

## BASICS OF ELECTRICAL ENGINEERING

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### 1.1 INTRODUCTION

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Electrical Engineering forms the foundation of Electrical, Electronics, Communications, Controls, Computers, Information, Instrumentation, etc. Hence a good grasp of the fundamentals of Electrical Engineering is an absolute necessity to become a good engineer in any discipline.

In this chapter we discuss the basics of Electrical Engineering like sources of electrical energy-voltage and current sources and their conversion, Ohm's law, calculation of electrical power and energy and DC circuit analysis using mesh and nodal analysis.

### 1.2 CURRENT FLOW

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#### 1.2.1 Potential and Potential Difference

An electrically charged particle sets up an electric field around it. If the particle is stationary, then the field set up by it is said to be *Electrostatic Field*. The electric field lines of a positive charge  $+q$  will be radial and directed away from the charge. The field set up by the negative charge  $-q$  will be radial and directed towards the negative charge. Like charges repel and unlike charges attract. The force of attraction

or repulsion between two charges  $q_1$  and  $q_2$  will be governed by **Coulomb's Law** which states that the force will be proportional to product of the charges  $q_1 \times q_2$  and inversely proportional to the square of the distance 'R' between them and depends upon the medium in which the charges are placed.

$$F = \frac{q_1 q_2}{4\pi \epsilon R^2} \quad \dots\dots\dots ( 1.2.1 )$$

where  $F$  is the force in Newtons  
 $q_1$  and  $q_2$  are the charges in coulombs  
 $R$  is the distance in meters  
 $\epsilon$  is the permittivity of the medium in Farads / meter

The Absolute Permittivity for free space or vacuum,

$$\epsilon_0 = 8.854 \times 10^{-12} = \frac{1}{36\pi} \times 10^{-9} \text{ Farads / meter}$$

For other media the Absolute Permittivity,

$$\epsilon = \epsilon_0 \times \epsilon_r$$

where  $\epsilon_r$  is the relative permittivity of the medium which is a mere number.  
 $\epsilon_r = 1$  for Air and  $\epsilon_r = 1$  for Mica

The force will be attractive if  $q_1$  and  $q_2$  are opposite charges and repulsive if  $q_1$  and  $q_2$  are like charges.

If we want to place any charge from one point to another point in the electrostatic field work has to be done against the electrostatic force or coulomb force experienced by that charge.

The work done in bringing a unit positive charge from infinity upto a given point  $p$  in an electrostatic field is defined as the potential at that point in the electro-static field. The unit for potential will be Joules/Coulomb. The unit is also called Volts.

The work done in moving a unit positive charge from one point in the electric field to another field in the electric field is known as the potential difference between the two points and is measured in volts. If  $V_A$  is the potential at point A and  $V_B$  is the potential at point B then the potential difference between the two points A and B will be  $V_{AB} = V_A - V_B$ . If  $V_A > V_B$  then  $V_{AB}$  will be positive and is known as potential drop from point A to point B.

If  $V_A < V_B$  then  $V_{AB}$  will be negative and is known as voltage rise from point B to point A. The voltage rise from point B to point A is generally denoted by the letter E.

$$E_{AB} = (E_A - E_B) = (V_B - V_A) = V_{BA} = -V_{AB} \quad \dots\dots (1.2.2)$$

### 1.2.2 Electric Current

An electron placed in an electric field will experience a force and move towards the positive potential of the field since it is negatively charged. Continuous flow of electrons constitute a current flow from negative potential to positive potential of the field. This current is known as **electron current**. The conventional current flow is opposite to that of the electron current in direction. The conventional current flow which is in opposite direction to electron current flow, will be flowing from a point of higher potential to a point of lower potential.

In metals (conducting materials), a large number of free electrons are available which move from one atom to the other at random when a potential difference is applied between two points of the conducting material and the current starts flowing.

The rate of flow of charges through any cross-section of a conductor is called a **current** and is denoted as 'i'. Current is expressed in terms of **amperes**. Ampere is denoted by A or sometimes by  $\alpha$ .

$$i = \frac{dq}{dt} \text{ Amperes} \quad \dots\dots\dots (1.2.3)$$

where  $i$  is the instantaneous value of the current (value at any particular instant of the current)

The **steady current** 'I' is given as,

$$I = \frac{Q}{t} \text{ Amperes} \quad \dots\dots\dots (1.2.4)$$

where Q is the charge flowing through the cross section of the conductor in time 't', if the flow of the charges is uniform.

Otherwise,

$$Q = \int i \, dt \text{ Coulombs} \quad \dots\dots\dots (1.2.5)$$

A wire is said to carry a current of **one ampere** when charge flows through it at the rate of one coulomb per second. Hence, one ampere is the current which flows when a charge of one coulomb moves across the cross-section of a conductor in one second.

### 1.2.3 Resistance or Resistance Parameter

When a potential difference is applied across a conductor ( or wire ), the free electrons start moving in a particular direction. While moving through the material, these electrons collide with other atoms and molecules. They oppose this flow of electrons ( or current ) through it. This opposition is called **Resistance**. Heat is produced because of the collisions of moving electrons with the other atoms and molecules. Thus whenever a current flows through a conductor, heat is produced in the conductor and this heat has to be dissipated fully. Otherwise, the insulation of the conductor ( the Sheath made of insulating material covering the conductor ) will get damaged.

*The opposition offered to the flow of current ( free electrons ) is called **Resistance**.*

Resistance is denoted by R and is measured in **ohms** named after a German mathematician **George Simon Ohm** and is represented by the Greek symbol  $\Omega$ .

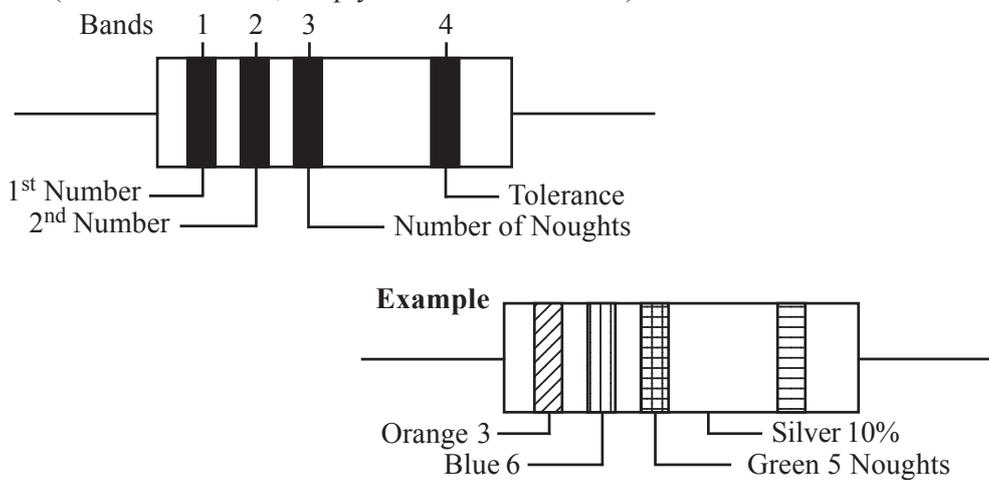
For very high resistance we use large units such as kilo-ohms (  $k\Omega$  which is equal to  $10^3 \Omega$  ) or Mega-ohms (  $M\Omega$  which is equal to  $10^6 \Omega$  ) while for small resistances we use smaller units such as milli-ohms (  $m\Omega$  which is equal to  $10^{-3} \Omega$  ) or micro-ohms (  $\mu\Omega$  which is equal to  $10^{-6} \Omega$  ).

In electronic circuits, the current will generally be very small in milli-Amperes ( mA or  $10^{-3}A$  ), micro-Amperes (  $\mu A$  or  $10^{-6}A$  ) or nano-Amperes ( nA or  $10^{-9}A$  ) and hence, the resistance or resistors used will be in kilo-ohms or Mega-ohms and will be denoted simply as k or M (  $\Omega$  is understood ). They will be made of carbon resistors and will have color codes for different digits. They will not be accurate and will have a tolerance limit denoted by another color band and the wattage of the resistors will also be specified as  $\frac{1}{2}$  Watt or 1 Watt. For higher wattages of 5 or 8 or 10 Watts etc., wire wound resistors will be used.

#### **Color Code of Resistors :**

There are resistors made from carbon mouldings or from metal-oxide film. Both are small, if not very small, and therefore we would find it most impossible to mark them with a rating such as  $47,000\Omega$ ,  $\frac{1}{2}$  Watt and hence, color coding is used. 1 Watt resistance will be bigger in size than  $\frac{1}{2}$  Watt resistance.

In the case of carbon resistors, it is usual to identify the ratings by means of rings painted around the resistors, as shown in Fig. 1.1. One of the bands is always placed near to the end of the resistor and should be taken as the first band. The first, second and third bands are used to indicate the resistance of the resistor by means of a color code which is also given in Fig. 1.1 which explains the colour coding clearly. In the code the first two bands are orange and blue which, from the table are 3 and 6 respectively. Therefore we are being told that the resistance has a numerical value of 36. The third band tells us how many zeroes to put after that number. In this case, the third band is green and there should be five zeroes, i.e., the resistance is 36,00,000 $\Omega$  (3.6M $\Omega$  or 36 K $\Omega$ , simply called 3.6 M or 36 K).



**Fig. 1.1** Color Code of Resistors

In power electronics, the power electronic devices can carry very high currents like hundreds of Amperes.

