CHAPTER 1

SYSTEM OVERVIEW, TERMINOLOGY, AND BASIC CONCEPTS

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CHAPTER OBJECTIVES

After completing this chapter, the reader will be able to:

- ☑ *Discuss the history of electricity*
- ☑ *Explain the differences between voltage, current, power, and energy*
- ☑ *Describe how electricity is generated using nature's physical laws*
- ☑ *Describe the three types of load (electrical consumption) and their characteristics*
- ☑ *Discuss the three main components of a generator*

HISTORY OF ELECTRIC POWER

Benjamin Franklin is known for his discovery of electricity. Born in 1706, he began studying electricity in the early 1750s. His observations, including his kite experiment, verified the nature of electricity. He knew that lightning was very powerful and dangerous. The famous 1752 kite experiment had a pointed metal piece on the top and a metal key at the base end of the kite string. The string went through the key and attached to a Leyden jar. (A Leyden jar consists of two metal conductors separated by an insulator.) He held the string with a short section of dry silk as insulation from the lightning energy. He then flew the kite into a thunderstorm. He first noticed some loose strands of the hemp string stood erect, avoiding one another. (Hemp is a perennial American plant used in rope making by native Americans.) He proceeded to touch the key with his knuckle and received a small electrical shock.

Between 1750 and 1850, there were many great discoveries in the principles of electricity and magnetism by Volta, Coulomb, Gauss, Henry, Faraday, Tesla, and others. It was found that electrical current produces a magnetic field. And, it was found that a moving magnetic field near a wire produces electricity. This led to many

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inventions such as the battery (1800), generator (1831), motor (1831), telegraph (1837) and telephone (1876), plus many other intriguing inventions.

In 1879, Thomas Edison invented a more efficient light bulb similar to those in use today. In 1882, he placed into operation the historic Pearl Street steam-electric plant and the first direct current (dc) distribution system in New York City powering over 10,000 electric light bulbs. By the late 1880s, power demand for electric motors brought in 24-hour service and dramatically raised electricity demand for transportation and other industry needs. By the end of the 1880s, small centralized areas of electrical power distribution centers sprinkled the U.S. cities. Each distribution center was limited to a few blocks because of the transmission inefficiencies of using direct current. Voltage could not be increased or decreased using direct current systems and the need to transport power longer distances was in order.

To solve the problem of transporting electrical power long distances, George Westinghouse developed a device called the "transformer." The transformer allowed electrical energy to be transported long distances efficiently by raising the voltage to reduce losses. This made it possible to supply electric power to homes and businesses located far from the electric generating plants. The application of transformers required the distribution system to be of the alternating current (ac) type opposed to direct current (dc) type.

The development of the Niagara Falls hydroelectric power plant in 1896 initiated the practice of placing electric power generating plants far from consumption areas. The Niagara plant produced electricity to Buffalo, NY over 20 miles away. With Niagara, Westinghouse, using technology developed by Nicolas Tesla, who convincingly demonstrated the superiority of transporting power long distances with electricity using alternating current (ac) instead of direct current (dc). Niagara was the first large power system to supply multiple large consumers with only one power line across a long distance.

Since the early 1900s, alternating current power systems began appearing throughout the United States. These power systems became interconnected to form what we know today as four major power grids in the United States and Canada.

It is interesting to note, however that direct current systems are coming back. For example, rooftop solar, dc transmission lines, and other dc generation and load devices are growing at a significant rate.

The remainder of this chapter discusses the fundamental terms and concepts used in today's electric power systems based on this impressive history.

SYSTEM OVERVIEW

Electric power systems are real-time energy delivery systems. Real-time meaning power is generated, transported, and supplied the moment you turn on the light switch. Electric power systems are not storage systems like water systems and gas systems. Instead, generators produce the energy as the demand calls for it!

Figure 1-1 shows the basic building blocks of an electric power system. Starting with *generation*, where electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable

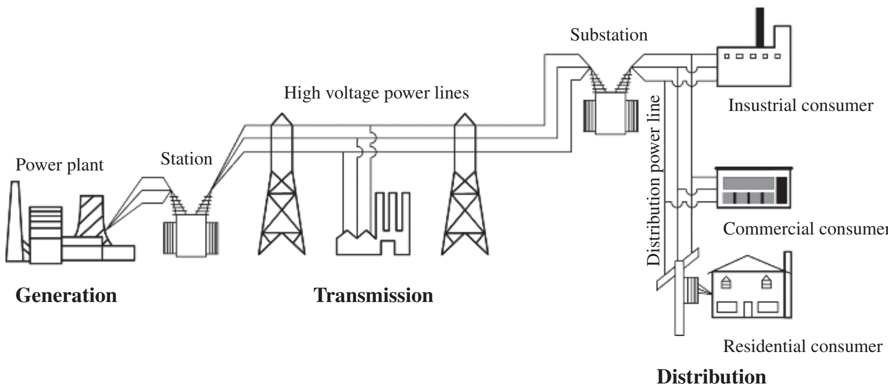

Figure 1-1 System overview.

for efficient long-distance transportation. The power plants transform other sources of energy as well in the process of producing electrical energy. For example, heat, mechanical, hydraulic, chemical, solar, wind, geothermal, nuclear, and other energy sources are used in the production of electrical energy. High-voltage (HV) power lines in the *transmission* portion of the electric power system efficiently transport electrical energy long distances to the consumption locations. Finally, the remote substations are responsible for transforming this HV electrical energy for delivery on lower high-voltage power lines called "Feeders" that are more suitable for the *distribution* of electrical energy. This electrical energy is again transformed to even lower voltage services for residential, commercial, and industrial consumption.

