As per National Education Policy - 2020 SPPU

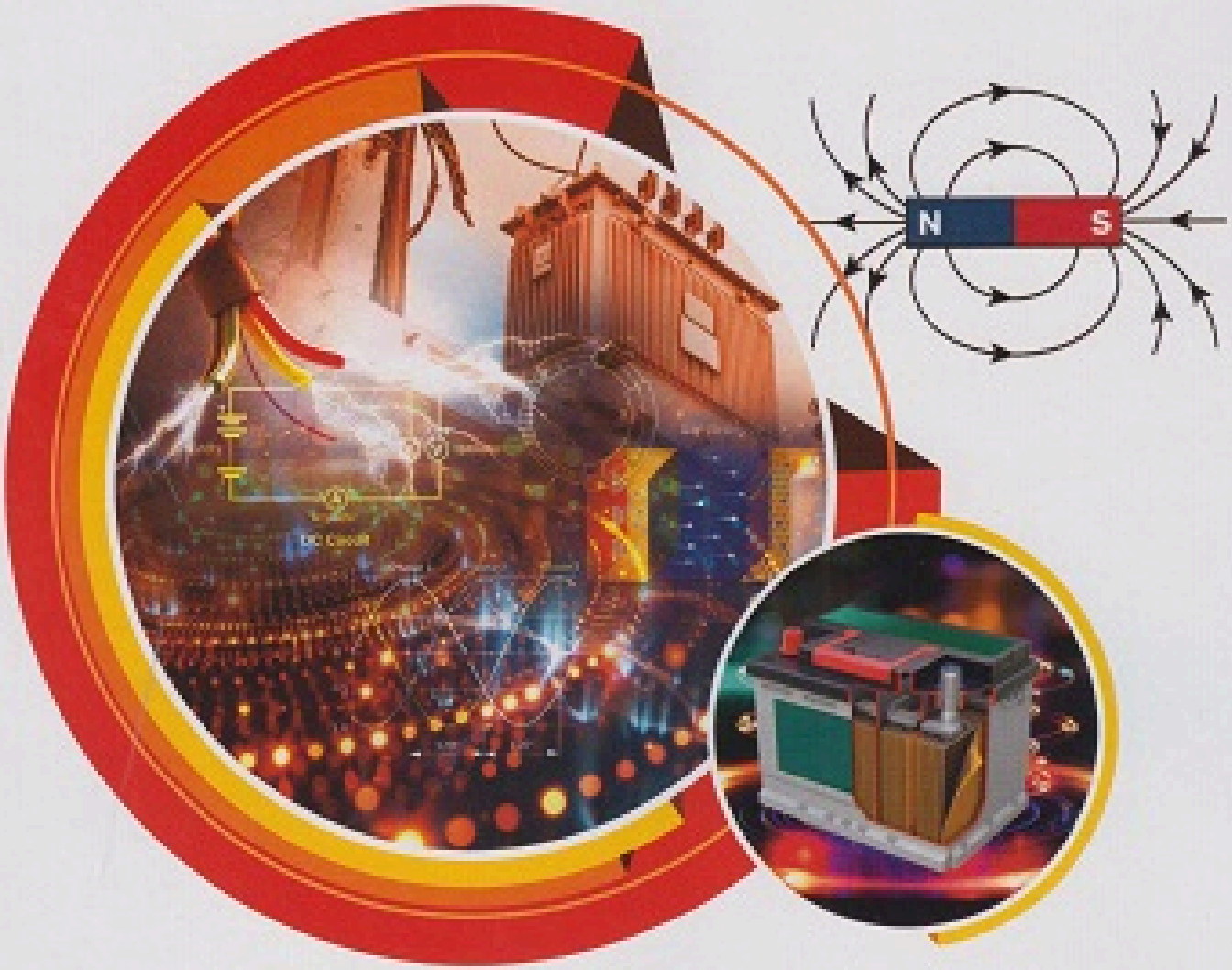
First Year Degree Course In Engineering

COMMON FOR ALL BRANCHES [SEMESTER - I/II]

BASIC ELECTRICAL ENGINEERING

THOROUGHLY REVISED EIGHTEENTH EDITION

B. H. DESHMUKH



www.pragationline.com
niralipune@pragationline.com
www.facebook.com/niralibooks
@nirali.prakashan

NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A Unique Text Book of

BASIC ELECTRICAL ENGINEERING

(SUBJECT CODE : ESE-102-ELE)

For

SEMESTER-I & II

FIRST YEAR DEGREE COURSE IN ENGINEERING

Strictly According to New Choice Based Credit System (CBCS) Syllabus, 2024 of

Savitribai Phule Pune University, Pune

(Effective from Academic Year 2024-2025)

COMMON FOR ALL DEGREE ENGINEERING BRANCHES

(THOROUGHLY REVISED EIGHTEENTH EDITION)

B. H. DESHMUKH

B. E. (Elect.), B. E. (Mech.), M.E. (Elect.)
Retired Assistant Professor of Electrical Engineering,
Government College of Engineering, Pune
Ex. Secretary, B.T.E., Maharashtra State
Formerly, Head of Electrical Engg. Department,
Government Polytechnic, Jalgaon

NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

N8075

BASIC ELECTRICAL ENGINEERING (F.E., S.P.P.U.) **ISBN 978-93-6109-621-1**

Thoroughly Revised Eighteenth Edition : September 2024
© : Author

The text of this publication, or any part thereof, should not be reproduced or transmitted in any form or stored in any computer storage system or device for distribution including photocopy, recording, taping or information retrieval system or reproduced on any disc, tape, perforated media or other information storage device etc., without the written permission of Authors with whom the rights are reserved. Breach of this condition is liable for legal action.

Every effort has been made to avoid errors or omissions in this publication. In spite of this, errors may have crept in. Any mistake, error or discrepancy so noted and brought to our notice shall be taken care of in the next edition. It is notified that neither the publisher nor the authors or seller shall be responsible for any damage or loss of action to any one, of any kind, in any manner, therefrom. The reader must cross check all the facts and contents with original Government notification or publications.

Published By :
NIRALI PRAKASHAN
Abhyudaya Pragati, 1312, Shivaji Nagar,
Off J.M. Road, Pune – 411005
Tel - (020) 25512336/37/39
Email : niralipune@pragationline.com

Polyplate

Printed By :
YOGIRAJ PRINTERS AND BINDERS
Survey No. 10/1A, Ghule Industrial Estate
Nanded Gaon Road
Nanded, Pune - 411041

DISTRIBUTION CENTRES

PUNE

Nirali Prakashan
(For orders outside Pune)
S. No. 28/27, Dhayari Narhe Road, Near Asian College
Pune 411041, Maharashtra
Tel : (020) 24690204; Mobile : 9657703143
Email : bookorder@pragationline.com

Nirali Prakashan
(For orders within Pune)
119, Budhwar Peth, Jogeshwari Mandir Lane
Pune 411002, Maharashtra
Mobile : 9657703145, 9890997937
Email : niralilocal@pragationline.com

MUMBAI

Nirali Prakashan
Rasdhara Co-op. Hsg. Society Ltd., 'D' Wing Ground Floor, 385 S.V.P. Road
Girgaum, Mumbai 400004, Maharashtra
Mobile : 7045821020, Tel : (022) 2385 6339 / 2386 9976
Email : niralimumbai@pragationline.com

DISTRIBUTION BRANCHES

DELHI
Nirali Prakashan
Room No. 2 Ground Floor
4575/15 Omkar Tower, Agarwal Road
Darya Ganj, New Delhi 110002
Mobile : 9555778814/9818561840
Email : delhi@niralibooks.com

BENGALURU
Nirali Prakashan
Maitri Ground Floor, Jaya
Apartments, No. 99, 6th Cross, 6th
Main, Malleswaram, Bengaluru
560003 Karnataka; Mob : 9686821074
Email : bengaluru@niralibooks.com

NAGPUR
Nirali Prakashan
Above Maratha Mandir, Shop No. 3,
First Floor, Rani Jhanshi Square,
Sitabuldi Nagpur 440012 (MAH)
Tel : (0712) 254 7129
Email : nagpur@niralibooks.com

KOLHAPUR
Nirali Prakashan
438/2, Bhosale Plaza, Ground Floor,
Khasbag, Opp. Balgopal Talim,
Kolhapur 416 012 Maharashtra
Mob : 9850046155
Email : kolhapur@niralibooks.com

JALGAON
Nirali Prakashan
34, V. V. Golani Market, Navi Peth,
Jalgaon 425001, Maharashtra
Tel : (0257) 222 0395
Mob : 94234 91860
Email : jalgaon@niralibooks.com

SOLAPUR
Nirali Prakashan
R-158/2, Avanti Nagar, Near Golden
Gate, Pune Naka Chowk
Solapur 413001, Maharashtra
Mobile 9890918687
Email : solapur@niralibooks.com

marketing@pragationline.com | www.pragationline.com

Also find us on www.facebook.com/niralibooks

Preface ...

The subject of **'Basic Electrical Engineering'** continues to be one of the core subjects included in the **New Choice Based Credit System Curriculum** prescribed by the Savitribai Phule Pune University for First Year Degree Courses in Engineering of all branches with effect from the academic year 2024-25. This is done mainly with a view to acquaint the students in overall manner with the electrical engineering principles and apparatus before they specialize in any branch of engineering. This book is exclusively written to serve as a text-book for the above subject.

The subject matter in the book is thoroughly revised and rearranged as per new syllabus. It includes topics on Elementary Concepts, D.C. Circuits, Magnetic Circuits, Electromagnetic Induction, A.C. Fundamentals, Single-Phase A.C. Circuits, Three-Phase A.C. Circuits, Single-Phase Transformers, D.C. Motors, Three-Phase Induction Motors, and Single-Phase Induction Motors. The international system of units (S.I.) is used throughout the book.

A considerable number of worked examples are included in each chapter to enable the students to understand the electrical principles thoroughly. Each chapter is concluded with 'Points to remember' and 'Important formulae at a glance'. Numerical examples (with solutions) and classified theory questions (for self-study) from large number of university papers are added at the end of each chapter to enhance the utility of the book. The opportunity has also been taken of rectifying the errors and omissions as have been brought to the author's notice by the readers of the previous editions. I am sure that the student fraternity as well as faculty members will find this book extremely useful.

I am really thankful to my publishers M/s Nirali Prakashan, Pune for bringing out this book in its present shape and that too in a very short period. Useful and constructive suggestions from the readers for further improvement of this book will be gratefully accepted by the author.

PUNE **AUTHOR**

Syllabus ...

Unit-I : ELEMENTARY CONCEPTS AND DC CIRCUITS (06 Hrs.)

Elementary Concepts: Resistance, E.M.F., Current, Potential Difference, Ohm's Law. Overview of Elementary Power System showing Stages such as Generation, Transmission, and Distribution of Electrical Energy.

