Chapter One: Basic concepts

1.1 Electrical Quantities and SI units

- Measurements are communicated in a standard language that virtually all professionals can understand. Such an international measurement language is the International System of Units (SI), adopted by the General Conference on Weights and Measures in 1960.
- One great advantage of the SI unit is that it uses prefixes based on the power of 10 to relate larger and smaller units to the basic unit.

  Example: 500 km=500,000 m=500,000,000 mm

TABLE 1.1 The six basic SI units.

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

TABLE 1.2 The SI prefixes.

Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

In electrical engineering, we are often interested in communicating or transferring energy from one point to another. To do this requires an interconnection of electrical devices. Such interconnection is referred to as an electric circuit, and each component of the circuit is known as an element.

> An **electric circuit** is an interconnection of electrical elements.

A simple electric circuit is shown in Fig. 1.1. It consists of three basic components: a battery, a lamp, and connecting wires. Such a simple circuit can exist by itself; it has several applications.

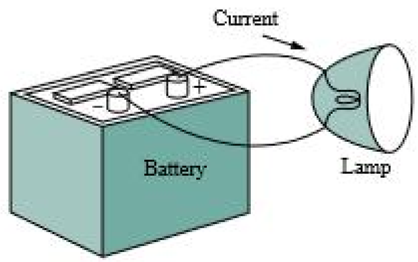


Fig.1.1 A simple electric circuit

Electric circuits are used in numerous electrical systems to accomplish different tasks. But our task is not to mention the uses and applications. Rather to study analysis of the electric circuit.

- Analysis means study of the behavior of the circuit:
  - How does it respond to a given input?
  - How do the interconnected elements and devices in the circuit interact?

1.2 Electric Charge and Current

- ✓ **Electric Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs(C).** The derived unit of charge, the coulomb (C), is equivalent to an ampere-second. The moving charges may be positive or negative.

The following points should be noted about electric charge:

- The coulomb is a large unit for charges. In 1 C of charge, there are $1/(1.602\times10^{-19}) = 6.24\times10^{18}$ electrons.
- According to experimental observations, the only charges that occur in nature are integral multiples of the electronic charge $e = -1.602\times10^{-19}$ C.
- The law of conservation of charge states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

- ✓ **Electric current is the time rate of change of charge, measured in amperes (A).**

Electric Current results from charges in motion. 1 ampere is equivalent to 1 coulomb of charge moving across a fixed surface in 1 second.

Mathematically, the relationship between current i, charge q, and time t is

$$i = \frac{dq}{dt}$$

where current is measured in amperes (A), and 1 ampere = 1 coulomb/second

The charge transferred between time t_0 and t is obtained by

$$q = \int_{t_0}^{t} i\,dt$$

If the current does not change with time, but remains constant, we call it a direct current (dc). Or

- ❖ A direct current (dc) is a current that remains constant with time.

By convention the symbol, I is used to represent such a constant current.

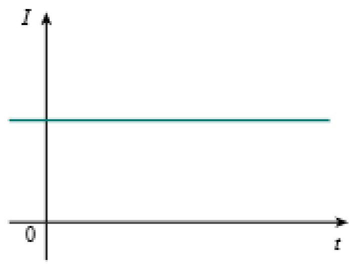


Fig.1.2 A direct current

A time-varying current is represented by the symbol i. A common form of time-varying current is the sinusoidal current or alternating current (ac).

- ❖ An alternating current (ac) is a current that varies sinusoidally with time.

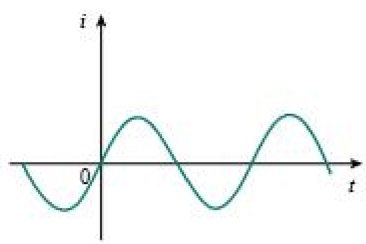


Fig.1.3 An alternating current

Example1: The total charge entering a terminal is given by q = 5t sin4πt mC. Calculate the current at t = 0.5 s.

Solution: $i = \frac{dq}{dt} = \frac{d}{dt}(5tsin4\pi t)\frac{mC}{s} = (5sin4\pi t + 20\pi tcos4\pi t)mA$

@ t = 0.5, $i = 5sin2\pi + 10\pi cos2\pi = 0 + 10\pi = 31.42mA$

Example2: Determine the total charge entering a terminal between t = 1s and t = 2s if the current passing the terminal is i = $(3t^2 - t)$ A.

