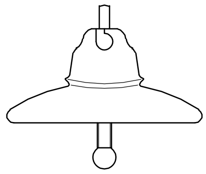
Ball and socket type (Fig 13): In this case insulators are assembled by sliding the ball of one insulator from the side. A cotter pin is slipped in from the back of the socket so that the ball cannot slide out. These are used at dead ends.

Fig 12



DISC INSULATOR TONGUE AND CLEVIS TYPE

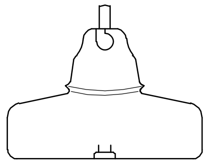
Fig 13



DISC INSULATOR BALL AND SOCKET TYPE

Insulators for cold climate (Fig 14): For cold climate the depth of the lower cap is increased to get creepage distance which becomes necessary in cold climates. Two designs known as fog type and anti-fog types are available.

Fig 14



DISC INSULATOR COLD AND CLIMATE TYPE

Overhead poles and method of joining aluminium conductors

Objectives: At the end of this lesson you shall be able to
- **state transmission and distribution by O.H lines**
- **list out the main components and explain each of them**
- **state the types of power lines with respect to the classification of voltage**
- **state sag in O.H lines.**

Overhead lines : Electric power, which is generated from generating plant / station to the consumer end is transmitted and distributed either by means of overhead lines (O.H) or by under ground cables (U.G. cables).

Main components used in O.H lines

An overhead line may be used to transmit or distribute electric power.

i Conductors which carry electric power from the sending end station to the receiving end station.

ii Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

iii Insulators which are attached to supports and insulate the conductors from the ground.

iv Cross arms which provide support to the insulators.

v Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Commonly used conductor materials

The most commonly used conductor material for overhead lines are copper, aluminium, steel reinforced aluminium, galvanized steel and cadmium copper.

All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24...

Line Supports : The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties:

i High mechanical strength to withstand the weight of conductors and wind loads etc.

ii Light in weight without the loss of mechanical strength

iii Cheap in cost and economical to maintain.

iv Longer life

v Easy accessibility of conductors for maintenance

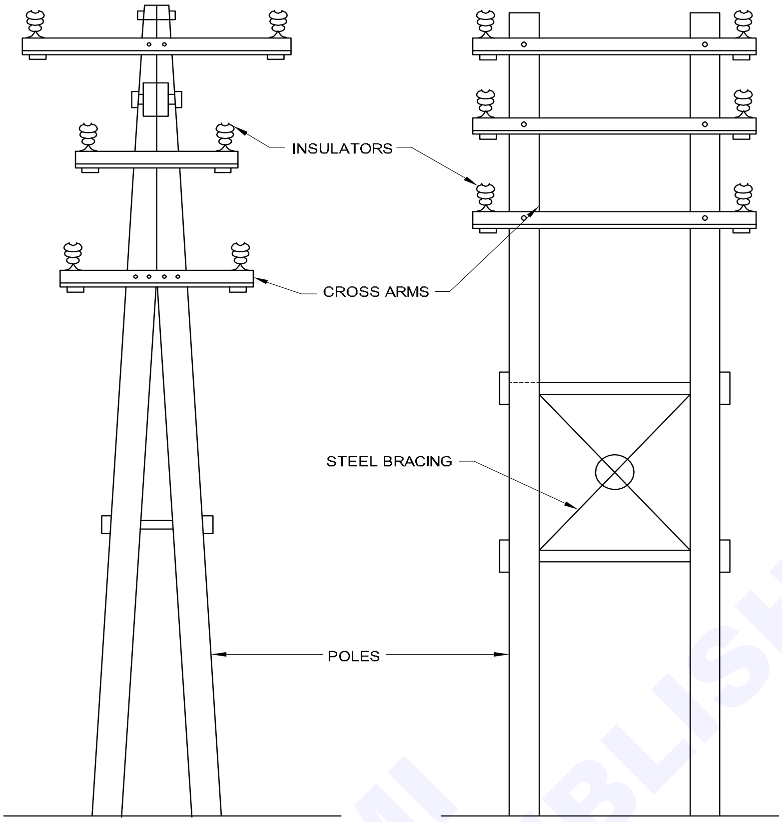
The line supports used for transmission and distribution of electric power are of various types including wooden, poles, steel poles, R.C.C poles and lattice steel towers.

Wooden poles (Fig 1) : These are made of seasoned wood (sal or ehir) and are suitable for lines of moderate cross sectional area and of, relatively shorter spans, say up to 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore are widely used for distribution purposes in rural areas as an economical proposition.

Steel poles : The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types viz (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

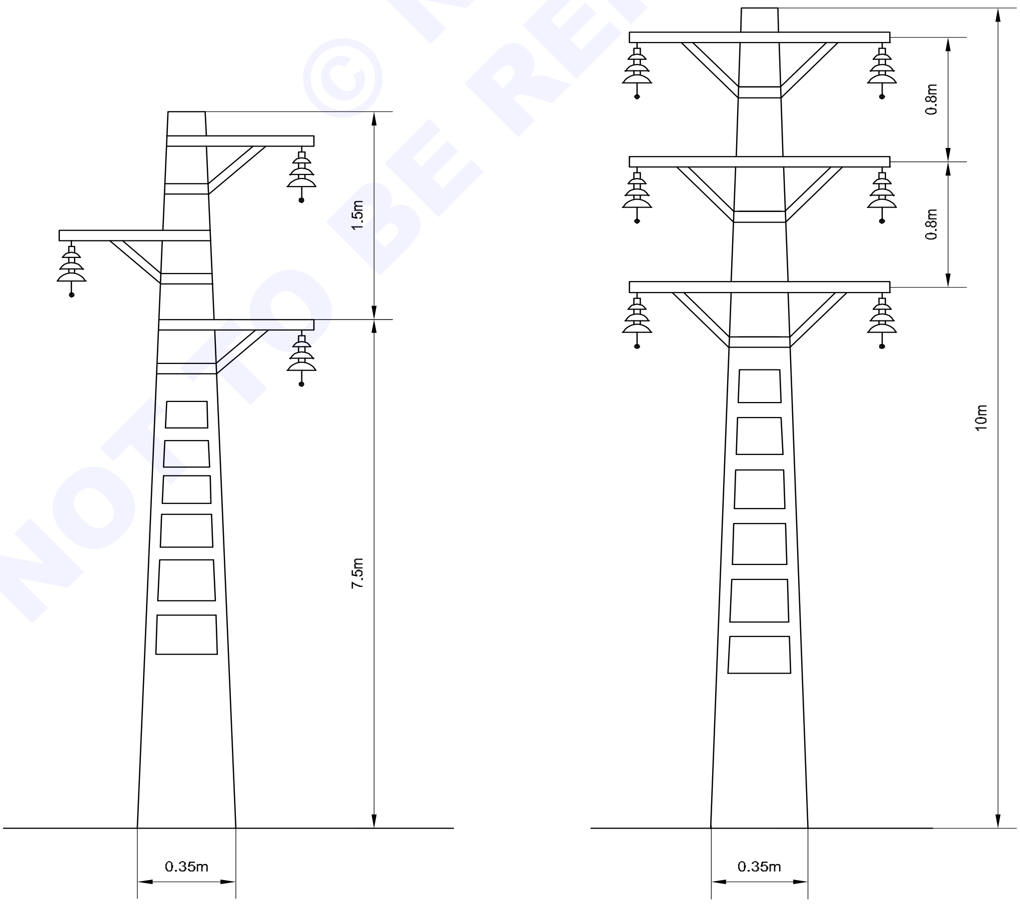
RCC Poles : The reinforced cement concrete (RCC) poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Fig 2 shows R.C.C poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

Fig 1



WOODEN POLES

Fig 2



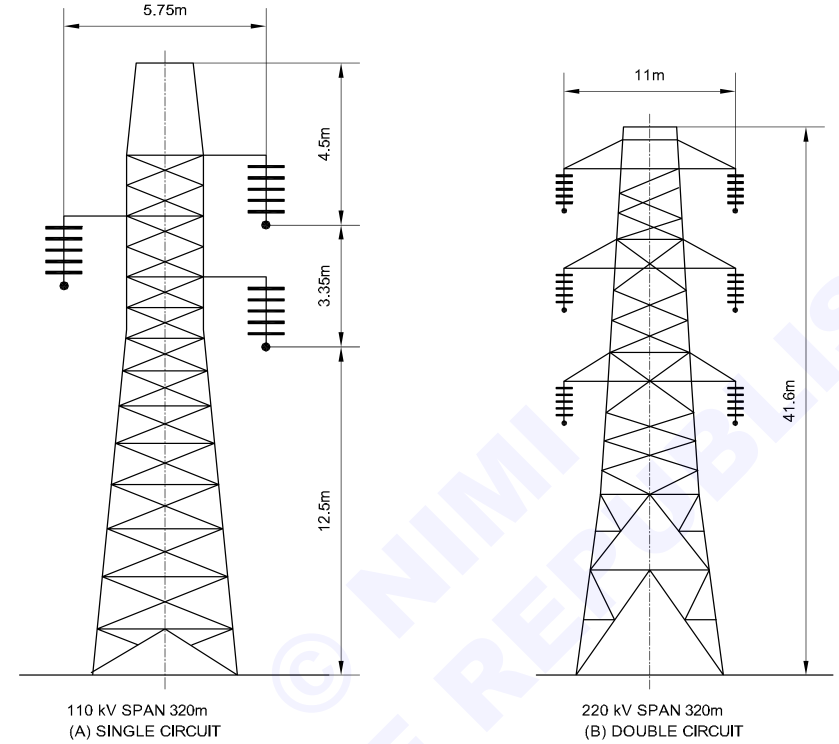
RCC POLES

Steel towers

In practice, wooden, steel and reinforced concrete poles are used for distribution purpose at low voltages, say upto 11 KV. However for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand more severe climatic conditions and permit the use of longer spans. The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

Fig 3(a) shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Fig 3(b). The double circuit has the advantage that it ensures continuity of supply. In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

Fig 3



STEEL TOWERS

The electric supply is transmitted at different voltages through over head lines and the types of power lines are furnished below:

a Low voltage line (should not exceed 250V)

b Medium voltage line (should not exceed 650V)

c High voltage line (should not exceed 33000V (33 KV)

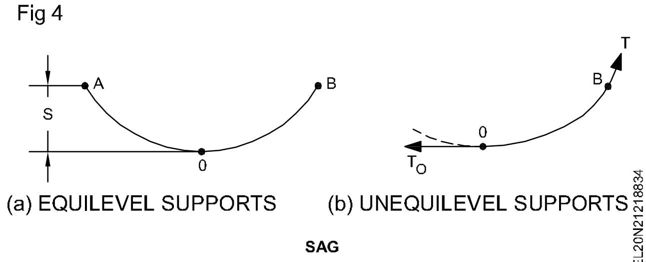
d Extra high voltage line (above 33KV)

Sag in Overhead Lines : The difference in level between points of supports and the lowers point on the conductor is called **'Sag'.**

Fig 4 (a) shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point of the conductor is O and the sag is S. Fig 4(b) shows unequal level supports.

Conductor sag and tension : This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level.

Fig 4

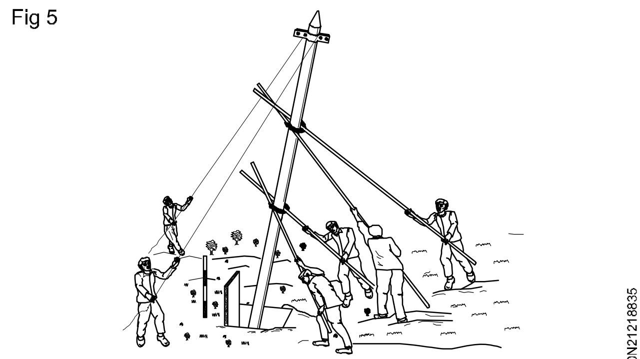


SAG

Method of erection of poles : The poles to be erected may be brought to the pit location by manual labour or by improvised carts. Then the pole may be erected in the pit. Wooden support poles may be utilized to facilitate lifting of the pole at the pit locations as in Fig 5.

Before the pole is placed into the pit, RCC padding or alternatively a suitable base plate maybe given below the pole to increase the surface contact between the pole and the soil. The padding will distribute the density of the pressure due to the weight of the pole on the soil.

Fig 5



ERECTION OF POLES

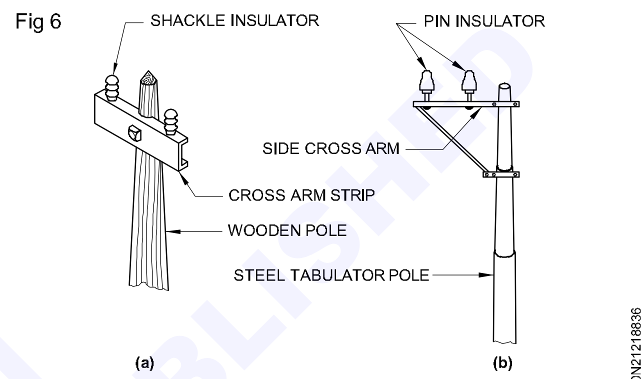
Having lifted the pole, the same should be kept in a vertical position with the help of Manila /sisal ropes of 20/25 mm dia. using the rope as a temporary anchor. As the poles are being erected, say, from an anchor point to the next angle point, the alignment of the poles are to be checked and set right by visual check. The verticality's of the poles are to be checked with a spirit level on both transverse and longitudinal directions.

