普通高等教育电气工程自动化系列规划教材

第2版

电气工程与自动化专业英语

ENGLISH FOR ELECTRICAL ENGINEERING AND AUTOMATION

◎ 主 编 王 伟 张殿海 裴素萍
◎ 副主编 马景兰 韩肖清

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本书分为电气工程基础、控制理论与技术、电机与电器、电力系统4大部分，共20章，涵盖了电气工程与自动化专业的主要专业基础理论内容，其中包括目前电气工程领域研究的热点内容。本书专业性和实用性强，注重从实际应用出发培养学生的专业英语阅读、表述和写作能力。每章后均补充了必要的专业英语词汇、短语及句子注释，便于不同读者对各章知识点的正确理解和自学。

本书既可作为高等院校电气工程与自动化专业学生的专业英语教材，也可作为相关专业学生和工程技术人员的参考用书。

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前　言

本书第1版自2010年8月出版以来，被多所高校的电气工程及其自动化专业及其他电气类专业作为教材用于专业英语的教学中。编者在教学过程中也收到了使用本书的教师们的反馈信息，他们在对本书给予充分肯定的同时，也提出了宝贵的建议和修改意见，在此表示由衷的感谢。

本书第2版在保持本书专业知识点突出、实用性强的基础上，主要做了以下三方面的修订和补充：

1）补充了与电气工程及其自动化专业发展相关的内容，如特种电机、微电网技术等方面的内容。

2）对部分章节的内容安排进行了调整，使整本书各知识点内容在突出专业特点和重点的同时，内容衔接更紧密。

3）为了便于相关专业和不同年级读者的使用，本书每章后增加了对重点或难点句子的中文注释，可帮助读者理解和学习有关知识点内容。

本书第2版由北京石油化工学院、沈阳工业大学、太原理工大学、中原工学院几所高校多年从事专业英语教学工作的老师联合修订。第2版共包括电气工程基础（第1~5章）、控制理论与技术（第6~10章）、电机与电器（第11~15章）及电力系统（第16~20章）4个部分，整体结构与本书第1版保持一致。参与本书修订工作的有王伟、韩肖清、张殿海、马景兰和裴素萍5位老师。全书由王伟和马景兰老师统稿。张艳丽老师由于工作原因未参加本版的修订工作，相关内容由沈阳工业大学张殿海老师负责修订，在此也对张艳丽老师在本书第1版中所做的工作表示感谢。此外，北京石油化工学院的李伟、太原理工大学的王鹏敏和河南省建筑科学研究院的刘禹等也对本书的修订做了许多工作，在此一并表示感谢。

由于编者水平和经验有限，书中难免存在疏漏和不足之处，敬请读者批评指正。

编　者

目　　录

PART 1 FUNDAMENTALS OF ELECTRIC ENGINEERING

Chapter 1 Circuit Fundamentals

1.1 Electrostatic Charges

Protons and electrons are parts of atoms that make up all things in our world. The positive charge of a proton is similar to the negative charge of an electron. However, a positive charge is the opposite of a negative charge. These charges are called electrostatic charges. Each charged particle is surrounded by an electrostatic field. [1]

The effect that electrostatic charges have on each other is very important. They either repel (move away) or attract (come together) each other. It is said that like charges repel and unlike charges attract. [2]

The atoms of some materials can be made to gain or lose electrons. The material then becomes charged. One way to do this is to rub a glass rod with a piece of silk cloth. The silk cloth pulls electrons (−) away from the glass. The glass rod loses electrons, so it now has a positive (+) charge. Since the silk cloth gains new electrons, it now has a negative (−) charge. Another way to charge a material is to rub a rubber rod with fur.

It is also possible to charge other materials when they are brought close to another charged object. If a charged rubber rod is touched against another material, the second material may become charged. [3] Remember that materials are charged due to the movement of electrons and protons.

Charged materials affect each other due to lines of force. These imaginary lines cannot be seen. However, they exert a force in all directions around a charged material. Their force is similar to the force of gravity around the earth. This force is called a gravitational field.