The resistance  $R$  of a conductor depends on

1. its length, in direct proportion
2. the area of cross section of the conductor, in inverse proportion
3. the material of the conductor, in direct proportion to the specific resistance of the material
4. the temperature, i.e. in direct proportion to the difference in temperature

Usually, the resistance is given per unit cross-section and unit length. This is called **specific resistance** or **resistivity** of the material represented by the letter,  $\rho$ . Since Copper and Aluminium have good electrical conductivity and cheaper compared to Silver, they are used for conductors. The resistivity of copper is 0.0173  $\mu\Omega$ -m and that of aluminium is 0.0283  $\mu\Omega$ -m.

The colour codes for the bands are given in Table 1.1

**Table 1.1** Color Code

Digit	Color	Tolerance	Color
0	Black	5%	Gold
1	Brown	10%	Silver
2	Red	20%	No Color Band
3	Orange		
4	Yellow		
5	Green		
6	Blue		
7	Violet		
8	Grey		
9	White		

*The color code can be remembered as,*  
**BBROY** of Great **Britain** has a **Very** Gracious **Wife**

If the resistance or resistivity is less the current flowing will be more. The resistance of a material is given by

$$R = \frac{\rho l}{a} \Omega \quad \text{..... ( 1.2.6 )}$$

where  $\rho$  is the specific resistance of the material of the conductor in  $\Omega$ -meters  
 $l$  is the length of the conductor in meters  
 $a$  is the area of cross-section of the conductor in square meters.

Not only conductors, but a coil wound with a conductor or any other electrical equipment offers resistance to current flow. A wire wound coil with two fixed terminals is called a **resistor** or **resistance**. A coil with two fixed terminals and a variable contact terminal which makes contact with the body of the coil is called a **Rheostat** or **Variable Resistor**. A rheostat can be connected in two ways as,

**1. Series Resistance ( as shown in Fig. 1.2 ( a ) )**

*If the moving contact is very near the starting terminal the resistance offered by the rheostat will be minimum and if it is nearer to the farthest end terminal, the resistance offered by the rheostat will be maximum. Sometimes the moving contact and one of the end terminals will be connected together in which case, the resistance offered will be the resistance of the remaining part of the winding. As the moving contact is varied the resistance offered by this part will be varying, as the moving contact is moved away from or towards the second terminal. If the moving contact is towards the starting terminal then the resistance offered by the rheostat will be less.*

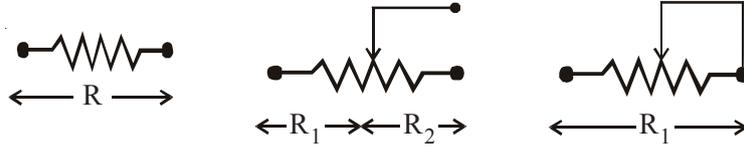


Fig. 1.2( a ) Series Rheostat

2. **Potential Divider** ( as shown in Fig. 1.2 ( b ) )

The two ends of the rheostat are connected across a voltage source which constitutes the input to the potential divider. The output is tapped between the moving contact and one of the end terminals, in which case, part of the input voltage will be the output voltage. The voltage tapped is given by,

$$V_{out} = V_{in} \times \frac{R_t}{R} \text{ Volts} \quad \dots\dots\dots ( 1.2.7 )$$

where  $R$  is the total resistance of the rheostat and  $R_t$  is the resistance of the tapped part of the rheostat winding.

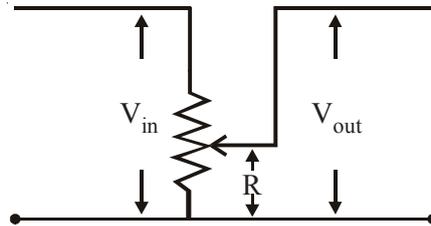


Fig. 1.2 ( b ) Rheostat as Potential Divider

**Example 1.1 :**

Find the resistance of a coil of mean diameter 4 cm containing 400 turns of manganese wire 0.05 cm in diameter. The resistivity of manganese is  $42 \mu\Omega - \text{cm}$ .

**Solution :**

Here

$$\begin{aligned} \rho &= 42 \mu\Omega\text{-cm.} \\ &= 42 \times 10^{-6} \Omega\text{cm} \\ &= 42 \times 10^{-8} \Omega - \text{m} \end{aligned}$$

$$\begin{aligned} a &= \frac{\pi}{4} d^2 \\ &= \frac{\pi}{4} ( 0.05 )^2 \text{ cm}^2 \\ &= \frac{\pi}{4} ( 0.05 )^2 \times 10^{-4} \text{ m}^2. \end{aligned}$$

Number of turns ( N ) of the coil,

$$N = 400$$

Length per turn of the coil is  $\pi \times D$

where D is the diameter of the coil.

Length ( l ) of the conductor of the coil,

$$\begin{aligned} l &= \pi \times D \times N \\ &= \pi \times 4 \times 400 \text{ cm} \\ &= 16 \pi \text{ m} \end{aligned}$$

Resistance of the coil,

$$R = \frac{42 \times 10^{-8} \times 16\pi \times 4}{\pi (0.05)^2 \times 10^{-4}} = 107.52 \Omega.$$

#### 1.2.4 Effect of Temperature on Resistance

As temperature increases the resistance of most of the conducting materials increase while for some material like Carbon, electrolytes, insulators the resistance decreases as the temperature increases. The change in resistance depends upon the temperature-coefficient of resistance, which will be positive if the resistance increases with temperature and negative if the resistance decreases with temperature. The change in resistance per ohm per degree temperature change is called **temperature-coefficient of resistance** and its symbol is  $\alpha$ .

If a metallic conductor of resistance  $R_0$  at  $0^\circ\text{C}$  is heated to a temperature  $t_1$ , then the resistance  $R_1$  at temperature  $t_1$  is given by

$$R_1 = R_0 ( 1 + \alpha_0 t_1 ) \quad \dots\dots\dots ( 1.2.8 )$$

Since the temperature-coefficient itself varies with temperature, it does not have the same value at all temperatures. Thus if  $R_1$  and  $R_2$  are the resistances of a conductor at temperatures  $t_1$  and  $t_2$ , we have

$$R_2 = R_1 ( 1 + \alpha_1 ( t_2 - t_1 ) ) \quad \dots\dots\dots ( 1.2.9 )$$

where  $\alpha_1$  is the temperature-coefficient of resistance at  $t_1^\circ\text{C}$ .

Variation of  $\alpha$  is obtained as

$$\frac{1}{\alpha_2} = \frac{1}{\alpha_1} + ( t_1 - t_2 )$$

or 
$$\alpha_2 = \frac{\alpha_1}{1 + \alpha_1 ( t_2 - t_1 )} \quad \dots\dots\dots ( 1.2.10 )$$

**Example 1.2 :**

The resistance of a coil decreases from  $70\Omega$  at  $75^\circ\text{C}$  to  $50\Omega$  at  $15^\circ\text{C}$ . Calculate the value of temperature-coefficient of resistance of the material of the coil at  $0^\circ\text{C}$ . Find the resistance at  $0^\circ\text{C}$ .

**Solution :**

Let  $\alpha_0$  be the temperature-coefficient of resistance and  $R_0$  be the resistance at  $0^\circ\text{C}$ .

$$70 = R_0 ( 1 + 75 \alpha_0 ) \quad \dots\dots\dots ( 1 )$$

and  $50 = R_0 ( 1 + 15 \alpha_0 ) \quad \dots\dots\dots ( 2 )$

Dividing Eq. ( 1 ) by Eq. ( 2 ) we get,

$$\frac{70}{50} = 1.4 = \frac{1 + 75\alpha_0}{1 + 15\alpha_0}$$

$$54 \alpha_0 = 0.4$$

or  $\alpha_0 = \frac{0.4}{54} = 0.0074074$

$$R_0 = \frac{70}{1 + 75\alpha_0} = \frac{70}{1.5555} = 45 \Omega$$

**1.2.5 Electrical Conductance**

The reciprocal of resistance of a conductor is called **Conductance** of the conductor and is denoted by 'G' and is expressed in terms of Siemen abbreviated as "S" or mhos ( $\oslash$ ).

$$\begin{aligned} G &= \frac{1}{R} \\ &= \frac{1}{\rho l/a} \\ &= \frac{a}{\rho l} = \sigma \frac{a}{l} \text{ Siemens} \quad \dots\dots\dots ( 1.2.11 ) \end{aligned}$$

where  $\sigma$  is called specific conductance or conductivity and is measured in Siemens per meter ( S/m ).

If the conductance or conductivity is less the current flowing will be less.

1.3 SOURCES OF ELECTRICAL ENERGY

1.3.1 The Voltage Source

The **voltage source** is assumed to deliver energy with a specified **terminal voltage**  $V_T$ , if it is a steady voltage source or  $v(t)$  or simply  $v$ , if the voltage changes with respect to time. An ideal voltage source is expected to deliver a constant voltage to the outside circuit whatever be the amount of current drawn from the voltage source. The voltage of the source is called the **Electro-Motive Force ( E.M.F. )** and is measured in Volts. It is denoted by the symbol  $E$ .