A full-scale actual interconnected electric power system is much more complex than that shown; however, the basic principles, concepts, theories, and terminologies are all the same. We will start with the basics and add complexity as we progress through the material.

TERMINOLOGY

Let us start with building a good understanding of the basic terms and concepts most often used by industry professionals and experts to describe and discuss electrical issues in small-to-large power systems. Please take the time necessary to grasp these basic terms and concepts. We will use them throughout this book to build a complete working knowledge of electrical power systems.

Voltage

The first term or concept to understand is *voltage*. Voltage is the *potential energy* source in an electrical circuit to make things happen. It is sometimes called *electromotive force* or EMF. The unit of Voltage is the ***Volt***. The Volt was named in honor of Allessandro Giuseppe Antonio Anastasio Volta (1745–1827), the Italian physicist who also invented the battery. Electrical voltage is identified by the symbol “e” or “E” (some references use symbols “v” or “V”).

Voltage is the electric power system’s potential energy source. Voltage does nothing by itself but has the potential to do work. Voltage is a push or a force. Voltage always appears between two points. Voltage is what pushes and pulls electrons through wires.

Normally, voltage is either constant (i.e., direct) or alternating. Electric power systems are based on alternating voltage applications from low voltage 120 V residential systems to ultra-high voltage 765,000 V transmission systems. There are lower- and higher-voltage applications involved in electric power systems, but this is the range commonly used to cover generation through distribution and consumption.

In water systems, voltage corresponds to the pressure that pushes water through a pipe. Similar to voltage in wires, pressure is present in water pipes even though no water is flowing!

Current

Current is the flow of electrons in a *conductor* (wire). Electrons are pushed and pulled by voltage through an *electrical circuit* or closed loop path. The electrons flowing in a conductor always return to their voltage source. The unit of Current is *ampere* (also called amps), named after Andre-Marie Ampere, a French physicist. (One ampere is equal to 628×10^{16} electrons flowing in the conductor per second.) The number of electrons never decreases in a loop or circuit. The flow of electrons in a conductor produces heat from the conductor’s *resistance* (i.e., friction).

Voltage always tries to push or pull current. Therefore, when a complete circuit or closed loop path is provided, voltage will cause current to flow. The resistance in the circuit will reduce the amount of current flow and will cause heat to occur. The *potential energy* of the voltage source is hereby converted into *kinetic energy* as the electrons flow. The kinetic energy is then utilized by the *load* (i.e., consumption device(s)), where it is converted into useful work.

Current flow in a conductor is similar to ping-pong balls lined up in a tube. Referring to Figure 1-2, a pressure on one end of the tube (i.e., voltage) pushes the balls through the tube. The pressure source (i.e., battery) collects the balls exiting the tube and re-enters them into the tube in a circulating manner (closed loop path).

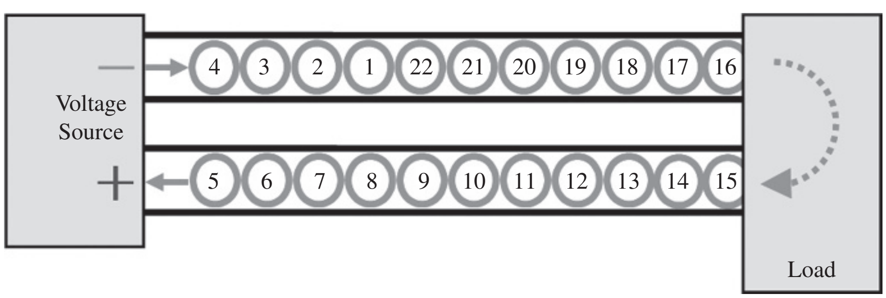

Figure 1-2 Current flow.

The number of balls traveling through the tube per second is analogous to current. This movement of electrons in a specified direction is called *current*. Electrical current is identified by the symbol "*i*" or "*I*."

Hole Flow vs. Electron Flow

Electron flow is when electrons go from one atom to the next while moving toward the positive side of the voltage source. As an electron leaves one atom and goes to the next, it leaves a hole or vacancy behind. The holes left behind can be thought of as a current of vacancies moving toward the negative side of the voltage source. Therefore, as electrons flow in a circuit one direction, holes are created in the same circuit that flow in the opposite direction. Current is defined as either electron flow or hole flow. *The standard convention used in electrical circuits is hole flow!* (One reason for this is that the concept of positive (+) and negative (−) terminals on a battery or voltage source was established long before the electron was discovered. The early experiments simply defined current flow as being from positive to negative, without really knowing what was actually moving!)

