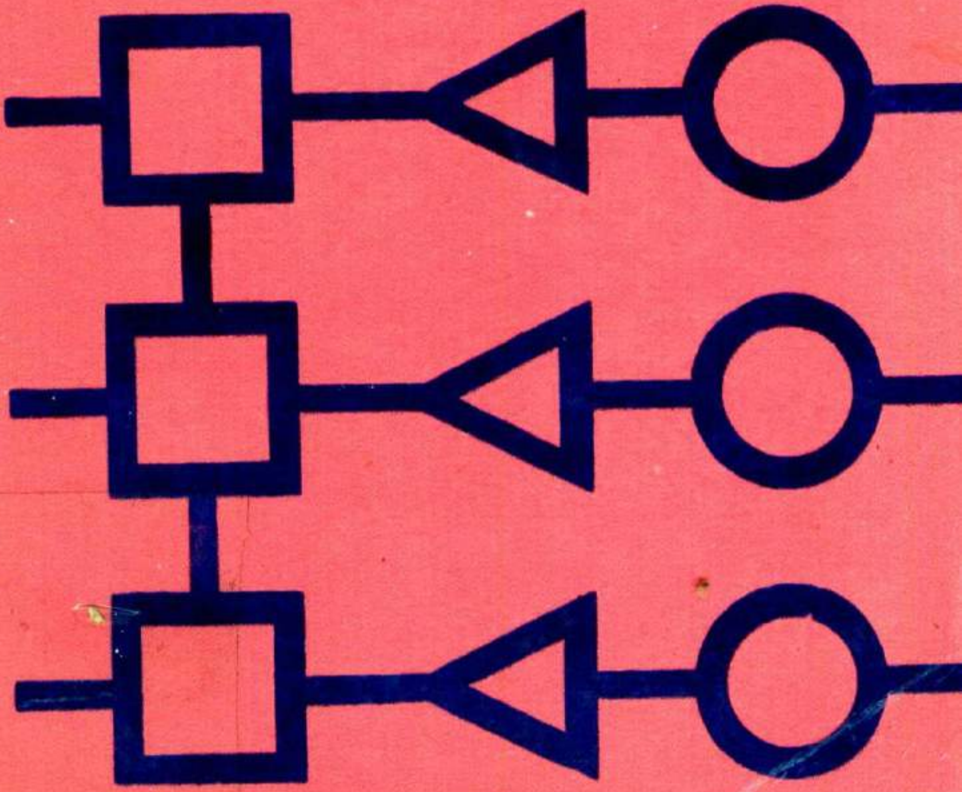
ELEMENTS OF ELECTRICAL POWER STATION DESIGN

M. V. DESHPANDE

THIRD EDITION



This work is respectfully dedicated to the memory of my beloved father Vinayakrao who is no more.

Preface

The first edition of the book was published by Sir Isaac Pitman and Sons, London. The second and enlarged edition was published by A H. Wheeler and Co Ltd. I am glad the book has been well received by the various university and engineering students and power organisations. There have been four reprints of the second edition. Considering the response, the book has been further revised and enlarged, and brought uptodate in this third edition.

In this edition, three chapters are added: Chapter 14 discusses the modern trends in power station design and operation. This includes load forecasting, economic load dispatch, unit commitment problem, methods of scheduling stations, allocation control, system reliability and system security. Chapter 15 deals with the trends in power plant instrumentation and control. In this Chapter introduction to solid state relaying, overcurrent and differential type is done. Important problem of pollution control and performance standards of thermal stations is discussed. Application of computers in power systems is touched. Chapter 16 explains the need of using unconventional sources of energy and plants to save fossil fuels. Rural energy demands and methods of forecasting energy demands are discussed. Biogas plants, biomass plants and their applications are mentioned. Solar electric systems and wind electric systems are explained with their principle, applications and preliminary design.

I hope with these additions, the book will be covering these modern trends and bring these developments to the notice of the students and the readers. I am thankful to my engineer friends who have made useful suggestions to bring the book uptodate.