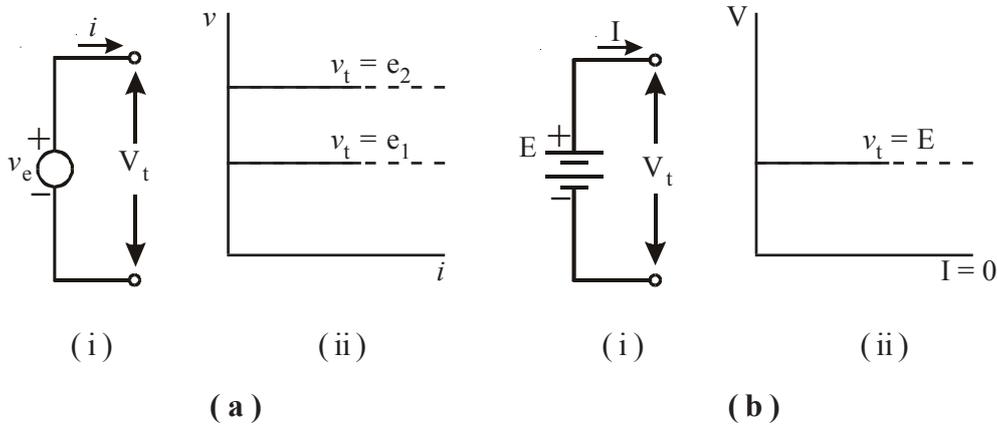


Fig. 1.3 ( a ) For a Time-Varying Voltage Source, ( b ) For a Time-Invariant Voltage Source ( represented by a Battery )

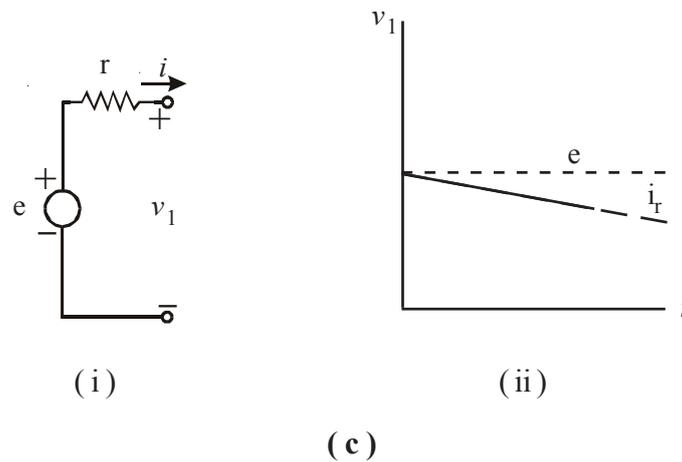


Fig. 1.3 ( c ) ( i ) Model for a Voltage Source in which 'r' represents Source Resistance. The internal resistance 'r' will be very low. For the model of ( i ), the Terminal Voltage depends on source current as shown in ( ii ) where  $v_1 = e - ir$

If the source has an internal resistance  $r$  then,

$$V = v(t) - i r \quad \dots\dots\dots ( 1.3.1 )$$

or  $V_t = E - I r$  Volts  $\dots\dots\dots ( 1.3.1a )$

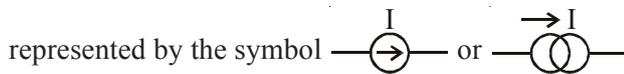
where  $I$  is the current drawn from the Voltage source in Amperes ( A )  
 $r$  is the internal resistance of the voltage source in Ohms (  $\Omega$  ).

In practice the terminal voltage of the voltage source will be decreasing as the current drawn from it is increased due to the voltage drop in the internal resistance of the voltage source. The internal resistance has to be very small in order that the voltage drop inside the source will be very small and maximum voltage may be available to the load.

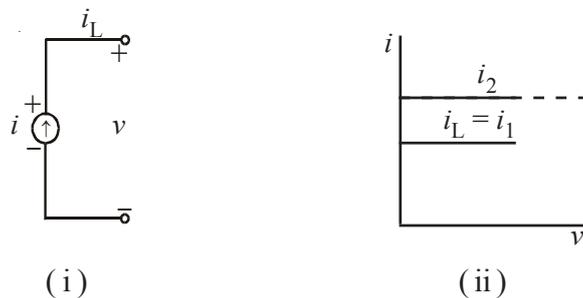
*Note :* For any D.C. source, the polarities at the terminals will be same at all instants of time. For Time Varying Sources to polarities indicate the polarities at different terminals at any particular instant of time.

### 1.3.2 Current Source

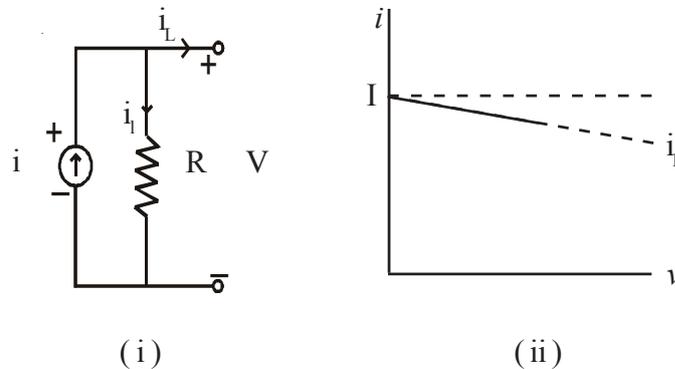
A current source is said to deliver a constant current  $i_2 = I$  to the circuit through the terminals, if it is a steady current source or  $i(t)$  or simply  $i$ , if the current changes with respect to time. An ideal current source is expected to deliver a constant current to the outside circuit whatever be the circuit. An ideal current source can be



In practice the current supplied by the current source will be decreasing as the voltage across the current source is increasing due to the internal resistance  $R$  of the current source, which is assumed to be across the current source. The internal resistance of the current source should be as high as possible so that maximum current will be delivered to the load connected across the current source with the current through the internal resistance being very very small.



**Fig. 1.4 ( a )** ( i ) Symbol for the Current Source for which  $i$  does not depend on  $v$  as shown in, ( ii ) Other lines may be drawn parallel to that shown for a specific current,  $i_1$ .



**Fig. 1.4 ( b ) ( i )** Model for a Current Source in which  $R$  represents shunt resistance. For the model of 1.4 ( i ), the Terminal Current in 1.4 (ii) is given by  $i_L = i - (1/R)v$  ( ii ) Other lines may be drawn parallel to that shown for a specific current,  $i_L$ . The internal resistance 'R' will be very high.

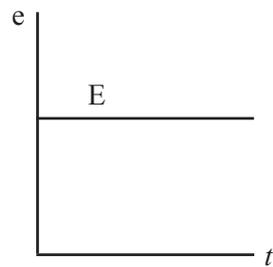
### 1.3.3 D.C. & A.C. Sources

If the voltage or current supplied by an electrical energy source is constant with respect to time as shown in Fig. 1.5 ( a ) ( i ) or Fig. 1.5 ( a ) ( ii ) then it is known as **D.C. Voltage Source** or **Direct Current Source** ( or **Steady Current Source** ). D.C. stands for **Direct Current**.

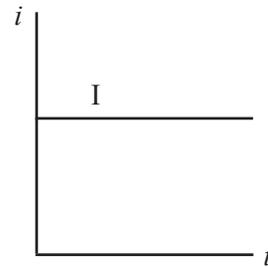
A D.C. Source has two terminals from which energy is supplied to the outside load. They are known as **Positive Terminal** which supplies the positive ions and **Negative Terminal** which receives the returning current or which can be assumed as supplying negative charges called electrons in the direction opposite to the conventional current direction. D.C. supply is provided by batteries or D.C. generators. The battery converts chemical energy into electrical energy. The generator converts mechanical energy into electrical energy.

If the voltage or current is varying with respect to time but, has the same polarity as shown in Fig. 1.5 ( b ) ( i ) then it is known as **Unidirectional Source**. If the polarity is positive, it is known as **Positive Source**. If the polarity is negative, it is known as **Negative Source**.

If the voltage or current supplied by an electrical energy source varies in both magnitude and polarity with respect to time as shown in Fig. 1.5 ( b ) ( ii ) then it is known as **A.C. Voltage Source** or **Alternating Current Source**. A.C. stands for **Alternating Current**.

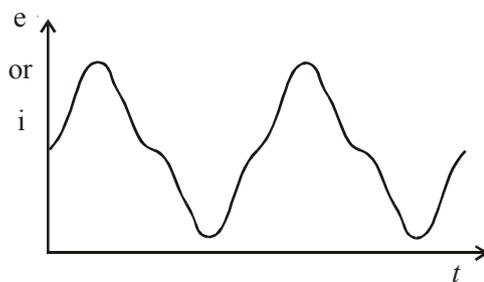


( i ) D.C. Voltage Source

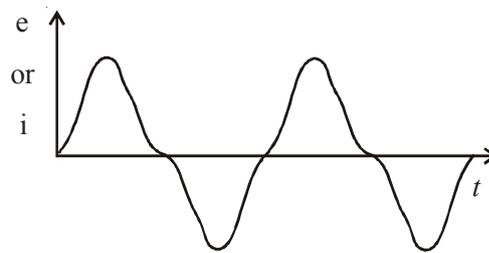


( ii ) D.C. Current Source

**( a ) D.C. Voltage & Current Sources**



( i ) Uni directional voltage or current



( ii ) A.C. Voltage or Current

**( b ) A.C. Uni-directional Voltage & Current Sources**

**Fig. 1.5 A.C and D.C. Voltage & Current Sources**

The value of the voltage or current of an A.C. supply at any instant is called **Instantaneous Value of Voltage or Current** and is denoted as  $v(t)$  or  $i(t)$ .