One important phenomenon about current flowing in a wire that we will discuss in more detail later is the fact that "*a current flowing in a conductor produces a magnetic field!*" See Figure 1-3. This is a physical law, similar to gravity being a physical law. For now, just keep in mind that when electrons are pushed or pulled through a

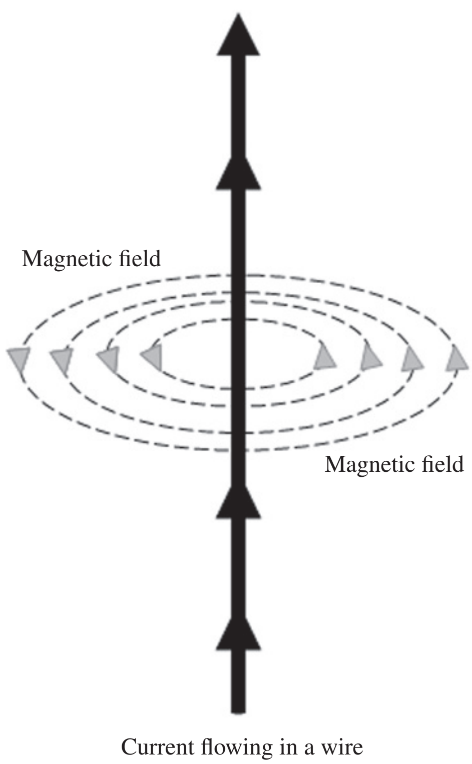

Figure 1-3 Current and magnetic field.

wire by voltage, a magnetic field is produced automatically around the wire. Note: Figure 1-3 is a diagram that corresponds to the direction of conventional or hole flow current according to the "right hand rule."

Power

The unit of *power* is the *Watt*, named after James Watt (1736–1819), also the inventor of the steam engine. Voltage by itself does not do any real work. Current by itself does not do any real work. However, voltage and current together can produce real work. The product of voltage and current is power. Power is used to produce real work.

For example, electrical power can be used to create heat, spin motors, light lamps, etc. The fact that power is part voltage and part current is that power equals zero if either voltage or current is zero. Voltage might appear at a wall outlet in your home and a toaster plugged into the outlet, but until someone turns on the toaster no current flows, and hence no power occurs until the switch is turned on and current is flowing through the high-resistive wires creating heat.

Energy

Electrical *energy* is the product of electrical power and time. The amount of time a load is on (i.e., current is flowing) times the amount of power used by the load (i.e., Watts) is energy. The measurement for electrical energy is *watt-hours*. The more common units of energy in electric power systems are kilowatt-hours (kWh, meaning 1000 watt-hours) for residential applications and megawatt-hours (MWh, meaning 1,000,000 watt-hours) for the large industrial applications or the power companies themselves.

DC Voltage and Current

Direct current (dc) is the flow of electrons in a circuit that is always in the same direction. Direct current (i.e., one direction current) occurs when the voltage is kept constant, as shown in Figure 1-4. A battery, for example, produces dc current when connected to a circuit. The electrons leave the negative terminal of the battery and move through the circuit toward the positive terminal of the battery. The holes, however, flow in the opposite direction.

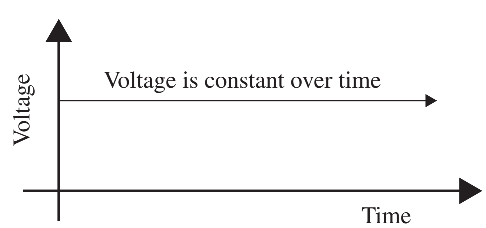

Figure 1-4 Direct (i.e., dc voltage).

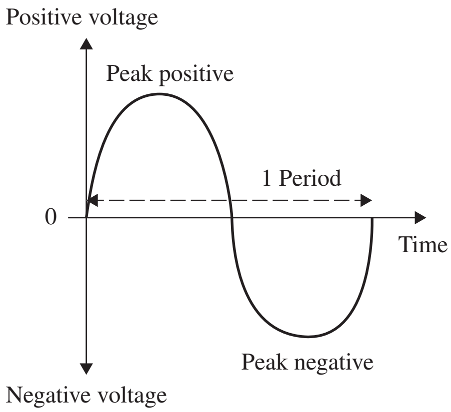

Figure 1-5 Alternating (i.e., ac voltage).

AC Voltage and Current

When the terminals of the potential energy source (i.e., voltage) alternate positive and negative, the current flowing in the electrical circuit likewise alternates positive and negative (or clockwise and counterclockwise in the closed loop path). Thus alternating current (ac) occurs when the voltage source alternates.

Figure 1-5 shows the voltage increasing from zero to a positive peak value then decreases through zero to a negative peak value and back through zero again completing one cycle or in mathematical terms; this describes a *sine wave*. The sine wave can repeat many times in a second, minute, hour, or day. The length of time it takes to complete one cycle in a second is called the *period* of the cycle.

Comparing AC and DC Voltage and Current

Electrical load such as light bulbs, toasters, and hot water heaters can be served by either ac or dc voltage and current. However, dc voltage sources continuously supply heat in the load while ac voltage sources cause heat to increase and decrease during the positive part of the cycle, then increase and decrease again in the negative part of the cycle. In ac circuits, there are actually moments of time when the voltage and current are zero and no additional heating occurs.

It is important to note that there is an equivalent ac voltage and current that will produce the same heating effect in electrical load as if the source were dc voltage and current. The equivalent voltages and currents are referred to as the *root mean squared* values, or *rms* values. The reason this concept is important to understand is that all electric power system equipment (including HV power lines) are rated in rms voltages and currents.