D.C. Circuits: Classification of Electrical Networks, Simplifications of Networks using Series-Parallel Combinations and Star-Delta Transformation Technique, Kirchhoff's Laws and their Applications for Network Solutions using Loop Analysis, Superposition Theorem.

Unit-II : ELECTROMAGNETISM (06 Hrs.)

Magnetic Circuit: Concept of Flux Density, Field Strength, Permeability, M.M.F., Reluctance, their Units, and Relationships. Simple Series Magnetic Circuit, Comparison of Electric and Magnetic Circuit.

Electromagnetic Induction: Faraday's Laws of Electromagnetic Induction, Fleming's Right-Hand Rule, Statically and Dynamically Induced E.M.F., Self and Mutual Inductance, Coefficient of Coupling. Energy Stored in Magnetic Field.

Unit-III : A.C. FUNDAMENTALS (06 Hrs.)

Generation of Single-Phase Sinusoidal Voltages and Currents, Their Mathematical and Graphical Representation, Concept of Cycle, Period, Frequency, Instantaneous, Peak, Average and R.M.S. Values, Peak Factor and Form Factor. Phase, Phase Difference, Lagging, Leading, In-Phase Quantities and their Phasor Representation. Rectangular and Polar Representation of Phasor.

Study of A.C. Circuits consisting of Pure Resistance, Pure Inductance, Pure Capacitance.

Unit-IV : A.C. CIRCUITS (06 Hrs.)

Single-Phase A.C. Circuits: Series R-L, R-C and R-L-C Circuits, Concept of Impedance, Power Factor, Phasor Diagrams, Voltage, Current and Power Waveforms. Concept of Active, Reactive and Apparent Power. Resonance in R-L-C Series Circuits.

Three-Phase A.C. Circuits: Concept of Three-Phase A.C. Symmetrical System, Phase Sequence, Balanced and Unbalanced Load. Voltage, Current and Power Relations in Three-Phase Balanced Star and Delta Connected Loads along with Phasor Diagrams.

Unit-V : INTRODUCTION TO ELECTRIC MACHINES (06 Hrs.)

Single-Phase Transformer: Construction, Working Principle, E.M.F. Equation, Transformation Ratio, Rating, Types, Losses, Regulation and Efficiency at Different Loading Conditions.

Electrical Motors :

(a) **D.C. Motors:** Construction, Working Principle, Types, Voltage Equation, Characteristics and Applications.

(b) **Three-Phase Induction Motors:** Working Principle using Rotating Magnetic Field Theory, Types and Applications.

(c) **Single-Phase Induction Motors:** Construction, Working Principle of Single-Phase Induction Motor. Applications of Split Phase, Capacitor Start and Capacitor Run Motors.



Contents ...

UNIT-I : ELEMENTARY CONCEPTS AND D.C. CIRCUITS

1. ELEMENTARY CONCEPTS **1.1 – 1.16**

1.1 Introduction 1.1
1.2 Electric Current 1.1
1.3 Electrical Charge and Current Flow 1.2
1.4 Electromotive Force and Potential Difference 1.2
1.5 Resistance 1.3
1.5.1 Factors Governing the Resistance 1.4
1.5.2 Specific Resistance or Resistivity 1.4
1.6 Conductance and Specific Conductance 1.6
1.7 Ohm's Law 1.6
1.8 Overview of an Elementary Power System 1.7
1.9 Generation of Electrical Energy 1.7
1.10 Conventional and Non-conventional Energy Sources 1.7
1.11 Generating Stations 1.8
1.11.1 Thermal or Steam Power Stations 1.8
1.11.2 Hydro-Electric Power Stations 1.10
1.11.3 Nuclear Power Stations 1.11
1.11.4 Comparison of Various Types of Power Stations 1.12
1.12 Electrical Power System 1.13
1.13 Transmission and Distribution of Electrical Power 1.13
1.14 Points to Remember 1.14
1.15 Important Formulae at a Glance 1.15
1.16 Exercises 1.16
1.16.1 Review Questions 1.16
1.16.2 Examples for Practice 1.16

2. D. C. CIRCUITS **2.1 - 2.52**

2.1 Introduction 2.1
2.2 Classification of Electrical Networks 2.1
2.3 Energy Sources 2.1
2.3.1 Independent Voltage Sources 2.2
2.3.2 Independent Current Sources 2.2
2.3.3 Source Conversion 2.3
2.4 Concept of Open and Short Circuits 2.6
2.5 Combinations of Resistances 2.7
2.6 Series Circuits 2.7
2.6.1 Voltage-Divider Rule 2.8
2.7 Parallel Circuits 2.8
2.7.1 Division of Current in Parallel Circuits 2.9
2.7.2 Comparison between Series and Parallel Circuits 2.10
2.8 Series-Parallel Circuits 2.11
2.9 Delta-Star and Star-Delta Transformations 2.13

2.9.1 Delta-Star Transformation 2.13
2.9.2 Star-Delta Transformation 2.14
2.10 Solution of Networks 2.18
2.11 Kirchhoff's Laws 2.18
2.11.1 Point Law or Current Law 2.18
2.11.2 Mesh Law or Voltage Law 2.18
2.11.3 Definition of Some Important Terms Related to Electric Circuits 2.19
2.11.4 Application of Kirchhoff's Laws for Network Solutions (Branch-Current Method) 2.19
2.12 Loop or Mesh Analysis (Maxwell's Loop Current Method) 2.23
2.12.1 Supermesh Technique 2.25
2.13 Superposition Theorem 2.26
2.14 Points to Remember 2.31
2.15 Important Formulae at a Glance 2.31
2.16 Solutions of Numerical Examples from University Papers 2.32
2.17 Exercises 2.48
2.17.1 Review Questions 2.48
2.17.2 Classified Theory Questions from University Papers 2.49
2.17.3 Examples for Practice 2.49

UNIT-II : ELECTROMAGNETISM

3. MAGNETIC CIRCUITS 3.1 - 3.24

3.1 Introduction 3.1
3.2 Magnetism and its Effects 3.1
3.3 Magnetic Field due to a Straight Conductor 3.2
3.4 Force on a Current Carrying Conductor in a Magnetic Field 3.3
3.5 Magnetic Field due to a Solenoid 3.5
3.6 Permeability 3.6
3.7 Magnetic Circuits 3.7
3.7.1 Quantities Associated with a Magnetic Circuit 3.8
3.7.2 Comparison of Magnetic and Electrical Circuits 3.8
3.7.3 Magnetization Curves 3.9
3.7.4 Series Magnetic Circuits 3.11
3.7.5 Parallel Magnetic Circuits 3.12
3.7.6 Magnetic Leakage and Fringing 3.13
3.8 Points to Remember 3.16
3.9 Important Formulae at a Glance 3.17
3.10 Solutions of Numerical Examples from University Papers 3.19
3.11 Exercises 3.22
3.11.1 Review Questions 3.22
3.11.2 Classified Theory Questions from University Papers 3.22
3.11.3 Examples for Practice 3.23

4. ELECTROMAGNETIC INDUCTION 4.1 - 4.26

4.1 Introduction 4.1
4.2 Faraday's Law of Electromagnetic Induction 4.1
4.3 Direction of Induced E.M.F. 4.3

4.3.1 Fleming's Right Hand Rule 4.3
4.3.2 Lenz's Law 4.3
4.4 Nature of Induced E.M.F. 4.4
4.5 Dynamically Induced E.M.F. 4.4
4.5.1 Magnitude of Dynamically Induced E.M.F. 4.4
4.6 Statically Induced E.M.F. 4.6
4.7 Self-Induced E.M.F. 4.6
4.7.1 Magnitude of Self-Induced E.M.F. 4.7
4.8 Co-efficient of Self-Induction and Dimensions of the Coil 4.7
4.9 Factors affecting the Inductance of a Coil 4.8
4.10 Mutually Induced E.M.F. 4.10
4.10.1 Magnitude of Mutually Induced E.M.F. 4.11
4.11 Co-efficient of Mutual Induction and Dimensions of the Coil 4.12
4.12 Co-efficient of Coupling 4.12
4.13 Inductance of Inductively-Coupled Coils in Series 4.15
4.14 Series and Parallel Combinations of Isolated Inductances 4.16
4.15 Energy Stored in the Magnetic Field 4.17
4.15.1 Energy Stored Per Unit Volume 4.18
4.16 Points to Remember 4.19
4.17 Important Formulae at a Glance 4.20
4.18 Solutions of Numerical Examples from University Papers 4.21
4.19 Exercises 4.25
4.19.1 Review Questions 4.25
4.19.2 Classified Theory Questions from University Papers 4.25
4.19.3 Examples for Practice 4.25

UNIT-III : A.C. FUNDAMENTALS

5. A.C. FUNDAMENTALS 5.1 - 5.32
5.1 Introduction 5.1
5.2 Generation of Alternating Current and Voltage 5.2
5.2.1 Elementary Alternator 5.3
5.3 Some Important Terms 5.4
5.4 Equations of Alternating Voltages and Currents 5.6
5.5 Effective or Root Mean Square (R.M.S.) Value of Sinusoidal Current or Voltage 5.7
5.6 Average Value of Sinusoidal Current or Voltage 5.9
5.7 Peak Factor and Form Factor 5.10
5.8 Phasor Representation of Alternating Quantities 5.15
5.9 Phase and Phase Difference 5.15
5.10 Phasor Diagrams 5.17
5.11 Addition and Subtraction of Sinusoidal Alternating Quantities 5.18
5.12 Complex Notation 5.21
5.13 Phasors in Rectangular Form 5.21
5.13.1 The j Operator 5.21
5.13.2 Addition and Subtraction of Phasors in Rectangular Form 5.22
5.13.3 Multiplication and Division of Phasors in Rectangular Form 5.22

5.14 Phasors in Polar Form 5.22
5.14.1 Multiplication and Division of Phasors in Polar Form 5.23
5.15 Interconversion of Rectangular and Polar Forms 5.23
5.16 Points to Remember 5.23
5.17 Important Formulae at a Glance 5.24
5.18 Solutions of Numerical Examples from University Papers 5.25
5.19 Exercises 5.31
5.19.1 Review Questions 5.31
5.19.2 Classified Theory Questions from University Papers 5.31
5.19.3 Examples for Practice 5.32