Example3: The current flowing through an element is

$$i = \begin{cases} 2\ \text{A}, & 0 < t < 1 \\ 2t^2\ \text{A}, & t > 1 \end{cases}$$

Calculate the charge entering the element from t = 0 tot = 2 s. Answer: 6.667 C.

1.3 Electric Potential, Force, Work, and Power

- Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).

1 volt = 1 joule/coulomb = 1 newton meter/coulomb

- From ''force equals mass times acceleration,'' the newton (N) is defined as the unbalanced force that imparts an acceleration of 1 meter per second squared to a 1-kilogram mass. Thus, $1N=1kg.m/s^2$.
- Work results when a force acts over a distance. A joule of work is equivalent to a newton-meter: 1J= 1N.m. Work and energy have the same units.
- Power is the rate at which work is done or the rate at which energy is changed from one form to another. The unit of power, the watt (W), is one joule per second (J/s).

EXAMPLE 1.1. In simple rectilinear motion a 10-kg mass is given a constant acceleration of 2.0m/s2.(a) Find the acting force F.(b) If the body was at rest at t=0, x=0, find the position, kinetic energy, and power for t=4s.

(a) $F = ma = (10\,\text{kg})(2.0\,\text{m/s}^2) = 20.0\,\text{kg}\cdot\text{m/s}^2 = 20.0\,\text{N}$

(b) At $t = 4\,\text{s}$,

$$x = \tfrac{1}{2}at^2 = \tfrac{1}{2}(2.0\,\text{m/s}^2)(4\,\text{s})^2 = 16.0\,\text{m}$$
$$\text{KE} = Fx = (20.0\,\text{N})(16.0\,\text{m}) = 3200\,\text{N}\cdot\text{m} = 3.2\,\text{kJ}$$
$$P = \text{KE}/t = 3.2\,\text{kJ}/4\,\text{s} = 0.8\,\text{kJ/s} = 0.8\,\text{kW}$$

1.4 Energy and Electrical Power

- The rate, in joules per second, at which energy is transferred is electric power in watts.
- Power is the time rate of expending or absorbing energy, measured in watts (W).

Furthermore, the product of voltage and current yields the electric power, p=vi; 1W=1V.1A. Also, V.A= (J/C).(C/s)=J/s =W. In a more fundamental sense power is the time derivative P=dw/dt, so that instantaneous power p is generally a function of time.

- Energy is the capacity to do work, measured in joules (J).

1.5 Circuit Element

An element is the basic building block of a circuit. An electric circuit is simply an interconnection of the elements. Circuit analysis is the process of determining voltages across (or the currents through) the elements of the circuit.

There are two types of elements found in electric circuits:

- passive elements and
- Active elements.

- An active element is capable of generating energy while a passive element is not. Examples of passive elements are resistors, capacitors, and inductors. Typical active elements include generators, batteries, and operational amplifiers. The most important active elements are voltage or current sources that generally deliver power to the circuit connected to them.

There are two kinds of sources:

- independent and
- Dependent sources.

- An ideal independent source is an active element that provides a specified voltage or current that is completely independent of other circuit variables.
    - ✓ A voltage source that is not affected by changes in the connected circuit is an independent source.

The symbol for an independent current source is displayed in Fig. below, where the arrow indicates the direction of current i.

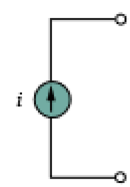


Fig. Symbol for independent current source.

- An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current.
    - ✓ A dependent voltage source which changes in some described manner with the conditions on the connected circuit.

Dependent sources are usually designated by diamond-shaped symbols, as shown in Fig. below. Since the control of the dependent source is achieved by a voltage or current of some other element in the circuit, and the source can be voltage or current, it follows that there are four possible types of dependent sources, namely:

- ♦ A voltage-controlled voltage source (VCVS).

- A current-controlled voltage source (CCVS).
- A voltage-controlled current source (VCCS).
- A current-controlled current source (CCCS)

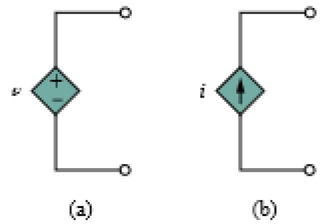


Fig. Symbols for: (a) dependent voltage source, (b) dependent current source.