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Contents

Principal Symbols and Abbreviations Used in this Book

Symbols for quantities are in *italic* type, and abbreviations for the names of units are in ordinary type.

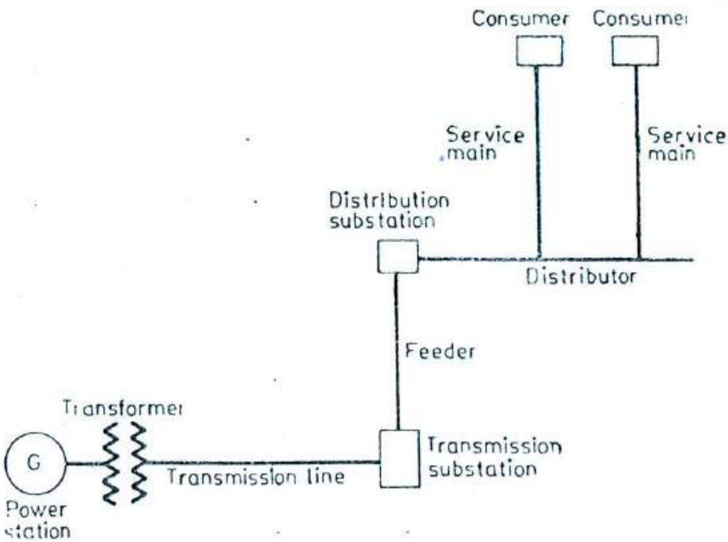
A	ampere
A	mass number
a. c.	alternating current
a_c	number of ampere-coductors per centimetre
amu	atomic mass unit
B	magnetic flux density
C	coulomb
C	capacitance
C_s	speed factor
c	speed of light
cm	centimetre
cm Hg	centimetre of mercury
cm/sec	centimetre per second
c/s	cycle per second
D	diameter
d	cylinder bore
d.c.	direct current
E	electromotive force
eV	electron-volt
F	farad
f	frequency
g	acceleration due to gravity
H	henry
h	hour
ha	hectare
hp	horsepower
I	electric current
J	moment of inertia
K	cyclic irregularity stroke/bore ratio
k	multiplication constant radius of gyration
kcal	kilocalorie
kg	kilogramme
kg/cm^2	kilogramme per square centimetre
kg/m^3	kilogramme per cubic metre
kg-m/s	kilogramme-metre per second
km	kilometre
kV	kilovolt
kVA	kilovolt-ampere
kVAr	kilovar (reactive kilovolt ampere)
kW	kilowatt
kWh	kilowatt-hour
L	inductance
l	length stroke
MeV	mega-electron-volt
MVA	megavolt-ampere
MW	megawatt
m	metre

m	mass
	model ratio
min	minute
mm Hg	millimetre of mercury
N	number of turns
n	rotational speed
P	power
p	number of poles
p. a.	per annum (per year)
Q	electric charge
	reactive power
	volume rate of flow
R	cut-off-ratio
	resistance
r	compression ratio
rev/min	revolution per minute
rev/sec	revolution per second
S	apparent power; rating in kVA or MVA
s, sec	second
T	time-constant
	torque
V	volt
V	voltage
	volume
v	velocity
W	watt
W	energy
	weight
Wb	weber
w	weight density
X	reactance
Y	admittance
Z	atomic number
	impedance
γ	ratio of specific heats
ϵ	percentage regulation
ϵ_x	percentage reactance voltage
η	efficiency
μF	microfarad
σ	cavitation coefficient
ϕ	magnetic flux
Ω	ohm

Note : The prices are rising. The present prices should be checked and used for economic studies.

Introduction

Electricity provides a very convenient form of power for lighting, motive power for driving various types of load and power for a number of utilization applications. Generally it is economical to use this form of power. Its other advantages are cleanliness and ease of control. The annual consumption of electrical energy has been increasing rapidly throughout the world. The standard of living in a country is related, to a certain extent, to the consumption of electricity in that country. Rapid industrialisation becomes



Main parts of a power system.

possible when cheap electric power is available. With industrialisation, the standard of living improves. In India, there has recently been considerable power development under various five-year plans. Methods of producing and distributing electric power economically are being studied and developed rapidly all over the world.