UNIT-IV : A.C. CIRCUITS

6. SINGLE-PHASE A.C. CIRCUITS 6.1 - 6.52
6.1 Introduction 6.1
6.2 Purely Resistive A.C. Circuit 6.1
6.3 Purely Inductive A.C. Circuit 6.2
6.4 Purely Capacitive A.C. Circuit 6.4
6.5 Series A.C. Circuits 6.6
6.6 Circuit with Resistance and Inductance in Series 6.6
6.6.1 Measurement of Power in an Inductive Circuit using Three-Voltmeter Method 6.12
6.7 Circuit with Resistance and Capacitance in Series 6.14
6.8 Circuit with Resistance, Inductance and Capacitance in Series 6.16
6.9 Active Power and Reactive Power in A.C. Circuit 6.19
6.10 Impedances in Series 6.23
6.11 Resonance in the R-L-C Series Circuit 6.25
6.11.1 Resonant Frequency 6.26
6.11.2 Bandwidth of a Resonant Circuit 6.26
6.11.3 Q-Factor of a Series Circuit 6.26
6.12 Application of Complex Notation Method to Single-Parameter A.C. Circuits and Series A.C. Circuits 6.28
6.12.1 Single-Parameter Circuits 6.28
6.12.2 Series Circuits 6.29
6.12.3 Determination of Power using Complex Notation 6.35
6.13 Points to Remember 6.36
6.14 Important Formulae at a Glance 6.37
6.15 Solutions of Numerical Examples from University Papers 6.39
6.16 Exercises 6.48
6.16.1 Review Questions 6.48
6.16.2 Classified Theory Questions from University Papers 6.48
6.16.3 Examples for Practice 6.50

7. THREE-PHASE A.C. CIRCUITS 7.1 - 7.24
7.1 Polyphase Systems 7.1
7.2 Generation of Three-Phase Voltages 7.2
7.3 Three-Phase Supply Systems 7.3
7.3.1 Three-Phase, Three-Wire System 7.3
7.3.2 Three-Phase, Four-Wire System 7.4

7.4 Balanced and Unbalanced Loads 7.5
7.5 Balanced System 7.6
7.6 Voltage, Current and Power Relations in a Star Connection 7.6
7.7 Voltage, Current and Power Relations in a Delta Connection 7.9
7.8 Apparent Power and Reactive Power 7.11
7.9 Applications of Star and Delta Connections 7.12
7.10 Points to Remember 7.16
7.11 Important Formulae at a Glance 7.16
7.12 Solutions of Numerical Examples from University Papers 7.18
7.13 Exercises 7.22
7.13.1 Review Questions 7.22
7.13.2 Classified Theory Questions from University Papers 7.23
7.13.3 Examples for Practice 7.24

UNIT-V : INTRODUCTION TO ELECTRIC MACHINES

8. SINGLE-PHASE TRANSFORMERS 8.1 – 8.31

8.1 Introduction 8.1
8.2 Principle of Working 8.1
8.3 Constructional Features 8.2
8.4 Types of Transformers 8.4
8.5 E.M.F. Equation of a Transformer 8.6
8.6 Voltage and Current Ratios of a Transformer 8.8
8.7 Kilovolt-Ampere Rating of a Transformer 8.9
8.8 Ideal Transformer 8.10
8.8.1 Ideal Transformer on No Load 8.11
8.8.2 Ideal Transformer on Load 8.11
8.9 Practical Transformers 8.12
8.9.1 Effect of Core Losses 8.12
8.9.2 Effect of Resistance and Leakage Reactance of Windings 8.13
8.9.3 Practical Transformer on Load 8.13
8.10 Regulation of a Transformer 8.14
8.11 Transformer Losses 8.15
8.12 Efficiency of a Transformer 8.16
8.12.1 Condition for Maximum Efficiency of a Transformer 8.16
8.13 Methods of Finding Efficiency and Regulation of a Transformer 8.20
8.13.1 Efficiency and Regulation by Direct Loading 8.20
8.14 Applications of Transformers 8.22
8.15 Points to Remember 8.22
8.16 Important Formulae at a Glance 8.23
8.17 Solutions of Numerical Examples from University Papers 8.24
8.18 Exercises 8.29
8.18.1 Review Questions 8.29
8.18.2 Classified Theory Questions from University Papers 8.29
8.18.3 Examples for Practice 8.31

9. D.C. MOTORS **9.1 – 9.16**

9.1 Introduction 9.1
9.2 General Principle of an Electric Motor 9.1
9.3 D.C. Motors 9.2
9.4 Principle of Operation of a D.C. Motor 9.2
9.5 Practical D.C. Motors 9.4
9.6 Constructional Features of a Practical D.C. Motor 9.4
9.6.1 Field System 9.4
9.6.2 Armature Assembly 9.4
9.6.3 Miscellaneous Parts 9.5
9.7 Types of Armature Winding 9.6
9.8 Back or Counter E.M.F. 9.7
9.8.1 Equation for Back E.M.F. 9.7
9.9 Torque Equation of a D.C. Motor 9.8
9.10 Types of D.C. Motors 9.10
9.11 Voltage and Current Relationships 9.10
9.12 Characteristics of D.C. Motors 9.11
9.12.1 Characteristics of Shunt Motors 9.11
9.12.2 Characteristics of Series Motors 9.12
9.12.3 Characteristics of Compound Motors 9.12
9.13 Applications of D.C. Motors 9.14
9.14 Points to Remember 9.14
9.15 Important Formulae at a Glance 9.15
9.16 Solutions of Examples from Equivalent Examination Papers 9.15
9.17 Exercises 9.16
9.17.1 Review Questions 9.16
9.17.2 Examples for Practice 9.16

10. THREE-PHASE INDUCTION MOTORS **10.1 – 10.10**

10.1 Introduction 10.1
10.2 Induction Type A.C. Motors 10.1
10.3 Production of Rotating Magnetic Field 10.1
10.4 Operating Principle of a Three-Phase Induction Motor 10.4
10.5 Synchronous Speed 10.5
10.6 Slip 10.5
10.7 Types of Three-Phase Induction Motors 10.6
10.7.1 Squirrel-Cage Induction Motors 10.6
10.7.2 Slip-Ring or Wound-Rotor Induction Motors 10.7
10.8 Operation of an Induction Motor on Load 10.8
10.9 Comparison of Squirrel-Cage and Slip-Ring Induction Motors 10.9

10.10 Applications of Three-Phase Induction Motors 10.9
10.11 Points to Remember 10.9
10.12 Important Formulae at a Glance 10.10
10.13 Exercises 10.10
10.13.1 Review Questions 10.10
10.13.2 Examples for Practice 10.10
11. SINGLE-PHASE INDUCTION MOTORS 11.1 – 11.8
11.1 Single-Phase Motors 11.1
11.2 Classification of Single-Phase Motors 11.1
11.3 Single-Phase Induction Motors 11.1
11.4 Types of Single-Phase Induction Motors 11.3
11.4.1 Resistance Split-Phase Motors 11.3
11.4.2 Capacitor Split-Phase Motors 11.4
11.4.3 Shaded-Pole Motors 11.6
11.5 Points to Remember 11.7
11.6 Exercises 11.8
11.6.1 Review Questions 11.8



CHAPTER

ONE

ELEMENTARY CONCEPTS

1.1 INTRODUCTION

- Before we start the study of magnetic circuits, electromagnetic induction, a.c. fundamentals, a.c. and d.c. circuits, and electric machines, in this chapter, initially a brief review is taken of some elementary concepts such as electric current, electrical charge, electric potential, potential difference, e.m.f., resistance and Ohm's law.
- We shall also have an overview of elementary power system at the end.

1.2 ELECTRIC CURRENT

- According to the modern electron theory, all matter whether solid, liquid or gas is made up of minute particles called ***molecules***, which can be further subdivided into ***atoms*** (Fig. 1.1).

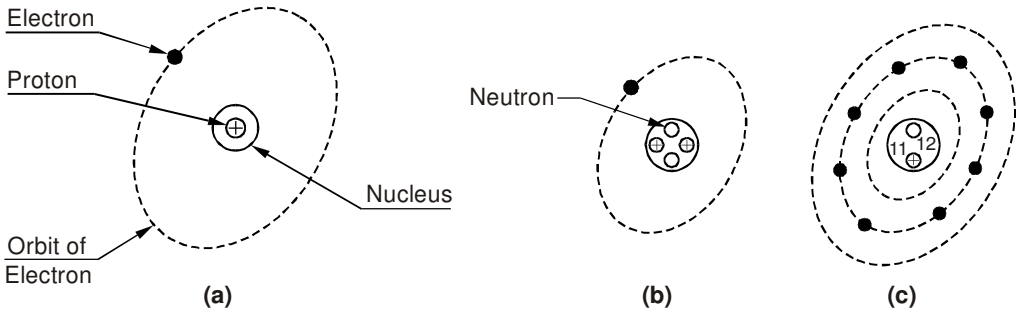


Fig. 1.1: (a) Hydrogen atom, (b) Helium atom, (c) Sodium atom

- An atom consists of a central hard core known as ***nucleus*** containing two types of particles, one known as ***proton*** carrying positive charge and the other ***neutron*** which is electrically neutral. Infinitesimally small particles known as ***electrons*** carrying negative charges are revolving round the relatively massive nucleus in one or more elliptical orbits. In the normal atom, the number of protons equals the number of electrons. Due to this, the atom as a whole is electrically neutral.
- The revolving electrons are firmly held to the nucleus by the force of attraction. But in some substances called ***conductors***, the outer revolving electrons are loosely held to the nucleus and are easily displaced due to the greater force of attraction exerted by the nuclei of neighbouring atoms producing a number of free electrons which move in random directions.
- A relatively small electrical ***effort*** makes these free electrons drift along the metal in a definite direction. This electrical effort is actually called an ***electromotive force*** (e.m.f.). As the name implies, an electromotive force is that which moves the electrons along the metal and this can be provided by a source such as a cell.
- An electromotive force gives rise to a positive charge at one end of the conductor and a negative charge at the other end. Since the free electrons in the conductor are negatively charged and unlike charges attract while like charges repel, the free electrons drift away from the negative charge towards the positive charge. Fig. 1.2 illustrates the drift of electrons through the conductor and the consequent transfer of positive charges.
- When an electron vacates an atom, the atom loses some negative electrical charge and so becomes positively charged. An atom which has lost one or more outer electrons is called a ***positive ion***. The positive ion created in this manner attracts a free electron from the next atom and so becomes neutral once more. The adjacent atom, having lost an electron, in turn, becomes positively charged. This is repeated from atom to atom along the conductor in a direction from positive to negative charge while the free electrons actually move from the negative to the positive charge. This movement of free electrons (or positive ions) is recognised as an ***electric current*** in the wire.