For example, the 120 Vac wall outlet is actually the rms value. Theoretically, one could plug a 120 Vac toaster into a 120 Vdc battery source and cook the toast in the same amount of time. The ac rms value has the same heating effect as its equivalent dc value.

(Optional Supplementary Reading)
Appendix A explains how rms is derived.

Frequency

Frequency is the term used to describe the number of sine wave cycles in a second. The number of cycles per second is also called *Hertz*. Hertz was named after Heinrich Hertz (1857–1894) a German physicist. Note: direct current (dc) has no frequency, therefore, frequency is a term used only for ac circuits.

For electric power systems in the United States, the standard frequency is 60 cycles/second or 60 Hz. The European countries have adopted 50 Hz as the standard frequency. Countries outside the United States and Europe use 50 and/or 60 Hz. (Note at one time the United States had 25, 50, and 60 Hz systems. These were later standardized to 60 Hz.)

Phase Angle

In ac power systems, the voltage and current have the same frequency but have different amplitudes and phase angles. The *phase angle* between voltage and current is shown in the Figure 1-6. Note in this figure the current wave crosses the horizontal axis after the voltage wave and therefore is said current lags the voltage. Load devices that make current lag voltage are considered *inductive* (more on this later).

Note too that the amplitude of current at the same time voltage peaked is less than the peak current. This difference in current amplitude has great significance when it comes to minimizing power losses and maximizing overall power system *efficiency*. In other words, *reducing the phase angle reduces the amount of current needed to get the same amount of work done by the loads.* For example, adding capacitors (leading devices, which behave opposite to inductors and discussed in more detail later) to motors reduces the total current required from the generation source. Reducing the total current reduces system losses and improves the overall efficiency of the power system.

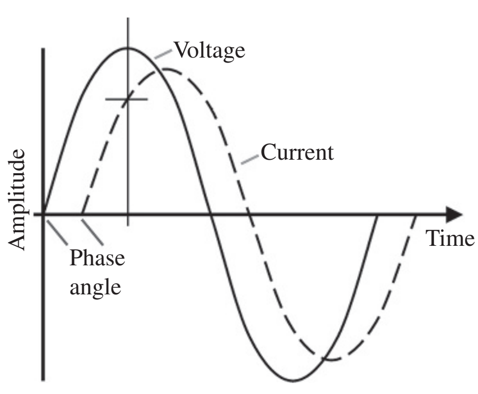

Figure 1-6 Phase angle between voltage and current.

AC VOLTAGE GENERATION

There are basically two physical laws that describe how electric power systems work. (Gravity is an example of a physical law.) One law has to do with generating a voltage from a changing magnetic field and the other has to do with a current flowing through a wire creating a magnetic field. Both physical laws are used throughout the entire electric power system from generation through transmission, distribution, and consumption. The combination of these two laws makes our electric power systems work. Understanding these two physical laws will enable the reader to fully understand and appreciate the fundamental concepts behind electric power systems operation.

Physical Law #1

AC voltage is generated in electric power systems by a very fundamental physical law called *Faraday's Law*. Faraday's Law represents the phenomena behind how electric motors turn and how electric generators produce electricity. Faraday's Law is the foundation for electric power systems.

Faraday's Law states, "A voltage is produced on any conductor in a changing magnetic field." It may be difficult to grasp the full meaning of that statement at first. It is however easier to understand the meaning and significance of this statement through graphs, pictures, and animations.

In essence, this statement is saying that if one takes a coil of wire and puts it next to a moving or rotating magnet a measurable voltage will be produced in that coil. Generators, for example, use a spinning magnet (i.e., rotor) next to a coil of wire to produce voltage. This voltage is then distributed throughout the electric power system.

We will now study how a generator works. Keep in mind that virtually all generators in service today have coils of wire mounted on stationary housings, called *stators*, where voltage is produced due to the changing *magnetic field* provided on the spinning *rotor*. The rotor is sometimes called the *field* because it is responsible for the magnetic field portion of the generator. The rotor's strong magnetic field passes the stator windings (coils), thus producing or generating an alternating voltage (ac) in the stator wires that is based on Faraday's Law. This principle will be shown and described in the following sections.

The amplitude of the generator's output voltage can be changed by changing the strength of rotor's magnetic field. Thus, the generator's output voltage can be lowered by reducing the rotor's magnetic field's strength. The means, by which the magnetic field in the rotor is actually changed will be discussed later in this book when Physical Law #2 is discussed.

Single-Phase AC Voltage Generation

Placing a coil of wire (i.e., conductor) in the presence of a moving magnetic field produces a voltage as discovered by Faraday. This principle is graphically presented in Figure 1-7. While reviewing the drawing, note that changing the rotor's speed

