Stephen W. Fardo
Dale R. Patrick

Electrical Power Systems Technology

Third Edition

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Preface

Electrical Power Systems Technology (Third Edition) provides a broad overview of the production, distribution, control, conversion, and measurement of electrical power. The presentation method used in this book will allow the reader to develop an understanding of electrical power systems. The units of the book are organized in a systematic manner, beginning with electrical power production methods. The fundamentals of each major unit of the book are discussed at the beginning of the unit. These fundamentals provide a framework for the information that follows in each unit. The last unit has been expanded to include control devices.

This book deals with many important aspects of electrical power, not just with one or two areas. In this way, it will give the reader a better understanding of the *total* electrical power system—from the production of electricity to its conversion to other forms of energy. Each unit deals with a specific system, such as production, distribution, control, conversion, or measurement. Each system is broken down into subsystems. The subsystems are then explored in greater detail in the chapters that make up each unit.

In order to understand the contents of this book in depth, the reader should have a knowledge of basic electrical fundamentals. The mathematical presentations given are very simple and are used only to show the practical relationships that are important in electrical power system operation. This book is recommended as a textbook for an "electrical power" or "electrical generators and motors" course. It would be a suitable text for vocational-technical schools, community colleges, universities, and, possibly, some technical high school programs. Many illustrations are shown, to make the presentations that are given easier to understand. The content is presented in such a way that any reader should be able to learn a great deal about the operation of electrical power systems.

Stephen W. Fardo
Dale R. Patrick
Eastern Kentucky University
Richmond, KY 40475

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Contents

UNIT I

Power Measurement Systems and Fundamentals

In order to understand *electrical power measurement systems,* we must first study the fundamentals of measurement. These fundamentals deal mainly with the characteristics and types of measurement systems. Measurement systems are discussed in Chapter 1.

Chapter 2 provides an overview of the *fundamentals* that are important in the study of electrical power systems.

Chapter 3 deals with *measurement equipment and methods* associated with electrical power systems. These measurement systems include single-phase and three-phase wattmeters, power factor meters, ground-fault indicators, and many other types of equipment used in the analysis of electrical power system operation.

Figure I shows a block diagram of the *electrical power systems model* used in this textbook. This model is used to divide electrical power systems into five important systems: (1) *Power Measurement,* (2) *Power Production,* (3) *Power Distribution,* (4) *Power Conversion,* and (5) *Power Control.*

UNIT OBJECTIVES

Upon completion of Unit I, Power Measurement Systems and Fundamentals, you should be able to:

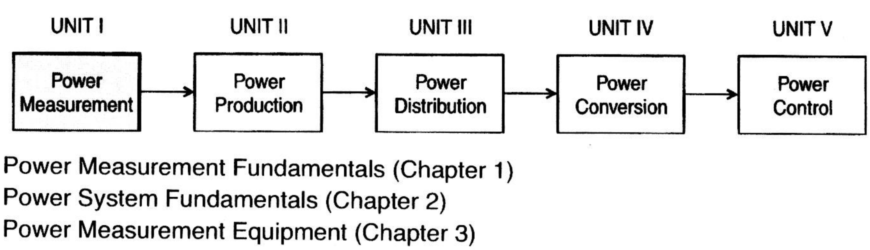

Figure I. Electrical power systems model

1. Compare the basic systems used for measurement.
2. Convert quantities from small units to large units of measurement.
3. Convert quantities from large units to small units of measurement.
4. Convert quantities from English to metric units.
5. Convert quantities from metric to English units.
6. Explain the parts of an electrical system.
7. Calculate power using the proper power formulas.
8. Draw diagrams illustrating the phase relationship between current and voltage in a capacitive circuit or inductive circuit.
9. Define capacitive reactance and inductive reactance.
10. Solve problems using the capacitive reactance formula and inductive reactance formula.
11. Define impedance.
12. Calculate impedance of series and parallel AC circuits.
13. Determine current in AC circuits.
14. Explain the relationship between AC voltages and current in resistive circuits.
15. Describe the effect of capacitors and inductors in series and in parallel.
16. Explain the characteristics of series and parallel AC circuits.
17. Solve Ohm's law problems for AC circuits.
18. Solve problems involving true power, apparent power, power factor, and reactive power in AC circuits.
19. Explain the difference between AC and DC.
20. Define the process of electromagnetic induction.
21. Describe factors affecting induced voltage.
22. Draw a simple AC generator and explain AC voltage generation.
23. Convert peak, peak-peak, average, and RMS/effective values from one to the other.
24. Describe voltage, current, and power relationships in three-phase AC circuits for wye and delta configurations.
25. Describe the following basic types of measurement systems:
    Analog Instruments
    Comparative Instruments
    CRT Display Instruments
    Numerical Readout Instruments
    Chart Recording Instruments