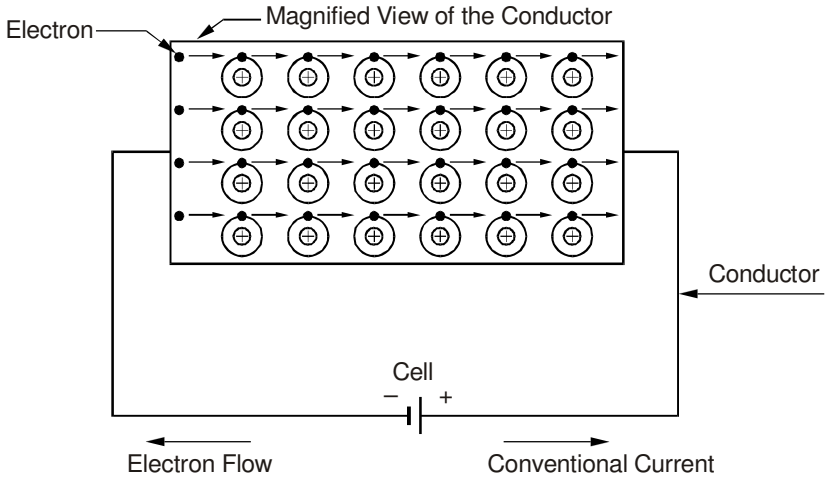


Fig. 1.2: Electron movement through a conductor under the influence of electromotive force

- Long before the electron theory was developed, it was thought that the current flows from the positive to the negative charge e.g. in the case of a cell, it was assumed that the current flows from its positive terminal to the negative terminal through the external circuit. This current direction is still used today.

The current flow in a direction from positive charge to negative charge is normally termed as ***conventional current*** or simply ***current***. But actually the true current i.e. electron flow is in opposite direction to that of conventional current.

This will be clear from Fig. 1.2.

1.3 ELECTRICAL CHARGE AND CURRENT FLOW

- As seen above, a material suffering a deficiency of electrons becomes positively charged and one possessing a surplus of electrons becomes negatively charged.

Thus, *total deficiency* or *excess of electrons in a body can be called its* ***charge***.

- The basic unit of electrical charge is the charge possessed by one electron. But this charge is infinitesimally small. So we consider the charge possessed by 6.24×10^{18} electrons to be a more convenient unit. This unit is called a ***coulomb***.
- Since current flow is caused by a large number of electrons moving in the same general direction through a piece of conducting material, the number of them passing a given point in the material per second forms a measure of the current flow.
- Therefore, quantitatively electric current can be defined as below :

Electric current (I) is defined as the rate of transfer of electric charge (Q) per unit time (t).

- Consequently, $$\text{Average current (I)} = \frac{\text{Total charge transferred (Q)}}{\text{Time elapsed (t)}}$$

Or, $$\text{Total charge (Q)} = \text{Current (I)} \times \text{Time (t)} \quad \ldots (1.1)$$

The practical unit of current is the ***ampere*** which can be defined as follows:

A current of one ampere is said to be flowing in the conductor when a charge of one coulomb (6.24×10^{18} electrons) is passing any given point on it in one second.

1.4 ELECTROMOTIVE FORCE AND POTENTIAL DIFFERENCE

- It is well known that heat flows from a body at a higher temperature to a body at a lower temperature and that water flows from higher water level to a lower level. In the study of electricity, electric pressure or electrical potential is somewhat analogous to the temperature and water level as in above cases.
- The current always flows from higher potential to lower potential in an electrical circuit.

The difference between the electrical potentials (or pressures) at any two given points in the electrical circuit is known as ***potential difference (p.d.)***.

A potential difference generated by a source of electrical energy across its terminals which tends to produce an electric current in a circuit is called an ***electromotive force*** *(abbreviated as e.m.f.).*

- E.M.F. is that way approximately similar to the pressure head of a water pump connected in the hydraulic system. The principal sources of e.m.f. are primary and secondary cells, generators, thermo-junctions, etc.
- As ***volt*** is the unit for electromotive force as well as potential difference, both are often indiscriminately referred to as ***voltage***. The identity of the unit quite often causes confusion between these two quantities. To make the difference between these two quantities more clear, let us consider a simple closed circuit as shown in Fig. 1.3.
- Since the conductor is connected between the terminals of a battery, current flows from its positive terminal to the negative terminal. There are two energy transformations going on concurrently. Chemical energy is being converted to electrical energy by the battery, electrical energy being converted to heat energy into the conductor.
- Whenever some form of energy capable of being converted into electrical energy is introduced in any part of an electrical circuit, we say that an electromotive force is acting in the circuit. On the other hand, if between any two points in a circuit, electrical energy is being converted into any other form of energy, we say that a potential difference is established between the two points. Thus in the simple circuit above, we can say that the battery converting chemical energy into electrical energy is supplying an electromotive force and there exists a potential difference between any two points on the conductor where electrical energy is being dissipated in the form of heat.

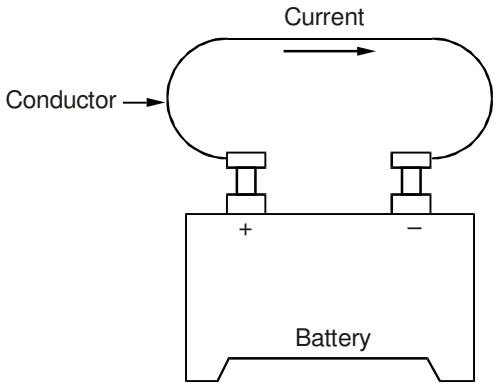


Fig. 1.3: Potential difference and electromotive force

Basically, *the electric potential at any point in an electric field is defined as equal to the work done, in joules, in moving a unit positive charge from infinity (which is considered as a place of zero potential) to that point against the electric field.*

- Thus, Electric potential (V) = $\frac{\text{Work done (W)}}{\text{Charge (Q)}}$. The unit of electric potential is ***volt (V)***.

The electric potential at a point in an electric field is said to be one volt when the work done in moving a unit positive charge from infinity to that point against the electric field is one joule.

- In practice, we are more concerned with the potential difference (p.d.) between two points in an electric field rather than the potential at one point with respect to infinity.

The potential difference between two points in the electric field is the work done, in joules, in moving a unit positive charge from the point of lower potential to the point of higher potential.

- Obviously, the unit for potential difference is also ***volt***.

Potential difference between two points in the electric field is said to be one volt when the work done in moving a unit positive charge from the point of lower potential to the point of higher potential is one joule.

1.5 RESISTANCE

Resistance is the property of a substance by virtue of which it opposes the flow of current through it. It can be compared with the friction due to which the flow of water is opposed through pipes.

- As you know, the current flow is the drift of free electrons through a material. Therefore, higher the number of free electrons available, lesser is the opposition of the substance for the current passage. For example, pure metals due to their large free electrons offer less resistance for the current flow.
- The unit of resistance is ***ohm*** *(symbolically represented as Ω)*.

A conductor is said to have a resistance of one ohm, if a steady (d.c.) current of one ampere flowing through it, produces heat at the rate of one joule per second.

1.5.1 Factors Governing the Resistance

- The resistance (R) of a conductor depends upon the following factors:

(i) Type and Nature of Material: The resistance varies from material to material depending on the availability of the number of free electrons. For example, silver is the best conductor whereas iron offers high resistance. Purity and hardness of the material also affect its resistance. Metals in their pure forms always have less resistance. Hardness (due to heat treatment) increases the resistance of the material.

(ii) Length of the Conductor: The resistance of the conductor is directly proportional to its length (l). This means that the resistance of the longer wire is greater.

(iii) Cross-sectional Area: The resistance is inversely proportional to the cross-sectional area (a) of the conductor. The greater the cross-sectional area, the lower is the resistance of the conductor.

(iv) Temperature: The temperature of the conductor affects its resistance. In most materials, resistance increases with temperature.

- Thus, for the conductor of some material at a given temperature, we can write

$$R \propto \frac{l}{a} \qquad \text{Or,} \quad R = \rho \frac{l}{a} \qquad \ldots (1.2)$$

where ρ (rho) is a constant which depends on the type of material used. It is known as the ***specific resistance*** or ***resistivity*** of the material.

1.5.2 Specific Resistance or Resistivity

The resistance of a specimen piece of a material having unit length and unit cross-sectional area is known as specific resistance or resistivity of that material. The unit of the specific resistance is ***ohm-m***.

- For example, consider a cubical piece of a material illustrated in Fig. 1.4.

Let l = 1 cm and a = 1 cm^2. Then using the expression :

$$R = \rho \frac{l}{a}$$

we have,

$$R = \rho \frac{1}{1} = \rho$$

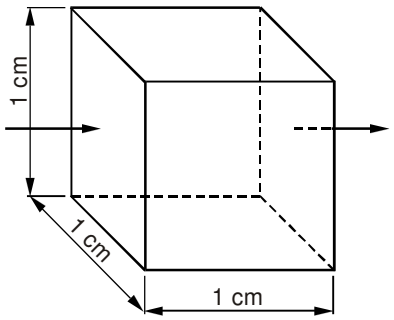


Fig. 1.4: Specific resistance of a material

Thus *the resistance between opposite faces of a unit cube of the material gives its specific resistance.*

- Now, let us derive its unit.

Since,

$$R = \rho \frac{l}{a}$$

$$\rho = \frac{aR}{l} \qquad \ldots (1.3)$$

Substituting the units of various quantities, we get

$$\rho = \frac{\text{metre}^2 \times \text{ohm}}{\text{metre}} = \text{ohm-metre}$$

Hence, the unit of the specific resistance is ***ohm-m***. The smaller unit is ***ohm-cm***.

Example 1.1 : *A coil consisting of 2000 turns of copper wire has cross-sectional area of 0.8 mm^2. The mean length per turn is 25 cm and the resistivity of copper is 2 $\times 10^{-8}$ Ω-m at normal working temperature. What is the resistance of a coil ?*

Solution : Given : N = 2000, a = 0.8 mm^2, $\rho = 2 \times 10^{-8}$ Ω-m, Mean length per turn = 25 cm.

Length of copper wire, l = N × Mean length per turn = 2000 × 0.25 = 500 m

$\therefore$ Resistance of the coil, $R = \rho \frac{l}{a} = 2 \times 10^{-8} \times \frac{500}{0.8 \times 10^{-6}}$ = **12.5 Ω** **… Ans.**

Example 1.2 : *A copper rod 1 m long and 5 mm in diameter has a resistance of 850 μΩ at 15°C. What is the resistivity of copper at this temperature ?*

Solution : Given : l = 1 m, d = 5 mm, R = 850 μΩ.

$$a = \frac{\pi}{4} \times 5^2 \times 10^{-6} = 19.635 \times 10^{-6} \text{ m}^2$$

Now, $$R = \rho \frac{l}{a}$$

$$\therefore \quad 850 \times 10^{-6} = \rho \times \frac{1}{(19.635 \times 10^{-6})}$$

$\therefore$ Resistivity of copper at 15°C, ρ = **1.669×10^{-8} Ω-m** **… Ans.**

Example 1.3: *Calculate the resistance of a 100 m length of wire having a uniform cross-sectional area of 0.01 mm² and having resistivity of 50 μΩ-cm.*

If the wire is drawn out to three times its original length, calculate the resistance.