Having satisfied that the vertical and longitudinal alignment are all right, earth filling is to be done. In some soils the poles are to be concreted up to ground level of the pit. After the poles have been set, the temporary anchors are to be removed.

Use of cross - arms : These are also known as insulator supports and are made of either wood or angle iron. Cross-arms are installed at the top of the pole for holding the insulators on which conductors are fastened. They are also known according to their relative position on the poles. If the cross - arm is fixed in the centre of the poles then it is called a cross - arm (Fig 6a) and if installed on one side of the pole, then it is termed as side cross -arm (Fig 6b) U-shaped cross - arms are specially used for three phase lines.

Channel iron cross-arms fabricated from channels of size 75 mm x 40 mm x 5.7 kg/m or size 100mm x 50 mm x 7.9 kg/m are used for H.T. lines, and those made from angle irons of size 50 mm x 50 mm x 6 mm are used for L.T lines.

Fig 6



CROSS-ARMS

Joining of aluminium conductors

Objectives: At the end of this lesson you shall be able to

- **state the type of joints**
- **explain the type and use of connectors used to joining conductors**
- **explain the steps to testing of O.H lines**
- **state the preliminary safety procedure for OH line erection.**

Joining accessories in O.H lines: Normally connectors are used for joining the O.H. aluminium conductors. Connectors maybe of several types of which few are described below.

1 Sleeved joints

2 Straight through connectors / taps

3 Vice - clamp connectors /taps with parallel grooves

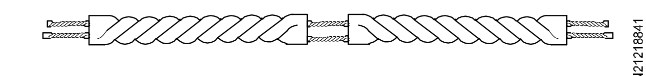
4 Nut and bolt connector

Sleeved joints

Twisted joints: Oval shaped aluminium sleeves are inserted over the conductors to be joined and then twisted as in Fig 1. Only one sleeve is sufficient for all aluminium conductors whereas two concentric sleeves are used for ACSR conductors. One each for the aluminium and steel portions. Twisting joints are recommended for conductors up to 15 mm diameter. Only special wrenches should be used for twisting the sleeves.

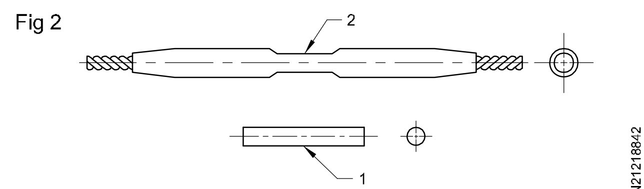
Compression joints : ACSR conductors are joined by compression joints having two sleeves as in Fig 2. The larger sleeve is of aluminium , fitting over the entire conductor, and the smaller one is of steel fitted on the steel portion of the wire eccentrically. Conductors to be joined are inserted into the sleeves one after the other and compressed either by hand or by hydraulic compressors. Compression joints for all aluminium conductors consist of aluminium sleeve only .

Fig 1



TWISTED JOINT

Fig 2

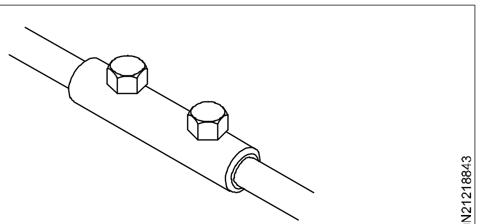


COMPRESSION JOINT FOR ASCR

Straight through connectors / taps : Two types of connectors are used to join two straight through run of wires in such locations where mass concrete foundations are to be adopted to avoid collapse of foundation in the black cotton soil.

Straight sleeve and nut connector: This is in Fig 3. It has a sleeve (round or oval in section) made of cadmium plated brass or aluminium. The conductors are inserted into the sleeve and tightened by the nuts.

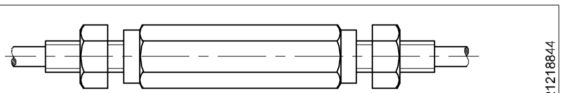
Fig 3



STRAIGHT SLEEVE AND NUT

Compression connector: In this, the conductors are wrapped at both ends and then compressed with nuts as in Fig 4.

Fig 4

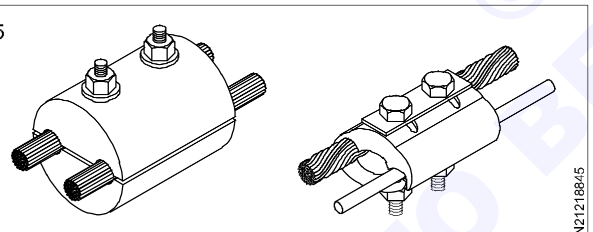


COMPRESSION CONNECTOR

Vice-clamp connectors/taps with parallel grooves (PG): There are several types as explained below.

Standard P.G. clamps: This clamp as in Fig 5 consists of two aluminium halves, having two semi-circular parallel grooves in each half. After inserting the conductors to be joined, the galvanized steel nuts are tightened. As the grooves are of the same size, it is useful only when the joining conductors are also of the same size.

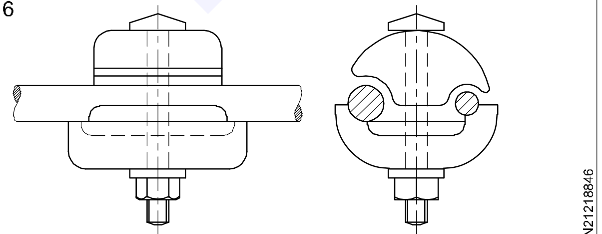
Fig 5



P.G. VICE CONNECTOR

Universal P.G. clamp: This is in Fig 6. It has grooves of slightly different shape to accommodate different sizes of conductors, and has only one bolt. This clamp is not for heavy duty service but can be used for tapping connections from the distribution line to individual consumers through aluminium conductors.

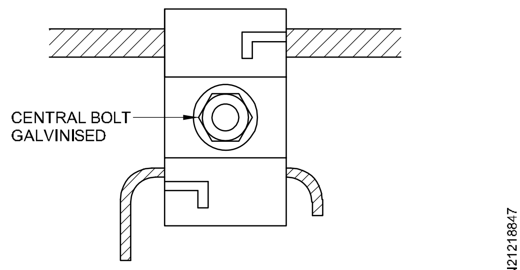
Fig 6



U.P.G. CLAMP

Bimetallic universal parallel groove clamps (B.M.P.G. clamps) : This clamp is in Fig 7. It has a brass body with cadmium plating. The two halves are tightened by a galvanised bolt. This is used for connecting copper wire to aluminium conductors in the case of consumer service connections.

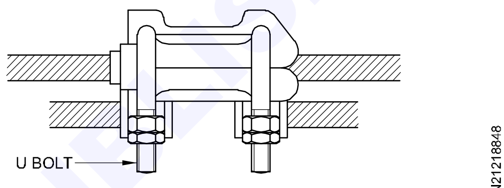
Fig 7



CENTRAL BOLT IS OF GALVANISED IRON

U bolt clamps: This is in Fig 8. It uses 'U' bolts as these bolts exert 4 times more pressure than the conventional straight bolts. Such clamps are suitable for heavy duty conductors.

Fig 8



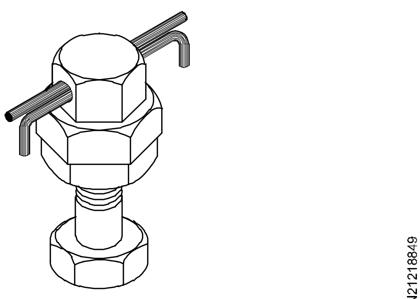
U BOLT CLAMP

Nut and bolt connectors are of two types

Nut connector

This is in Fig 9. It has a transverse hole through which the conductors to be joined are inserted and then tightened by the bolt.

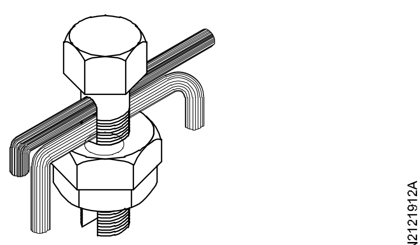
Fig 9



NUT CONNECTOR

Split bolt connector: This is in Fig 10. It is split at the stem. The conductors to be joined are to be inserted into the split and then tightened by the external nut.

Fig 10



SPLIT BOLT CONNECTOR

Domestic service line - IE rules

Objectives: At the end of this lesson you shall be able to
- **explain the domestic service connection with bare and insulated conductors**
- **state the method of laying the service cable from the pole to the consumer premises**
- **state the safety precautions to be followed in domestic service connections**
- **list out the IE rules pertaining to domestic service connections**
- **explain the methods of taping service connections.**

Service connections

The distribution networks ends at consumer premises either single phase or three phase connections. The category of connections either single phase or three phase depends as the maximum load demand by the consumer and the wiring of the house or the premises. The decision of power allocation by the electricity officials after surveying the wiring and load demand by the consumer.

Once the power requirement finalised and arrived the connection to the consumer the point from where the service line to be connected. It is also decided the drawing of line from the pole cross arm structure to the consumer mains panel either in over head or through UG cable. If the distance from over head pole terminal to consumer panel board is more than 50 Mtrs separate pole should be erected and OH line to be drawn from the distribution pole cross arm structure.

Service connection with bare conductor: Any of the following methods shall be adopted as specified.

The bare conductors shall be strung with shackle insulators fixed to the cross arms on both ends. The feeding end cross-arms shall be fixed to the support and the one at the receiving end shall be mounted on a G.I. pipe of a maximum diameter of 5 cm. The bare conductors shall be kept at a height of atleast 2.5 m from the top of the structure in accordance with Rule 79 of I.E. rules.

The G.I. pipe shall be provided with double bends at the top. The pipe shall be secured by alteast 2 clamps made of 50 mm X 6 mm. with M.S. flats fixed firmly to the wall in the vertical position. It shall in addition be provided with a G.I. stay wire of 7/3.15 mm size anchored to the building with one eye bolt. Service connection shall be given with weather proof/PVC insulated cable through this G.I. pipe. Wooden/PVC pushings shall be provided at both ends of this G.I. pipe.

The bare conductors shall be strung with shackle insulators as above except at the receiving end where the insulators shall be fixed to a bracket made of an angle iron, of a size not less than 50 mm x 50 mm x 6 mm. The ends of the bracket shall be cut and split and embedded in the wall with cement mortar. The bare conductor shall be kept atleast 1.2 m away from the edge of the structure, in accordance with Rule 79 of I.E. Rules.

The service connection shall be given with weather proof/ PVC insulated cable through GI pipe of a minimum diameter of 4 cm. fixed to the wall. The GI pipe shall be bent downwards near the service entry. Wall fitting wooden/ PVC bushes shall be provided at both ends of the G.I. pipe.

Service connection with insulated conductors: Service connection may be given by weather-proof/PVC insulated cable on a GI bearer wire. The cables shall be supported by the bearer wire by means of suitable link clips spaced 30 cm apart or by wooden/porcelain cleats 50 cm. apart. The GI bearer wire shall be of a minimum 10 SWG size.

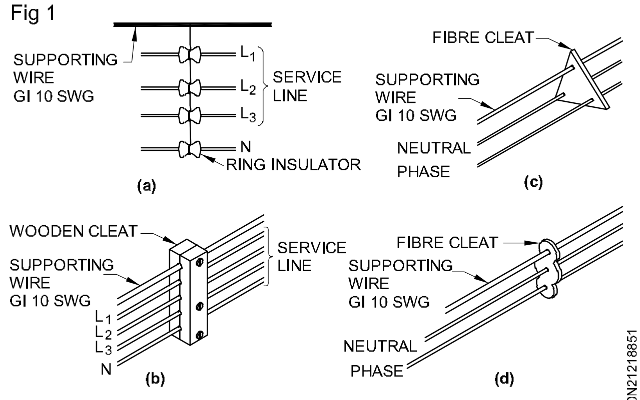
One end of the GI bearer wire shall be attached to a clamp which is fastened to the nearest pole carrying distribution lines from where the service connection is intended to be given. The other end of the GI bearer wire shall be fastened to a 5 cm. dia. GI pipe for a span up to 4.5m which is fixed to the wall with guy etc.

The GI pipe shall be fixed to an angle iron of size 40 mm x 40 mm x 6 mm with a suitable guy for high supports and for a span exceeding 4.5 m. Alternatively when the height of the structure permits minimum ground clearance, the other end of this GI bearer wire may be fixed to a hook, eye bolt or bracket embedded with cement mortar in the wall.

The weather proof/PVC insulated cable shall pass through a GI pipe of minimum diameter 5 cm, which is bent downwards. Wall fittings wooden/PVC bushes shall be provided at both ends of the GI pipe.