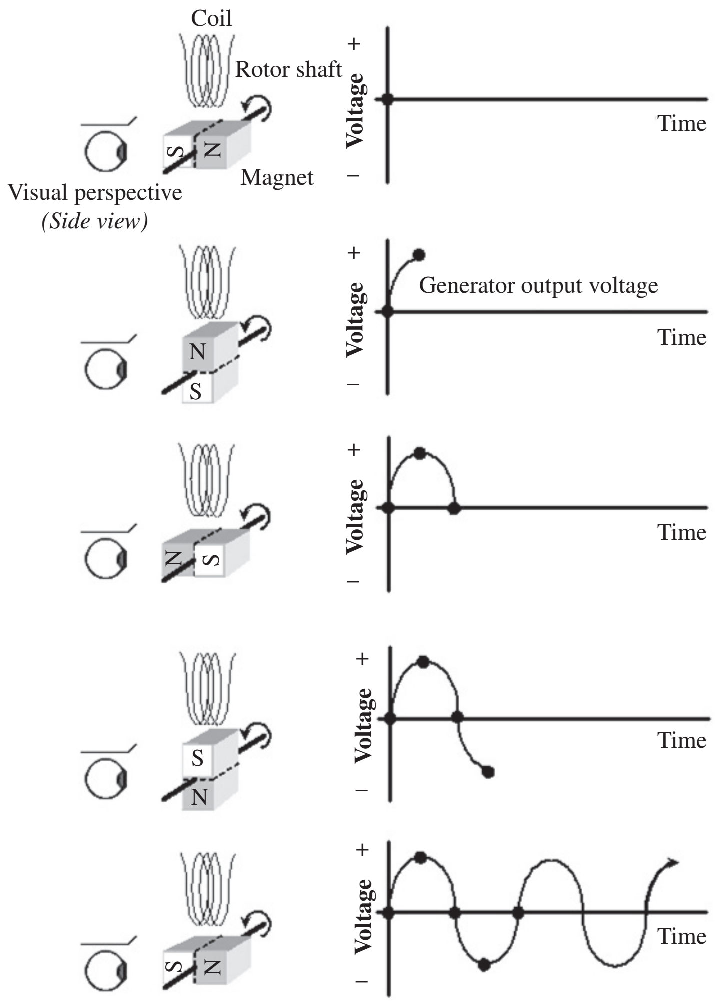

Figure 1-7 Magnetic sine wave.

changes the frequency of the sine wave. Also recognize the fact that increasing the number of turns (loops) of conductor or wire in the coil increases the resulting output voltage.

Three-Phase AC Voltage Generation

When *three* coils of wire are placed in the presence of a changing magnetic field, three independent voltages are produced. When the coils are spaced 120 degrees apart in a 360-degree circle, *three-phase* ac voltage is produced. As shown in Figure 1-8, three-phase generation can be viewed as three separate single-phase generators, each of which are displaced 120 degrees, and all of which share the same rotor's magnetic field.

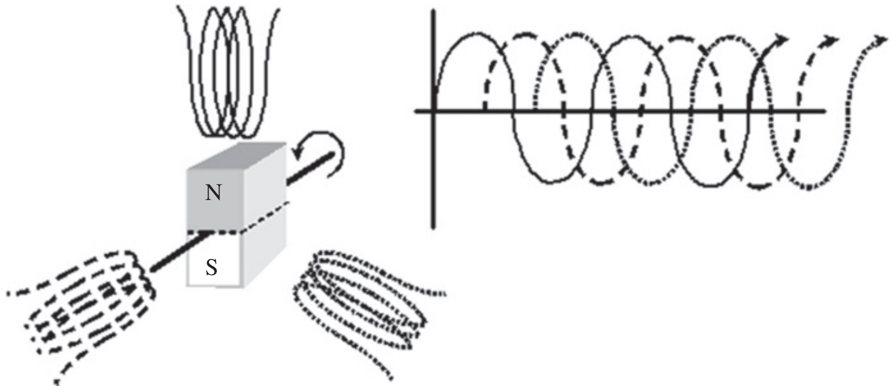

Figure 1-8 Three-phase voltage production.

The Three-Phase AC Generator

Large and small generators that are connected to the power grid system have three basic components; stator, rotor, and exciter. This section discusses these three basic components.

The Stator

A three-phase ac generator has three single-phase windings. These three windings are mounted on the stationary part of the generator, called the *stator*. The windings are physically spaced so that the changing magnetic field presented on each winding is 120 degrees out of phase with the other windings. A simplified drawing of a three-phase generator is shown in Figure 1-9.

The Rotor

The *rotor* is the center component that when turned moves the magnetic field. A rotor could have a *permanent magnet* or an *electromagnet* and still function as a generator. Large power plant generators use electromagnets so that the magnetic field strength

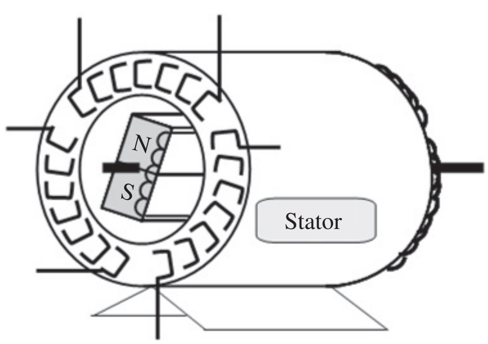

Figure 1-9 Three-phase generator–stator.