Solution: We know that $R = \rho \frac{l}{a}$

Here, $\rho = 50$ μΩ-cm $= 50 \times 10^{-6}$ Ω-cm

$l = 100$ m $= 100 \times 10^2$ cm

$a = 0.01$ mm² $= 0.01 \times 10^{-2}$ cm²

Substituting these values in the above expression,

$$R = 50 \times 10^{-6} \times \frac{100 \times 10^2}{0.01 \times 10^{-2}} = \textbf{5000 Ω}$$ **… Ans.**

New length, $l' = 3\,l$

Let new cross-sectional area be a'.

Since the volume of the wire remains the same after drawing,

Volume = Cross-sectional area x Length = a x l = a' x l' = a' x $3l$

$\therefore$ $$a' = \frac{a}{3}$$

Therefore, with $l' = 3l = 100 \times 10^2 \times 3 = 300 \times 10^2$ cm and

$$a' = \frac{a}{3} = \frac{0.01 \times 10^{-2}}{3} \text{ cm}^2$$

New resistance, $R' = \rho \frac{l'}{a'}$

$$= 50 \times 10^{-6} \times \frac{300 \times 10^2}{\left(\frac{0.01 \times 10^{-2}}{3}\right)} = \textbf{45000 Ω}$$ **… Ans.**

Example 1.4 : *A piece of silver has a resistance of 3 Ω. What will be the resistance of a manganin wire one-third the length and one-third the diameter that of silver ? The resistivity of manganin is 30 times that of silver.*

(May 2013) **(6 Marks)**

Solution : Given : $R_s = 3\ \Omega$, $l_m = \frac{1}{3} l_s$, $d_m = \frac{1}{3} d_s$, $\rho_m = 30\ \rho_s$.

We know that, $$R = \rho \frac{l}{a}$$

Hence, under the given conditions,

$$\frac{R_s}{R_m} = \frac{\rho_s}{\rho_m} \times \frac{l_s}{l_m} \times \frac{a_m}{a_s} = \frac{\rho_s}{\rho_m} \times \frac{l_s}{l_m} \times \left(\frac{d_m}{d_s}\right)^2 \qquad (\because a \propto d^2)$$

$$\therefore \quad \frac{3}{R_m} = \frac{1}{30} \times 3 \times \left(\frac{1}{3}\right)^2$$

∴ Resistance of the manganin wire, R_m = **270 Ω** **… Ans.**

1.6 CONDUCTANCE AND SPECIFIC CONDUCTANCE

Conductance is defined as the reciprocal of resistance.

- Since the resistance is a measure of opposition offered by the conductor to the flow of current, conductance is taken as a measure of the ease with which current may flow through a conductor.
- Conductance is symbolically represented by the letter G and its unit is ***siemens*** (symbol, S).

Thus,
$$G = \frac{1}{R} = \frac{a}{\rho l} \qquad \left(\because R = \rho \frac{l}{a}\right)$$
$$= \frac{\sigma \cdot a}{l}$$

where σ is called the ***specific conductance*** or ***conductivity*** of a conductor.

Hence, *specific conductance or conductivity of a conductor is nothing but the reciprocal of its specific resistance*. The unit of specific conductance or conductivity is **siemens / metre**.

- Now, $\sigma = \frac{1}{\rho}$

Therefore from the equation for conductance, we have,

$$\sigma = \frac{G \cdot l}{a} \qquad \ldots (1.4)$$

Substituting the units of various quantities, we get

$$\sigma = \frac{\text{siemens} \times \text{metre}}{\text{metre}^2} = \text{siemens / metre}$$

Hence, the unit of specific conductance or conductivity is ***siemens / metre***.

1.7 OHM'S LAW

- This law gives the relationship between the potential difference (V), the current (I) and the resistance (R) of a d.c. circuit. Dr. Ohm in 1827 discovered that the current flowing through a solid conductor is directly proportional to the difference of potential across the conductor, provided the temperature remains constant. He also found that this current is inversely proportional to the resistance of the conductor. Thus, combining these two experimental results, Ohm's law can be stated as follows:

The current flowing through a solid conductor is directly proportional to the difference of potential across the conductor and inversely proportional to its resistance, provided the temperature remains constant.

i.e. $I \propto \frac{V}{R}$ Or, $I = \frac{V}{R} \times \text{Constant}$

- The unit for the potential difference is defined in such a fashion that this constant becomes unity.

$$\therefore \quad I = \frac{V}{R} \qquad \ldots (1.5)$$

- From the above relationship, the practical units for resistance, potential difference and current may be defined as follows:

Ohm: *It is the resistance of a conductor which requires the application of one volt across its terminals in order that the current of one ampere may flow through it.*

Volt: *It is the potential difference across a resistance of one ohm carrying a current of one ampere.*

Ampere: *It is that current which flows in a conductor having the resistance of one ohm when the potential difference of one volt is applied across its terminals.*

Example 1.5: *An ammeter connected in series with an unknown resistance reads 0.5 A (Fig. 1.5). A voltmeter placed across the ends of the resistance shows a reading of 25 V. Compute the value of the resistance.*

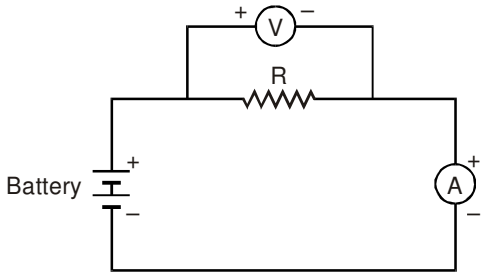


Fig. 1.5: Measurement of unknown resistance

Solution:

$$R = \frac{V}{I} = \frac{25}{0.5} = \mathbf{50\ \Omega}$$ **... Ans.**

1.8 OVERVIEW OF AN ELEMENTARY POWER SYSTEM

- In the following sections, a brief review is taken of different stages of an elementary power system such as generation, transmission and distribution of electrical energy.

1.9 GENERATION OF ELECTRICAL ENERGY

- Electrical energy is utmost essential for the all-round development of any country. The per capita consumption of electricity in any country is an index of the standard of living of the people in that country. Actually, energy exists in different forms in nature, but the most important form is the electrical energy. This is because it can be generated centrally in bulk and transmitted economically over long distances. Further, it can be adapted easily and efficiently to innumerable domestic, commercial, industrial and agricultural applications.

1.10 CONVENTIONAL AND NON-CONVENTIONAL ENERGY SOURCES

- Electrical energy is basically a converted form of energy. It is produced from energy available in various forms in nature. Conventionally, electrical energy is obtained by conversion from fossil fuels (e.g. coal, oil, natural gas), the nuclear and hydro sources. However, the necessity to conserve fastly depleting stocks of fossil fuels has forced scientists and technologists across the world to search for non-conventional energy sources for producing electrical energy. Some of these sources which are presently being explored, include solar, wind, tidal and geo-thermal sources. All these conventional and non-conventional sources along with the techniques of electrical energy generation used, are briefly discussed below :

  (i) Fossil Fuels : Fossil fuels such as coal, oil and natural gas are the main sources of energy. Heat energy released by burning fossil fuels is first converted into mechanical energy with the help of suitable devices like steam engines, steam turbines, internal combustion engines, gas turbines, etc. which are in turn used as prime movers for alternators*. Alternators then convert this mechanical energy into electrical energy.

  (ii) Water : Water is a great source of energy. Potential energy of the water stored in the reservoir is converted into mechanical energy with the help of water turbines. This mechanical energy is then converted into electrical energy by using water turbines as prime movers for the alternators.

  (iii) Nuclear Fuels : The heat produced due to nuclear fission (nuclear disintegration) of materials like uranium, thorium and plutonium is utilized to produce the steam from water to run the steam turbines which, in turn, drive the alternators. It is estimated that heat produced by 1 kg of nuclear fuel is equal to that produced by about 2750×10^3 kg of coal.

---

* *A.C. generators are normally known as alternators. For more details, refer to Chapter 5.*

(iv) Sun : The sun is the primary source of energy. Large parabolic reflectors are used to collect the heat energy radiated by the sun. This heat is then used to raise the steam which runs the steam turbines. Turbine-driven alternators then finally generate electrical energy.

- In the alternative method which is used on very small scale, photovoltaic cells are used. These cells convert sunlight to electricity directly. The energy available during the day is then used to charge the batteries to ensure continuous supply of power during night time.
- Because of its dependence on weather conditions and non-availability at night, commercial use of solar energy on a large scale is not yet possible.

(v) Wind : Wind is a cheapest and most common source of energy. Wind energy is used to run the wind mills which, in turn, drive small generators. However, the wind as a source of energy is not reliable. Moreover, generation of electrical power on large scale is not possible by this method.

(vi) Ocean Tides and Waves : Ocean tides and waves possess a tremendous amount of energy and efforts are going on to extract this energy for the development of electrical power. A small dam with larger gates is constructed across the mouth of the bay for this purpose and low head water turbines are used for generation of electrical power.

(vii) Geo-Thermal Sources : Geo-thermal energy is available in the form of live steam wells in some places with fresh volcanic activity. This steam can be used for electrical power generation. However, such places are very rare.

1.11 GENERATING STATIONS

- Generating stations are the centres where electrical energy is produced in bulk, exclusively in the form of alternating current*. Depending upon the basic source of energy used for producing electrical energy, there are different types of generating stations, the principal among them being :
  - (i) Thermal or steam power stations,
  - (ii) Hydro-electric power stations,
  - (iii) Nuclear power stations.
- About 58 % of total electrical power in India is generated by thermal power stations. Contribution of hydro-electric power stations is about 37 % whereas nuclear power stations contribute to the extent of about 2 %. These three types of power stations are briefly discussed in the following sections.

1.11.1 Thermal or Steam Power Stations

- The chemical energy stored in coal is transformed into electrical energy in thermal power stations.

General Arrangement and Working :

- The heat released by the combustion of coal in a boiler converts water into steam at high pressure and temperature. This steam when passed through a steam turbine produces mechanical energy. The steam turbine is used as a prime mover for the alternator which ultimately converts mechanical energy provided by the steam turbine into electrical energy.
- Apart from boiler, steam turbine and alternator, a thermal power station needs varieties of other auxiliary equipments to achieve efficient conversion of heat energy into electric energy. Fig. 1.6 shows a schematic layout of a typical coal-fired modern thermal power station.
- The various equipments used and their functions are briefly discussed below :

Functions of Various Components Used :

Coal Handling Plant : From coal storage, coal is delivered to coal handling plant consisting of crushers, magnetic separators (for the removal of iron contents, if any, from the coal) and the pulverising mills. Pulverised coal is finally supplied by this plant to the boiler. Pulverising increases surface exposure of coal and promotes its rapid combustion without using large quantity of air.