Method of laying the service cable from the pole to the consumer main: In practice either a glass or porcelain ring insulator or wooden fibre cleats are used to lay the overhead service line from the pole to the consumer mains as in Fig 1.

Fig 1



LAYING OF SERVICE LINES

Safety Precautions to follow while connecting pole to consumer premises

1 The cable conductor size must be as per the IE rule standard either single phase or three phase.

2 If the service line crosses public road the clearance must be as per IE rule.

3 The conductor slag should not exceed as per the IE rules.

4 If UG cables are providing the depth of cable in ground should be as per IE rules.

5 Do not keep much more cable unused and buried in soil in the coil form in case of UG cable laying.

6 The excess cable should not be kept by making coil and kept on the pole cross arm. Use only required cable for connection.

7 If the cable passing through excess heat producing areas in near to chimney, kitchen etc; adequate protection from heat to be provided.

8 Service cable run along with stay wire tightly tied with stay wire to avoid tension on service cable.

9 No rain water flows along with service cable and reach to consumer main panel. Necessary looping of cable to be provided either side.

10 The connection to main line is to be made so tight and clean surface, so that loose contact, sparking and formation of oxide coating can be avoided.

I.E. Rules pertaining to domestic service connection

Rule 10. Construction, installation, protection, operation and maintenance of electric supply lines and apparatus

All electric supply lines and apparatus shall be sufficient in power and size and of sufficient mechanical strength for the work they may be required to do, and so far as practicable, shall be constructed, installed, protected, worked and maintained in accordance with standards of the Indian Standards Institution so as to prevent danger.

Rule 30. Service lines and apparatus on consumer's premises.

1 The supplier shall ensure that all electric supply lines, wires, fittings and apparatus belonging to him or under his control which are on a consumer's premises are in a safe condition and in all respects fit for supplying energy, and the supplier shall take due precautions to avoid danger arising in the premises from such supply lines, wires, fittings and apparatus.

2 The consumer shall also ensure that the installation under his control is maintained in a safe condition.

Rule 31. Cut-out on consumer's premises.

The supplier shall provide a suitable cut-out in each conductor of every line other than an earthed or earthed neutral conductor, or the earthed external conductor of concentric cables within a consumer's premises, in an accessible position. Such cut-out shall be contained within adequately enclosed fire-proof receptacle.

Where more than one consumer is supplied through a common service line, each such consumer shall be provided with an independent cut-out at the point of junction to the common service.

Rule 33. Earthed terminal on consumer's premises.

The supplier shall provide and maintain on the consumer's premises, for the consumer's use, a suitable earthed terminal in an accessible position at or near the point of commencement of supply as defined under Rule 58.

Provided that in the case of medium, high or extra high voltage installation the consumer shall, in addition to the afore-mentioned arrangement provide his own earthing system with an independent electrode.

Rule 48. Precautions against leakage before connecting.

1 The supplier shall not connect with his works the installation or apparatus on the premises of any applicant for supply unless he is reasonably satisfied that the connection will not at the time cause a leakage from the installation or the apparatus exceeding five thousandth part of the maximum current supplied to the premises.

2 If the supplier declines to make connection under the provisions of sub-rule(1) he shall serve upon the applicant a notice in writing stating his reason for so declining.

Rule 54. Declared voltage of supply to consumer.

Except with the written consent of the consumer or the previous sanction of the State Government, a supplier shall not permit the voltage at the point of commencement of supply as defined under Rule 58, to vary from the declared voltage by more than 5 percent in the case of low or medium voltage or by more than 12½ percent in the case of high or extra high voltage.

Rule 77. Clearances above ground of the lowest conductor.

1 No conductor of an overhead line, including service lines erected across a street shall at any part thereof be at a height less than :-

   a for low and medium voltage lines 5.791 m

   b for high voltage lines 6.096 m.

2 No conductor of an overhead line including service lines erected along any street shall at any part thereof be at a height less than:

   a for low and medium voltage lines 5.486 m

   b for high voltage lines 5.791 m.

3 No conductor of an overhead line including service lines, erected elsewhere than along or across any street shall be at a height less than:

   a for low, medium and high voltage lines upto and including 11,000 V if bare 4.572 m

   b for low, medium and high voltage lines upto and including 11,000 V if insulated 3.963 m.

Rule 79. Clearances from building of low and medium voltage lines and service lines

1 Where a low or medium voltage overhead line passes above or adjacent to or terminates on any building, the following minimum clearances from any accessible point, on the basis of maximum sag, shall be observed.

a for any flat roof, open balcony, verandah, roof and lean-to-roof.

i when the line passes above the building, a vertical clearance of 2.439 m from the highest point.

ii when the line passes adjacent to the building, a horizontal clearance of 1.219 m from the nearest point.

b For pitched roof

i when the line passes above the building, a vertical clearance of 1.219 m immediately under these lines.

ii when the line passes adjacent to the building, a horizontal clearance of 1.219 m.

2 Any conductor so situated as to have a clearance less than that specified in sub-rule (i) shall be adequately insulated and shall be attached by means of metal clips at suitable intervals to a bare earthed bearer wire having a breaking strength of not less than 517.51 kg.

3 The horizontal clearance shall be measured when the line is at maximum deflection from the vertical due to wind pressure.

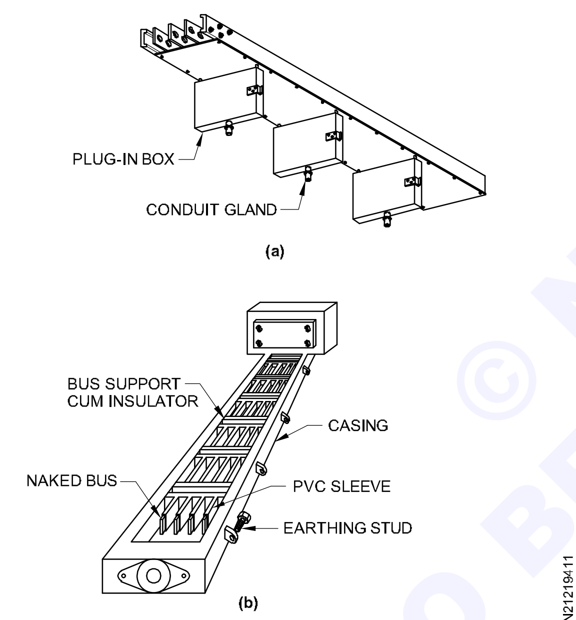
Tapping service connections: No service connection line should be tapped from an OH line from any point mid span, except at the point of support. When a service connection is taken overhead with a bare conductor, it should be provided with guard wires.

Bus-bar system - power tariff terms and definitions

Objectives: At the end of this lesson you shall be able to
- **explain the bus-bar system and the method of installation**
- **state the advantages of the bus-bar system**
- **determine the rating of the bus-bar**
- **state the use of plug-in boxes and their construction**
- **state the method of cable or conduit termination in plug-in boxes**
- **state various terms like max demand etc.**

In industrial workshops and factories, a number of machines are installed in the shop floor closely but apart from each other. connecting these machines to electrical supply through underground cables or overhead wires or cables may involve cumbersome methods resulting in shock hazards. For such places, an overhead enclosed bus-bar system as in Fig 1a and 1b is recommended.

Fig 1



OVERHEAD BUSBAR SYSTEM

This bus-bar system is sometimes referred to as bus way or bus duct.

Bus-bar assembly should be installed at a height of 2.75metre from ground, suspended by M.S. angles or flats from ceiling/roof or supported by framed structure from ground as in Fig 2.

Bus coupler

The bus-bars are either of high conductivity, high purity copper or alloy aluminium having rectangular sections mounted on insulating supports enclosed in standard length of metal trunking. The bus-bar sections are available in standard lengths (3.65metre for 200 ampere and 2.44metre for 400 ampere) which can be connected to another bus-bar by blowing the respective bus-bar ends thus forming a continuous bus-bar along the entire length of the workshop. Method of coupling two bus-bars is in Fig 3.

Fig 2

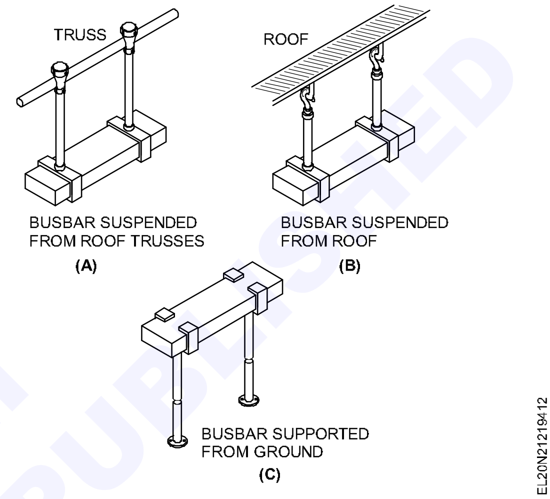
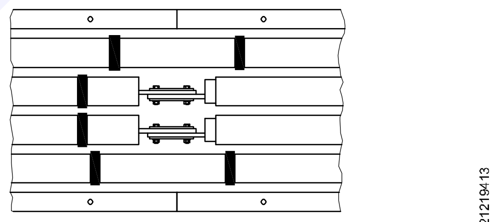


Fig 3



TWO SECTIONS OF 400 AMPS BUSBARS COUPLED TOGETHER

The standard rating of bus-bar are 100, 200, 400, 600, 800, 1200, 1600, 2000, 2400 and 3600 ampere with rated voltage of 500V. These bus-bars also available for indoor or outdoor use as point to point feeders or as plug-in take off points for power. These bus-bars are used in generating stations, sub stations, in metal industry and textile industry. These bus-bars are also used in multi storied flats to facilitate connection to various stories from the mains by using vertically mounted bus-bars as in Fig 4. These vertical bus-bars are provided with a fine barrier made up of high grade fire-resisting material positioned at the top of each fixed section of the trucking passing through the floors. This barrier is the collecting points for dirt, dust and moisture which could be removed at intervals.

Recommended current density for a copper bus-bar which is not enclosed should not exceed 165A/sqcm and for aluminium 118A/sqcm.

Recommended section of aluminium and copper bus-bars and their respective ratings are in Table.

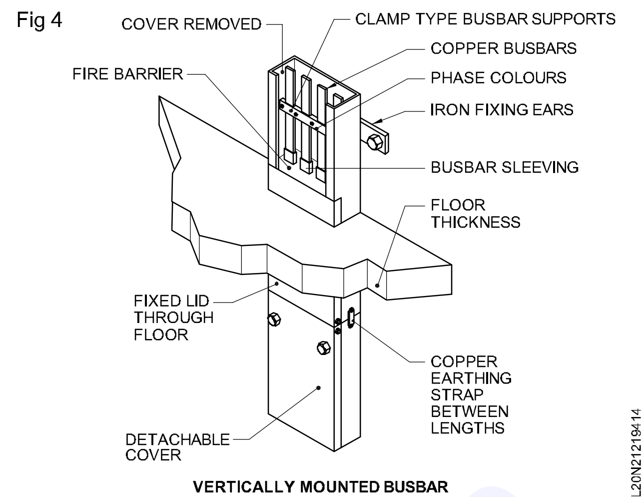
Earthing continuity is provided by two strips of aluminium or copper running throughout the bus-bar assembly. When extending the bus-bar lengths, these earthing strips also to be connected to have earth continuity.

Note:

1 **Above rating is for rectangular cross-section of E-91 E-WP grade as per IS : 5082-1969 in still unconfined air without enclosure, presuming longer section vertical.**

2 **Denting factor of 0.88 may be applied for ambient of 30°C and temperature rise of 35°C. Similarly in outdoor application denting may be done for 0.85 to 0.9. Indoor well ventilated 0.6 to 0.8 and partly ventilated areas 0.5 to 0.6.**

Fig 4



VERTICALLY MOUNTED BUSBAR

Bus-bar size in mm		**Rating at 50Hz AC current at average ambient of 35°C and 40°C maximum and temperature rise of 50°C.**				
		Aluminium				**Copper**
Sl.No	**size in mm**	**Single bar**	**Two bars**	**Three bars**	**Four bars**	**Single bar**
1	50 x 6	675	1300	1700	1925	760
2	75 x 6	950	1750	2300	2600	1080
3	100 x 6	1225	2150	2800	3200	1380
4	125 x 6	1500	2500	3200	3700	1680
5	25 x 10	—	—	—	—	540
6	50 x 10	85	1500	1950	2250	960
7	75 x 10	1180	2050	2650	3000	1350
8	100 x 10	1500	2475	3150	3550	1710
9	125 x 10	1850	2925	3600	4200	2070
10	150 x 10	2100	3325	4000	4606	2430

Advantages of Bus-bar system

Following are the advantages of bus-bar system

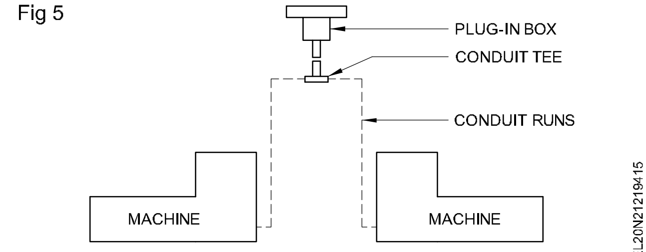
1 **Reduced cost:** Simple rapid installation with complete elimination of expensive floor chasing (cutting) reduces cost at the initial period of installation and needs no expenditure for maintaining the bus-bar system while in regular use.