Most people have observed the effect of static electricity. Whenever objects become charged, it is due to static electricity. A common example of static electricity is lightning. Lightning is caused by a difference in charge (+ and −) between the earth's surface and the clouds during a storm. The arc produced by lightning is the movement of charges between the earth and the clouds. Another common effect of static electricity is being "shocked" by a doorknob after walking across a carpeted floor. Static electricity also causes clothes taken from a dryer to cling together and hair to stick to a comb.

Electrical charges are used to filter dust and soot in devices called electrostatic filters. Electrostatic precipitators are used in power plants to filter the exhaust gas that goes into the air. [4] Static electricity is also used in the manufacture of sandpaper and in the spray painting of automobiles. A device called an electroscope is used to detect a negative or positive charge.

1.2 Conductors, Insulators and Semiconductors

1.2.1 Conductors

A material through which current flows is called a conductor. A conductor passes electric current very easily. Copper and aluminum wire are commonly used as conductors. Conductors are said to have low resistance to electrical current flow. Conductors usually have three or fewer electrons in the outer orbit of their atoms. [5] Remember that the electrons of an atom orbit around the nucleus. Many metals are electrical conductors. Each metal has a different ability to conduct electric current. Materials with only one outer orbit or valence electron (gold, silver, copper) are the best conductors. For example, silver is a better conductor than copper, but it is too expensive to use in large amounts. Aluminum does not conduct electrical current as well as copper, but it is cheaper and lighter than other conductors, so it was commonly used in the past. Copper is used more than any other conductor at present.

1.2.2 Insulators

There are some materials that do not allow electric current to flow easily. The electrons of materials that are insulators are difficult to release. In some insulators, their valence shells are filled with eight electrons. The valence shells of others are over half-filled with electrons. The atoms of materials that are insulators are said to be stable. [6] Insulators have high resistance to the electric currents that pass through them. Some examples of insulators are plastic and rubber.

1.2.3 Semiconductors

Materials called semiconductors have become very important in electronics. Semiconductor materials are neither conductors nor insulators. Their classification also depends on the number of electrons that their atoms have in their valence shells. Semiconductors have 4 electrons in their valence shells. [7] Remember that conductors have outer orbits less than half-filled and insulators ordinarily have outer orbits more than half-filled. Some common types of semiconductor materials are silicon, germanium, and selenium.

1.3 Current, Voltage and Resistance

We depend on electricity to do many things that are sometimes taken for granted. There are three basic electrical terms which must be understood, current, voltage, and resistance.

1. 3. 1 Current

Static electricity is caused by stationary charges. However, electrical current is the motion of electrical charges from one point to another. Electric current is produced when electrons are removed from their atoms. [8] A force or pressure applied to a material causes electrons to be removed. The movement of electrons from one atom to another is called electric currentflow.

1. Current Flow

The usefulness of electricity is due to its electric current flow. Current flow is the movement of electrical charges along a conductor. Static electricity, or electricity at rest, has some practical uses due to electrical charges. Electric current flow allows us to use electrical energy to do many types of work.

The movement of valence shell electrons of conductors produces electrical current. The outer electrons of the atoms of a conductor are called free electrons. Energy released by these electrons as they move allows work to be done. [9] As more electrons move along a conductor, more energy is released. This is called an increased electric current flow.

To understand how current flow takes place, it is necessary to know about the atoms of conductors. Conductors, such as copper, have atoms that are loosely held together. Copper is said to have atoms connected together by metallic bonding. A copper atom has one valence shell electron, which is loosely held to the atom. These atoms are so close together that their valence shells overlap each other. Electrons can easily move from one atom to another. In any conductor the outer electrons continually move in a random manner from atom to atom. The random movement of electrons does not result in current flow, since electrons must move in the same direction to cause current flow.