---

* *Refer to Chapter 5 for numerous advantages offered by alternating current over direct current.*

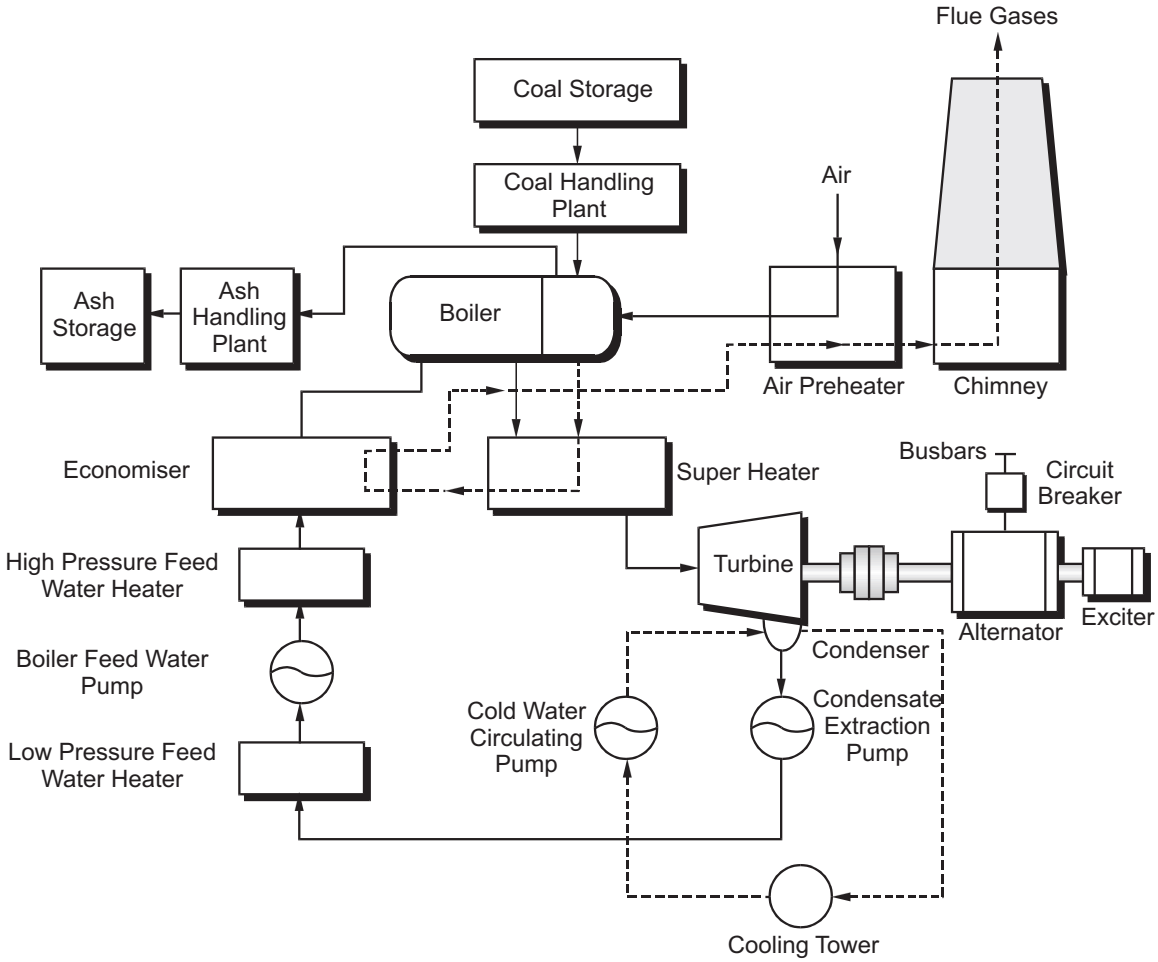


Fig. 1.6 : Schematic layout of a typical thermal power station

Ash Handling Plant : This plant consists of means of removing the ash (produced after complete combustion of coal) from the boiler, loading it onto a conveyor and delivering it finally to the ash storage plant for further disposal.

Air Preheater : Before the flue gases (combustion gases) are exhausted to atmosphere through chimney, part of the heat in these gases is recovered by air preheater and utilized to increase the temperature of air supplied for the combustion of coal in the boiler. Hot air is desirable for better combustion.

Boiler : Boiler is a device meant for converting water into a steam at high temperature and pressure. The heat produced by the combustion of coal is utilized for this purpose. Thermal plants mostly use water tube boilers in which water flows through the tubes and hot flue gases are outside. Flue gases from the boiler make their journey through superheater, economiser, air pre-heater and are finally exhausted to atmosphere through the chimney.

Superheater : Superheater removes the last traces of moisture from the steam coming out of the boiler and superheats it to the desired temperature. Heat from the flue gases is used for this purpose.

Steam Turbine : The dry and superheated steam from the superheater is fed to the steam turbine. A steam turbine converts the heat energy of steam into mechanical energy and thereby works as a prime mover for the alternator.

Condenser : The condenser condenses the steam exhausted from turbine and thereby improves the plant efficiency. Condensate (in the form of hot water) is used as feed water for the boiler.

Low Pressure and High Pressure Feed Water Heaters : These heaters progressively increase the temperature of the feed water by using the steam taken out from the different sections of the turbine.

Economiser : An economiser further heats the feed water before it is supplied to the boiler. Heat extracted from flue gases is used for this purpose.

Cooling Towers : The quantity of cooling water required for condensing steam in the condenser is quite large. Hence, when sufficient supply of natural cool water is not available, the warm water coming out of the condenser is cooled using cooling towers and reused.

Alternator : The alternator which is coupled to the steam turbine converts mechanical energy into electrical energy. The electrical output from the alternator is delivered to the bus bars through circuit breaker.

- Feed water and steam flow cycle, air and flue gas flow cycle, fuel and ash flow cycle and condenser cooling water flow cycle are clearly shown in Fig. 1.1 with the help of arrows.

1.11.2 Hydro-Electric Power Stations

- The hydro-electric power stations convert the potential energy of water into electrical energy by using water turbines coupled with alternators.

General Arrangement and Working : Fig. 1.7 shows a schematic layout of a typical hydro-electric power station. Availability of ample quantity of water at sufficient head is the basic requirement of such a power station. This requirement is generally met by constructing a dam across a river at a suitable point where width of the river is minimum and the region is surrounded by large mountains. The water from the catchment area is collected at the back of the dam to form a reservoir. The water from the reservoir is then carried through a pressure tunnel upto the surge tank and then to a valve house. From valve house, the water is taken to water turbines through huge steel pipes known as penstocks. The water turbine converts the potential energy of water into mechanical energy. The alternator coupled with the water turbine then converts this mechanical energy into electrical energy.

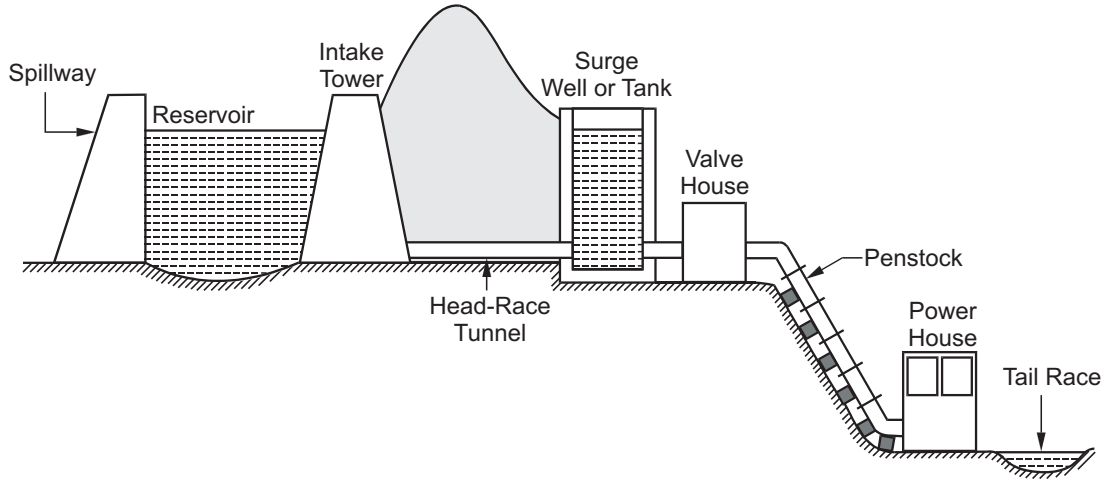


Fig. 1.7 : Schematic layout of a typical hydro-electric power station

Functions of Various Components Used :

Dam : A dam is the most expensive and important part of a hydro-electric project. The function of the dam is to create an artificial reservoir (water storage) with sufficient hydraulic head. Dams may have either masonry or earthern construction.

Spillway : Spillway serves to discharge surplus water in the reservoir when its level exceeds full permissible limit. Thus, it acts as a safety valve for the dam.

Intake Tower : It is the arrangement made from where water is taken from the reservoir for generation purpose. Intake tower is equipped with different types of regulating gates, valves, hoists, etc.

Head-Race Tunnel : It carries water from intake tower to surge tank. Tunnel walls are steel lined and reinforced in concrete.

Penstocks : Penstocks are closed reinforced concrete or steel conduits which carry water from surge well to the turbines. They are held firmly to the ground in concrete or timber saddles.

Surge Tank : A surge tank is a small tank (open at the top) located near the beginning of the penstocks to control the pressure variations resulting from the rapid changes in water flow in penstocks and thereby to protect the penstocks from bursting or collapsing.

- When the loading on the alternator decreases, the governor closes the turbine gates (valves). Sudden closure of turbine gates creates an increased pressure, known as *water hammer*, in the penstock. The excess water at the lower end of the penstock then rushes back to the surge tank, causing a rise in its water level. Thus, the conduit is prevented from bursting. On the other hand, when the load on the alternator increases, the governor opens the turbine gates. Sudden opening of the turbine gates may cause a vacuum in the water system. The water then flows out of surge tank, thus lowering its water level. A surge tank thus meets all the sudden changes in water requirements of a turbine (it should be noted that the function of a surge well is similar to that of a flywheel fitted to an I.C. engine).

Tail Race : It is the arrangement made to discharge the water leaving the turbine into the river.

1.11.3 Nuclear Power Stations

- These power stations convert nuclear energy into electrical energy.

General Arrangement and Working : The schematic layout of a typical nuclear power station is shown in Fig. 1.8. The nuclear power station is basically a thermal power station in which nuclear reactor and heat exchanger are used in place of conventional boiler for steam generation. The heat is produced due to nuclear fission of radio-active materials like uranium, thorium and plutonium in the reactor. The coolant carries this heat from the reactor to heat exchanger where it is utilized to produce steam from water. The steam is then used to drive the steam turbine. The alternator coupled to steam turbine finally converts the mechanical energy provided by steam turbine into electrical energy.

- The reactor and the cooling circuit are heavily shielded to eliminate radiation hazards.