2 **Maximum flexibility:** As plug-in-points are provided at intervals of 60.96cm (2 feet) along every length of bus-bar the connections can be taken for machines installed on either side. Refer Fig 5.

3 **Complete safety:** As the plug-in-point are completely insulated, safety is ensured for operating and maintenance personnel.

4 **'Live' connection:** As the plug-in-boxes could be connected to 'live' bus-bars quickly and safely without shut down and the time is saved without disturbing the normal work of the factory.

Fig 5



5 **Guaranteed protection:** As the fuse in the plug-in boxes of HRC type the circuit is protected positively and reliably against short circuit.

6 **Easily extended for layout modification in the factory:** As the bus-bars can be extended in straight lengths or at an angle to suit the layout with the help of standard accessories, the bus-bars can be remounted or rearranged within a short time.

7 **Saving of time while initial erection:** The advantages of this system are that the trucking and bus-bars can

be erected before the installation of the machinery, and the latter can be connected up and set to work as soon as they are installed.

8 **Reduction of voltage drop in feeders:** By bringing the heavy main feeders near to the actual loads, the circuit wiring is reduced to a minimum and voltage drop is lower than would otherwise be the case.

9 **Addition and alterations:** Subsequent additions and alterations to plant layout can be easily accomplished, and where bus-bar sections have to be removed they can be used again in other positions.

10 **Internal grid for welders:** The overhead bus-bar system is especially advantageous where a large number of electric welders have to be fed with heavy currents from a step down transformer.

11 **Branching from plug-in-boxes for small loads:** If a large number of small machines are to be fed it is usual to fix a distribution box near the trucking system and to protect this with a tap-off fitted with HRC fuses of suitable capacity.

12 **Durable and trouble free service:** Normally bus-bars give much durable service than U.G. Cables and give many years of trouble free service.

Method of determining the ratings of the bus-bars

In a small factory, ten motors having each of 5 HP ratings to be installed. The total load is approximately 10 x 5 i.e. 50 HP Assuming 5 HP motor takes approximately full load current at 7.5A. The total current in the factory load will be 75A and has to be supplied through a single bus-bar. Normally the ratings of bus-bar is 200A or 400A. Hence a 200A rating bus-bar is selected for this case as the same bus-bar also could be used when there is expansion of load in the factory in future. Considering the overload, bus-bars are manufactured in standard sections of 3.65m (200A) and 2.44m (400A). We can decide the number of bus-bars to meet the entire length of machine layout.

Technical Data

Rating	Overall dimensions in mm	No.of plug
200A	3658 x 248 x 76	6
400A	2440 x 248 x 108	4

Bus-bar length can be increased by providing mechanical coupling and any length at run in multiples of the standard length may be thus achieved.

Plug-in-Boxes : Plug-in-boxes (Fig 6) are compact sheet steel boxes with hinged doors housing the HRC fuse holders, which are solidly connected to high conductivity copper clip on contacts reinforced by spring steel strips. These clip on contacts plug directly to the bus-bars at the plug-in-points. Two earth pins are located at the two ends of these boxes which also serves to mount the plug-in-boxes on bus-bars.

Fig 6

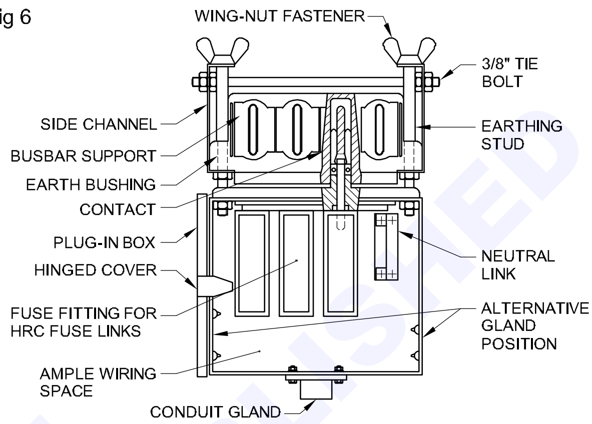


DIAGRAM SHOWING MAIN FEATURES OF PLUG-IN BOXES FITTED TO BUSBARS

Rating of plug in boxes : Plug in Boxes must be able to withstand faults current capability of bus-bars. There are rated in 16, 32, 63 and 100Amp at 415/500V (TPN).

Cables (or) conductors with termination connection to plug-in-boxes for outgoing supply by using conduit pipe to conduit glands supplied with plug in boxes either vertically down or on to either side.

However remember to use oxide inhibiting grease at all aluminium joint to maintain conductivity.

Power tariff - terms and definitions

Objectives: At the end of this lesson you shall be able to
- **state the term maximum demand**
- **explain the concept of average demand**
- **explain load factor**
- **state the term of diversity factor and its application**
- **explain the importance of plant utility factor.**

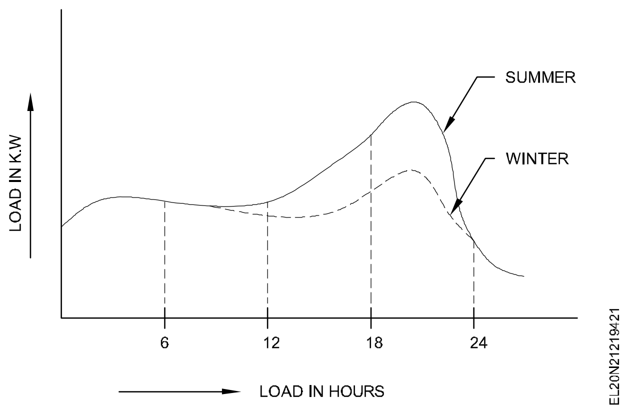
Introduction : The alternators in the power station should run at their rated capacity for maximum efficiency and on the other hand, the demands of the consumers have wide variations from time to time due to uncertain demands of the consumers. This makes the design of a power station highly complex. We shall focus our attention on the problems of variable load on power stations.

Maximum Demand : It is the highest level or greatest electrical demand monitored in a particular period or a month.

The maximum demand is in between 18 hours and 24 hours in the night during summer as well as in winter seasons as in Fig 1. All other times the maximum demand falls very low to the connected load. However the maximum load demand less than the connected load because all the consumers do not switch 'ON' their connected load of the system at a time.

The importance of the maximum demand knowledge is very important as it helps in determining the installed capacity of the stations, and the station must be capable of meeting the maximum demand.

Fig 1



The ratio of maximum demand as the power station to its connected load is known as demand factor; Mathematically

$$\text{Demand factor} = \frac{\text{Max. Demand}}{\text{Connected load}}$$

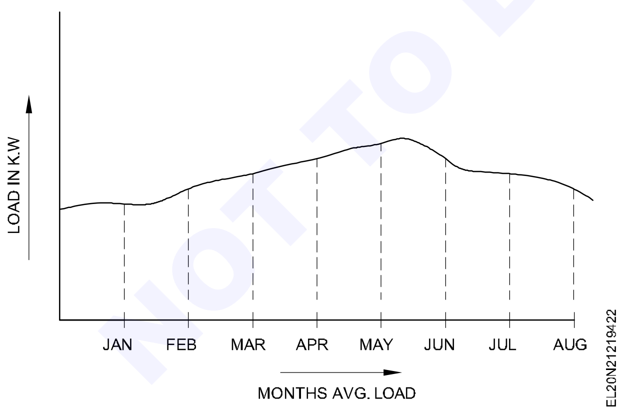
Usually it always less than one. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Average demand

It is the total demand in a month divided by number of days in that time period.

The average demand in a month taken to find the load requirement for a certain period is in Fig 2. It is evident that average load requirement is not uniform among all the months consumption as it depend on the environmental conditions; such as Winter, Summer, Monsoon seasons.

Fig 2



Load factor

In electrical engineering the load factor is defined as the total load divided by the peak load in specified time period. It is a measure of the utilization rate, or efficiency of electrical energy usage; a low load factor indicates that load is not putting a strain on the electric system, whereas consumers or generators that put more of a strain on the electric distribution will have a high load factor.

$$f_{Load} = \frac{\text{Total load}}{\text{Maximum load in given time period}} \text{ or } \frac{\text{Total load}}{\text{Peak load.}}$$

An example, using a large commercial electrical bill:

- peak demand = 436 KW
- use = 57 200 kWh
- number of days in billing cycle = 30

Hence:

- load factor = { 57 200 kWh/ (30 d x 24 hours per day x 436 kW) } x 100% = 18.22%

Diversity factor

Diversity factor (Or simultaneity factor K_S) is a measure of the probability that a particular piece of equipment will turn on coincidentally to another piece of equipment. For aggregate system it is defined as the ratio of the sum of the individual non - coincident maximum loads of various sub divisions of the system to the maximum demand of the complete system.

$$\text{Diversity factor} = \frac{\text{Sum of individual max Demands}}{\text{Maximum Demand}}$$

The diversity factor is almost always larger than 1 since all components would have be on simultaneously at full load for it to be one.

Plant utility factor

The utility factor or use factor is the ratio of the time that a piece of equipment is in use to total time that it could be in use. If is often averaged over time in the definition such that the ratio becomes the amount of energy used divided by the maximum possible to be used. These definitions are equivalent.

The utility factor, K_u, is the ratio of the maximum load which could be drawn to rated capacity of the system. This is closely related to the concept of load factor. The factor is the ratio of the load that piece of equipment actually draws (time averaged) when it is in operation to the load it could draw (which we call full load.

$$\text{Utility Factor} = \frac{\text{Ratio of maximum power}}{\text{Plant capacity}} \times 100$$

For example, an oversized motor - 15 kW - drives a constant 12 kW load whenever it is on. The motor load factor is then 12/15 = 80%. The motor above may only be used for eight hours a day, 50 weeks a year, The hours of operation would then be 2800 hours, and the motor use factor for a base of 8760 hours per year would be 2800/ 8760 = 31.96%. With a base of 2800 hours per year, the motor use factor would be 100%.

In power plant utility factor various according to the demand on the plant from the electricity market.

Types of relays and its operation

Objectives: At the end of this lesson you shall be able to
- **state the classification of relays**
- **list the types of relays and their uses**
- **explain the principle of operation of over current, differential, earth fault, distance and non directional relays**
- **state the characteristics of relays**
- **explain the principle of operation of a over voltage under voltage relay**
- **state the necessity of time multiplier setting of relay.**

Introduction

The relays is the element that senses as abnormal condition in the circuit and commands the operation of the breaker. It interpret the fault quantities ie, CT output current and PT output voltage and sending the command to the tripping circuits of breaker for operation in accordance with the characteristic set in the relay and the value of the time multiplier setting.

Classification of Relays

Relays are classified mainly in three categories; they are according to:

1 **Quantity sensed :** Current, Voltage, active power, reactive power & impedance

2 **Tripping :** Instantaneous trip, delayed trip inverse time response and definite time

3 **Operating principle:** Electro magnetic relays, Induction relays, Thermal relays and static or digital relays

Types or relays : Various types of relays are used as per the requirement; they are:

1 Over current relay

2 Over voltage relay

3 Under voltage relay

4 Differential relay

5 Earth fault relay

6 Distance relay

7 Impedance relay

8 Admittance relay

9 Reactance relay

Relay is one of the main device used for switch gear protection networks to protect the transmission lines, transmission equipments and sub station equipments. The equipments used for transmission and in substation for distribution such as transformers, lightening arrestors,earth switches, isolators, CTs & PTs etc; are very costly and needs continuous protection from damage. Replacement or repairs are not easy and to provide an uninterrupted supply to consumers. So, protection of these devices/equipments are very essential

Reasons for over current, Over voltage and under voltage fault:

Many reasons constituted for over current, over and under voltage or earth faults; type of fault and the cause effect is listed in Table 1.