When electric charges are placed on each end of a conductor, there is a difference in the charges at each end of the conductor. Current flow takes place because the free electrons move in one direction. Remember that like charges repel and unlike charges attract. Free electrons have a negative charge, so they are repelled by the negative charges at the same side. The free electrons are attracted to the positive charges on the other side and move to the other side from one atom to another. If the charges on each end of the conductor are increased, more free electrons will move. This increased movement causes more electric current flow.

Current flow is the result of electrical energy caused as electrons change orbits. This impulse moves from one electron to another. When one electron moves out of its valence shell, it enters another atom's valence shell. An electron is then repelled from that atom. This action goes on in all parts of a conductor. Remember that electric current flow produces a transfer of energy.

2. Electronic Circuits

Current flow takes place in electronic circuits. A circuit is a path or conductor for electric current flow. Electric current flows only when it has a complete, or closed-circuit, path. There must be a source of electrical energy to cause current to flow along a closed path. [10] The electrical energy is converted into more useful energy, for example the light energy.

Electric current cannot flow if a circuit is open. An open circuit does not provide a complete path for current flow. Free electrons of the conductor would no longer move from one atom to another. An example of an open circuit is a "burned-out" light bulb. Actually, the filament (the part that produces light) has become open. The open filament of a light bulb stops current flow from the source of electrical energy. This causes the bulb to stop burning, or producing light.

Another common circuit term is a short circuit. A short circuit, which can be very harmful, occurs when a conductor connects directly across the terminals of an electrical energy source. For safety purposes, a short circuit should never happen because short circuits cause too much current to flow from the source. If a wire is placed across a battery, a short circuit occurs. The battery would probably be destroyed and the wire could get hot or possibly melt due to the short circuit.

1.3.2 Voltage

Water pressure is needed to force water along a pipe. Similarly, electrical pressure is needed to force current along a conductor. If a motor is rated at 220 V, it requires 220 V of electrical pressure applied to the motor to force the proper amount of current through it. More pressure would increase the current flow and less pressure would not force enough current to flow. The motor would not operate properly with too much or too little voltage. An electrical energy source such as a battery or generator produces current flow through a circuit. As voltage is increased, the amount of current in the circuit is also increased. Voltage is also called electromotive force (EMF).[11]

1.3.3 Resistance

The opposition to current flow in electrical circuits is called resistance. Resistance is not the same for all materials. The number of free electrons in a material determines the amount of opposition to current flow. Atoms of some materials give up their free electrons easily. These materials offer low opposition to current flow. Other materials hold their outer electrons and offer high opposition to current flow.[12]

Electric current is the movement of free electrons in a material. Electric current needs a source of electrical pressure to cause the movement of free electrons through a material. An electric current will not flow if the source of electrical pressure is removed. A material will not release electrons until enough force is applied. With a constant amount of electrical force (voltage) and more opposition (resistance) to current flow, the number of electrons flowing (current) through the material is smaller. With constant voltage, current flow is increased by decreasing resistance. Decreased current results from more resistance. By increasing or decreasing the amount of resistance in a circuit, the amount of current flow can be changed.

Even very good conductors have some resistance, which limits the flow of electric current through them. The resistance of any material depends on four factors:

1) The material of which it is made;

2) The length of the material;

3) The cross-sectional area of the material;

4) The temperature of the material.

The material of which an objectbeing made affects its resistance. The ease with which different materials give up their outer electrons is very important in determining resistance. Silver is an excellent conductor of electricity. Copper, aluminum, and iron have more resistance but are more commonly used, since they are less expensive. All materials conduct an electric current to some extent, even though some (insulators) have very high resistance.

Length also affects the resistance of a conductor. The longer a conductor, the greater the resistance is. A material resists the flow of electrons because of the way in which each atom holds onto its outer electrons. The more material that is in the path of an electric current, the less current flow the circuit will have. If the length of a conductor is doubled, there is twice as much resistance in the circuit.