In general, the instantaneous values may also be denoted as  $v$  or  $i$ . Generally no polarities will be marked for A.C. voltage or current. If at all polarities are marked for A.C. voltage or current, they mean the polarities of the voltage or current at the marked terminals, at any one particular instant and will be changing from time to time.

## 1.4 OHM'S LAW

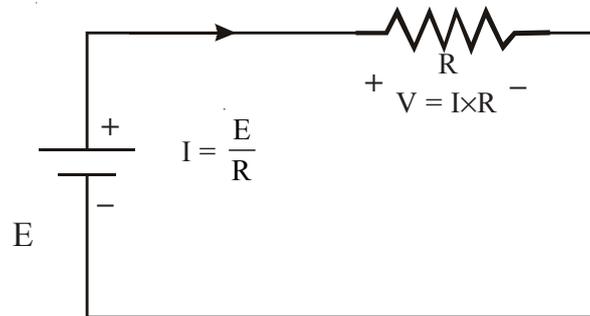
The relationship between the current flowing through a conductor and the potential difference across the conductor is given by **Ohm's Law**.

The *Ohm's Law* states that *the potential difference across a conductor is directly proportional to the current flowing through the conductor, the temperature of the conductor remaining constant*. The constant of proportionality is R, the resistance.

$$V = I \times R \text{ Volts} \quad \dots\dots\dots ( 1.4.1 )$$

or 
$$V = R \times I \text{ Volts} \quad \dots\dots\dots ( 1.4.1a )$$

Here, V is the voltage drop across the conductor.



**Fig. 1.6** Circuit for Ohm's Law

**Note :** *In the circuit, the voltage drop caused in the conducting wires connecting the battery and resistance are assumed to be zero as it will be negligible because the wire is a conducting material.*

**Note :** *While writing the equations for Volt-Ampere relationships in matrix form the second form i.e. Eq. ( 1.4.1a ) will be applicable and can be expressed as,*

$$[ V ] = [ R ][ I ] \quad \dots\dots\dots ( 1.4.1b )$$

Ohm's Law can also be expressed as

$$E = I \times R \text{ Volts} \quad \dots\dots\dots ( 1.4.1c )$$

Here, E is the voltage rise across the conductor.

$$E_{AB} = -V_{AB}$$

The equation for Ohm's Law can also be written as,

$$I = \frac{V}{R} \text{ Amperes} \quad \dots\dots\dots ( 1.4.2 )$$

Ohm’s Law also gives the Volt-Ampere relationship for an element. Ohm’s Law can be applied to a part of a circuit or to the full circuit in which the current flows.

Ohm’s Law can also be applied to A.C. Circuits or to circuits with Unidirectional Source in Laplace Transform domain for instantaneous values. For steady state conditions of A.C Ohm’s Law using impedances and using RMS values for voltages and currents, all in complex form will be discussed later. However, for resistive circuits consisting of only resistances Ohm’s Law can be written as,

$$v = i \times R \text{ Volts} \quad \dots\dots\dots ( 1.4.3 )$$

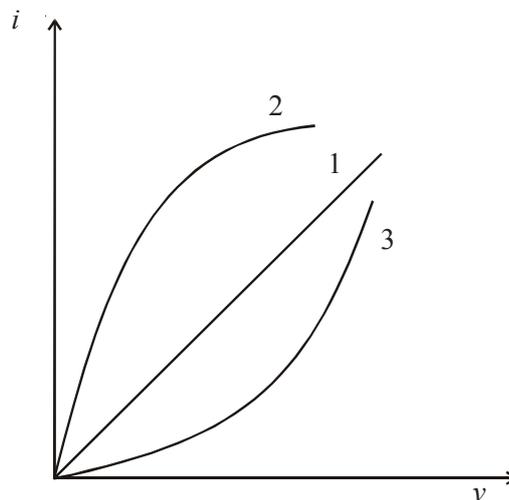
or  $v = R \times i \text{ Volts} \quad \dots\dots\dots ( 1.4.3a )$

or  $i = \frac{v}{R} \text{ Amperes} \quad \dots\dots\dots ( 1.4.3b )$

where  $v$  and  $i$  are instantaneous values of Voltage and Current respectively.

**1.4.1 Linear & Non-Linear Resistances**

Those resistances in which the current flow changes in direct proportion with changes in the voltage applied across them are called **Linear Resistances**. (curve 1 of fig. 1.7) The  $v$ - $i$  characteristics for linear resistances will be current increasing as the voltage across increases. Ohm’s Law is applicable as the resistance remains constant.



**Fig. 1.7 Linear & Non-Linear Resistances**

Those resistances for which the current through them does not vary in direct proportion are called **Non-Linear Resistances**. For nonlinear resistances the  $v-i$  characteristics will be nonlinear. (curves 2 and 3 of fig.1.7)

In certain nonlinear resistances like Thyrite, the current increases more than proportionately with applied voltage with resistance decreasing rapidly like in curve 2 of Fig. 1.7. Hence, it is used in Lightning Arrestors.

In certain other nonlinear resistances like Semiconductors, Thermistors, the current decreases as the voltage across increases like in curve 3 of Fig. 1.7. Hence, thermistor is used in over current protection in Motors, etc.

**Example 1.3 :**

A current of 0.75A is passed through a coil of nichrome wire which has an area of cross-section of  $0.01 \text{ cm}^2$ . If the resistivity of the nichrome is  $108 \times 10^{-6} \Omega\text{-cm}$  and the potential difference across the ends of the coil is 81V. What is the length of the wire? What is the conductivity and conductance of the wire?

**Solution :**

Resistance,

$$R = \frac{\rho l}{a}$$

where,  $R = \frac{V}{I}$

$$= \frac{81}{0.75}$$

$$= 108 \Omega$$

$$a = 0.01 \text{ cm}^2 = 0.01 \times 10^{-4} \text{ m}^2$$

$$l = \frac{R \times a}{\rho}$$

$$= \frac{108 \times 0.01 \times 10^{-4}}{108 \times 10^{-8}} = 100 \text{ m}$$

Conductivity,

$$\sigma = \frac{1}{\rho}$$

$$= \frac{1}{108 \times 10^{-8}}$$

$$= 92.59 \times 10^4 \text{ } \Omega/\text{m}$$

Conductance,

$$G = \frac{1}{R}$$

$$= \frac{1}{108}$$

$$= 9.259 \times 10^{-3} \text{ } \Omega \text{ or Siemens}$$

## 1.5 ELECTRICAL POWER

Power is the rate of doing work and is expressed in Joules per second. When one coulomb of electrical charge moves through a potential difference of one volt in one second the work done is one Joule/sec and in electrical engineering it is expressed as one Watt and is denoted by the symbol P.

So Power supplied,

$$P = E \times I \text{ Watts} \quad \text{..... ( 1.5.1 )}$$

where E is the source voltage.

Power expended,

$$P = V \times I \text{ Watts} \quad \text{..... ( 1.5.1a )}$$

where V is the voltage drop.

Applying Ohm's Law for V,

$$P = (I \times R) \times I \text{ Watts}$$

$$P = I^2 \times R \text{ Watts} \quad \text{..... ( 1.5.2 )}$$

or Applying Ohm's Law for I,

$$P = V \times \left( \frac{V}{R} \right) \text{ Watts}$$

$$P = \frac{V^2}{R} \text{ Watts} \quad \left( \because I = \frac{V}{R} \right) \quad \text{..... ( 1.5.3 )}$$

For A.C. circuits or circuits with unidirectional source, the equations for electrical power can be written using instantaneous values as,

$$p = e \times i \text{ Watts} \quad \text{..... ( 1.5.4 )}$$

where  $e$  is the source voltage.

Power expended,

$$p = v \times i \text{ Watts} \quad \text{..... ( 1.5.4a )}$$

where  $v$  is the voltage drop.

Applying Ohm's Law for  $v$ ,

$$p = i^2 \times R \text{ Watts} \quad \text{..... ( 1.5.5 )}$$

or Applying Ohm's Law for  $i$ ,

$$p = \frac{v^2}{R} \text{ Watts} \quad \text{..... ( 1.5.6 )}$$

The power expended is also known as **Power Loss** or **Copper Loss** since the power loss takes place in the conductor ( generally made of copper ). It is called copper loss, even though the conductor material is not made of copper.

The power loss or copper loss appears in the form of heat. This heat has to be dissipated properly or else the insulation of the conductor or the insulation coating ( varnish )of the coil will get damaged and there will be short circuits between turns of the coil and the coil may get burnt away in the case of machines and other equipments using coils.

## 1.6 ENERGY CALCULATIONS

---

Energy is the work done in a given time to achieve the required state of heating, lighting, lifting weights, moving the objects, etc. As such energy calculations are very important. Of late to have good efficiency in getting the work done and to have good economy Energy Auditing is resorted to in Industries and because energy charges are recurring charges involving expenditure.

According to the *Law of Conservation of Energy*, energy can neither be created nor destroyed. As such energy can atmost be converted from one form of energy into another form like converting mechanical energy into electrical energy and vice versa, converting electrical energy into heat energy and vice versa, etc. In this process the efficiency of the equipment used in conversion plays an important role. Also the constants of conversion are to be considered.