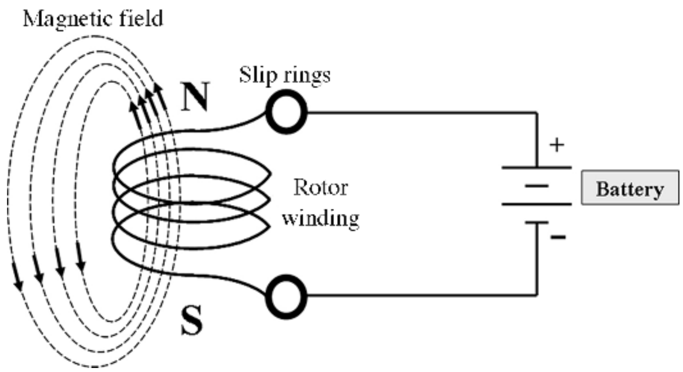

Figure 1-10 Electromagnet and slip rings.

can be varied. Varying the magnetic field of the rotor enables generation control systems to adjust the output voltage according to load demand and system losses. A drawing of an electromagnet is shown in Figure 1-10.

The operation of electromagnets is described by Physical Law #2.

Ampere's Law and Lenz's Law (Physical Law #2) The second basic physical law that explains how electric power systems work is the fact that current flowing in a wire produces a magnetic field. Ampere's and Lenz's law state that "*a current flowing in a wire produces a magnetic field around the wire*." These laws together describe the relationship between the production of magnetic fields and electrical current flowing in a wire. In essence, when current flows through a wire, a magnetic field surrounds the wire.

Electromagnets Applying a voltage (e.g., battery) to a coil of wire produces a magnetic field. The coil's magnetic field will have a north and a south pole as shown in Figure 1-10. Increasing the voltage or the number of turns in the winding increases the magnetic field. Conversely, decreasing the voltage or number of turns in the winding decreases the magnetic field. *Slip rings* are electrical contacts that are used to connect the stationary battery to the rotating rotor as shown in Figure 1-10.

Rotor Poles Increasing the number of magnetic poles on the rotor enables rotor speeds to be slower and still maintain the same electrical output frequency. Generators that require slower rotor speeds to operate properly use multiple pole rotors. For example, hydropower plants use generators with multiple pole rotors because the prime mover (i.e., water) is very dense, moves relatively slow compared to high-pressure steam turbines and harder to control than light-weight steam.

The relationship between the number of poles on the rotor and the speed of the shaft is determined using the following mathematical formula:

$$\text{Revolutions per minute} = \frac{7200}{\text{Number of poles}}$$

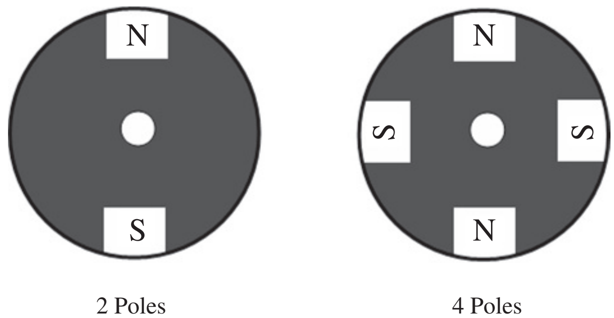

Figure 1-11 Rotor poles.

Figure 1-11 shows the concept of multiple poles in a generator rotor. Since these poles are derived from electromagnets, having multiple windings on a rotor provide the multiple poles.

Example 1. A two-pole rotor would turn 3600 rpm for 60 Hz.

Example 2. Some of the generators at Hoover Dam near Las Vegas, Nevada, use 40-pole rotor. Therefore, the rotor speed is 180 rpm or 3 revolutions per second, yet the electrical frequency is still 60 cycles/second (or 60 Hz). One can actually see the shaft turning at this relatively slow rotational speed.

The Exciter

The voltage source to the rotor that eventually creates the rotor's magnetic field is called the *exciter* and the coil on the rotor is called the *field*. Figure 1-12 shows

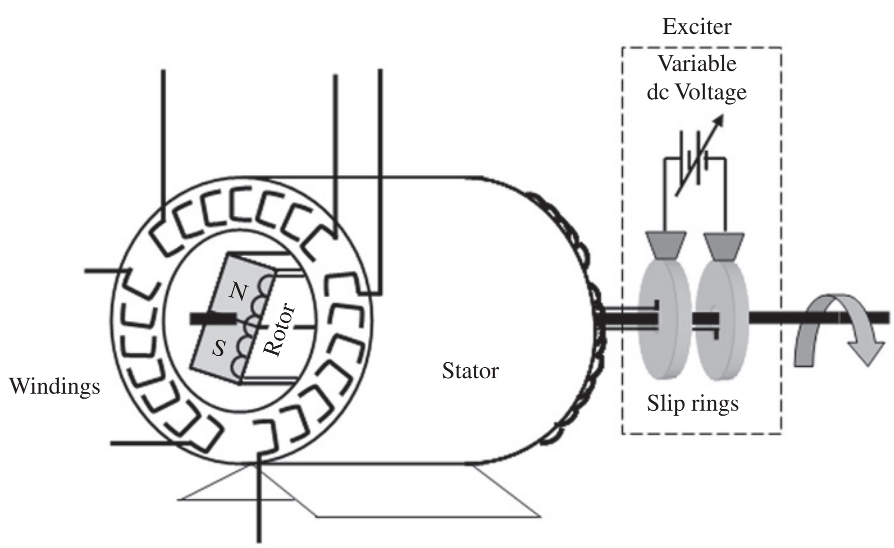

Figure 1-12 Three-phase voltage generator components.

the three main components of a three-phase ac generator; the stator, rotor, and exciter.