Another factor that affects resistance is the cross-sectional area of a material. The greater the cross-sectional area of a material is, the lower the resistance. If two conductors have the same length but twice the cross-sectional area, there is twice as much current flow through the wire with the larger cross-sectional area.

Temperature also affects resistance. For most materials, the higher the temperature, the more resistance it offers to the flow of electric current. This effect is produced because a change in the temperature of a material changes the ease with which a material releases its outer electrons. A few materials, such as carbon, have lower resistance as the temperature increases. The effect of temperature on resistance varies with the type of material. The effect of temperature on resistance is the least important of the factors that affect resistance.

1.4 Measuring Resistance, Voltage and Current

Another important activity in the study of electronics is measurement. Measurements are made in many types of electronic circuits. The proper ways of measuring resistance, voltage, and current should be learned.

Volt-Ohm-Milliammeters (VOMs), or multimeters, are the most used meters for doing electronic work. A VOM is often used to measure resistance, voltage, and current by electronics technicians. The type of measurement is changed by adjusting the "function-select switch" to the desired measurement.

The test leads used with the VOM are ordinarily black and red. These colors are used to help identify which lead is the positive and which is the negative side of the meter. Red indicates positive (+) polarity and black indicates the negative (−) polarity. The red test lead is put in the hole, or jack, marked V − Ω − A, or volts − ohms − amperes. The black test lead is put in the hole, or jack, labeled-COM.

1.4.1 Measuring Resistance

Many important electrical tests may be made by measuring resistance. Resistance is opposition to the flow of current in an electrical circuit. The current that flows in a circuit depends upon the amount of resistance in that circuit. You should learn to measure resistance in an electronic circuit by using a meter.

The ohmmeter ranges of a VOM, or multimeter, is used to measure resistance. The basic unit of resistance is the ohm (Ω). When the test leads are touched together, or "shorted", the meter is operational, indicating zero (0) ohms.

Never measure the resistance of a component until it has been disconnected, if not the reading may be wrong. Voltage should never be applied to a component when its resistance is being measured.

1.4.2 Measuring Voltage

Voltage is applied to electrical equipment to cause it to operate. It is important to be able to measure voltage to check the operation of equipment. Many electrical problems develop when either too high or too low voltage is applied to the equipment. Voltage is measured in volts (V). A voltmeter ranges of a VOM is used to measure voltage in an electrical circuit.

When making voltage measurements, connect the red and black test leads to the meter by putting them into the proper jacks. The red test lead should be put into the jack labeled V-Ω-A. The black test lead should be put into the jack labeled-COM.

The proper voltage range is chosen. Before making any measurements, adjust the function-select switch to the highest voltage range. The value of the range being used is the maximum value of voltage that can be measured on that range. For example, when the range selected is 12 V, the maximum voltage that the meter can measure is 12 V. Any voltage above 12 V could damage the meter. To measure a voltage that is unknown, start by using the highest range on the meter. Then slowly adjust the range downward until a voltage reading is indicated on the right side of the meter scale.

AC (Alternating Current) voltage is measured with a VOM and polarity of the meter leads is not important because AC changes direction. Matching the polarity of the meter to the voltage polarity is very important when measuring DC (Direct Current) voltage, since direction current flows only in one direction. Meter polarity is simple to determine. The positive (+) red test lead is connected to the positive side of the DC voltage being measured. The negative (–) black test lead is connected to the negative side of the DC voltage being measured. The meter is always connected across (in parallel with) the DC voltage or AC voltage being measured.

1.4.3 Measuring Current

Current flows through a complete electrical circuit when voltage is applied. Many important tests are made by measuring current flow in electrical circuits. The current values in an electrical circuit depend on the amount of resistance in the circuit. The basic unit of current is ampere (A). Current is commonly measured in units called milliamperes (mA) and microamperes (μA). Learning to use an ammeter to measure current in an electrical circuit is very important.