## 1.7. ELECTRICAL ENERGY

**Electrical Energy** is the total amount work done and is expressed in Joules or in Watt-seconds in electrical engineering. It is denoted by W. If E is the voltage rise or electromotive force and I is the current then, the energy generated or the energy supplied for a time t seconds is given as,

$$W = P \times t = E \times I \times t \text{ Watt-sec} \quad \text{..... ( 1.7.1 )}$$

or 
$$W = I^2 \times R \times t \text{ Watt-sec} \quad \text{..... ( 1.7.2 )}$$

or 
$$W = \frac{E^2}{R} \times t \text{ Watt-sec} \quad \text{..... ( 1.7.3 )}$$

For A.C. circuits or circuits with unidirectional source,

$$w = p \times dt = e \times i \times dt \text{ Watt-sec} \quad \text{..... ( 1.7.4 )}$$

or 
$$w = i^2 \times R \times dt \text{ Watt-sec} \quad \text{..... ( 1.7.5 )}$$

or 
$$w = \frac{e^2}{R} \times dt \text{ Watt-sec} \quad \text{..... ( 1.7.6 )}$$

where  $p, v, i$  all stand for instantaneous values and dt is the differential time

So,

$$W = \int p dt \text{ Watt-sec} \quad \text{..... ( 1.7.7 )}$$

or 
$$W = \int e \times i dt \text{ Watt-sec} \quad \text{..... ( 1.7.8 )}$$

or 
$$W = \int \frac{e^2}{R} dt \text{ Watt-sec} \quad \text{..... ( 1.7.9 )}$$

The energy expended can be obtained by using the above equations substituting V for E or v for e.

If the power is supplied for time  $t_1$  to  $t_2$  seconds then, the total energy W will be given as,

$$W = \int_{t_1}^{t_2} p dt \text{ Watt-sec} \quad \text{..... ( 1.7.10 )}$$

Since the Watt-sec is a small unit, for practical purposes, energy is expressed in terms of Kilo-Watt-Hour ( KWH ) or units.

1 unit of energy = 1 KWH

$$1 \text{ unit of energy} = \frac{\text{Power in Watts} \times \text{Time in seconds}}{1000 \times 60 \times 60}$$

Power distribution companies charge the electrical energy supplied to the consumer in terms of Standard Energy Units ( Board of Trade Units ) known as Kilo-Watt-Hours.

## 1.8 KIRCHOFF'S LAWS

There are two more important laws governing the performance of a circuit known as

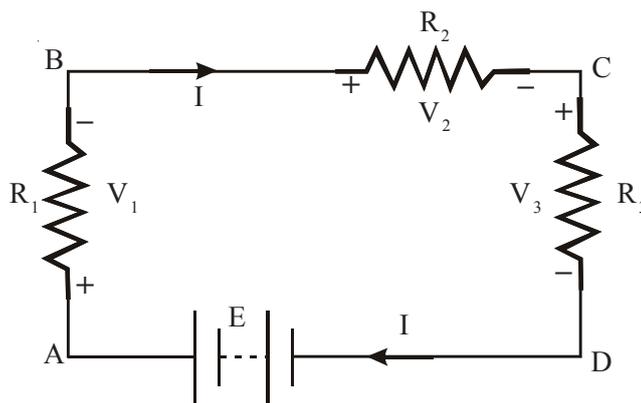
1. *Kirchoff's Voltage Law ( KVL )*
2. *Kirchoff's Current Law ( KCL or KIL)*

where I stands for current in KIL.

### 1.8.1 Kirchoff's Voltage Law ( KVL )

**Kirchoff's Voltage Law** states that, *in a closed electric circuit the algebraic sum of E.M.F.s and Voltage drops is zero.*

By convention, the E.M.F.s or Voltage rises are taken to be positive and Voltage drops are taken to be negative.



**Fig. 1.8** Circuit for Kirchoff's Voltage Law

In the closed circuit ABCDA given in Fig. 1.8, applying Kirchoff's Voltage Law, we have,

$$E - V_1 - V_2 - V_3 = 0 \quad \text{..... ( 1.8.1 )}$$

$$E - IR_1 - IR_2 - IR_3 = 0 \quad \text{..... ( 1.8.1a )}$$

or  $IR_1 + IR_2 + IR_3 = E \quad \text{..... ( 1.8.1b )}$

Sum of voltage drops = Sum of E.M.F.s or Voltage rises

Kirchoff's Voltage Law can be applied to any closed loop ( closed circuit ) even if there is no voltage source in which case the right hand side of Eq. ( 1.8.1b ) will be zero for several loops. KVL in matrix form is given as,

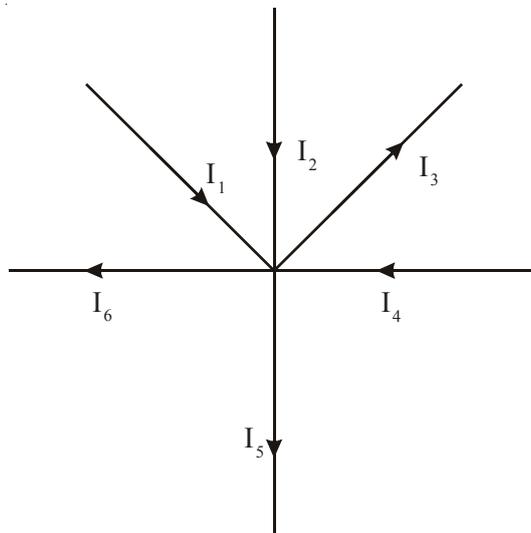
$$[ R ][ I ] = [ E ] \quad \text{..... ( 1.8.1c )}$$

**1.8.2 Kirchoff's Current Law ( KCL or KIL )**

**Kirchoff's Current Law** states that, *at any junction ( or node ) at which different elements are connected, the algebraic sum of the current at the junction is zero* A junction or node is the meeting point of more than one element in a circuit. For eg. point B in the circuit given for Example 1.9 is a junction or node.

By convention, a currents entering the junction are taken to be positive and currents leaving the junction are taken to be negative.

The currents of the current sources entering the junction are positive.



**Fig. 1.9 Kirchoff's Current Law**

In the Fig. 1.9

, applying Kirchoff's Current Law to the junction A, we have,

$$I_1 + I_2 + I_4 - I_3 - I_5 - I_6 = 0 \quad \text{..... ( 1.8.2 )}$$

or 
$$I_3 + I_5 + I_6 = I_1 + I_2 + I_4 \quad \text{..... ( 1.8.2a )}$$

$$\text{Sum of currents leaving the junction} = \text{Sum of currents entering the junction}$$

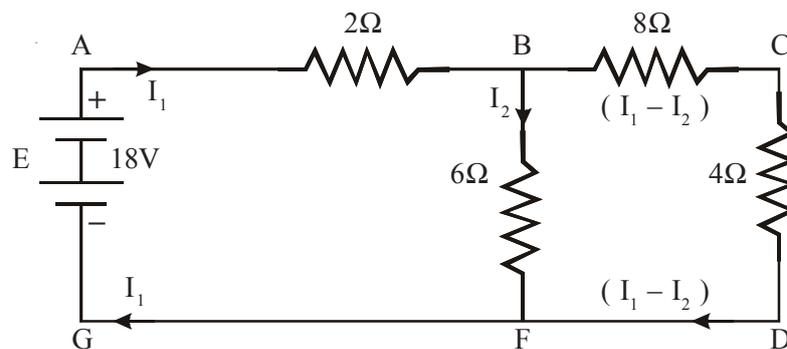
**Note :** Kirchoff's Voltage Law and Kirchoff's Current Law can also be applied to A.C. Circuits or to circuits with Unidirectional Source using instantaneous values for Voltages and currents. In A.C., for steady state values using impedances and using RMS values for voltages and currents, all in complex form will be discussed later. However, for resistive circuits consisting of only resistances Kirchoff's Voltage and Current Laws can be written as,

$$\text{KVL :} \quad iR_1 + iR_2 + iR_3 = e \quad \text{..... ( 1.8.2c )}$$

$$\text{KCL :} \quad i_3 + i_5 + i_6 = i_1 + i_2 + i_4 \quad \text{..... ( 1.8.2d )}$$

**Example 1.4 :**

Applying KCL and KVL, find the currents in the various elements of the circuit given in Fig. 1.9. Find the power delivered by the battery and the energy supplied by the battery for a period of half an hour. Also calculate the power loss in the  $6\Omega$  resistor.



**Solution :**

Let the current supplied by the battery to junction A be  $I_1$ . The same current  $I_1$  flows through the  $2\Omega$  resistance towards junction B. At B a part of this current of  $I_1$  flows through the  $6\Omega$  resistance towards junction F. Let it be  $I_2$ .

Applying Kirchoff's Current Law to junction A, the current  $8\Omega$  resistance will be  $(I_1 - I_2)$  towards junction C.