Table 1

Sl No	Type of Fault	Cause	Effect
1	Phase to neutral short	- Insulation failure - Components failure - Human error	- High current flow in line. - Fire
2	Phase to phase short in transmission lines	- Tree branches falls on line - Snakes crossing on tower lines and - Birds falls - Strong winds - Natural calamities - Riots, and human made faults	- Very high current flows - Fire - Extensive damage of equipments
3	Phase to ground fault	- Insulation failure - Component failure	- High current flow in line - Fire - Low voltage

Sl No	Type of Fault	Cause	Effect
4	Lightening storm etc;	- Natural calamities	- Very high current flows - Fire - High voltage spikes
5	Sudden removal of heavy load	- Fuse failure	- High voltage
6	Increasing Load beyond the rated level	- Human Error	- Low voltage in line - Over loading the line

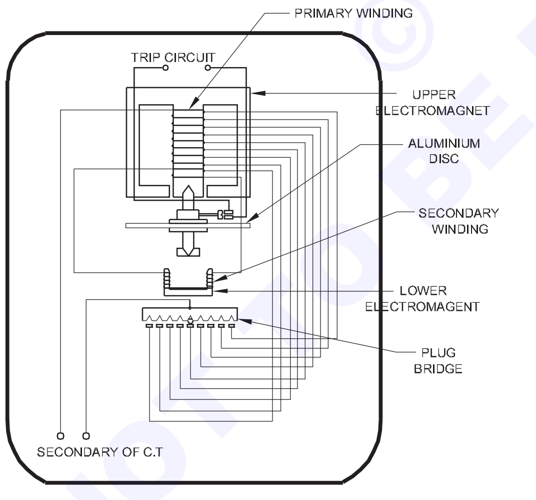
Sensors used for Relays

The relay cannot accept the total line voltage or load current. A small part of the electrical quantity is supplied to the relay through sensors. A current transformer popularly known as CT and a potential transformer PT, is serves the purpose of sensors in current relay and voltage relay. Various input and output ratios are in practice to supply the sensing quantity to the relays according to the load conditions.

Working principle of current relay

The electro magnetic relay widely using in the substation and transmission lines are serves the protection from the disaster conditions. The latest version of modern static or digital relays are now a days out dated the conventional electro magnetic relays, because of their many of advancements compare to electro magnetic relay. (Fig 1)

Fig 1



INDUCTION TYPE NON-DIRECTIONAL OVERCURRENT RELAY

Fig 2 shows the front panel setting of a electric magnetic relay.

1 Time multiplier setting (TMS)

2 Trip flag

3 Aluminium rotating disc

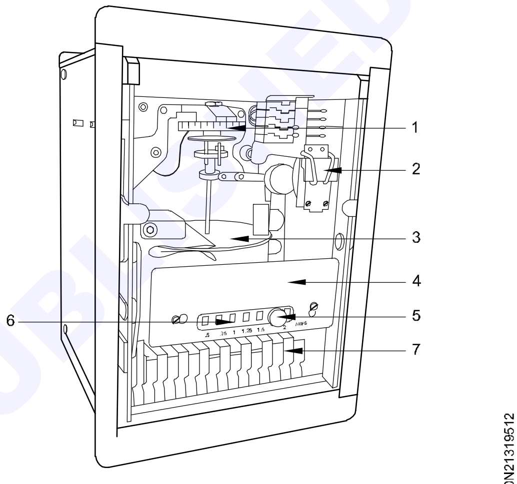
4 Percentage fault quantity time reference dial

5 Tap setting plug

6 Input fault quantity (V_{ONI})

7 Contact plug terminals

Fig 2



ELECTRO - MECHANICAL RELAY

An induction type over current relay giving inverse time operation with a definite minimum time characteristic is in Fig 1. It consists essentially of an ac energy meter mechanism with slight modification to give required characteristics. The relay has two electromagnets. The upper electromagnet has two windings, one of these is primary and is connected to the secondary of a CT in the line to be protected and is tapped at intervals.

The tappings are connected to a plug setting bridge by which the number of turns in use can be adjusted, thereby giving the desired current setting. The plug bridge is usually arranged to give seven sections of tappings to give over current range from 50% to 200% in steps of 25%. If the relay is required to response for earth fault the steps are arranged to give a range from 10% to 70% or 20 to 80% in steps of 10%. The values assigned to each tap are expressed in terms of percentage of full-load rating of CT with which the relay is associated and represents the value above which the disc commences to rotate and finally closes the trip circuit.

Thus pick-up current equals the rated secondary current of CT multiplied by current setting. For example suppose that an over current relay having a current setting of 150% is connected to a supply circuit through a CT of 500/5A. The rated secondary current of CT is 5 A and, therefore, the pick-up value will be 1.5 x 5i.e., 7.5 A. It means that with above current setting, the relay will actually operate for a relay current equal to or greater than 7.5 A.

Similarly for current settings of 50, 100 and 200% the relay will operate for relay currents of 2.5A, 5 A and 10 A respectively. Adjustment of current setting is made by inserting a pin between the spring loaded jaws of the bridge socket at the tap value required. When the pin is withdrawn for the purpose of changing the setting value while the relay in service, the relay automatically adopts higher setting, thus the CT's secondary is not open-circuited.

Time multiplier setting

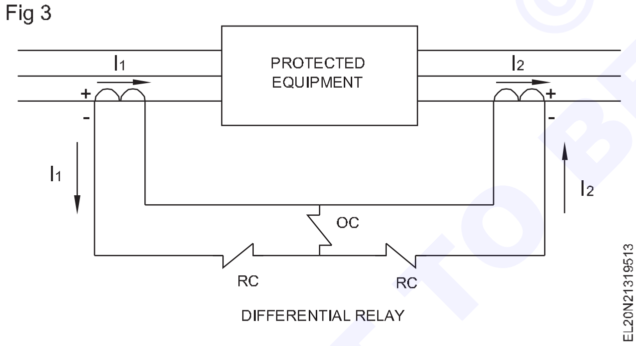
This setting is helps the relay to shorten the time selected without change of any other settings made in the relay. Time multiplier helps the relay to activate fast the breaker in case the fault quantity is more than 50% of the fault quantity selected by the tap setting.

Differential protection relay

Differential protection is a very reliable method of protecting generators, transformers, busbar and transmission lines from the effects of internal faults. In normal operating conditions the current through the CTs is the same. So the relay sense no differential current. This is also the case for external faults. Differential protection can be used for protecting generators from faults to ground. Differential protection of busbars in substations uses one CT for each incoming line. All incoming currents are added up and compared to the sum of all out going currents.

General schematic diagram of differential protection relay is in Fig 3.

Fig 3



The installation of differential relay for protection of power transformers used in transmission line is in Fig 4.

Distance relays / Admittance relay

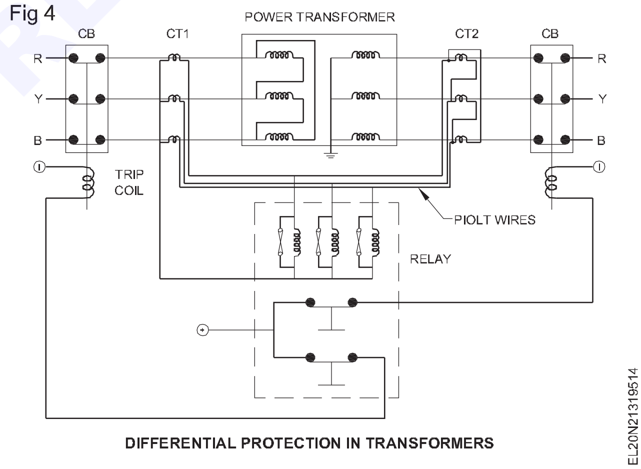
The impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point) Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections

Reactance relays (or) Shaded pole type non directional relay

The reactance relay is a straight line characteristic that responds only to the reactance (X_L) of the protected line . It is non directional and is used to supplement the admittance relay as a tripping relay to make the overall protection independent of resistance. It is particularly useful on short lines where the fault arc resistance is the same order of magnitude as the line length.

The relay serves an important part in switchgear protection. The electromagnetic relay is the first generation of protective relays and it has many moving parts and working in the principles of induction. Electromagnetic relay can carry one function ie., over current, over voltage or under voltage at a time. This draw back is overcome by the use of static or digital relay which can use for multi function, as well as more accurate than electromagnetic relays.

Fig 4



Circuit breakers - parts - functions- tripping mechanism

Objectives: At the end of this lesson you shall be able to
- **state about circuit breaker**
- **list the various types of circuit breakers**
- **explain the parts of each circuit breakers**
- **explain the principle of operation of circuit breaker**
- **explain the application and uses of circuit breaker.**

Circuit breaker

Circuit breakers are the electrical device (or) equipment, which makes or breaks the electrical circuit. In a 240 volt single phase system a low rated single pole switch can use the circuit to break or make. But in this case the resultant spark at the contacts are negligible and this will not make any fire, in the circuit or contacts since the current is very low.

But in the case of heavy loads; say some hundreds, of ampere are flowing in a circuit the resultant spark at contact are heavy and this leads to electrical fire. To overcome this problem the sparks at the contacts are to be controlled or quenched, when any load makes or breaks. The equipment or device used to make or break a circuit under control at the same time it prevents or quenching the resultant fire is called as a circuit breaker. The breakers are named after the quenching medium used to control the fire such (1) air circuit breaker, (2) oil circuit breaker, (3) vaccum circuit breaker and (4) Sulphur hexafluoride (SF_6) circuit breaker.

Air circuit breaker (ACB) : A circuit breaker which uses the either natural air or blast air as an Arc quenching medium is termed as Air-circuit breakers.

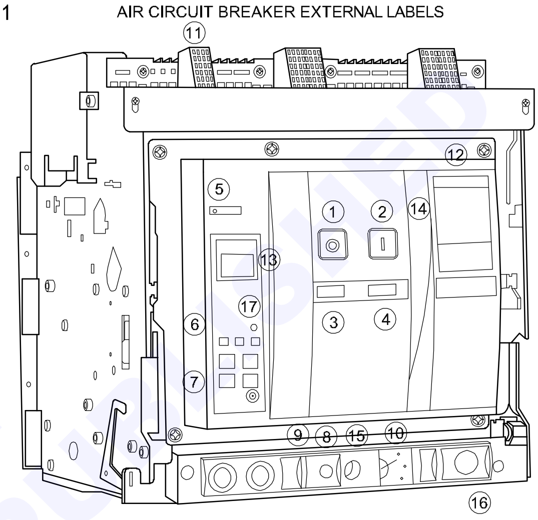
ACB is widely used upto 15KV in place of oil circuit breaker because there is no chance of the fire due to the quenching oil as in case of OCB.

Air- Circuit breakers are widely used in industries as well as power system for controlling and protection of different section of the circuit like, Transformers, Motors, Generators / Alternator etc and leads the system stable and reliable. Other components are also associated with circuit breakers like fuses, relays, switches etc.

Construction of air - circuit breaker

External lables / parts of ACB in Fig.1

Fig 1 AIR CIRCUIT BREAKER EXTERNAL LABELS



EXTERNAL VIEW OF ACB

1 OFF button (O)

2 ON button (I)

3 Main contact position indicator

4 Energy storage mechanism status indicator

5 Reset button

6 LED indicators

7 Controller

8 "Connection" "Test" and "isolated" position latching / locking mechanism

9 User padlock

10 Connection, "Test", and isolated position indication

11 Connection test and isolated position indication contacts

12 Name plate

13 Digital displays

14 Energy storage handle

15 Draw out /in hole

16 Rocker repository

17 Trip reset button

Internal construction of air circuit breaker

The internal parts of an ACB in Fig.2

1 Sheet steel supporting structure

2 Current transformer for protection trip unit

3 Pole group insulating box

4 Horizontal rare terminals

5 Plate for fixed main contacts

6 Plates for fixed arcing contacts

7 Plate for main moving contacts

8 Plates for moving arcing contacts

9 Arcing chamber

10 Terminal box for fixed version - sliding contacts for withdrawable version

11 Protection trip unit

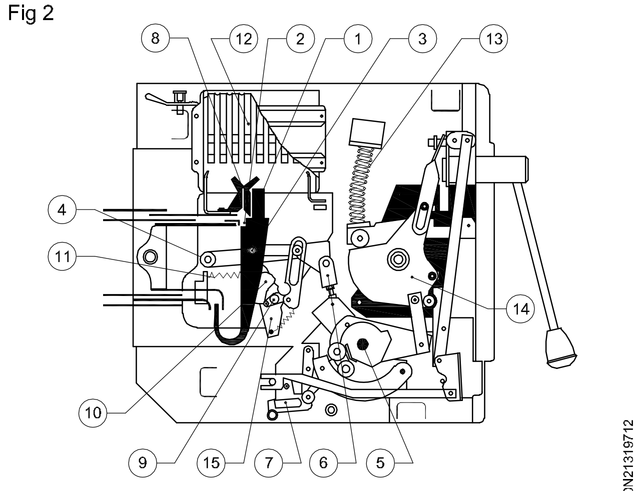
12 Circuit breaker closing and opening control

13 Closing springs

14 Spring loading arrangement

15 Manual releasing lever

Fig 2



INTERNAL VIEW OF CIRCUIT BREAKER

Principle of operation of air circuit breaker

- When the circuit breaker opens the circuit either under the normal condition or in the fault condition, some Arc is produced between the main contacts and some current flows to the load, called **transition current** through the arc.
- This Arc and the current should be suppressed / eliminated especially during the fault condition otherwise the severity of the fault level will be more and damages the circuit which leads to the electric fire.
- During the period of Arc some voltage appears across the main contacts called **transition voltage**, which will be more than the rated system / supply voltage.
- To quench the Arc, this transition voltage should be reduced or the Arc voltage to be increased. The minimum voltage required to maintain the arc is called as **Arc voltage**. In ACB, the Arc voltage is increased in the following three ways.
- Arc voltage can be increased by cooling arc plasma by air. The temperature of arc plasma is reduced, more voltage will be required to maintain the arc.
- By splitting the arc into a number of series in Arc chute will increases the arc voltage.
- Arc voltage can be increased by lengthening the arc path. As length of arc path is increased its resistance of the arc path will increase hence the arc voltage is increased.

