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普通高等教育“十二五”电气信息类规划教材

电气工程与自动化专业英语

■ 王 伟 张艳丽 主 编

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本书分为电气工程基础、控制理论与技术、电机与电器设备、电力系统4大部分，共20章。为便于学生对文章的正确理解，每章后均补充了必要的专业英语词汇、短语及句子注释。本书涵盖了电气工程与自动化专业的主要专业基础理论内容，注重从实际应用出发培养学生的专业英语阅读和写作能力。

本书既可作为高等院校电气工程与自动化及相关专业高年级学生的专业英语教材，也可作为从事电气信息类各专业工程技术人员的参考用书。

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前　　言

随着我国国际交往的日趋加强和深化，专业英语作为科技工作者进行国际学术交流的主要语言，在国际交往中扮演着越来越重要的角色。大学生在校期间的各类科技活动和在未来的工作中，不可避免地要利用到自身掌握的专业英语知识。加强培养大学生的专业英语阅读和写作能力，是其了解世界专业领域前沿知识以及撰写科技文章参与国际交流的迫切要求，也是整个人才培养知识体系中的重要环节。

本书可作为高等院校电气工程与自动化专业的专业英语教材，也可供工程技术人员参考阅读。本书参考学时为60学时，不同院校可根据自身的人才培养方向和课时安排选取本书的部分章节作为学习的内容，剩余部分也可作为学生的自学阅读材料。

本书注重从实际应用的角度培养大学生的专业英语水平。编者结合多年来从事专业英语教学的经验和体会，编写了内容难度适中、表述规范的文章作为本书的阅读材料。书中涵盖了电气工程与自动化专业的主要知识点内容，覆盖面广。书中所涉及的专业词汇和句型具有较强的专业特色和代表性，也是了解相关专业领域内容的基础。全书共包括电气工程基础（第1~5章）、控制理论与技术（第6~11章）、电机与电器设备（第12~16章）和电力系统（第17~20章）4个部分。

本书由北京石油化工学院、沈阳工业大学、太原理工大学、中原工学院等几所高校多年从事专业英语教学工作的老师联合编写。其中，第1~5章由王伟老师编写，第6、7章由马景兰老师编写，第8~10章由裴素萍老师编写，第11~15章由张艳丽老师编写，第16~20章由韩肖清老师编写。全书由王伟和马景兰老师统稿。此外，北京石油化工学院李伟、万京生、郭屹松，太原理工大学王鹏敏和上海应用技术学院裴素鹏等老师也参与了本书的部分资料编辑和整理工作。北京理工大学邓甲昊教授负责本教材的审阅，并提出了许多宝贵意见，在此表示衷心的感谢。

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.*

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. [1]

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 glass rod loses electrons (−), so it now has a positive (+) charge. The silk cloth pulls electrons (−) away from the glass. 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 because some materials are charged 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. [2] Remember that materials are charged due to the movement of electrons and protons. Also, remember that when an atom loses electrons (−), it becomes positive (+). These facts are very important in the study of electronics.

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. 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. 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 commonly used, since it is cheaper and lighter than other conductors. Copper is used more than any other conductor.

1.2.2 Insulators

There are some materials that do not allow electric current to flow easily. The electrons of insulation materials 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 insulation materials are said to be stable. Insulators have high resistance to the movement of electric current. 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 their atoms have in their valence shells. Semiconductors have 4 electrons in their valence shells. 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. Some electrons in the outer orbits of the atoms or certain elements are easy to remove. 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 current flow.

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. [3] 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. If electric charges are placed on each end of a conductor, the free electrons move in one direction. Current flow takes place because there is a difference in the charges at each end of the conductor. Remember that like charges repel and unlike charges attract.

When an electrical charge is placed on each end of the conductor, the free electrons move. Free electrons have a negative charge, so they are repelled by the negative charge on the left. The free electrons are attracted to the positive charge on the right and move to the right 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 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.[4] 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 high or too low 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*).

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.

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 object is 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. 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, 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. It 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.

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 volt-ohm-milliammeter (VOM), or multimeter, is used to measure resistance. The basic unit of resistance is the ohm (Ω). VOMs are the most used meters for doing electronic work. A VOM is often used to measure resistance, voltage, or 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. This is important when measuring Direct Current (DC) values. 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. 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, or the reading may be wrong. Voltage should never be applied to a component when measuring resistance.

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 is used to measure voltage in an electrical circuit.

When making voltage measurements, adjust the function-select switch to the highest range of DC voltage. 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.

Before making any measurements, the proper DC voltage range is chosen. 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 12V, the maximum voltage the meter can measure is 12V. Any voltage above 12V could damage the meter. To measure a voltage that is unknown (no indication of its value), 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.

Matching the meter polarity to the voltage polarity is very important when measuring DC voltage. 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 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.

