3.1. Network Terminology

While discussing network theorems and techniques, one often comes across the following terms:

(*i*) **Linear circuit.** A linear circuit is one whose parameters (*e.g.* resistances) are constant *i.e.* they do not change with current or voltage.

(*ii*) **Non-linear circuit.** A non-linear circuit is one whose parameters (*e.g.* resistances) change with voltage or current.

(*iii*) **Bilateral circuit.** A bilateral circuit is one whose properties are the same in either direction. For example, transmission line is a bilateral circuit because it can be made to perform its function equally well in either direction.

(*iv*) **Active element.** An active element is one which supplies electrical energy to the circuit. Thus in Fig. 3.1, E_1 and E_2 are the active elements because they supply energy to the circuit.

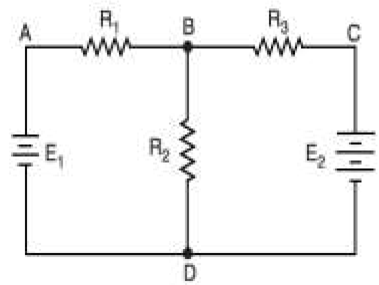


Fig. 3.1

(*v*) **Passive element.** A passive element is one which receives electrical energy and then either converts it into heat (resistance) or stores in an electric field (capacitance) or magnetic field (inductance). In Fig. 3.1, there are three passive elements, namely R_1, R_2 and R_3. These passive elements (*i.e.* resistances in this case) receive energy from the active elements (*i.e.* E_1 and E_2) and convert it into heat.

(*vi*) **Node.** A node of a network is an equipotential surface at which *two or more* circuit elements are joined. Thus in Fig. 3.1, circuit elements R_1 and E_1 are joined at A and hence A is the node. Similarly, B, C and D are nodes.

(*vii*) **Junction.** A junction is that point in a network where *three or more* circuit elements are joined. In Fig. 3.1, there are only two junction points *viz.* B and D. That B is a junction is clear from the fact that three circuit elements R_1, R_2 and R_3 are joined at it. Similarly, point D is a junction because it joins three circuit elements R_2, E_1 and E_2.

(*viii*) **Branch.** A branch is that part of a network which lies between two junction points. Thus referring to Fig. 3.1, there are a total of three branches *viz.* BAD, BCD and BD. The branch

BAD consists of R_1 and E_1 ; the branch *BCD* consists of R_3 and E_2 and branch *BD* merely consists of R_2.

(*ix*) **Loop.** A loop is any closed path of a network. Thus in Fig. 3.1, *ABDA*, *BCDB* and *ABCDA* are the loops.

(*x*) **Mesh.** A mesh is the most elementary form of a loop and cannot be further divided into other loops. In Fig. 3.1, both loops *ABDA* and *BCDB* qualify as meshes because they cannot be further divided into other loops. However, the loop *ABCDA* cannot be called a mesh because it encloses two loops *ABDA* and *BCDB*.

(*xi*) **Network and circuit.** Strictly speaking, the term network is used for a circuit containing passive elements only while the term circuit implies the presence of both active and passive elements. However, there is no hard and fast rule for making these distinctions and the **terms "network" and "circuit" are often used interchangeably**.

(*xii*) **Parameters.** The various elements of an electric circuit like resistance (R), inductance (L) and capacitance (C) are called parameters of the circuit. These parameters may be lumped or distributed.

(*xiii*) **Unilateral circuit.** A unilateral circuit is one whose properties change with the direction of its operation. For example, a diode rectifier circuit is a unilateral circuit. It is because a diode rectifier cannot perform rectification in both directions.

(*xiv*) **Active and passive networks.** An active network is that which contains active elements as well as passive elements. On the other hand, a passive network is that which contains passive elements only.

2.17. Kirchhoff's Laws

Kirchhoff gave two laws to solve complex circuits, namely ;

1. Kirchhoff's Current Law (KCL)   2. Kirchhoff's Voltage Law (KVL)

1. KIRCHHOFF'S CURRENT LAW (KCL)

This law relates to the currents at the *junctions of an electric circuit and may be stated as under :

The algebraic sum of the currents meeting at a junction in an electrical circuit is zero.