Functions of Various Components Used :

Reactor : Reactor is the heart of the nuclear power station. It is this part where the nuclear fuel (radio-active materials like uranium, thorium, plutonium) is subjected to controlled nuclear fission for producing heat energy. There are number of methods of starting a nuclear chain reaction in the reactor. Generally, neutrons are used as bombarding particles which split the nuclei of fissionable radio-active material and thereby liberate tremendous amount of energy in the form of heat. Each fissioned nucleus ejects more number of fast moving neutrons which are slowed down and reused to continue nuclear fission. The reactor (Fig. 1.8) consists of following principal parts :

(i) Fuel Elements : These are in the form of plates or rods and are made up of fissionable materials like uranium, thorium, plutonium, etc.

(ii) Coolant : Coolant transfers the heat from the reactor to the heat exchanger where it is utilized for generation of the steam. The coolants commonly used are gases (carbon-di-oxide, air, hydrogen, helium), water, heavy water, liquid metals (sodium or potassium alloys), some organic liquids and molten salts.

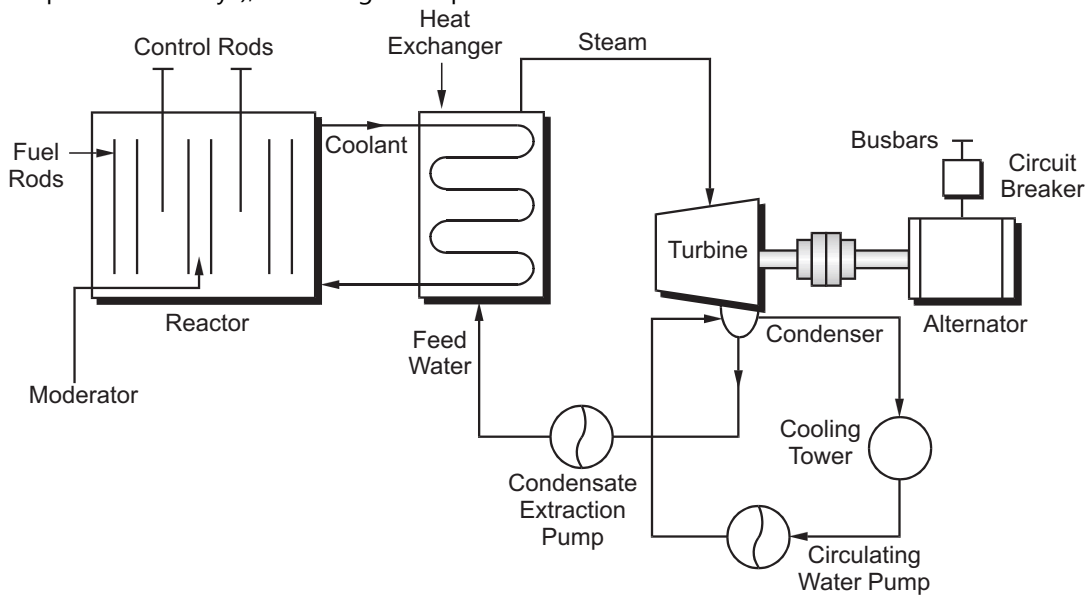


Fig. 1.8 : Schematic layout of a typical nuclear power station

(iii) Moderator : The purpose of moderator is to moderate or reduce the speed of fast moving neutrons freshly released during nuclear fission and reuse them to continue further nuclear fission. Materials like graphite, heavy water, beryllium, ordinary water, etc. can be used as moderators in the reactor.

(iv) Control Rods : Control rods are used to control the nuclear chain reaction and thereby the rate of fission in the reactor. They are made up of neutron absorbing materials such as cadmium, boron or hafnium. The movement of the control rods, in or out of the reactor core, controls the number of neutrons causing fission.

Heat Exchanger : In heat exchanger, the heat carried by coolant is given to the feed water. This heat converts feed water into steam which is utilized in driving the steam turbine.

- Other equipments like steam turbines, condensers, cooling towers, alternators, etc. are similar to those used in the conventional thermal power stations.

1.11.4 Comparison of Various Types of Power Stations

Table 1.1 : Comparison of Various Types of Power Stations

Particulars	Thermal Power Stations	Hydro-Electric Power Stations	Nuclear Power Stations
Source of Energy and its Availability	The source of energy is coal. Limited coal reserves are available all over the world.	Water is the source of energy. It has replenishable reserves.	The source of energy is the nuclear fuels which are available in sufficient quantity.
Site	Such power stations are generally located near the load centres. However, they are also installed near the coal mines to reduce the transportation cost.	These power stations are normally located in mountainous regions away from the load centres.	These power stations can be located anywhere. But are preferably located away from thickly populated areas to avoid the radiation hazards.
Space	Require sufficiently large space.	Require very large space.	Require minimum space.
Completion Period	3 to 4 years	10 years.	10 years.
Starting Time	Require sufficiently large time for starting.	Can be started instantaneously.	Require less time.
Initial Cost	Initial cost is comparatively low.	Initial cost is very high because of huge civil engineering construction works involved.	Initial cost is the highest.
Running Cost	Comparatively higher.	Practically nil.	Minimum running cost, even though higher than hydro-electric power stations.
Maintenance Cost	Quite high.	Quite low.	Very high.
Transmission and Distribution Cost	Quite low, being near to the load centres.	Quite high, being away from the load centres.	Quite low, being near to the load centres.
Simplicity and Cleanliness	Complex and least clean.	Simple and clean.	Most complex, however, clean.
Standby Losses	Maximum	No standby losses.	Less standby losses.
Overall Efficiency	Least efficiency.	Most efficient.	Sufficiently efficient.
Field of Application	Generally used to supply the base load.	Can be used to supply the peak load or base load.	Used to supply the base load.

1.12 ELECTRICAL POWER SYSTEM

- In general, the modern power system consists of the following three principal elements :
  (i) Generating stations,
  (ii) Transmission lines,
  (iii) Distribution systems.
- As already seen, electrical energy is produced in bulk at the generating stations. Transmission lines transmit this energy to distribution systems and thus serve as connecting links between the generating stations and distribution systems. Distribution systems then distribute the energy received by them to all the individual loads.

1.13 TRANSMISSION AND DISTRIBUTION OF ELECTRICAL POWER

- While discussing the three-phase supply systems later on in Section 7.3, we have assumed there that the electrical power is directly supplied by an alternator to the load. However, this is the case with only small alternators supplying power over relatively short distances. The present-day electric systems involve the extensive use of transformers to step up the generation voltage before the power is transmitted to the distant load centres. The reasons for adoption of high voltage for transmission of electrical power are discussed briefly in the Section 5.1. The power stations (particularly the hydro-power stations) are normally located at favourable places, quite away from the load centres. Under such conditions, it is the high voltage which makes the long distance transmission economical. However, since the cost of the transmission equipments is rising with the increase in transmission voltage, compromise is to be made in the selection of transmission voltage. The high voltage at the transmitting end is again reduced at the load centres.

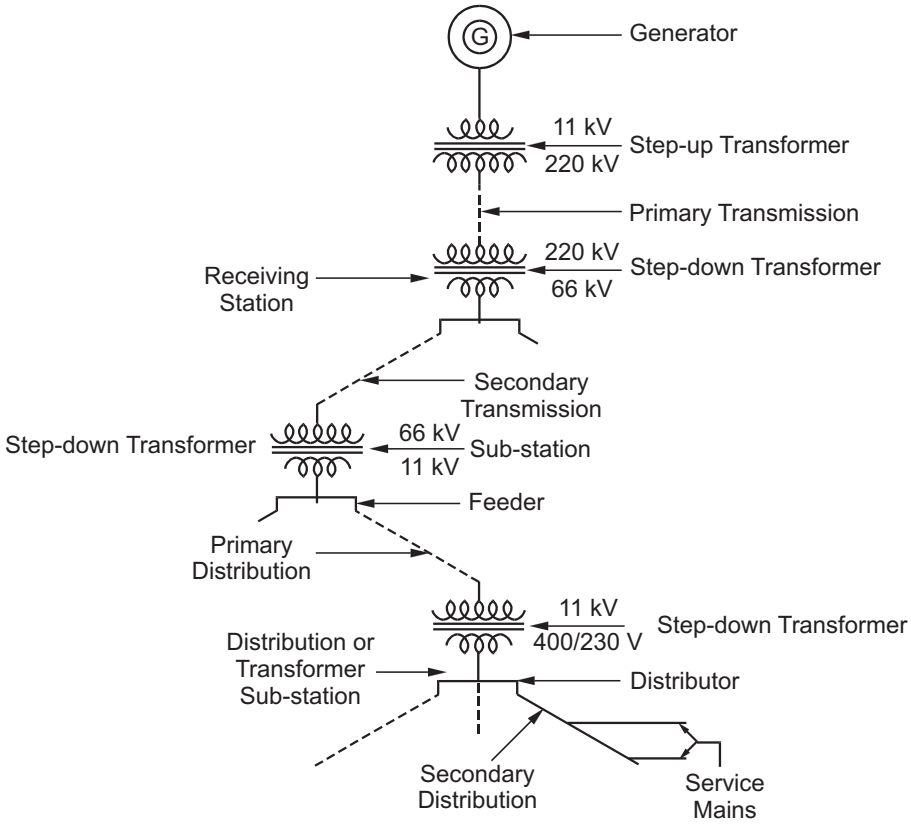


Fig. 1.9 : Layout of a typical power system

- Fig. 1.9 shows a typical alternating current transmission and distribution system with the help of a single line diagram.

Stages Involved in Transmission and Distribution of Electrical Power : The various stages involved in the transmission and distribution of electrical power are as follows :

(i) Generating Station : The generating station, as already seen, is equipped with number of three-phase alternators. These alternators run in parallel to generate large power and are driven by various types of prime movers depending upon the type of power station.

- Usual generation voltages are 6.6, 11 or 33 kV. The generation voltage is then stepped up with the help of transformers to some suitable value such as 132, 220, 275 or 400 kV for transmission purposes.

(ii) Primary or High-Voltage Transmission : The transmission lines carry the power at the high voltage from generating station to the receiving station which is usually located at the outskirts of a city. This forms the primary transmission system. It should be noted that the distance between the generating station and the receiving station is normally very large.

(iii) Secondary or Low-Voltage Transmission : At the receiving station which is also equipped with the transformers, the primary transmission voltage is stepped down to 33 or 66 kV. The power is further transmitted at this voltage to the sub-stations located in different areas in the city. This stage is known as secondary or low-voltage transmission.

(iv) Primary or High-Voltage Distribution : During this stage, the transformers at the substations step down the voltage to a value as low as 3.3, 6.6 or 11 kV and feed the transformer sub-stations (also known as distribution sub-stations) serving the various localities. Big factories may be supplied directly at this voltage.