The function-select switchof a VOM may be adjusted to any one of the current ranges. The value of the current set on the range is the maximum value that can be measured on that range. For example, when the function-select switch is placed in the 120 mA range, the meter is capable of measuring up to 120 mA of current. The function-select switch should first be adjusted to the highest range of direct current. Current is measured by connecting the meter into a circuit, i. e. connecting the meter in series with the circuit. Current flows from a voltage source when some device that has resistance is connected to the source. [13]

Always remember the following safety tips when measuring current:

1) Turn off the voltage before connecting the meter in order not to get an electrical shock. This is an important habit to develop.

2) Set the meter to its highest current range.

3) Disconnect a wire from the circuit and put the meter in series with the circuit.

4) Use the proper meter polarity.

1.5 DC Series Electrical Circuit

There are three types of electrical circuits. They are called series circuits, parallel circuits, and combination circuits. The easiest type of circuit to understand is the series circuit. [14] Series circuits are different from other types of electrical circuits. In a series circuit, there is only one path for current to flow. Since there is only one current path, the current flow is the same value in any part of the circuit. The voltages in the circuit depend on the resistance of the components in the circuit. When a series circuit is opened, there is no path for current flow. Thus, the circuit does not operate. It is important to remember the characteristics of a series circuit.

In the circuit examples that follow, subscripts (such as in R_T, V_T, I_1) are used to identify electrical components in circuit diagrams. The circuit shown in Fig. 1-1 has two resistors and a battery. The resistors are labeled R_1 and R_2. The subscripts identify each of these resistors. Subscripts also aid in making measurements. The voltage drop across resistor R_1 is called voltage drop V_1. The term total is represented by the subscript T, such as in V_T, which is total voltage applied to a circuit. The current measurement I_2 is the current through resistor R_2. Total current is I_T. The voltage drop across R_2 is called V_2.

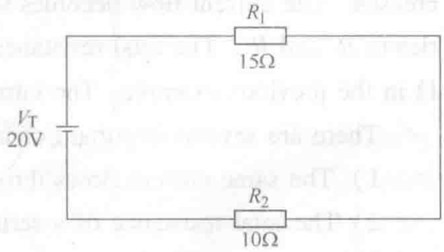

Fig. 1-1 Series Electrical Circuit

Subscripts are also valuable in troubleshooting and repair of electronic equipment. It would be impossible to isolate problems in equipment without components that are easily identified.

The main characteristic of a series circuit is that it has only one path for current flow. In the circuit shown in Fig. 1-1, current flows from the positive side of the voltage source through resistor R_1, through resistor R_2, and then to the negative side of the voltage source. Another characteristic of a series circuit is that the current is the same everywhere in the circuit. A VOM can be placed into the circuit to measure current.

In any series circuit, the sum of the voltage drops is equal to the voltage applied to the circuit. The circuit shown in Fig. 1-1 has voltage drops of 12 V plus 8 V, which is equal to 20 V. Another characteristic of a series circuit is that its total resistance to current flow is equal to the sum of all resistance in the circuit. In the circuit shown in Fig. 1-1, the total resistance of the circuit is the sum of the two resistances if the internal resistance is not considered, so the total resistance is equal to 15 Ω plus 10 Ω, i. e. 25 Ω.

When a series circuit is opened, there is no longer a path for current flow. The circuit will not operate. In the circuit of Fig. 1-1, if R_1 and R_2 are replaced respectively by Lamp 1 and Lamp 2, when the Lamp 1 is burned out, its filament is open. Since a series circuit has only one current path, that path is broken. No current flows in the circuit. The Lamp 2 will not work either. If one light burns out, the others go out also.