Some ACB contains two pairs of contact . The main pair carries the current and the made of copper. An additional pair of contact (Arc contact) is made of carbon. When the breaker is opened, the main contact opens first. and the arc contact remains in touch. The arcing gets initiated when arc contacts are separated.

Hence transition voltage will be reduced.

Application and uses of air circuit breaker

- It is used for protection of plants
- It is used for common protection of electrical machines
- Air circuit breaker is also used in electricity sharing system upto 15KV
- Also used in low as well as high voltage and current applications.
- It is used for protection of transformers, capacitors and generators.

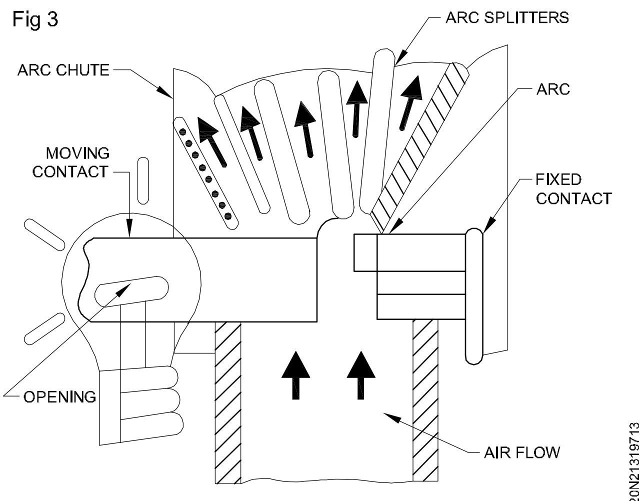
Types of air circuit breaker

- Plain air circuit breaker
- Air blast circuit breaker

Plain air circuit breaker : In this circuit breaker a chamber is fitted surrounding the contact. The chamber is known as **"arc chute"**. The arc chute will help in achieving cooling. Arc chute is made from some refractory material.

The arc chute is divided into a number of small compartments by using metallic separation plates called **arc splitters** and behave as a mini arc chute as in Fig 3. Initial arc will split into a series of arcs and make the arc voltages higher than system voltage. They are preferable choice in low voltage application.

Fig 3



AIR BLAST CIRCUIT BREAKER

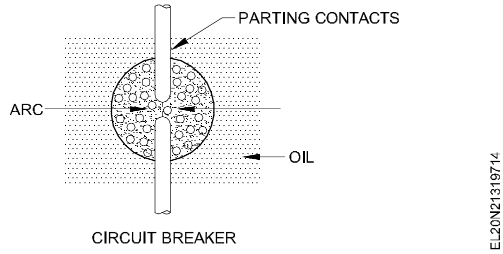
Oil circuit breakers (OCB)

Circuit breakers which uses the insulating oil (e.g transformer oil) as an arc quenching medium is called as oil circuit breaker. The main contacts of the OCB are opened under the oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into gaseous of hydrogen at high pressure.

The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region of the contacts. The arc extinction is completed by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts.

Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arc as in Fig 4. The result is that arc is extinguished and circuit current is interrupted.

Fig 4



The advantages of oil as an arc quenching medium

i It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

ii It acts as an insulator and permits smaller clearance between main contacts.

iii The surrounding oil presents the cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium.

i It is inflammable and there is a risk of a fire.

ii It may form an explosive mixture with air.

iii The arcing products (e.g. carbon) remain in the oil and it deteriorates the quality of insulating oil.

iv Periodic checking and replacement of the insulating oil is required.

Types of oil circuit breakers

a Plain break oil circuit breakers

b Arc control oil circuit breakers.

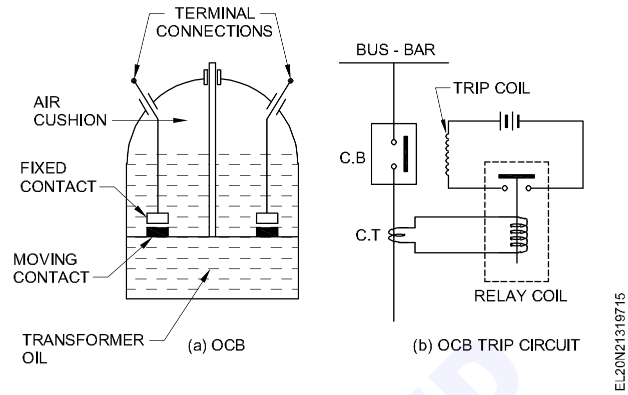
ii Low oil circuit breakers

Plain break oil circuit breakers : In plain- break oil circuit breaker the main contacts are placed under the whole oil in the tank. There is no special system for arc control other than the increase in length of separation of the contacts. The arc extinction occurs when a critical gas is reached between the contacts.

The plain - break oil circuit breaker is the oldest type and has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather- tight earthed tank containing transformer oil upto a certain level and an air cushion above the oil level.

The air cushion provides sufficient room to arc gases without the generation of unsafe pressure in the circuit breaker. It also absorbs the upward oil movement. Fig 5 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Fig 5



Principle of working

Under normal operating conditions, the fixed and moving contacts remain closed and carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the tripping mechanism and an arc is produced which vaporizes the oil into hydrogen gas. The arc extinction is completed by the following processes.

i The hydrogen gas bubble generated around the arc, cools the arc.

ii The gas sets up turbulence in the oil and helps in eliminating the arc.

iii As the arc lengthens due to the separation of contacts, the Arc voltage is increased.

The result is at some critical gap, the arc is extinguished and the circuit current is interrupted.

Disadvantages

i There is no special control over the arc other than the increase in gap length.

ii These breakers have long and inconsistent arcing times.

iii The speed of interruption is less.

Due to these disadvantages, plain - break oil circuit breakers are used only for low - voltage not exceeding 11 KV applications where high breaking- capacities are not important.

Vacuum circuit breaker (VCB)

Circuit breaker which uses vacuum as an arc quenching medium is called as vacuum circuit breaker.

Vacuum offers the highest insulating strength and have the superior arc quenching properties than any other medium. When the contacts of a breaker are opened in vacuum, the interruption occurs instantly as the dielectric strength between the contacts are many times higher than the other circuit breakers.

The technology is only suitable for medium voltage application. For higher voltage application, the vacuum technology has been developed.

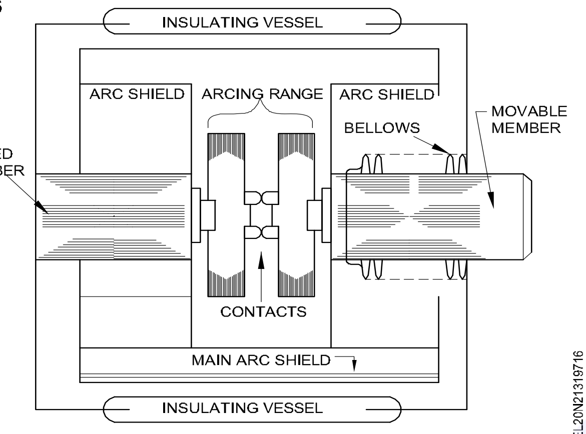
Principle of vacuum circuit breaker

- When the contacts of the breaker are opened in vacuum (10^7 to 10^5 torr), an arc is produced between the contacts by the ionisation of metal vapours i.e, combination of electrons and ions of contacts. However, the arc is quickly extinguished because the metallic vapours, rapidly cools resulting quick recovery of dielectric strength.
- The salient feature of vacuum is, as soon as the arc is produced in vacuum, it is quickly extinguished due to the rapid recovery of dielectric strength of vacuum.

Construction of vacuum circuit breaker

Fig 6 shows the typical parts of vacuum circuit breaker

Fig 6



- It consists of the fixed contact, moving contact and arc shield mounted inside a vacuum chamber.
- The movable member is sealed by a stainless steel bellows, is connected to the control mechanism . This enables the permanent sealing of the vacuum chamber, to eliminate the possibility of leak.
- A glass vessel or ceramic vessel is used as the outer insulating body.
- The arc shield prevents the metallic vapours falling on the inside surface of the outer insulating cover.

Working of vacuum circuit breaker

- When the breaker opens, the moving contact is separated from the fixed contact and an arc is produced between the contacts. The production of arc is due to the ionisation of metal ions and depends upon the material of contacts.
- The arc is quickly extinguished because the metallic vapours , are diffused in a short time and condensed on the surfaces of moving and fixed members and arc shields.
- Since vacuum has rapid Arc recovery rate of dielectric strength, the arc extinction in a vacuum breaker occurs with a short separation (say 0.625 cm) of contacts.

Application of VCB

- Vacuum circuit breakers are employed for outdoor applications ranging from 22KV to 66KV.
- They are suitable for majority of applications in rural areas.

Sulphur hexafluoride (SF_6) circuit breaker

Circuit breakers which uses the sulphur hexafluoride gas (SF_6) as an arc quenching medium is called as SF_6 circuit breaker.

The sulphur hexafluoride gas (SF_6) is an electronegative gas and has a strong tendency to absorb the free electrons. When the contacts of the breaker are opened in a high pressure sulphur hexafluoride (SF_6) gas medium and an arc is struck between them.

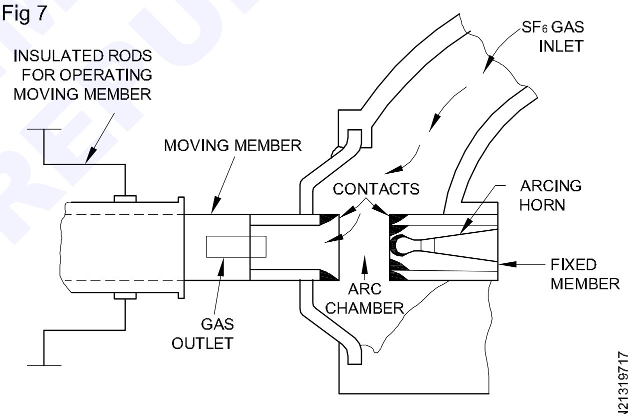
The SF_6 gas capture the conducting free electrons in the arc and form immovable negative ions. This loss of conducting electrons in the arc quickly improve the insulation strength to extinguish the arc.

The sulphur hexafluoride (SF_6) circuit breakers are very effective for high power and high voltage applications.

Construction of SF6 circuit breaker

A sulphur hexafluoride (SF_6) circuit breaker consists of fixed and moving contacts enclosed in a chamber as in Fig 7. The chamber is called arc interruption chamber which contains the sulphur hexafluoride (SF_6) gas and it is connected to sulphur hexafluoride (SF_6) gas reservoir.

Fig 7



TYPICAL INTERNAL VIEW OF SF_6 - CB

When the contacts of breaker are opened, the valve mechanism permits a high pressure sulphur hexafluoride (SF_6) gas from the reservoir to flow towards the arc interruption chamber.

The fixed contact is a hollow cylindrical contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides. The holes permit the sulphur hexafluoride gas (SF_6) to let out through them after flowing along and across the arc.

The tips of fixed contact, moving contact and arcing horn are coated with copper - tungsten arc resistant material. Since sulphur hexafluoride gas is costly, it is reconditioned and reclaimed using suitable auxiliary system after each operation of breaker.

Working of SF_6 circuit breaker

In the closed position of the breaker, the contacts remain surrounded by SF_6 gas at a pressure of about 2.8 kg/cm^2.

When the breaker opens, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF_6 gas at 14kg /cm^2 pressure from the reservoir to the arc interruption chamber.

The high pressure flow of SF_6 gas rapidly absorbs the free electrons in the arc path to form immovable negative ions which are ineffective as charge carriers. The result is that the medium between the contacts rapidly improve the dielectric strength and causes the extinction of the arc. After the breaker operation (i.e. after arc extinction), the valve mechanism is closed by a set of springs.

Advantage of SF_6 circuit breaker

Due to the superior arc quenching properties of SF_6 gas, the sulphur hexafluoride gas circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below.

1 Such circuit breakers have very short arcing time.

2 Since the dielectric strength of SF_6 gas is 2 to 3 times more than the air, such breakers can interrupt much larger currents.

3 SF_6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to the atmosphere unlike the air blast circuit breaker.

Tripping mechanism of circuit breakers

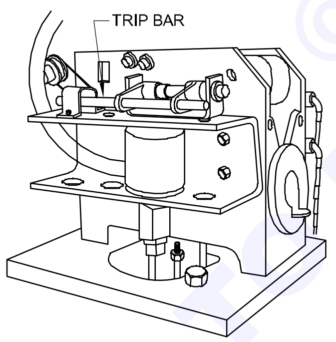
Objectives: At the end of this lesson you shall be able to
- **state the necessity of tripping mechanism**
- **state the types of tripping mechanism.**

Tripping mechanism of circuit breakers

Trip mechanism : Trip mechanism is incorporated in the circuit breaker to switch off the circuit breaker at faulty condition either automatically or manually at the desired time.