An algebraic sum is one in which the sign of the quantity is taken into account. For example, consider four conductors carrying currents I_1, I_2, I_3 and I_4 and meeting at point O as shown in Fig. 2.60.

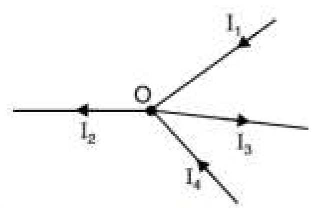


Fig. 2.60

* A junction is that point in an electrical circuit where *three or more* circuit elements meet.

If we take the signs of currents flowing towards point O as positive, then currents flowing away from point O will be assigned negative sign. Thus, applying Kirchhoff's current law to the junction O in Fig. 2.60, we have,

$$(I_1) + (I_4) + (-I_2) + (-I_3) = 0$$

or $$I_1 + I_4 = I_2 + I_3$$

i.e., Sum of incoming currents = Sum of outgoing currents

Hence, Kirchhoff's current law may also be stated as under :

The sum of currents flowing towards any junction in an electrical circuit is equal to the sum of currents flowing away from that junction. Kirchhoff's current law is also called junction rule.

Kirchhoff's current law is true because electric current is merely the flow of free electrons and they cannot accumulate at any point in the circuit. This is in accordance with the law of conservation of charge. Hence, Kirchhoff's current law is based on the law of conservation of charge.

2. KIRCHHOFF'S VOLTAGE LAW (KVL)

This law relates to *e.m.fs* and voltage drops in a closed circuit or loop and may be stated as under :

In any closed electrical circuit or mesh, the algebraic sum of all the electromotive forces (e.m.fs) and voltage drops in resistors is equal to zero, i.e.,

In any closed circuit or mesh,

Algebraic sum of e.m.fs + Algebraic sum of voltage drops = 0

The validity of Kirchhoff's voltage law can be easily established by referring to the closed loop *ABCDA* shown in Fig. 2.61. If we start from any point (say point *A*) in this closed circuit and go back to this point (*i.e.*, point *A*) after going around the circuit, then there is no increase or decrease in potential. This means that algebraic sum of the *e.m.fs* of all the sources (here only one *e.m.f.* source is considered) met on the way *plus* the algebraic sum of the voltage drops in the resistances must be zero. Kirchhoff's voltage law is based on the law of *conservation of energy, *i.e.*, net change in the energy of a charge after completing the closed path is zero.

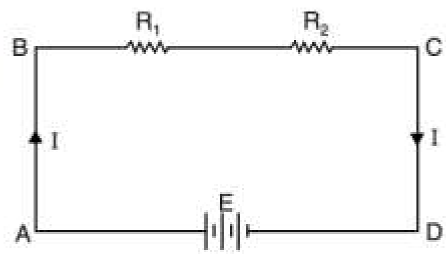


Fig. 2.61

Note. Kirchhoff's voltage law is also called *loop rule*.

2.18. Sign Convention

While applying Kirchhoff's voltage law to a closed circuit, algebraic sums are considered. Therefore, it is very important to assign proper signs to *e.m.fs* and voltage drops in the closed circuit. The following convention may be followed :

A **rise in potential should be considered positive and fall in potential should be considered negative.

(*i*) Thus if we go from the positive terminal of the battery to the negative terminal, there is fall of potential and the *e.m.f.* should be assigned negative sign. Thus in Fig. 2.62 (*i*), as we go from *A* to *B*, there is a fall in potential and the *e.m.f.* of the cell will be assigned negative

* As a charge traverses a loop and returns to the starting point, the sum of rises of potential energy associated with *e.m.fs* in the loop must be equal to the sum of the drops of potential energy associated with resistors.