Dependent sources are useful in modeling elements such as transistors, operational amplifiers and integrated circuits.

Assignment 1

Define the following with their circuit diagram

- A voltage-controlled voltage source (VCVS).
- A current-controlled voltage source (CCVS).
- A voltage-controlled current source (VCCS).
- A current-controlled current source (CCCS)

1.6 Circuit Concepts

1.6.1 Passive and Active Elements

An electrical device is represented by a circuit diagram or network constructed from series and parallel arrangements of two-terminal elements. The analysis of the circuit diagram predicts the performance of the actual device. Active elements are voltage or current sources which are able to supply energy to the network. Resistors, inductors, and capacitors are passive elements which take energy from the sources and either convert it to another form or store it in an electric or magnetic field.

Figure 2-2 illustrates seven basic circuit elements. Elements (a) and (b) are voltage sources and (c) and (d) are current sources. A voltage source that is not affected by changes in the connected circuit is an independent source, illustrated by the circle in Fig. 2-2(a). A dependent voltage source which changes in some described manner with the conditions on the connected circuit is shown by the diamond-shaped symbol in Fig. 2-2(b). Current sources may also be either independent or dependent and the corresponding symbols are shown in (c) and (d). The three passive circuit elements are shown in Fig. 2-2(e), (f), and (g).

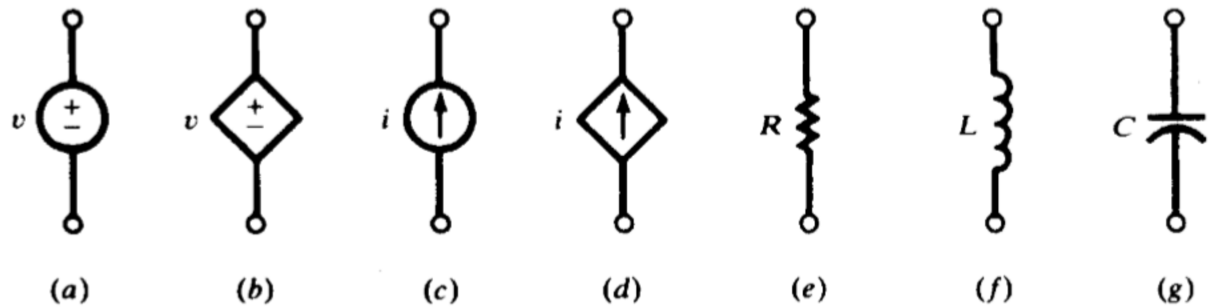


Fig. 2-2

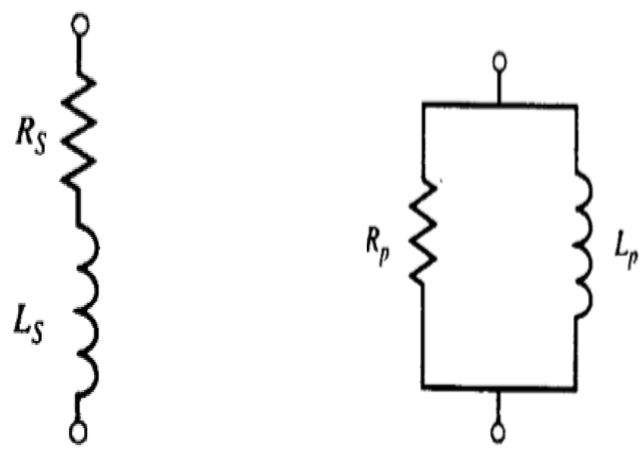
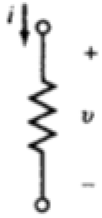
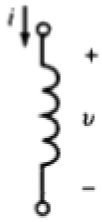
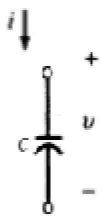


Fig2-3. Series and parallel conection

1.6.2 Voltage-Current Relations

The passive circuit elements resistance R, inductance L, and capacitance C are defined by the manner in which the voltage and current are related for the individual element. For example, if the voltage v and current i for a single element are related by a constant, then the element is a resistance, R is the constant of proportionality, and V=Ri. Similarly, if the voltage is the time derivative of the current, then the element is an inductance, L is the constant of proportionality, and V=Ldi/dt. Finally, if the current in the element is the time derivative of the voltage, then the element is a capacitance, C is the constant of proportionality, and i=C dv/dt.