26. Explain the operation of an analog meter movement.
27. Describe the function of a Wheatstone bridge.
28. Explain the use of the dynamometer movement of a wattmeter to measure electrical power.
29. Describe the use of a watt-hour meter to measure electrical energy.
30. Interpret numerical readings taken by a watt-hour meter.
31. Explain the use of a power analyzer to monitor three-phase power.
32. Describe the measurement of power factor with a power factor meter.
33. Calculate power demand.
34. Explain the monitoring of power demand.
35. Explain the methods of measuring frequency.
36. Explain the use of a synchroscope.
37. Describe the use of a ground fault indicator.
38. Describe the use of a megohmmeter to measure high resistance values.
39. Describe the operation of a clamp-on current meter.
40. Describe a telemetering system.

Chapter 1

Power Measurement Fundamentals

Electrical power measurements are important quantities, which must be measured precisely. Electrical power systems are dependent upon accurate measurements for everyday operation. Thus, many types of measurements and measuring equipment are associated with electrical power systems. Measurement fundamentals will be discussed in the following sections.

Today, most nations of the world use the metric system of measurement. In the United States, the National Bureau of Standards began a study in 1968 to determine the feasibility and costs of converting the nation to the metric measurement system. Today, this conversion is incomplete.

The units of the metric system are decimal measures based on the kilogram and the meter. Although the metric system is very simple, several countries have been slow to adopt it. The United States has been one of these reluctant countries, because of the complexity of actions required by a complete changeover of measurement systems.

IMPORTANT TERMS

Chapter 1 deals with power measurement fundamentals. After studying this chapter, you should have an understanding of the following terms:

Units of Measurement
Measurement Standards
English System of Units
International System of Units (SI)
Unit Conversion Tables
Base Units

- Derived Units
- Small Unit Prefixes
- Large Unit Prefixes
- Conversion Scale
- Scientific Notation
- Powers of 10
- Electrical Power Units

UNITS OF MEASUREMENT

Units of measurement have a significant effect on our lives, but we often take them for granted. Almost everything we deal with daily is measured by using some unit of measurement. For example, such units allow us to measure the distance traveled in an automobile, the time of day, and the amount of food we eat during a meal. Units of measurement have been in existence for many years; however, they are now more precisely defined than they were centuries ago. Most units of measurement are based on the laws of physical science. For example, distance is measured in reference to the speed of light, and time is measured according to the duration of certain atomic vibrations.

The *standards* we use for measurement have an important effect on modern technology. Units of measurement must be recognized by all countries of the world. There must be ways to compare common units of measurement among different countries. Standard units of length, mass, and time are critical to international marketing and to business, industry, and science in general.

The *English system of units,* which uses such units as the inch, foot, and pound, has been used in the United States for many years. However, many other countries use the metric system, which has units such as kilometers, centimeters, and grams. The metric system is also called the *International System of Units,* and is abbreviated SI. Although the English and SI systems of measurement have direct numerical relationships, it is difficult for individuals to change from one to the other. People form habits of using either the English or the SI system.

Since both systems of measurement are used, this chapter will familiarize you with both systems, and with the conversion of units from one to the other. The *conversion tables* of Appendix C should be helpful. The SI system, which was introduced in 1960, has several advantages over the English system of measurement. It is a decimal system that uses units commonly used in business and industry, such as volts, watts, and grams. The SI system can also be universally used with ease. However, the use of other units is sometimes more convenient.

The SI system of units is *based on seven units,* which are shown in Table 1-1. Other units are derived from the base units and are shown in Table 1-2.