Fig 1 shows the arrangement. When the circuit breaker is closed, the mechanism is locked in position by a system of linkages. This lock can be released by lifting the trip bar.

Fig 1



Trip bar is attached to the tripping lever which in turn can be operated manually. The tripping lever is generally kept locked. When the trip bar is lifted the mechanism opens the breaker contacts.

Trip coils: When remote operation is desired, trip coils are used. The trip coils are small solenoids either operated by AC or DC supplies. Fig 2 shows the general arrangement of the trip coil mechanism. A plunger moves freely inside the solenoid. When the solenoid is energised by the trip switch the plunger moves up and release the lock which holds the trip bar. Further the trip coils are also actuated by short circuit /overload and under -voltage relays as described in the following paragraphs.

Shunt trip coils : The shunt trip coil requires an auxiliary supply, a C.T and a relay. The relay can be set to give time-graded protection. The relay closes the trip coil circuit when the load current exceeds the stipulated value. This relay is in Fig 3.

Fig 2

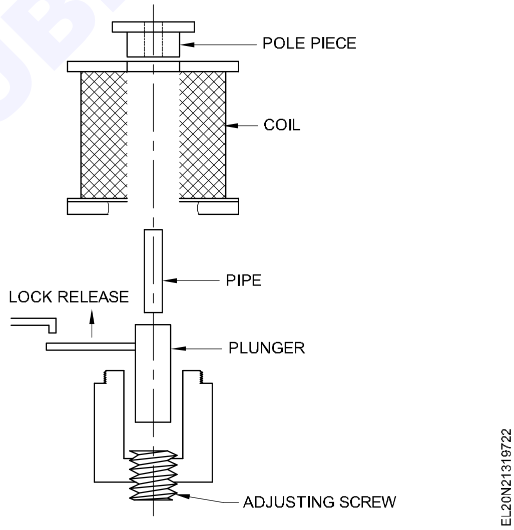
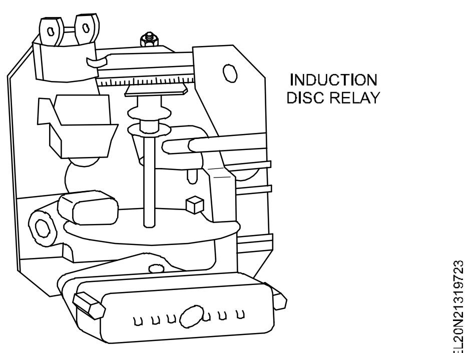


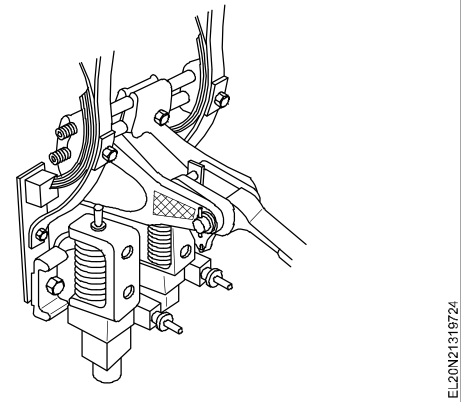
Fig 3



Series trip coil: The series trip coil mechanism is in Fig 4 consists of a series solenoid with a plunger controlled by a spring. When current in the load become excessive the plunger rises and trips the mechanism.

The current necessary to trip the circuit breaker is regulated by a screw which adjusts the tension of the spring controlling the plunger. Time-lag can be adjusted by the position of the dash pot which holds the piston of the plunger in the oil bath.

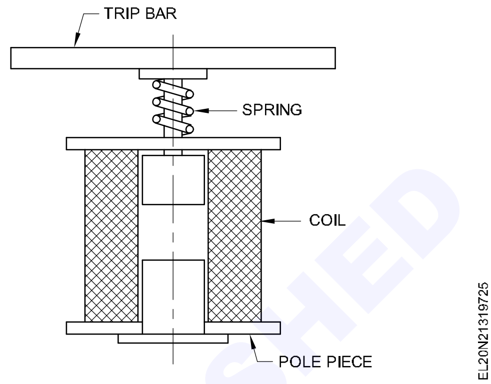
Fig 4



In three-phase circuit breakers, there are three series trip coils, three dash pots, three plungers. They can operate the trip mechanism together or independently.

Under voltage release coils : The under-voltage release coil is used in installations where detection and isolation of abnormally low voltage is required. The construction of the under-voltage trip coil is in Fig 5 is similar to the trip coils discussed above except that the plunger is held away from the pole piece by a coiled spring. Under normal operating conditions, the solenoid is energised and the plunger is held down against the force of the spring. When the supply voltage falls, the under - voltage release coil will not be in a position to hold the plunger down against the spring tension. Thus the plunger moves up and pushes the trip bar to trip the circuit breaker.

Fig 5



Repair and maintenance of CBs

Objectives: At the end of this lesson you shall be able to
- **explain the procedure to carry out maintenance and repair of a OCB**
- **state the method to adopt checking and maintenance/repair of ACB & VCB**
- **explain the procedure of the condition of SF_6 circuit breakers and their repair and maintenance.**

Any circuit breaker has the fundamental operation is to make and break the circuit. The design and operating procedure depends on the breaking/making load current in the circuit. Selection of quenching medium (oil, air, vacuum or gas) and the volume is involved main factors and proper maintenance is very important to keep the breaker accurate performance and long life.

Maintenance & repair of oil breaker

It is the first generation of circuit breaker used in the electrical protection circuit and it is still in use. High insulated oil is the main quenching medium and the oil storage maintenance is quite difficult. Frequent purification, reconditioning, refilling and leak proof storage etc. keeps the breaker always healthy. Due to this oil storage, recondition and refilling problem, oil circuit breakers are replaced by modern vacuum circuit breaker. Troubleshooting chart at this end will help to carryout smooth maintenance and repair of OCB.

Maintenance & repair of ACB, & VCB

Air circuit breaker are found in variety of applications such as very low, low, medium and high current applications. Natural air with arc chutes in chamber found useful in very low and low to medium circuit breaker. Very high voltage to EHT lines the VCB are used very extensively.

Natural air or forced air used for ACBs arc chutes are common in both ACB chamber, but in high voltage ACB forced or compressed air blow is used. To produce compressed air, air chamber, air compressor is necessary in order to operate ACB.

Maintenance is also required at fixed and moving contacts of OCB. Alloy metals are used to make the tips of contacts part in conductors. But in usage these contacts are partially melted or damaged or repaired frequently otherwise quenching time will increase rapidly.

The tension of loading springs and manual operating levers are to be checked and rectified if any mechanical part is found defective. The coils, electromagnets and other electrical parts are to be checked for its effectiveness. A comprehensive service flow chart is attached for detailed repair and maintenance.

Maintenance & repair of SF_6 circuit breaker

It is a advanced version and compact to use mainly for indoor substation. Since the SF_6 gas is poisonous proper protective gadgets are to be used while handling SF_6 circuit breaker.

The loading, tripping mechanism almost same as that of VCB and air blast ACB. The maintenance and repair mentioned may have to follow in this case also.

The main maintenance requirement in SF_6 circuit breaker are handling gas or charging gas. No recondition is possible the SF_6 total replacement is required in case of any gas failure. More cycle of operation will cause the reduction of gas strength and reducing gas pressure also will be the reason of SF_6 circuit breaker failure.

The SF_6 chart illustrate the relevant failure/repair of the circuit breaker.

Troubleshooting chart - 1

S.No	Type of fault	Cause	Effects/remedy
1	Excessive heat in oil	- Poor dielectric strength	- Heavy spark inside the tank in long duration - Change the oil
2	Oil level diminishing fast	- Leak in tank	- Arrest the leak
3	Sledge deposit in bottom of tank	- Adultered oil, very old oil filled	- No proper contacts in the bottom of tank - Filter the oil
4	Spark continuing in the electrode contact after making circuit	- Conductor tip damaged - No proper contact - Pressure spring defect	- Increased oil temperature - Leads to breakage of the tank - Rectify spring (or) contact tip

S.No	Type of fault	Cause	Effects/remedy
5	Manual breaking not functioning	- Loading spring defect - Loading mechanism defective	- No breaking is possible - Rectify
6	No tripping in fault condition	- Defective tripping mechanism - Defective tripping coil	- Fault condition will continue - Damage the machine connected in line
7	Very loud noise in ACB while operation	- Insufficient air flow air pressure in chamber	- Continuous vibration once it is operated. - Maintain air pressure
8	Moving contact broken	- Excessive heat - Excess spring tension - Miss alignment	- Moving contact fail to make contact with fixed contact - Change the contact
9	Melting of electrode tip	- Excessive current produces heavy spark - Substandard alloy metal - Arc quenching is extended beyond the set values	- Check the source of excessive current - Use standard alloy metal - Maintain arc quenching medium in good condition
10	Intermittent tripping of breaker	- Wrong setting in relay - Deflective or faulty loading spring - Faulty moving mechanism	- Correct the setting - Repair spring and loading mechanism
11	Shock in the breaker	- Earth fault	- Do proper earth connection

EV scenario in India and EV charging

Objectives: At the end of this lesson you shall be able to
- **explain about EV scenario in India**
- **state the basic theory of EV charging batteries**
- **state the safety requirements for EV charging.**

Introduction to Electric Vehicle

In recent years, green house gas problem increases and also the gasoline fuel rate also increases days by day in India and global wide so that public also suffer financially due to this reason, automobile manufacture and new companies put their effort to convert the conventional vehicle into electric vehicle that provide reliable solution.

Electric vehicle is propelled with electric motors and draw power from on board electric source in an electric vehicle, it is more durable and mechanically simpler than gasoline vehicle. It gives more fuel efficiency that gasoline because it does not produce emission like internal combustion engine. However, automobile industry is not completely moving towards pure electric vehicle production, because there is in here problem of existing batteries technology for storing the electric energy.

However now a days increasing the usage of hybrid and electric vehicle in our country and globalise.

Electric Vehicle: This type of vehicle uses one or more electric motor for propulsion. Electric vehicle are the automobiles that are propelled by one or more electric motors using the energy stores in batteries.

India need to reduce dependency on a fossil-fuel based economy. India's crude oil imports for 2021-22 was 163.91 billion dollars approximately 13,000,00 crore rupees.

Air quality indices related to India indicate that the air in many cities of India is no longer healthy. Automobile related pollution has been one of the causes for this.

People living in some of Indian cities are being affected by noise pollution. Some of the Indian cities have the worst noise pollution levels in the world Electric Vehicles may contribute to a reduction in noise pollution levels in the cities.

Current Status of EV in India

The Indian Electric Vehicles (EV) market is at a very initial stage comprising of only 2% of the total automobile sales. 95% of the Indian EV market is dominated by 2 and 3 wheelers. The EV market in India is set to see the entry of a flurry of new players of foreign and domestic origin in the 2 and 3 wheeler segments.

In 2012 the National Electric Mobility Mission Plan (NEMMP) 2020 was established to promote hybrid and Electric Vehicles. In early 2018 the Ministry of Power launched the New National Electric Mobility Programme to focus on creating the charging infrastructure and a policy frame work to set a target of more than 30% electric vehicles by 2030.

EV Charging Basic Theory

EV charging is the process of using EV charging equipment to deliver electricity to the Car's battery AM EV charging stations taps into electrical grid to charge an EV. The technical term for EV charging stations is Electric Vehicle Supply Equipment (EVSE).

Methods of Charring an EV

Three methods of charging an EV (Electric Vehicle)

i Trickle charging method

ii AC charging method (charging from AC mains)

iii DC charging method

Types of Electric Vehicle

i Battery Electric Vehicles (BEVs)

ii Plug-in Hybrid Electric Vehicles (PHEVs)

iii Hybrid Electric Vehicles (HEVs)

Electric traction motor is used in EV. Most EVs can take in about 32 amps adding around 25 miles of Range Per Hour of charging so a 32 amp charging station is a good choice for many vehicles.

Generally electric Cars charged at home use about 7200 watts of electricity which can vary depending on the mode and home charger.

A charging station also known as a charge point or Electric Vehicle Supply Equipment (EVSE) is a piece of equipment that supplies electrical power for charging plug in electric vehicles (including electrical Cars, electrical trucks, electric buses, neighborhood electric vehicles and plug in hybrids).