** The reverse convention is equally valid *i.e.* rise in potential may be considered negative and fall in potential as positive.

sign. On the other hand, if we go from the negative terminal to the positive terminal of the battery or source, there is a rise in potential and the *e.m.f* should be assigned positive sign. Thus in Fig. 2.62 (*ii*) as we go from *A* to *B*, there is a rise in potential and the *e.m.f.* of the cell will be assigned positive sign. *It may be noted that the sign of e.m.f. is independent of the direction of current through the branch under consideration.*

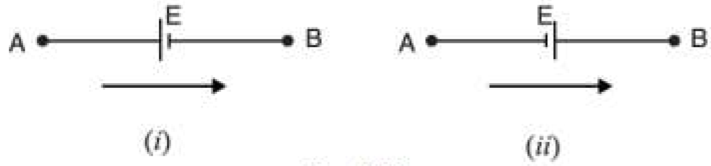


Fig. 2.62

(*ii*) When current flows through a resistor, there is a voltage drop across it. If we go through the resistor in the same direction as the current, there is a fall in potential because current flows from higher potential to lower potential. Hence this voltage drop should be assigned negative sign. In Fig. 2.63 (*i*), as we go from *A* to *B*, there is a fall in potential and the voltage drop across the resistor will be assigned negative sign.

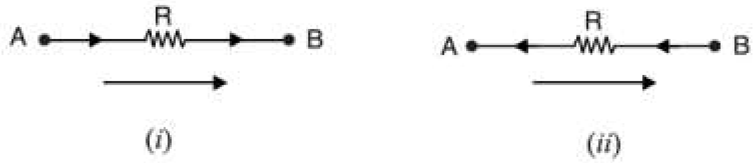


Fig. 2.63

On the other hand, if we go through the resistor against the current flow, there is a rise in potential and the voltage drop should be given positive sign. Thus referring to Fig. 2.63 (*ii*), as we go from *A* to *B*, there is a rise in potential and this voltage drop will be given positive sign. *It may be noted that sign of voltage drop depends on the direction of current and is independent of the polarity of the e.m.f. of source in the circuit under consideration.*

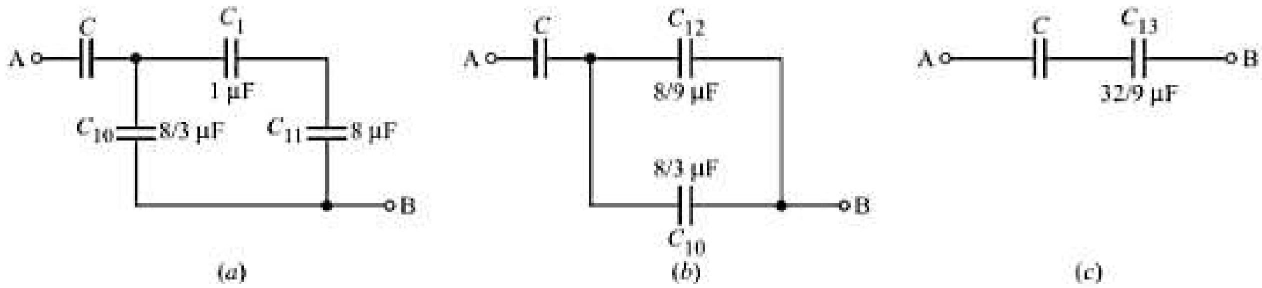


Fig. 3.7

3.3 ENERGY SOURCES

An electric circuit must have one or more energy sources. Just as we can view Ohm's law with two perspectives ($V = RI$ or $I = GV$), similarly an energy source could be taken as a *voltage source* or a *current source*. Let us first see what an *ideal voltage source* and an *ideal current source* mean.

Ideal Voltage Source

It is defined as an energy source whose terminal voltage (V) is independent of the output current (I). It means its terminal voltage is independent of the load resistance (R_L) connected to it. For any value of R_L, right from zero (i.e., a short circuit) to infinity (i.e., an open circuit), the terminal voltage remains constant. The mathematical definition of an ideal dc voltage source is described by Fig. 3.8*a*, and its graphical characteristic is shown in Fig. 3.8*b*. **Note** that the source determines the voltage, but the current is determined by the load. Figure 3.9 shows the circuit symbols for different types of *ideal voltage sources*.