Applying Kirchoff's Voltage Law to the loop ABFGA,

$$2 \times I_1 + 6 \times I_2 = 18$$

or  $2I_1 + 6I_2 = 18$  ..... ( 1 )

Applying Kirchoff's Voltage Law to the loop BCDFB,

$$8 \times (I_1 - I_2) + 4 \times (I_1 - I_2) - 6 \times I_2 = 0$$

i.e.,  $12I_1 - 18I_2 = 0$  ..... ( 2 )

Solving Eq. ( 1 ) and ( 2 ) we obtain,

$$I_1 = 3 \text{ A}$$

and  $I_2 = 2 \text{ A}$

Also, Eq. ( 1 ) and ( 2 ) can be solved using Cramer's Rule,

$$\begin{aligned} I_1 &= \frac{\begin{vmatrix} 18 & 6 \\ 0 & -18 \end{vmatrix}}{\begin{vmatrix} 2 & 6 \\ 12 & -18 \end{vmatrix}} \\ &= \frac{18 \times (-18) - 6 \times 0}{2 \times (-18) - 6 \times 12} \\ &= \frac{-324}{-72} = 3 \text{ A} \end{aligned}$$

Similarly,

$$\begin{aligned} I_2 &= \frac{\begin{vmatrix} 2 & 18 \\ 12 & 0 \end{vmatrix}}{\begin{vmatrix} 2 & 6 \\ 12 & -18 \end{vmatrix}} \\ &= \frac{2 \times 0 - 18 \times 12}{2 \times (-18) - 6 \times 12} \end{aligned}$$

$$= \frac{-216}{-108} = 2 \text{ A}$$

or  $2I_1 + 6I_2 = 18$

Substituting the values of  $I_1 = 3$  we obtain,

$$I_2 = 2 \text{ Amperes}$$

Current in  $2\Omega$  resistor,

$$I_1 = 3 \text{ A}$$

Current in  $6\Omega$  resistor,

$$I_2 = 2 \text{ A}$$

Current in  $8\Omega$  resistor,

$$I_1 - I_2 = 1 \text{ A}$$

Current in  $4\Omega$  resistor,

$$I_1 - I_2 = 1 \text{ A}$$

Current supplied by the battery,

$$\begin{aligned} P &= EI_1 \\ &= 18 \times 3 = 54 \text{ Watts} \end{aligned}$$

Energy,  $W = P \times t$

Energy supplied by the battery for half an hour ( 1800 sec ),

$$W = 54 \times 1800 = 97200 \text{ Watt-sec.}$$

$$= \frac{97200}{60 \times 60}$$

$$= 27 \text{ Watt-hours}$$

$$= \frac{27}{1000}$$

$$= 0.027 \text{ KWH}$$

Power Loss,

$$P = I^2R \text{ Watts}$$

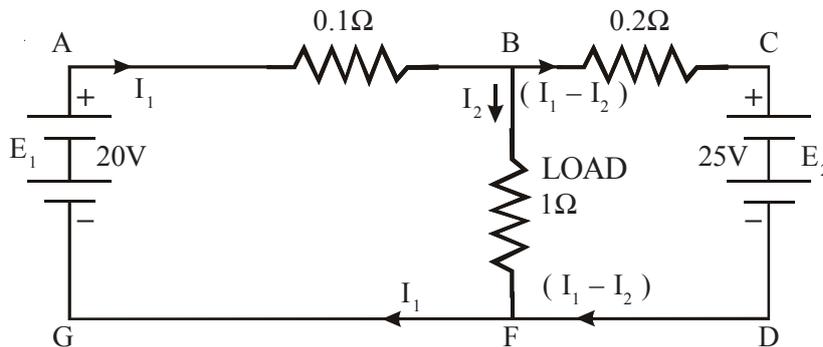
$$\text{Power Loss in the } 6\Omega \text{ resistor} = (I_2)^2 \times 6$$

$$= 2^2 \times 6$$

$$= 24 \text{ Watts}$$

**Example 1.5 :**

In the circuit of given figure, find the power supplied to the load. Find also the voltage at the load using KCL and KVL Equations. Also find the current through  $0.2\Omega$  resistance.



**Solution :**

Let the current entering node B be  $I_1$  and let the current flowing through the resistance  $1\Omega$  resistance be  $I_2$ . Applying KCL for node B, the current through  $0.2\Omega$  resistance will be  $(I_1 - I_2)$ .

Writing KVL for loop ABFGA,

$$0.1I_1 + 1 \times I_2 = 20$$

i.e.,  $0.1I_1 + I_2 = 20$  ..... ( 1 )

Writing KVL for loop BCDFB,

$$0.2x(I_1 - I_2) + 1x(-I_2) = -25$$

i.e.,  $0.2I_1 - 1.2I_2 = -25$  ..... ( 2 )

Solving Eq. ( 1 ) and ( 2 ) we get,

$$I_1 = -3.125 \text{ A}$$

$$I_2 = -20.3125 \text{ A}$$

Hence, the current in the load is  $I_2$

$$= 20.3125 \text{ A.}$$

Current through  $0.2\Omega$  resistance is,

$$(I_1 - I_2) = (-3.125 - 20.3125) = -23.4375 \text{ A}$$

The negative signs for  $I_1$ ,  $I_2$ ,  $(I_1 - I_2)$  mean that the direction of the current flow is opposite to the assumed direction i.e., the current flows from B to A and not from A to B as assumed,  $I_2$  from C to B and  $(I_1 - I_2)$  from F to B.

Voltage at the load is

$$\begin{aligned} V &= IR \\ &= 20.3125 \times 1 \\ &= 20.3125 \text{ Volts} \end{aligned}$$

Load Power,

$$\begin{aligned} P &= I^2R \\ &= (20.3125)^2 \times 1 \\ &= 412.598 \text{ Watts.} \end{aligned}$$

## 1.9 RESISTANCES IN SERIES

If the ending terminal of the resistance  $R_1$  is connected to the beginning terminal of the resistance  $R_2$  and the ending terminal of  $R_2$  is connected to the beginning terminal of the resistance  $R_3$  and so on then the resistances  $R_1$ ,  $R_2$ ,  $R_3$ , etc., are said to be connected in series.

In series circuits, the elements in the series can be connected in any order. For example,  $R_2$ ,  $R_3$ ,  $R_1$ , etc., instead of  $R_1$ ,  $R_2$ ,  $R_3$  etc.

In series circuits, the same current will flow through all the elements in series.

In D.C. series circuits, while connecting the elements in series, one should be very careful of the polarities of the meters used to measure the currents or voltages or the polarities of the equipment. Positive polarities of the meters or the equipments should always be connected to the positive of the supply point and the negative terminals should be connected to the negative of the supply point. While two equipments are connected in series, the positive of the first equipment should be connected to the positive terminal of the supply point. Negative terminal of the first equipment should be connected to the positive terminal of the second equipment and the negative terminal of the second equipment should be connected to the positive terminal of the third equipment and so on.

Ammeters are used to measure the currents. The ammeters should always be connected in series in the circuit so that the current to be measured flows through the ammeters. In order that, the voltage drop across the ammeter to be very very small

so that full current flows through the circuit, the resistance of the ammeter should be very very small. Hence, if the ammeter is connected across the supply or across two points having large voltage drop, very heavy current will flow through the ammeter and the ammeter will get burnt.

Voltmeters are used to measure the voltage of the supply or voltage drop between two points in order that the voltmeter does not draw more current so as to

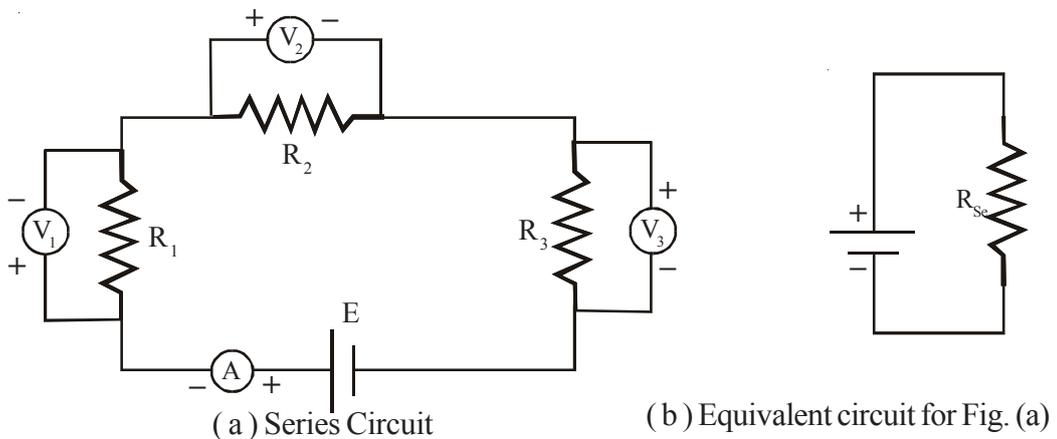


Fig. 1.10 Circuit with Resistances in Series

allow full current in the circuit, the voltmeters should have very high resistance. If the voltmeter is connected in series, it causes high voltage drop across it and the voltage supplied to the remaining circuit will be less. Hence, voltmeters should be connected only in parallel and not in series.