The main parts of an electric power system are power stations, transmission systems, and distribution networks. These are shown in the single-line diagram.

Power stations. An electric power station is a factory in which energy is converted from one form or another into electrical energy. In a conventional thermal station, the energy is first in the form of heat in the fuel, which may be coal, gas or oil. This heat is liberated by combustion in the boiler furnace and is then used to convert water into steam. The energy in the steam is converted to the mechanical energy of a rotating shaft by some form of steam engine, either reciprocating or turbine, and this energy is converted into electrical energy by means of a generator. In a nuclear or atomic station, the energy from the splitting of the atomic fuel is released in the form of heat in the reactor, and the heat is used to convert water into steam. From this point onwards, the station is similar to a conventional thermal station, i.e., a nuclear station is similar to any other thermal station except that it is equipped with a reactor instead of a boiler. With gas or oil as the initial source of energy an alternative means of conversion is provided by the use of internal-combustion engines. In a hydro-electric station, the potential energy of water stored at a height is converted into mechanical energy by the use of a water turbine, and a generator coupled to the water turbine converts this energy into electrical energy.

The three-phase alternating-current system is almost universal. In India and in Britain the standard frequency is 50 c/s; in the United States of America it is 60 c/s. The a.c. system has the advantage that voltages can easily be stepped up or down by the use of transformers only, and no rotating machinery is required for this change-over. This facilitates the transmission and distribution of power.

Transmission and distribution. When a large bulk of power is to be transmitted over a long distance, it is economical to transmit it at a voltage higher than the distribution voltage. The most suitable voltage for the transmission of power over a certain distance should be chosen to give the best transmission efficiency, regulation and economy. The high-voltage transmission line is the second important part of a power system. A transformer to step up the generation voltage to the transmission-line voltage forms an important link between generation and transmission. The function of the transmission line is to transmit power from the sending end to the receiving end, from which the power will be distributed.

The power is received at the transmission sub-station, where transformers step down the high voltage of transmission to medium voltage to supply the feeders at the required voltage of the primary distribution network. Feeders are conductors which carry power from the transmission sub-station to various distribution sub-stations. Feeders are not tapped for direct power consumption.

The distribution sub-stations have transformers to step down the voltage of the primary network – the feeder system – to the low voltage of the distribution network. Distributors form a network of conductors from which power is distributed to the consumers at distribution voltage. The distribution network is normally 3-phase 4-wire, and the standard voltage in India is 415/240 V. Three-phase balanced loads of industrial motors, etc., are connected across the three phases, and the lighting load, with other single-phase loads, is divided into three parts, each connected between a phase and neutral. The three parts should be made nearly equal, so that the imbalance in the network is a minimum. Distributors are conductors which are tapped and which deliver power to consumers' premises through service mains.

In practice, a system is quite complicated and has a number of power stations of different types interconnected by a system of transmission lines and distribution networks to supply different types of load to various consumers. In the above discussion we have considered the main parts of the power system and their functions. In studying the design aspects of the power system we have to start from the requirements of the consumers. A number of questions crop up:

What are the various types of load? How are they to be supplied by the distributors?

What are the various methods of distributing power?

How are the sizes of the distributors determined?

How are the sizes of transformers in sub-stations and the locations of substations chosen?

How are the voltage and size of transmission-line conductors to transmit a certain power over a certain distance determined?

What are the various types of power stations?

How should the type of power station be chosen?

How are sizes of generators and prime movers selected?

How much power is to be obtained from the power stations?

What space will be required for a particular size and type of power station?

How can power be obtained and distributed economically?

How can the load be shared economically between various power stations in the power system?

The questions are numerous and the details of design which they evoke are complicated. In this book, and in a companion volume on *Electrical Power System Design*, the author aims at giving the reader the elements of power-system design and tries to answer some of the questions in a simple and logical way chapter by chapter.

Let us begin with the consumers, their requirements of power and how they affect the total power required in the system.