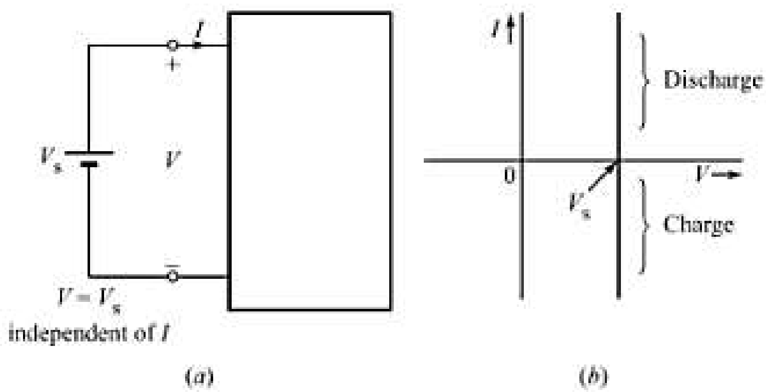


Fig. 3.8 *Ideal voltage source.*

(*a*) Ideal dc voltage source. (*b*) Ideal ac voltage source. (*c*) Ideal battery.

Fig. 3.9 *Symbols for different types of ideal voltage sources.*

Ideal Current Source

It is defined as a source which delivers a constant current, independent of its output voltage. Thus, the output current of such a source remains unchanged for R_L varying from zero (i.e., a short circuit) to infinity (i.e., an open circuit). The mathematical definition of an ideal dc current source is described by Fig. 3.10*a*, and its graphical characteristic is shown in Fig. 3.10*b*. **Note** that the source determines the current, but the voltage is determined by the load. Figure 3.11 shows the circuit symbols for different types of *ideal current sources*.

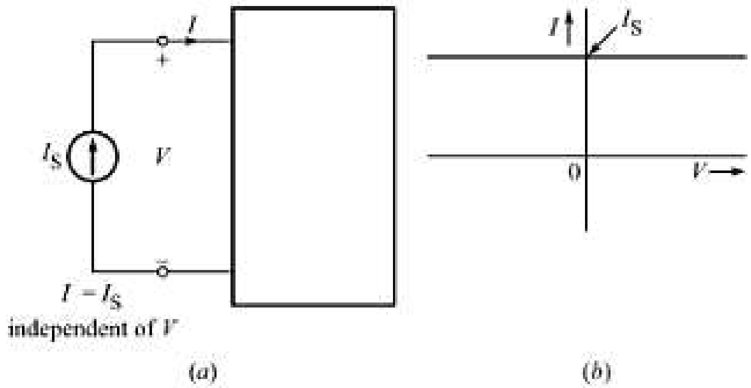


Fig. 3.10 *Ideal current source.*

Note that practically no such device as an *ideal voltage source* or an *ideal current source* exists. A source would meet the requirement of an ideal source only if it could supply an infinite amount of power. Practically, it is impossible. However, the concept of ideal sources helps us to describe the characteristics of practical sources.

(*a*) Ideal dc current source. (*b*) Ideal ac current source.

Fig. 3.11 *Symbols for different types of ideal current sources.*

Practical Voltage Source

Consider a load resistance R_L connected to the terminals A-B of a practical voltage source such as a battery (Fig. 3.12*a*). What happens when we increase the load* on the source (by decreasing the value of the load resistance R_L)? Our experience is that the terminal voltage V_L decreases. To account for this fact, a *practical voltage source* is modelled as *an ideal voltage source in series with a resistance* (as shown in the dotted box in Fig. 3.12*a*). This resistance is named as '*internal resistance*' or '*source resistance*', R_{SV}. The voltage of this ideal source is called the ***electromotive force (emf)*** of the practical voltage source.

Note that the resistance R_{SV} has no physical existence. Point C inside the source is not accessible. This internal resistance is merely introduced to account for the non-ideality of the practical voltage source.