Circuit element	Units	Voltage	Current	Power
 **Resistance**	ohms (Ω)	$v = Ri$ **(Ohms's law)**	$i = \frac{v}{R}$	$p = vi = i^2R$
 **Inductance**	henries (H)	$v = L\frac{di}{dt}$	$i = \frac{1}{L}\int v\,dt + k_1$	$p = vi = Li\frac{di}{dt}$
 **Capacitance**	farads (F)	$v = \frac{1}{C}\int i\,dt + k_2$	$i = C\frac{dv}{dt}$	$p = vi = Cv\frac{dv}{dt}$

1.6.3 Resistance, Inductance and Capacitance

- All electrical devices that consume energy must have a resistor (also called a resistance) in their circuit model. Inductors and capacitors may store energy but over time return that energy to the source or to another circuit element.
- The circuit element that stores energy in a magnetic field is an inductor (also called an inductance). With time-variable current, the energy is generally stored during some parts of the cycle and then returned to the source during others. When the inductance is removed from the source, the magnetic field will collapse; in other words, no energy is stored without a connected source. Coils found in electric motors, transformers, and similar devices can be expected to have inductances in their circuit models.

Energy stored in the magnetic field of an inductance is $wL=1/2Li^2$.

- The circuit element that stores energy in an electric field is a capacitor (also called capacitance). When the voltage is variable over a cycle, energy will be stored during one part of the cycle and returned in the next. While an inductance cannot retain energy after removal of the source because the magnetic field collapses, the capacitor retains the charge and the electric field can remain after the source is removed. This charged condition can remain until a discharge path is provided, at which time the energy is released. The charge, q=Cv, on a capacitor results in an electric field in the dielectric which is the mechanism of the energy storage

The energy stored in the electric field of capacitance is $WC=1/2Cv^2$.

1.6.4 Circuit Diagrams

Every circuit diagram can be constructed in a variety of ways which may look different but are in fact identical. The diagram presented in a problem may not suggest the best of several methods of solution. Consequently, a diagram should be examined before a solution is started and redrawn if necessary to show more clearly how the elements are interconnected. An extreme example is illustrated in Fig. 2-9, where the three circuits are actually identical. In Fig. 2-9(a) the three ''junctions'' labeled A are shown as two ''junctions'' in (b). However, resistor R4 is bypassed by a short circuit and may be removed for purposes of analysis. Then, in Fig. 2-9(c) the single junction A is shown with its three meeting branches.

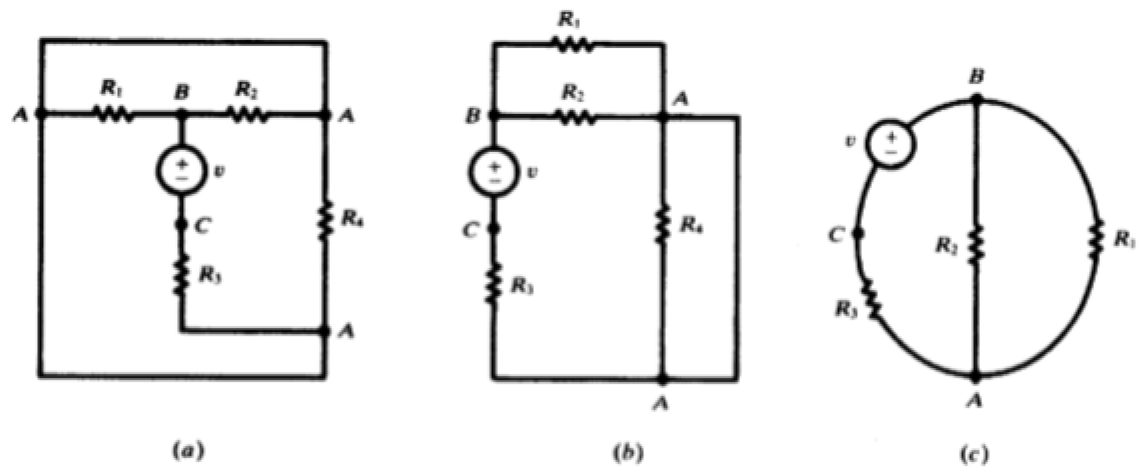


Fig. 2-9