In the closed circuit ABCDA given in Fig. 1.10 (a), applying Kirchoff’s Voltage Law, we have,

$$E - V_1 - V_2 - V_3 = 0 \quad \text{..... ( 1.9.1 )}$$

$$E - IR_1 - IR_2 - IR_3 = 0 \quad \text{..... ( 1.9.1a )}$$

or  $IR_1 + IR_2 + IR_3 = E \quad \text{..... ( 1.9.1b )}$

or  $I( R_1 + R_2 + R_3 ) = E \quad \text{..... ( 1.9.1c )}$

For the equivalent circuit of Fig. 1.10 (b),

$$IR_{se} = E \quad \text{..... ( 1.9.2 )}$$

Comparing Eq. ( 1.9.1c ) and ( 1.9.2 ) we have,

$$R_{Se} = ( R_1 + R_2 + R_3 )$$

In general for n resistances in series,

$$R_{Se} = \sum_{i=1}^n R_i \quad \text{..... ( 1.9.3 )}$$

In terms of conductances for resistances in series,

$$\frac{1}{G_{Se}} = \sum_{i=1}^n \frac{1}{G_i} \quad \text{..... ( 1.9.4 )}$$

**Example 1.6 :**

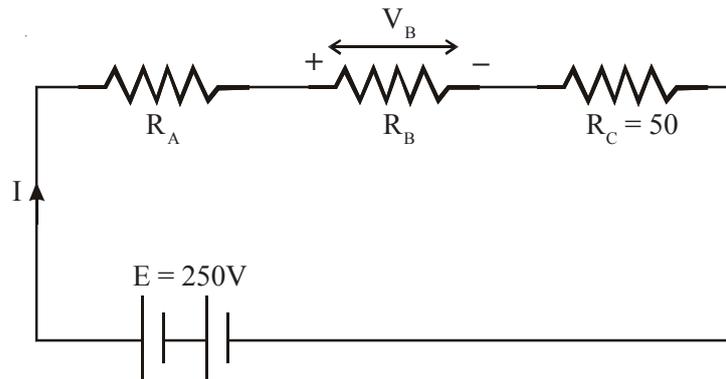


Fig. 1.14 shows three resistors  $R_A$ ,  $R_B$  and  $R_C$  connected in series to a 250V source; Given  $R_C = 50\Omega$ , and  $V_B = 80\text{Volts}$  when the current is 2 Amperes, calculate the total resistances,  $R_A$  and  $R_B$ .

**Solution :**

Since  $I = 2$  Amperes

$$\begin{aligned} V_B &= IR_B \\ &= 80\text{V} \end{aligned}$$

$$R_B = 40\Omega$$

$$\text{Also, } I = \frac{E}{(R_A + R_B + R_C)}$$

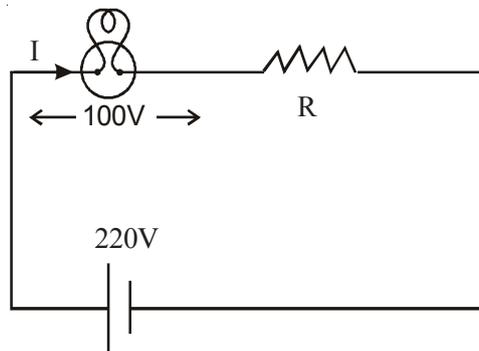
Therefore,

$$R_{Se} = R_A + R_B + R_C = \frac{E}{I} = \frac{250}{2} = 125\Omega$$

$$\text{Therefore, } R_A = R_{Se} - (R_B + R_C) = 35\Omega.$$

**Example 1.7 :**

A lamp rated 500W, 100V is to be operated from 220V supply. Find the value



of the resistor to be connected in series with the lamp. What is the power lost in the resistance.

**Solution :**

$$\begin{aligned} \text{Current in the lamp} &= \frac{W}{E} \\ &= \frac{500}{100} = 5 \text{ Amperes} \end{aligned}$$

Since the Voltage drop across the lamp is 100 V, Voltage to be dropped in the series resistor is 120V.

$$\text{Therefore, Value of the resistor} = \frac{120}{5}$$

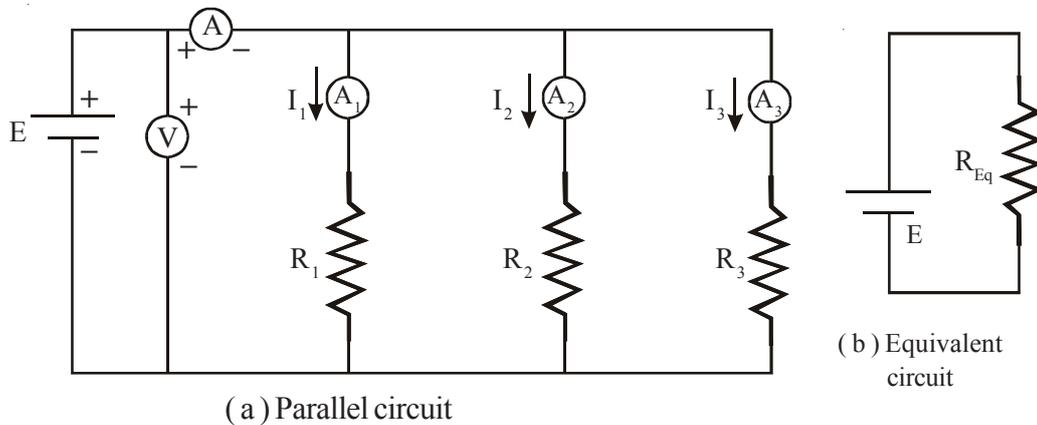
$$= 24 \Omega$$

$$\text{Power Lost in this resistor} = I^2 R$$

$$= 5^2 \times 24 = 600 \text{ W}$$

### 1.10 RESISTANCES IN PARALLEL

If the starting terminal of two or more elements are connected together and the ending terminals of these elements are connected together then the elements are said to be connected in parallel. A parallel element may also be known as a Shunt Element.



**Fig. 1.11** Circuit with Resistances in Parallel

The voltage across all the elements that are connected in parallel will be same.

In D.C. circuits, if the elements of the meters or the equipments with polarities marked are connected in parallel then terminals of the same polarities should be connected together.

In the parallel circuit given in the Fig. 1.14(a), applying Kirchoff's Current Law to the junction A,

$$I = I_1 + I_2 + I_3 \quad \text{..... ( 1.10.1 )}$$

Applying Ohm's Law,

$$I = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} \quad \text{..... ( 1.10.1a )}$$

For the equivalent circuit given in Fig. 1.14b,

$$I = \frac{E}{R_p} \quad \text{..... ( 1.10.2 )}$$

Comparing Eq. ( 1.16.2 ) and ( 1.16.1a) we have,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{..... ( 1.10.3 )}$$

or In terms of conductances,

$$G_p = G_1 + G_2 + G_3 \quad \text{..... ( 1.10.4 )}$$

In general for parallel circuits with n resistances in parallel,

$$\frac{1}{R_p} = \sum_{i=1}^n \frac{1}{R_i} \quad \text{..... ( 1.10.5 )}$$

or 
$$G_p = \sum_{i=1}^n G_i \quad \text{..... ( 1.10.6 )}$$

If two resistances  $R_1$  and  $R_2$  are in parallel,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{..... ( 1.10.7 )}$$

or 
$$R_p = \frac{R_1 R_2}{R_1 + R_2} \quad \text{..... ( 1.10.7a )}$$

If the two resistances are equal and in parallel

i.e., 
$$R_1 = R_2 = R$$

then,

$$R_p = \frac{R}{2} \quad \text{..... ( 1.10.7b )}$$

If three resistances  $R_1$ ,  $R_2$  and  $R_3$  are parallel,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{..... ( 1.10.8 )}$$

or

$$R_p = \frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1} \quad \text{..... ( 1.10.8a )}$$

If three resistances are equal, i.e.,  $R_1 = R_2 = R_3 = R$  then,

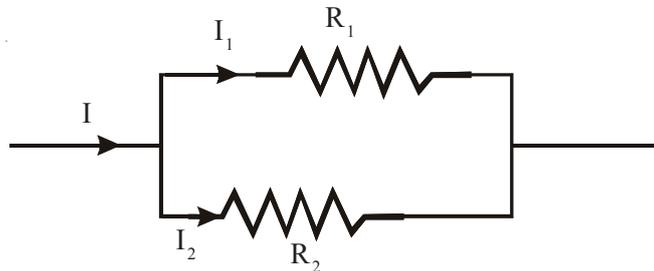
$$R_p = \frac{R}{3} \quad \text{..... ( 1.10.9 )}$$

In general, if  $n$  resistances, each of value  $R$  are in parallel the,

$$R_p = \frac{R}{n} \quad \text{..... ( 1.10.10 )}$$

### 1.10.1 Division of Currents in Parallel Circuits

If two resistances  $R_1$  and  $R_2$  are connected in parallel and if the total current



**Fig. 1.12** Division of Currents in Parallel Circuits

entering the parallel combination is  $I$  then this current  $I$  divides into two parts  $I_1$  flowing through  $R_1$  and  $I_2$  flowing through  $R_2$ . The Voltage Drop across the parallel combination will be

$$V_p = I \times R_p = I \times \left( \frac{R_1 R_2}{R_1 + R_2} \right) \text{ Volts}$$

The current  $I_1$  flowing through  $R_1$  will be given as,

$$I_1 = \frac{V_p}{R_1} = \frac{1}{R_1} \times I \times \left( \frac{R_1 R_2}{R_1 + R_2} \right) \text{ Amps}$$

$$I_1 = I \times \left( \frac{R_2}{R_1 + R_2} \right) \text{ Amps} \quad \dots\dots\dots ( 1.10.11 )$$

When two resistances  $R_1$  and  $R_2$  are in parallel, Current through  $R_1$  is given as,

$$I_1 = \text{Total Current} \times \frac{\text{Second Resistance}}{\text{Sum of the Two Resistances in Parallel}} \quad \dots\dots\dots ( 1.10.12 )$$

This form is used frequently in Electronic Circuits.