Table 1-1. Base Units of the SE System

Measurement Quantity	*Unit*	*Symbol*
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd
Amount of substance	mole	mol

Table 1-2. Derived Units of the SI System

Measurement Quantity	*Unit*	*Symbol*
Electric capacitance	farad	F
Electric charge	coulomb	C
Electric conductance	siemen	S
Electric potential	volt	V
Electric resistance	ohm	Ω
Energy	joule	J
Force	newton	N
Frequency	hertz	Hz
Illumination	lux	lx
Inductance	henry	H
Luminous intensity	lumen	lm
Magnetic flux	weber	Wb
Magnetic flux density	tesla	T
Power	watt	W
Pressure	pascal	Pa

Some definitions of *base units* are included below:

1. Unit of length: METER (m)—the length of the path that light travels in a vacuum during the time of 1/29,792,458 second (the speed of light).
2. Unit of mass: KILOGRAM (kg)—the mass of the international prototype, which is a cylinder of platinum-iridium alloy material stored in a vault at Sevres, France, and preserved by the International Bureau of Weights and Measures.
3. Unit of time: SECOND (s)—the duration of 9,192,631,770 periods of radiation corresponding to the transition between two levels of a Cesium-133 atom. (This is extremely stable and accurate.)
4. Unit of electric current: AMPERE (A)—the current that, if maintained in two straight parallel conductors of infinite length, placed 1 meter apart in a vacuum, will produce a force of 2×10^{-7} newtons per meter between the two conductors.
5. Unit of temperature: KELVIN (K)—an amount of 1/273.16 of the temperature of the triple point of water. (This is where ice begins to form, and ice, water, and water vapor exist at the same time.) Thus, 0 degrees Centigrade = 273.16 Kelvins.
6. Unit of luminous intensity: CANDELA (cd)—the intensity of a source that produces radiation of a frequency of 540×10^{12} Hertz.
7. Unit of amount of substance: MOLE (mol)—an amount that contains as many atoms, molecules, or other specified particles as there are atoms in 0.012 kilograms of Carbon-12.

As you can see, these are highly precise units of measurement. The definitions are included to illustrate that point. Below, a few examples of *derived units* are also listed:

1. Unit of energy: JOULE (J)—the work done when one newton is applied at a point and displaced a distance of one meter in the direction of the force; 1 joule = 1 newton meter.
2. Unit of power: WATT (W)—the amount of power that causes the production of energy at a rate of 1 joule per second; 1 watt = 1 joule per second.
3. Unit of capacitance: FARAD (F)—the capacitance of a capacitor in which a difference of potential of 1 volt appears between its plates when it is charged to 1 coulomb; 1 farad = 1 coulomb per volt.

4. Unit of electrical charge: COULOMB (C)—the amount of electrical charge transferred in 1 second by a current of 1 ampere; 1 coulomb = 1 ampere per second.

CONVERSION OF SI UNITS

Sometimes it is necessary to make conversions of SI units, so that very large or very small numerals may be avoided. For this reason, decimal *multiples* and *submultiples* of the base units have been developed, by using standard prefixes. These standard prefixes are shown in Table 1-3. Multiples and submultiples of SI units are produced by adding prefixes to the base unit. Simply multiply the value of the unit by the factors listed in Table 1-3. For example:

1 kilowatt = 1000 watts
1 microampere = 10^{-6} ampere
1 megohm= 1,000,000 ohms

Table 1-3. SI Standard Prefixes

Prefix	*Symbol*	*Factor by Which the Unit is Multiplied*
exa	E	1,000,000,000,000,000,000 = 10^{18}
peta	P	1,000,000,000,000,000 = 10^{15}
tera	T	1,000,000,000,000 = 10^{12}
giga	G	1,000,000,000 = 10^{9}
mega	M	1,000,000 = 10^{6}
kilo	k	1,000 = 10^{3}
hecto	h	100 = 10^{2}
deka	da	10 = 10^{1}
deci	d	0.1 = 10^{-1}
centi	c	0.01 = 10^{-2}
milli	m	0.001 = 10^{-3}
micro	μ	0.000001 = 10^{-6}
nano	n	0.000000001 = 10^{-9}
pico	P	0.000000000001 = 10^{-12}
femto	f	0.000000000000001 = 10^{-15}
atto	a	0.000000000000000001 = 10^{-18}