Most VOMs will also measure DC current. The function-select switch may be adjusted to any of the ranges of direct current. For example, when the function-select switch is placed in the 120mA range, the meter is capable of measuring up to 120mA of current. The value of the current set on the range is the maximum value that can be measured on that range. 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. This is referred to as 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.

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.

1.4.4 Digital Meters

Many digital meters are now in use. They employ numerical readouts to simplify the measurement process and to make more accurate measurements. Digital meters rely on the operation of digital circuitry to produce a numerical readout of the measured quantity. The readout of a digital meter is designed to transform electric signals into numerical data. Both letter and number readouts are available, as are seven-segment, discrete-number, and bar matrix displays. Each method has a device designed to change electric energy into light energy on the display.

1.5 DC Series Electrical Circuit

One type of electrical circuit is referred to as a series circuit. 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.

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.[5] Series circuits are different from other types of electrical circuits. 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.

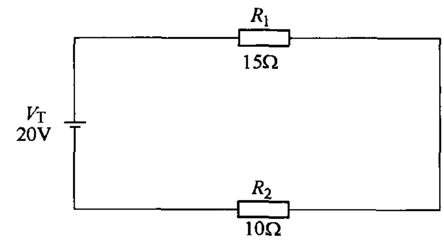

Fig. 1-1 Series electrical circuit

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, then 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 12V plus 8V, which is equal to 20V. 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 15Ω plus 10Ω, i. e. 25Ω.

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 lamp1 and lamp2, when the lamp1 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 lamp2 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 15Ω plus 10Ω, i. e. 25Ω. 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 20V divided by 25Ω, which is 0.8A. If a current meter were connected into this circuit, the current measurement would be 0.8A. Voltage drops across each of the resistors may also be found. Voltage is equal to current times resistance ($V = IR$). The voltage drop across R_1 (V_1) is equal to the current through R_1 (0.8A) times the value of R_1 (15Ω), which is 0.8A × 15Ω, i. e. 12V. The voltage drop across R_2 (V_2) equals 0.8A × 10Ω, i. e. 8V. The sum of these voltage drops is equal to the applied voltage. To check these values, add 12V plus 8V, which is equal to 20V.

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 5Ω resistor) added in series to R_1 and R_2. The total resistance is now 15Ω + 10Ω + 5Ω, i. e. 30Ω, compared to 25Ω in the previous example. The current is now 0.67A.

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 (AC) Voltage

When an 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.

If the time required for an AC generator to produce five cycles were 1s, 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 60AC sine waves are produced every second, a speed of 60 revolutions per second is needed. This produces a frequency of 60 cycles per second.

AC voltage is measured with a VOM and polarity of the meter leads is not important because AC changes direction. (Remember that polarity is important when measuring DC, since direction current flows only in one direction.)

Fig. 1-2 shows several voltage values associated with 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 220V, which is used in homes.

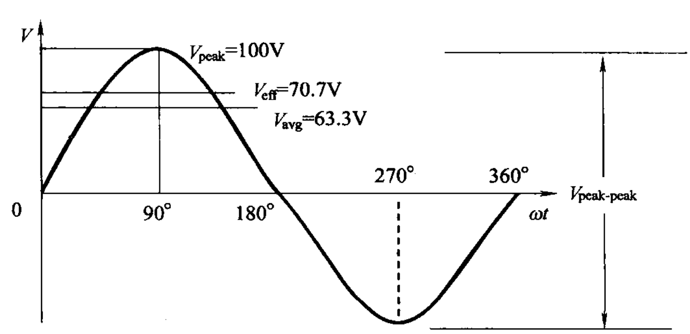

Fig. 1-2 AC voltage waveform for a cycle

This is an effective value voltage. Its peak value is about 311V. 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 10V DC applied. When AC voltage is measured with a meter, the reading indicated is effective value.

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

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

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

is used. When 220V is multiplied by the conversion factor 1.414, the peak voltage is found to be about 311V.

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.

1.6.1 Single-phase and Three-phase AC

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, which is grounded to help prevent electrical shocks. Single-phase power is the type of power distributed to our homes. A three-phase AC source has three power lines. Three-phase voltage is produced by three-phase generators at power plants and is a combination of three single-phase voltages, which are electrically connected together. 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.

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.[6] 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

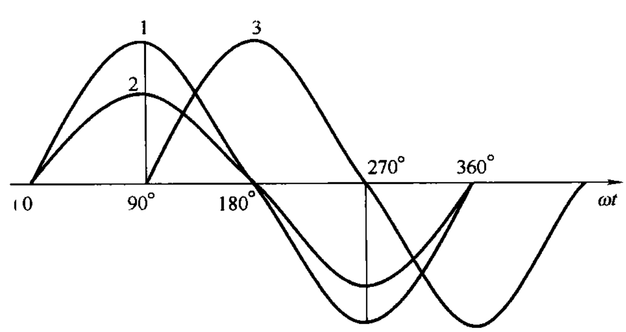

Fig. 1-3 The phase waveforms of AC voltages