The linear relationship between V_L and I_L is given as

$$V_L = V_{SV} - R_{SV} I_L$$

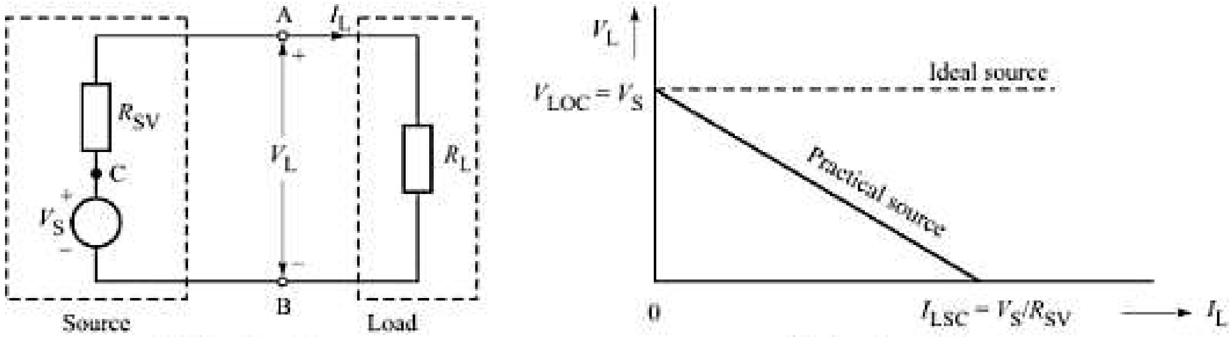
This characteristic line is plotted in Fig. 3.12*b*. The figure also shows the characteristic line (dotted) for an ideal voltage source. The open-circuit voltage (V_{LOC}) and short-circuit current (I_{LSC}) are given as

$$V_{LOC} = V_S \tag{3.16}$$

and

$$I_{LSC} = \frac{V_S}{R_{SV}} \tag{3.17}$$

* In electrical engineering, the term 'load' means the 'load current (I_L)', and **not** the 'load resistance (R_L)'.



(*a*) Circuit model.

(*b*) Characteristics.

Fig. 3.12 *A practical voltage source.*

Practical Current Source

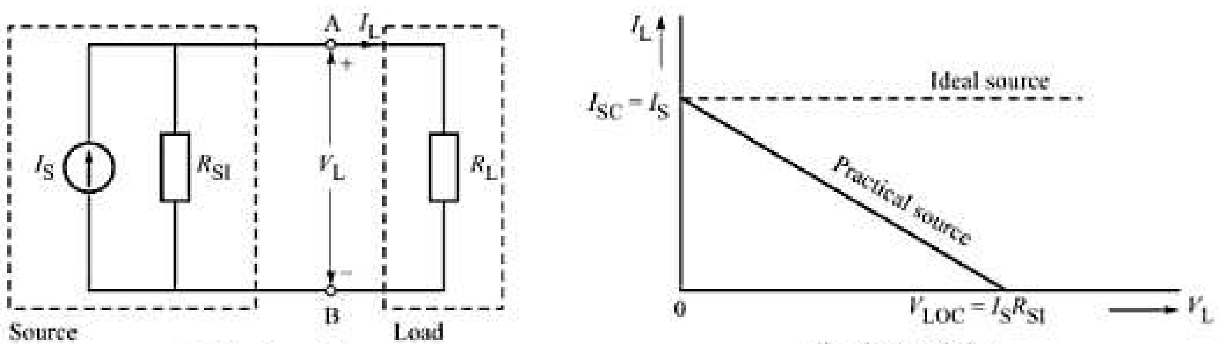
A *practical current source* is modelled as *an ideal current source in parallel with a resistance* (as shown in the dotted box in Fig. 3.13*a*). This resistance R_{SI} is called the *internal resistance*. (**Note** that a practical current source is *dual* of a practical voltage source.) The characteristic of a practical current source is described by the straight line

$$I_L = I_S - \frac{V_L}{R_{SI}}$$

This characteristic line is plotted in Fig. 3.13*b*. The figure also shows the characteristic of an ideal current source. The open-circuit voltage (V_{LOC}) and short-circuit current (I_{LSC}) are given as

$$V_{LOC} = R_{SI} I_S \tag{3.18}$$

$$I_{LSC} = I_S \tag{3.19}$$



(*a*) Circuit model.

(*b*) Characteristics.

Fig. 3.13 *A practical current source.*

EXAMPLE 3.8

A battery of emf 3 V and internal resistance of 1 Ω is used to supply power to a variable load resistance R_L of range (*a*) 100 Ω to 1000 Ω; (*b*) 1 mΩ to 10 mΩ, as shown in Fig. 3.14. Determine in the two cases, the % change in V_L and I_L.