Figure 1-12 shows the *slip rings* used to complete the circuit between the stationary exciter voltage source and the rotating coil on the rotor, where the electromagnet produces the north and south poles.

Note: adding load to a generator's stator windings reduces rotor speed because of the repelling forces between the stator's magnetic field and the rotor's magnetic field, since both windings have electrical current flowing through them. Conversely, removing load from a generator increases rotor speed. Therefore, the *mechanical energy* of the prime mover that is responsible for spinning the rotor must be adjusted to maintain rotor speed or frequency under varying load conditions.

AC CONNECTIONS

There are two ways to connect the three windings that have a total of six leads (the ends of the winding wires) symmetrically. The two symmetrical connection configurations of a three-phase generator (or motor) are called *delta* and *wye*. Figure 1-13 shows these two connection types. Generators usually have their stator winding connected internally in either a delta or wye configuration.

The generator *nameplate* specifies which winding configuration is used on the stator.

Delta

Delta configurations have all three windings connected in series as shown in Figure 1-13. The phase leads are connected to the three common points where windings are joined.

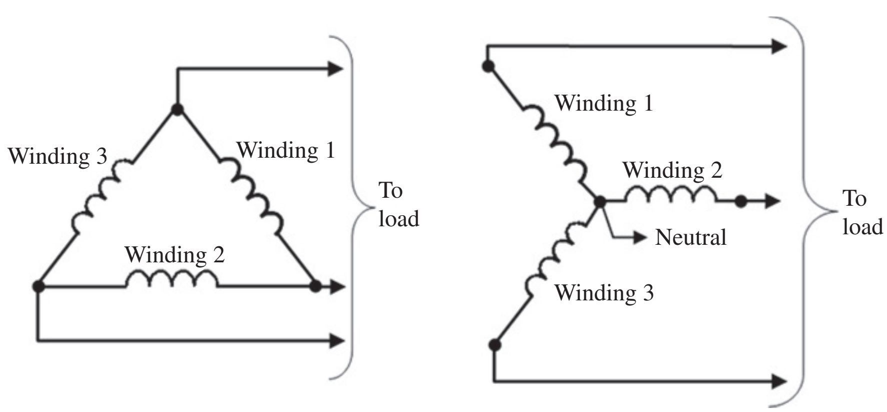

Figure 1-13 Delta and wye configurations.

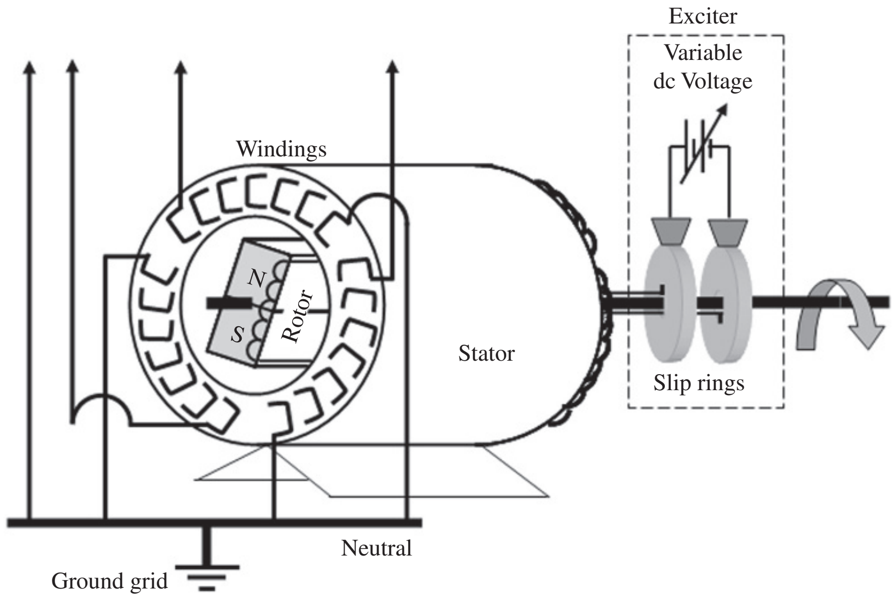

Figure 1-14 wye-connected generator.

Wye

The wye configuration connects one lead from each winding to form a common point called the *neutral*. The other three phase leads are brought out of the generator separately for external system connections. The neutral is often *grounded* to the station ground grid for voltage reference and stability purposes. Grounding the neutral is discussed later.

Wye and Delta Stator Connections

Electric power plant generators use either wye or delta stator connections. The phase leads from the generator are connected to the plant's *step-up transformer* (not shown yet), where the generator output voltage is increased significantly to transmission voltage levels for the efficient transportation of electrical energy. Step-up transformers are discussed later in this book. Figures 1-14 and 1-15 show both the wye and the delta generator connections.

THREE TYPES OF ELECTRICAL LOAD

Devices that are connected to the power system are referred to as electrical *load*. A toaster, refrigerator, bug zapper, etc. are considered electrical load. There are three types of electrical load. They vary according to their *leading* or *lagging* time or phase relationship between voltage and current.