(v) Secondary or Low-Voltage Distribution : The voltage is further reduced to 400/230 volts at the transformer sub-stations to suit the secondary distribution system which feeds the consumers.

- In the context of the a.c. transmission and distribution systems, the following points are worth noting :
  - (i) All the existing systems do not include all the stages discussed above. e.g. Some may have no primary transmission and others may be so small that there is, in effect, distribution only and so on.
  - (ii) Generation, transmission and distribution are almost exclusively three-phase.
  - (iii) For transmission and primary distribution, the three-phase, three wire system with high voltage has been universally adopted. For secondary distribution, the three-phase, four wire system has been standardized as it gives 400 volts between phases for large industrial loads such as motors and 230 volts between any phase and the neutral for small domestic consumers.
  - (iv) For ensuring continuity of service and to meet the future demand, transmission is generally by the duplicate lines. Such lines are known as ***double circuit lines***. These two 3-phase transmission lines work in parallel and are run on the same towers.
  - (v) In general, the conductors in the distribution system may be grouped under three headings, ***feeders, distributors*** and ***service mains***. Feeders are the conductors, between the sub-station and distribution sub-station and distributors normally radiate off from the distribution sub-station and are tapped at various points for supply to the consumers. The tappings in the consumer's premises from the distributors are known as service mains.

1.14 POINTS TO REMEMBER

- Total deficiency or excess of electrons in a body can be called its ***charge***. It is the charge possessed by 6.24×10^{18} electrons.
- The ***electric current*** is defined as the rate of transfer of electric charge per unit time. The practical unit of current is the ***ampere***. A current of one ampere is said to be flowing in the conductor when a charge of one coulomb (6.24×10^{18} electrons) is passing any given point on it in one second.
- The ***electric potential*** at any point in an electric field is defined as equal to the work done, in joules, in moving a unit positive charge from infinity (which is considered as a place of zero potential) to that point against the electric field. The unit of electric potential is ***volt***. The electric potential at a point in an electric field is said to be one volt when the work done in moving a unit positive charge from infinity to that point against the electric field is one joule.
- The ***potential difference*** between two points in the electric field is the work done, in joules, in moving a unit positive charge from the point of lower potential to the point of higher potential. The unit for potential difference is also ***volt***. Potential difference between two points in the electric field is said to be one volt when the work done in moving a unit positive charge from the point of lower potential to the point of higher potential is one joule.
- The potential difference generated by a source of electrical energy across its terminals which tends to produce an electric current in the circuit is called an ***electromotive force*** (abbreviated as e.m.f.). Similar to potential difference, its unit is also ***volt***.
- ***Resistance*** is the property of a substance by virtue of which it opposes the flow of current through it. The unit of resistance is ***ohm***. A conductor is said to have a resistance of one ohm, if a steady (d.c.) current of one ampere flowing through it, produces heat at the rate of one joule per second.
- The resistance of a specimen piece of a material having unit length and unit cross-sectional area is known as ***specific resistance*** or ***resistivity*** of that material. The unit of the specific resistance is ***ohm-m***.

- ***Conductance*** is defined as the reciprocal of resistance. Its unit is ***siemens***.
- ***Specific conductance*** or ***conductivity*** of a conductor is nothing but the reciprocal of its specific resistance. The unit of specific conductance or conductivity is ***siemens/metre***.
- ***Ohm's law*** can be stated as follows : The current flowing through a solid conductor is directly proportional to the difference of potential across the conductor and inversely proportional to its resistance, provided the temperature remains constant.
- Energy exists in different forms in nature, but the most important form is the electrical energy. This is because it can be generated centrally in bulk and transmitted economically over long distances.
- Conventionally, electrical energy is obtained by conversion from fossil fuels (e.g. coal, oil, natural gas), the nuclear and hydro sources. Non-conventional energy sources which are presently being explored for producing electrical energy include solar, wind, tidal and geo-thermal sources.
- Generating stations are the centres where electrical energy is produced in bulk, exclusively in the form of alternating current.
- Chemical energy stored in coal is transformed into electrical energy in ***thermal power stations***, whereas ***hydro-electric power stations*** convert the potential energy of water into electrical energy. Nuclear energy is converted into electrical energy by ***nuclear power stations***.
- Electrical energy is produced in bulk at the generating stations. Transmission lines transmit this energy to distribution systems and thus serve as connecting links between the generating stations and distribution systems. Distribution systems distribute the energy received by them to all the individual loads.
- Generation, transmission and distribution are almost exclusively three-phase.
- For transmission and primary distribution, the three-phase, three-wire system with high voltage has been universally adopted. For secondary distribution, the three-phase, four-wire system has been standardized.
- ***Feeders*** are the conductors between the sub-station and distribution sub-station. ***Distributors*** normally radiate off from the distribution sub-station and are tapped at various points for supply to the consumers. The tappings in the consumer premises from the distributors are known as ***service mains***.

1.15 IMPORTANT FORMULAE AT A GLANCE

- $$R = \rho \frac{l}{a} \text{ ohms}$$

  where, ρ = Specific resistance of the material, in Ω-m
  l = Length of the conductor, in m
  a = Cross-sectional area of the conductor, in m^2

- $$G = \frac{1}{R} = \frac{a}{\rho l} \text{ siemens}$$

  where, R = Resistance of the material, in ohms
  l = Length of the conductor, in m
  a = Cross-sectional area of the conductor, in m^2
  ρ = Specific resistance of the material, in Ω-m

- $$\sigma = \frac{1}{\rho} = \frac{Gl}{a} \text{ siemens/metre}$$

  where, G = Conductance of the material, in siemens
  l = Length of the conductor, in m
  a = Cross-sectional area of the conductor, in m^2
  ρ = Specific resistance of the material, in Ω-m

- $$I = \frac{V}{R} \text{ amperes}$$

  where, V = Potential difference across the conductor, in volts
  R = Resistance of a conductor, in ohms

1.16 EXERCISES

1.16.1 Review Questions

1. Describe the mechanism of current or the flow of electricity, according to the modern theory.
2. What is charge ? What is its unit ?
3. Explain the relation between charge and current.
4. What is the difference between e.m.f. and potential difference ?
5. Define the terms : Electric potential, Potential difference, E.M.F.
6. Define the terms resistance, specific resistance, conductance and specific conductance of a material. State their units. Also write their formulas.
7. What fundamental relation does Ohm's law express ? Give the three forms in which the law may be expressed.
8. Name the different types of generating stations and discuss in brief any one of them with the help of a neat schematic diagram.
9. Draw a layout of a typical power system and explain in brief the stages involved in the transmission of electrical power from the generating station to consumer's premises.

1.16.2 Examples for Practice

1. Find the resistance of a 200 m length of wire having a uniform cross-sectional area of 0.02 mm^2 and resistivity of 50 μΩ-cm. (5000 Ω)
2. Two aluminium conductors have the same length but one has cross-sectional area twice that of the other. If the conductor having larger cross-sectional area has a resistance of 30 Ω, find the resistance of the other. (60 Ω)
3. If the resistance of a metallic wire 100 m in length and with a diameter of 0.45 mm is 10 Ω, find the specific resistance of its material. (1.6×10^{-8} Ω-m)
4. When a voltage of 5 V is applied across a circuit, it draws a current of 15 μA. Find the conductance of a circuit. (3×10^{-6} S)
5. The resistance of a 250 m long wire of some material with uniform cross-sectional area is 500 Ω. If this wire is redrawn to 3 times its original length without any change in volume, find its new resistance. (4500 Ω)

CHAPTER

TWO

D. C. CIRCUITS

2.1 INTRODUCTION

- The ***electrical circuit*** serves as a means of energy transfer from the source of electrical energy to the load with the help of the connecting wires or in simple words, provides a path for the current flow from the source to the load.
- In the study of electrical engineering which involves the study of the behaviour of electrical systems and devices, the knowledge of electric circuit theory is very essential. We are therefore beginning our study of electrical circuit theory with the study of various methods of network analysis and principal theorems which have been developed for solving problems on complex electrical networks.
- Even though the discussion in this chapter is restricted to d.c. circuits only, it is equally applicable to a.c. networks. In the case of a.c. networks, the only difference is that the impedances are used instead of just ohmic resistances. Since the impedances as well as currents and voltages in such circuits are expressed by complex numbers, the algebraic manipulations are more extensive.

2.2 CLASSIFICATION OF ELECTRICAL NETWORKS

- An electrical circuit or network is a combination of various elements consisting of sources of energy and components like resistors, capacitors and inductors, either in lumped or distributed form.
- The behaviour of entire network depends on the behaviour of its individual elements and accordingly, they can be classified as follows:
  - **(i) Linear Circuits:** A circuit whose parameters are always constant irrespective of variations in voltage or current is known as *a* ***linear circuit***. The current flowing in each parameter of such a circuit is directly proportional to the voltage applied across it.
  - **(ii) Non-linear Circuits:** A ***non-linear circuit*** is one whose parameters change with voltage or current.
  - **(iii) Bilateral Circuits:** It is that circuit whose characteristics are the same irrespective of its direction of operation, e.g. a transmission line. It has the same relationship between the current and the voltage for the current flowing in either direction.
  - **(iv) Unilateral Circuits:** A circuit whose characteristics are dependent on the direction of its operation is called a ***unilateral circuit***, e.g. circuits containing elements like vacuum diodes, silicon diodes, selenium rectifiers, etc., which allow the current to pass only in one direction.
  - **(v) Active Networks:** When a network contains a source of energy, it is said to be ***active***. An energy source may be a voltage or a current source.
  - **(vi) Passive Networks:** A network is said to be ***passive*** if it contains no source of energy.

2.3 ENERGY SOURCES

- All electric circuits are driven by several kinds of sources of electrical energy. These sources may be independent of other network variables as in the case of d.c. generators, batteries, etc. On the other hand, they may be of dependent type, such as is frequently encountered in electronic circuits. The discussion here is confined to the independent type of energy sources only.

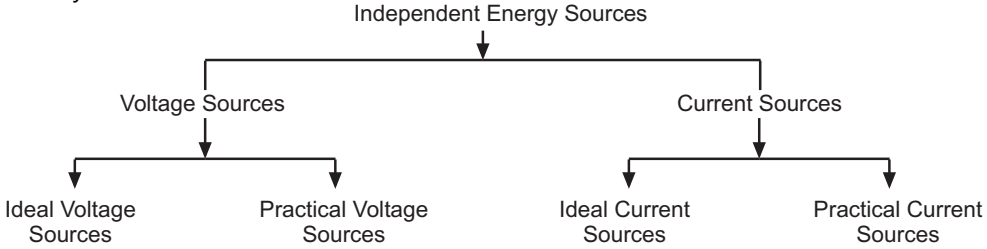


Fig. 2.1: Classification of independent energy sources