Hybrid Electric Vehicles (HEVs)

Today's Hybrid Electric Vehicles (HEVs) are powered by an internal combustion engine in combination with one or more electric motors that use energy stored in batteries. HEVs combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles. (Fig 1)

Plug-In Hybrid Electric Vehicles (PHEVs)

Plug-in Hybrid Electric Vehicles (PHEVs) use batteries to power an electric motor and another fuel, such as gasoline to power in Internal Combustion Engine (ICE). The vehicle typically runs on electric power until the battery is nearly depleted and then the car automatically switches over to use the internal combustion engine. (Fig 2)

Fig 1

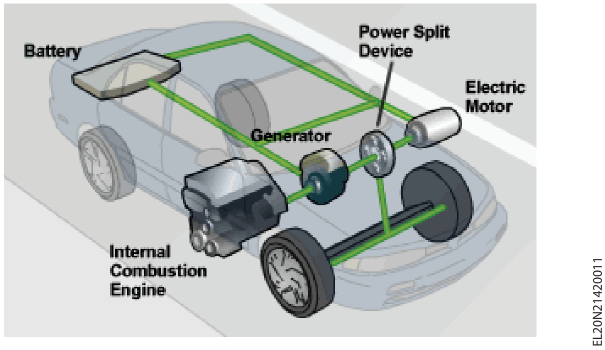
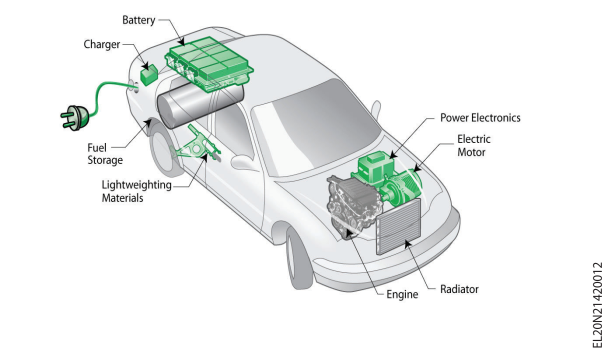


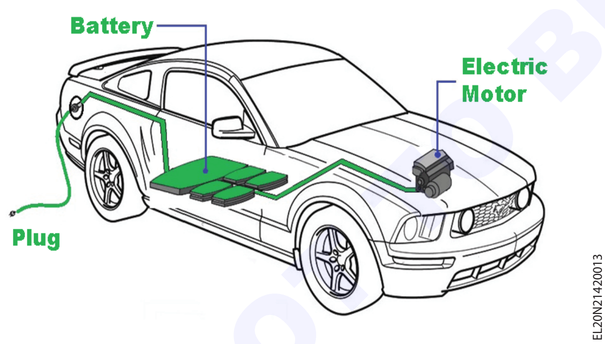
Fig 2



Battery Electric Vehicles (BEVs)

A Battery Electric Vehicles (BEVs), pure electric vehicle, only electric vehicle or all electric vehicle is a type of electric vehicle (EV) that exclusively uses chemical energy stores in rechargeable battery packs, with no secondary source of propulsion (e.g. hydrogen fuel cell, combustion engine etc) (Fig 3)

Fig 3



EV Basic Working Principle

An electric vehicle works on a basic principle of conversion of Electrical energy into mechanical energy. There is a motor used in the electric system to carry on this duty of conversion.

Main Components of EV Chargers

- Battery
- Power Conversion System
- Software

EV battery voltage is 12V for the lead acid battery any typically some where between 400-800 V for the lithium-ion battery pack. Lithium-ion battery capacity is measures in KWH (Kilo Watt Hours). The average capacity is around 40 kwh, but some Cars now have upto a 100 kwh capacity.

EV batteries are projected to last between 1,00,000 and 2,00,000 miles or about 15 to 20 years.

An electric current is a flow of charges particles. The size of an electric current is the rate of flow of charge

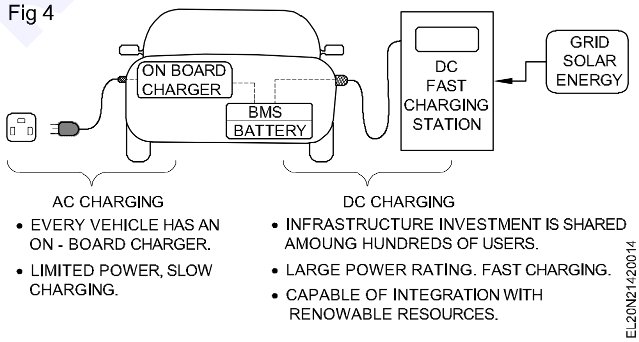
Quantity of Charge (Q) = Current (I) x Time (t)

(Q) = It

In rainy season there is no issue regards to driving your EV. Plus even in the worst case there are many protective layers to a car and battery will remain safe and separate itself if at all water come in.

Working of Public charging Stations

- Electricity from the grid is delivered as Alternating Current (AC) but the EV require Direct Current (DC). A rectifier needs to sit between the grid and the battery to convert one of the other. For home and third party public charging this AC-to-DC conversion is done by EV, on-board rectifier. AC current at charge port is converted to DC for the battery by the rectifier.
- Supercharges deliver high voltage, high current DC electricity directly to the EV's battery, by passing the on-board rectifier. This allows the supercharger to push electricity into the battery as fast as the battery can take it- typically ten times faster than home charging. (Fig 4)



- Using induction, which is more energy efficient, the taxis can be charged as they wait in what's known as a taxi rank, or a slow-moving queue where cans line up to wait for passengers.
- The project aims to install wireless charging using induction technology. charging plates are installed in the ground where the taxi is parked and a receiver is installed in the taxi. This allows for charging up to 75 kilowatts.
- The project will be the first wireless fast-charging infrastructure for electric taxis anywhere in the world, and will also help the further development of wireless charging technology for all EV drivers.

- Fortnum charge & Drive has long been working with the taxi industry to enable electrification of the taxi fleet.

Public charging station (Fig 5)

EV charging Safety Requirements

The global safety standards are marked as following:

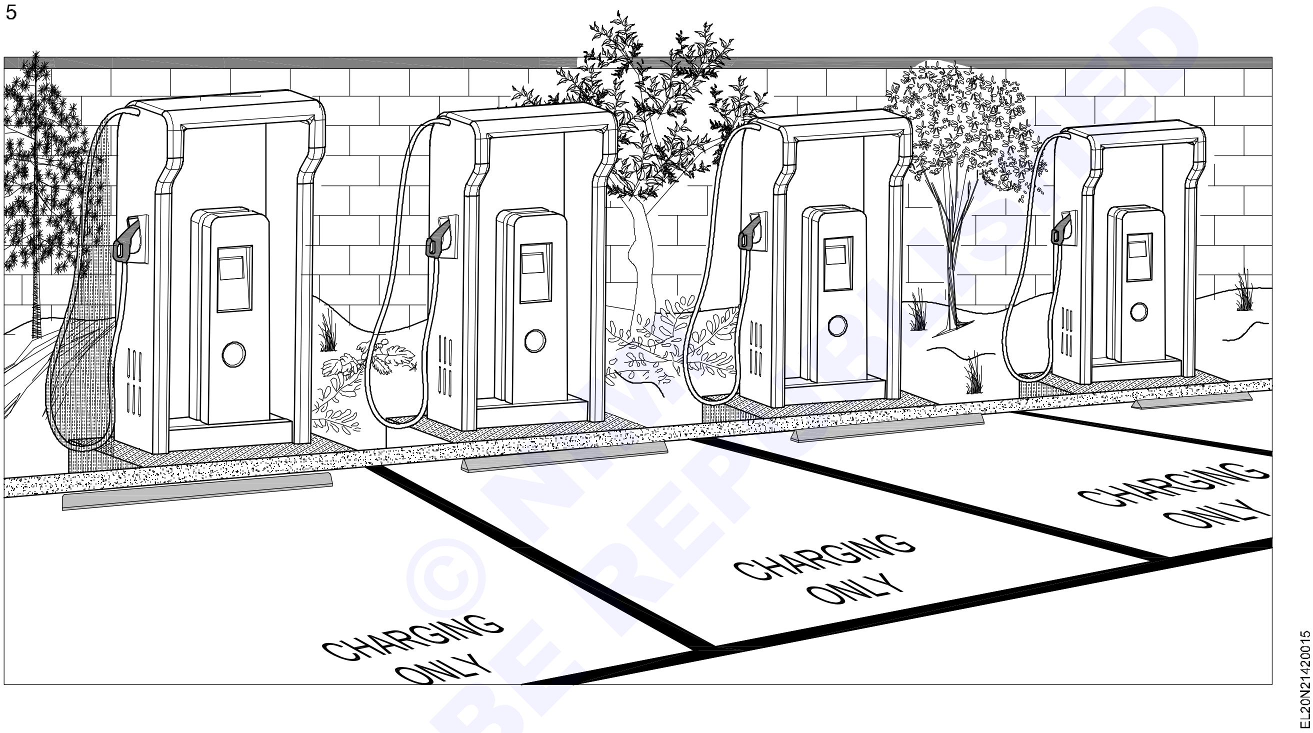
1 **Unintended Vehicle Movement**

   - Indication to driver when vehicle is first put into "active driving possible mode".
   - Signal to driver when exciting the vehicle if the vehicle is still in "active driving possible mode".
   - Indication to driver of vehicle drive direction

2 **Shock Protection**

   - Protection against direct contact
   - Physical barrier/access protection
   - Marking (enclosures/electrical protection barriers and colour coding of high voltage wires/cables)
   - Protection against indirect contact
   - Minimum isolation resistance
   - Fuel cell isolation resistance monitoring
   - Protection against water effects

Fig 5



3 **Elimination Explosive Events**

   - Vibration (Component test)
   - Over Charge Protection
   - Over Discharge Protection
   - Over Temperature Protection
   - Over Current Protection

4 **"Rechargeable Energy Storage System (REESS)"**

   - Installation Integrity/Protection
   - Restricts mounting locations for impact protection.
   - REESS placed/shielded from contact with road debris
   - Shall remain attached and not enter the passenger compartment
   - Battery placement management

Indian Safety standards of Electric Vehicles

Some Basic electric Vehicle safety requirement are as follows

- Occupant protection from electric shock
   - Safety requirement for rechargeable energy storage systems
   - Electrical isolation
   - Battery integrity
   - Best practices or guidelines for manufactures and/ or emergency responders.

Advantages of Electric Vehicles

1 ECO friendly - Because electric vehicles do not utilise fuel for combustion, there are no emissions or gas exhaust.

2 Renewable Energy Source - Electric vehicles run on renewable power, where as conventional auto- mobiles function on the combustion of fossil fuels which reduces the world's fuel stocks.

3 Less Noise and Smoother motion - Electricity is far less expensive than fuel such as gasoline and diesel which are subject to regular price increases.

4 Low maintenance - Because electric cars have fewer moving components, wear and tear is reduced when compared to traditional auto parts.

5 Government Support - Governments thought the world have granted tax breaks to encourage people to drive electric vehicles as part of green program.

Disadvantages of Electric Vehicles

1 High Initial Cost - Electric Vehicles continue to be quite expensive and many buyers believe they are not as in expensive as traditional automobiles.

2 Charging Station Limitations- People who need to travel long distances are concerned about finding adequate charging stations in the middle as their journey which are not always accessible.

3 Recharging Takes Time - Unlike conventional automobiles which require only a few minutes to replenish their gas tanks, charging an electric vehicles takes many hours.

4 Limited Options - Currently there are not many electric car models to pick from in terms of appearances style or customized variations.

5 Less Driving Range - When compared to conventional automobiles electric vehicles have a shorter driving range.

Project work

Objectives: At the end of this project, you shall be able to
- **plan to prepare the project report for selected project**
- **draw circuit diagram/layout diagram**
- **list the specification of the material/component to be procured**
- **list the plan of action to be executed**
- **develop the project report complete and submit it.**

Selection of project and its execution

- Discuss in details of the project - necessity, marketing facility, cost involvement, availability of material and hope of future development and expansion.
- Collect all materials and tools required to start the work.
- The project has to be agreed by all the members involved and get the approval of the concerned authority.
- Prepare an action oriented plan to execute the work within a stipulated time table which is to be accepted by all the members and also the approval of instructor concerned.
- Complete the project as per the plan.
- Test, calibrate and finish the project as per the plan and execution.
- Keep the project with optimum finish and good workmanship.

Preparation of project report

- Report should start with an introductory information connected with a known subject and highlight its importance in present conditions.
- A survey to be conducted regarding the marketing and its commercial applications.
- A brief working principle and its operation has to be illustrated in the report.
- Highlight the maintenance, repair and periodic servicing etc in the report.
- Costing should be competitive and affordable to the concerned without any reservations.
- Project should have the flexibility for further expansion to an advanced version without major changes.
- Report should be listed with reference books and website details.
- Complete the report and submit

List of project works

1 Battery charger/Emergency light

2 Control of motor pump with tank level

3 DC voltage converter using SCRs

4 Logic control circuits using relays

5 Alarm/indicator circuits using sensors

Note :

1 Some of the sample project works (indicative only) are given against each semester.

2 Instructor may design their own project and also inputs from local industry may be taken for designing such new project.

3 The project should proudly cover maximum skills in the particular trade and must involve some problem solving skill. Emphasis should be on Teamwork: Knowing the power of synergy/collaboration, work to be assigned in a group (Group of at least 4 trainees). The group should demonstrate Planning, Execution, Contribution and Application of Learning. They need to submit Project report.

4 If the instructor feels that for execution of specific project more time is required than he may plan accordingly to produce components /sub-assemblies in appropriate time i.e., may be in the previous semester or during execution of normal trade practical.