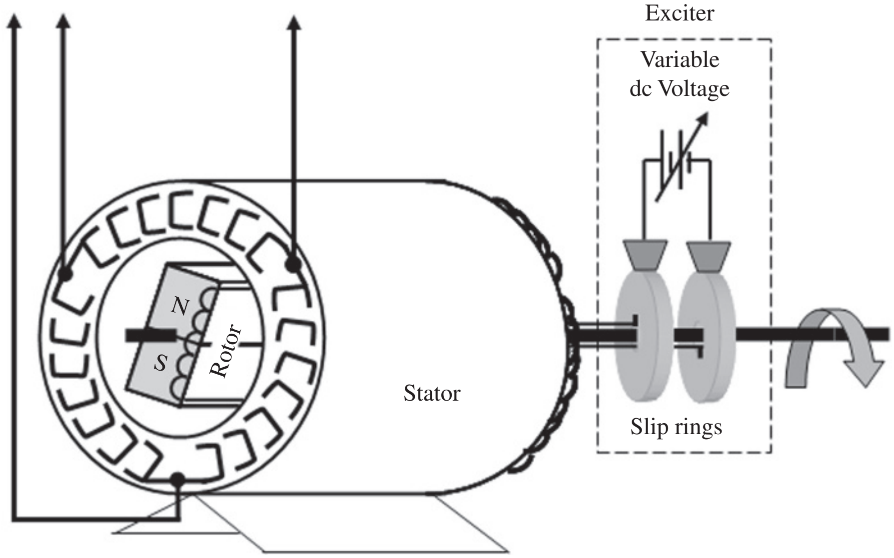

Figure 1-15 Delta-connected generator.

The three load types are *resistive*, *inductive*, *and capacitive*. Each type has specific characteristics that make them unique from each other. Understanding the differences between these load types help explain how power systems can operate efficiently. Power system engineers, system operators, maintenance personnel, and others try to maximize system efficiency on a continuous basis by having a good understanding of the three types of loads and how they interact with each other. They understand how having them work together efficiently can minimize system losses, provide additional equipment capacity, and maximize system reliability.

The three different types of load; Resistive, Inductive, and Capacitive are summarized below. The standard units of measurement are in parentheses and their symbols and abbreviations follow.

Resistive Load

The resistance in a wire (i.e., conductor) causes friction and reduces the amount of current flow if the voltage remains constant. By-products of this electrical friction are heat and light. The unit of resistance is the *Ohm*, named after George Ohm, a German mathematician and physicist. The unit of electrical power associated with resistive load is *Watts*. Examples of resistive load are shown in Figure 1-16; Light bulbs, toasters, electric hot water heaters, etc. are resistive loads.

Resistive
(Ohms)

Figure 1-16 Resistive loads.

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Inductive
(Henrys)

Figure 1-17 Inductive loads.

Inductive Load

Inductive loads require a magnetic field to operate. All electrical loads that have a coil of wire to produce the magnetic field in order to function are called inductive loads. Examples of inductive loads are shown in Figure 1-17; hair dryers, fans, blenders, vacuum cleaners, drills, and many other motorized devices. In essence, all motors are inductive loads. The unique difference about inductive load, as compared to the other load types, is that the current in an inductive load *lags* the applied voltage. Inductive loads take time to develop their magnetic field when the voltage is applied, so the current is delayed. The unit of inductance is the *Henry*, named after Joseph Henry, a U.S. physicist.

Regarding electrical motors, load placed on the spinning shaft to perform work functions draws what is referred to as *real* power (i.e., Watts) from the electrical energy source. In addition to real power, what is referred to as *reactive* power is also drawn from the electrical energy source to produce the magnetic fields in the motor. The *total power* consumed by the motor is therefore the sum of both real and reactive power. The units of electrical power associated with reactive power are called *positive VARs*. (The acronym VARs stands for volts-amps-reactive.)

Capacitive Load (Figure 1-18)

A capacitor is a device made of two metal conductors separated by an insulator, called a *dielectric* (i.e., air, paper, glass, and other non-conductive materials). These dielectric materials become charged when voltage is applied to the attached conductors. Capacitors can remain charged long after the voltage source has been removed. Examples of capacitor loads are old TV picture tubes, long extension cords, discrete components used in electronic devices, and many other devices.

Opposite to inductors, the current associated with capacitors *lead* (instead of lag) the voltage because of the time it takes the dielectric material to charge up to full voltage from the charging current. Therefore, it is said that the current in a capacitor leads the voltage. The unit of capacitance is called *Farad*, named after Michael Faraday, a British physicist.

Capacitive
(Farads)

Figure 1-18 Capacitive loads.

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Similar to inductors, the power associated with capacitors is also called reactive power, but has the opposite polarity. Thus, inductors have positive VARs and capacitors have *negative VARs*. Note: the negative VARs of inductors can be cancelled by the positive VARS of capacitors to have a net zero reactive power requirement. Therefore, when VARs cancel total power equals real power. How capacitors cancel out inductors in electrical circuits to improve system efficiency will be discussed later.

As a general rule, capacitive loads are not items that people purchase at the store in massive quantities like they do resistive and inductive loads. For that reason, power companies install capacitors on their power systems on a regular basis to maintain a reactive power balance with the typically high inductive demand.

Note: it is very helpful to understand how the three types of load (i.e., resistors, inductors, and capacitors) interact in power systems because their relationships influence system load, overall losses, revenues, and system reliability. These load types are discussed in more detail later in this book.