Ohm's law is used to explain how a series circuit operates. In the circuit of Fig. 1-1, the total resistance is equal to 15 Ω plus 10 Ω, i. e. 25 Ω. The applied voltage is 20V. Current is equal to voltage divided by resistance, i. e. $I = V/R$. In the circuit shown, current is equal to 20 V divided by 25 Ω, which is 0. 8 A. If a current meter were connected into this circuit, the current measurement would be 0. 8 A. Voltage drops across each of the resistors may also be found. Voltage is equal to current times resistance ($V = I \times R$). The voltage drop across R_1 (V_1) is equal to the current through R_1 (0. 8 A) times the value of R_1 (15 Ω), which is 0. 8 A × 15 Ω, i. e. 12 V. The voltage drop across R_2 (V_2) equals 0. 8 A × 10 Ω, i. e. 8 V. The sum of these voltage drops is equal to the applied voltage. To check these values, add 12V plus 8V, which is equal to 20 V.

If another resistance is added to a series circuit, the resistance of the total circuit will be increased. The current flow becomes smaller. The circuit now has R_3 (a 5 Ω resistor) added in series to R_1 and R_2. The total resistance is now 15 Ω + 10 Ω + 5 Ω, i. e. 30 Ω, compared to 25 Ω in the previous example. The current is now 0. 67 A.

There are several important characteristics of series circuits:

1) The same current flows through each part of a series circuit.

2) The total resistance of a series circuit is equal to the sum of the individual resistances.

3) The voltage applied to a series circuit is equal to the sum of the individual voltage drops.

4) The voltage drop across a resistor in a series circuit is directly proportional to the size of the resistor.

5) If the circuit is broken at any point, no current will flow.

1.6 Alternating Current Voltage

When an Alternating Current (AC) source is connected to some type of load, current direction changes several times in a given unit of time. Remember that DC flows in one direction only. This waveform is called an AC sine wave. When the AC generator shaft rotates one complete revolution, or 360°, one AC sine wave is produced. Note that the sine wave has a positive peak at 90° and then decreases to zero at 180°. It then increases to a peak negative voltage at 270° and then decreases to zero at 360°. The cycle then repeats itself. Current flows in one direction during the positive part and in the opposite direction during the negative half-cycle.

1.6.1 Parameters Associated with AC Sine Wave

If the time required for an AC generator to produce five cycles were 1 s, the frequency of the AC would be 5 cycles per second. AC generators at power plants in the United States operate at a frequency of 60 cycles per second, or 60 hertz (Hz). The hertz is the international unit for frequency measurement. If 60 AC sine waves are produced every second, a speed of 60 revolutions per second is needed. This produces a frequency of 60 cycles per second.

Fig. 1-2 shows several voltage values associated with single-phase AC. Among these are peak positive, peak negative, and peak-to-peak AC values. Peak positive is the maximum positive voltage reached during a cycle of AC. Peak negative is the maximum negative voltage reached. Peak-to-peak is the voltage value from peak positive to peak negative. These values are important to know when working with radio and television amplifier circuits. For example, the most important AC value is called the effective, or measured, value. This value is less than the peak positive value. A common AC voltage is 220 V, which is used in homes. This is an effective value voltage. Its peak value is about 311V. [15] Effective value of AC is defined as the AC voltage that will do the same amount of work as a DC voltage of the same value. For instance, a lamp should produce the same amount of brightness with a 10V AC effective value as with 10 V DC applied. When AC voltage is measured with a meter, the reading indicated is effective value.

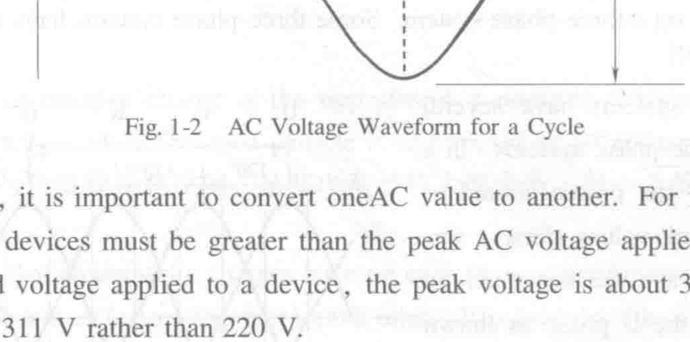

Fig. 1-2 AC Voltage Waveform for a Cycle

In some cases, it is important to convert oneAC value to another. For instance, the voltage rating of electronic devices must be greater than the peak AC voltage applied to them. If 220 V AC is the measured voltage applied to a device, the peak voltage is about 311 V, so the device must be rated over 311 V rather than 220 V.

To determine peak AC, when the measured or effective value is known, the formula

$$V_{peak} = 1.414 V_{eff}$$

is used. When220 V is multiplied by the conversion factor 1.414, the peak voltage is found to be about 311 V.

Two other important terms are RMS value and average value. RMS stands for *root mean square* and is equal to 0.707 times peak value. RMS refers to the mathematical method used to determine effective voltage. RMS voltage and effective voltage are the same. Average voltage is the mathematical average of all instantaneous voltages that occur at each period of time throughout an alternation. The average value is equal to 0.636 times the peak value.

The term *phase* refers to time, or the difference between one point and another. If two sine-wave voltages reach their zero and maximum values at the same time, they are in phase. [16] Fig. 1-3 shows two AC voltages, 1 and 2 that are in phase. If two voltages reach their zero and maximum values at different times, they are out of phase. Fig. 1-3 shows two AC voltages, 1 and 3 that are out of phase. Phase difference is given in degrees. The voltages shown are out of phase by 90°.

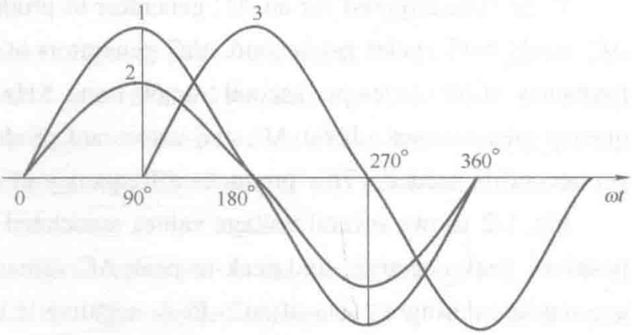

Fig. 1-3 The Phase Waveforms of AC Voltages

1.6.2 Single-Phase and Three-Phase AC Voltages

Single-phase AC voltage is produced by single-phase AC generators or is obtained across two power lines of a three-phase system. A single-phase AC source has a hot wire and a neutral wire. Single-phase AC voltage is used for low-power applications. The type of power distributed to our homes is single-phase AC voltage.

Three-phase AC voltage is produced by three-phase generators at power plants and is a combination of three single-phase voltages, which are electrically connected together. Almost all electrical power is generated and transmitted over long distances as three-phase AC. This voltage is similar to three single-phase sine waves separated in phase by 120°. Three-phase AC is used to power large equipment in industry and commercial buildings. It is not distributed to homes. There are three power lines on a three-phase system. Some three-phase systems have a neutral connection and others do not. [17]

Three-phaseAC systems have several advantages over single-phase systems. In a single-phase system, the power is said to be pulsating. The peak values along a single-phase AC sine wave are separated by 360°, for example, the U phase as shown in Fig. 1-4. This is similar to a one-cylinder gas engine. A three-phase system is some what like a multi-cylinder gas en-

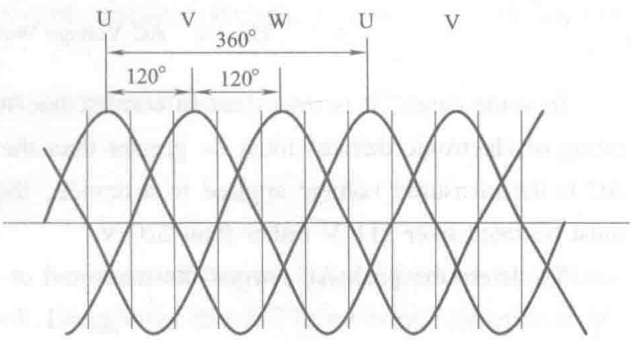

Fig. 1-4 Waveform for Three-Phase AC Voltages