Similarly,

$$I_2 = \frac{V_p}{R_2}$$

$$= \frac{1}{R_2} \times I \times \left( \frac{R_1 R_2}{R_1 + R_2} \right) \text{ Amps}$$

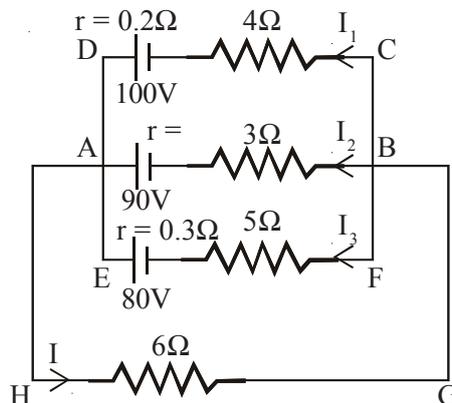
$$I_2 = I \times \left( \frac{R_1}{R_1 + R_2} \right) \text{ Amps} \quad \dots\dots\dots ( 1.10.13 )$$

Also,  $I_2 = ( I - I_1 ) \text{ Amps}$

In general, *the current through any parallel path is given as the product of the total current and the parallel equivalent resistance divided by the resistance of that path.*

**Example 1.8 :**

Solve the network shown in the figure for the current through  $6\Omega$  resistor.



**Solution :**

Let the current flowing through various branches be as marked in the figure.  
Applying Kirchoff's Voltage Law to the following closed circuits,

Circuit CDAHGBC,

$$-4I_1 - 0.2I_1 + 100 - 6(I_1 + I_2 + I_3) = 0$$

or  $10.2 I_1 + 6I_2 + 6I_3 = 100$  ..... ( 1 )

Circuit BAHGB,

$$-3I_2 - 0.25I_2 + 90 - 6(I_1 + I_2 + I_3) = 0$$

or  $6I_1 + 9.25 I_2 + 6I_3 = 90$  ..... ( 2 )

Circuit FEAHGBF,

$$-5I_3 - 0.3I_3 + 80 - 6(I_1 + I_2 + I_3) = 0$$

or  $6I_1 + 6I_2 + 11.3 I_3 = 80$  ..... ( 3 )

Subtracting ( 2 ) from ( 1 ), we get,

$$4.2 I_1 - 3.25 I_2 = 10$$
 ..... ( 4 )

Eqn.(2) x 11.3 - Eqn. (3) x 6 gives

$$31.8 I_1 + 68.525 I_2 = 537$$
 ..... ( 5 )

Eqn.(5) x 4.2 - Eqn.(4) x 31.8 gives

$$391.51I_2 = 1937.4$$

$$I_2 = 4.953A$$

From Eqn.(5) substituting for  $I_2$

$$I_1 = 6.21A$$

From Eqn. (3), substituting for  $I_1$  and  $I_2$

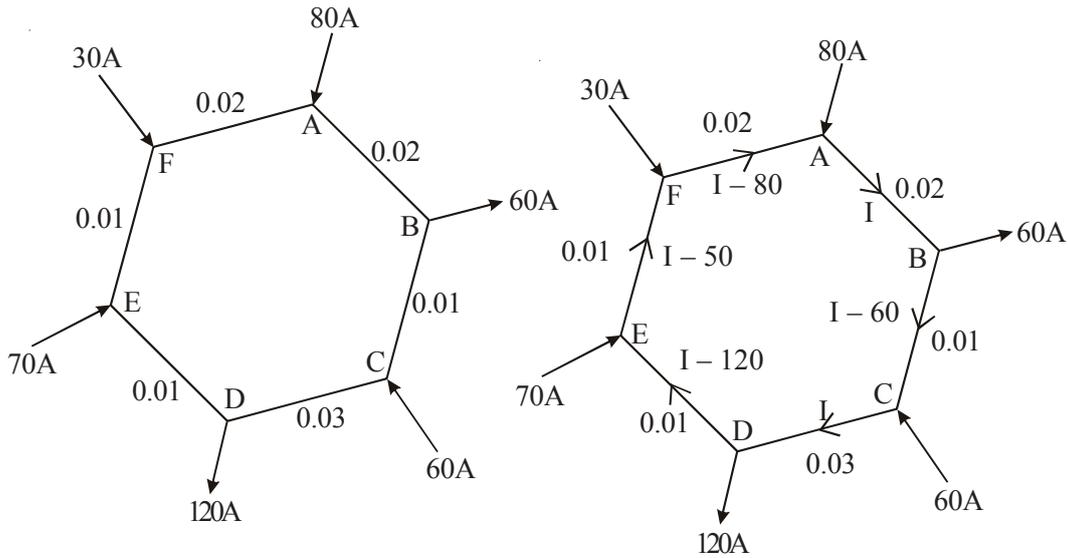
$$I_3 = 1.15A$$

Current in  $6\Omega$  resistor,

$$\begin{aligned} I &= I_1 + I_2 + I_3 \\ &= 6.21 + 4.953 + 1.15 \\ &= 12.313A \end{aligned}$$

**Example 1.9 :**

Find the magnitude and direction of the currents in all branches of the circuit shown in the figure using Kirchoff's Laws. All resistances are in Ohms.



**Solution :**

Let current from A to B junctions be I Amps. Applying Kirchoff's First Law, let current flowing through various branches be as shown in the figure.

Applying Kirchoff's Current Law to current in each branch and Kirchoff's Voltage Law to a closed loop ABCDEFA, we get,

$$-0.02I - 0.01(I - 60) - 0.03I - 0.01(I - 120) - 0.01(I - 50) - 0.02(I - 80) = 0$$

$$\text{or } 0.02I + 0.01I + 0.03I + 0.01I + 0.01I + 0.02I = 0.6 + 1.2 + 0.5 + 1.6$$

$$\text{or } 0.1I = 3.9$$

$$\text{or } I = 39A$$

Current in various branches is as under :

$$I_{AB} = 39\text{A} \quad (\text{i.e., A to B})$$

$$I_{BC} = I - 60 = -21\text{A} \quad (\text{i.e., C to B})$$

$$I_{CD} = I = 39\text{A} \quad (\text{i.e., C to D})$$

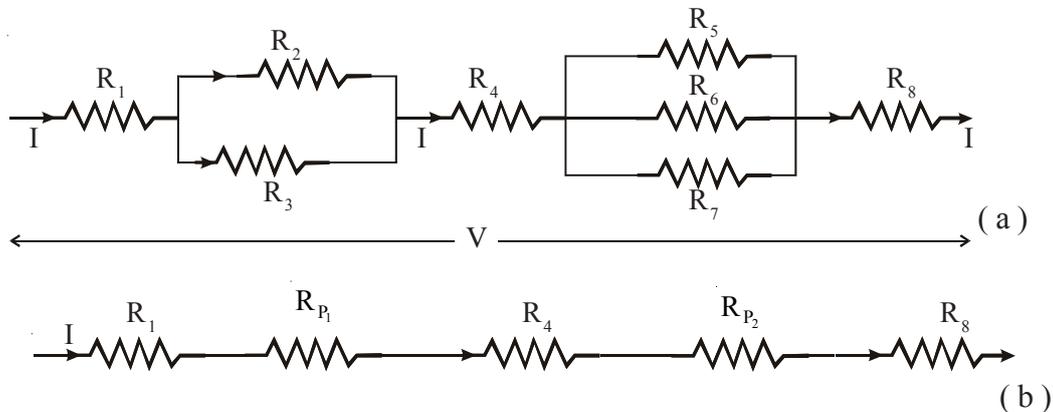
$$I_{DE} = I - 120 = -81\text{A} \quad (\text{i.e., E to D})$$

$$I_{EF} = I - 50 = -11\text{A} \quad (\text{i.e., F to E})$$

$$I_{FA} = I - 80 = -41\text{A} \quad (\text{i.e., A to F})$$

### 1.11 SERIES-PARALLEL RESISTANCES

In the case of series-parallel resistances, the parallel equivalent of the resistances in parallel are obtained first as a single resistance which will be in series with the other resistances, thus bringing the circuit into a single series circuit. After finding the current flowing through this equivalent series circuit again the parallel equivalent resistance may be replaced with the corresponding parallel circuit and the current in the parallel paths are calculated as given in the Section 1.10, *the current through any parallel path is given as the product of the total current and the parallel equivalent resistance divided by the resistance of that path.*



**Fig. 1.13** Resistance in Series-Parallel

Typical values of currents are given below for the above circuit,

$$R_{p1} = \frac{R_2 R_3}{(R_2 + R_3)}$$

$$R_{p_2} = \frac{R_5 R_6 R_7}{R_5 R_6 + R_6 R_7 + R_7 R_5}$$

$$I = \frac{V}{R_1 + R_{p_1} + R_4 + R_{p_2} + R_8}$$

$$I_2 = I \times \frac{R_3}{(R_2 + R_3)}$$

$$I_6 = \frac{I}{R_6} \left( \frac{R_5 R_6 R_7}{(R_5 R_6 + R_6 R_7 + R_7 R_5)} \right)$$

**Example 1.10 :**

A Wheatstone Bridge consists of  $AB = 4\Omega$ ,  $BC = 3\Omega$ ,  $CD = 6\Omega$  and  $DA = 5\Omega$ . A 2V Cell is connected between B and D and a Galvanometer of  $10\Omega$  resistance between A and C. Find the current through the Galvanometer.

**Solution :**

The circuit is shown in the figure. Applying Kirchoff's Current Law at junction B, A and C, the current in various branches is marked.

Applying Kirchoff's Voltage Law to various closed loops and considering loop BACB, we get,

$$-4I_1 - 10I_3 + 3I_2 = 0$$

$$\text{or } 4I_1 + 10I_3 - 3I_2 = 0 \quad \dots\dots\dots (1)$$

Considering loop ADCA, we get

$$-5(I_1 - I_3) + 6(I_2 + I_3) + 10I_3 = 0$$

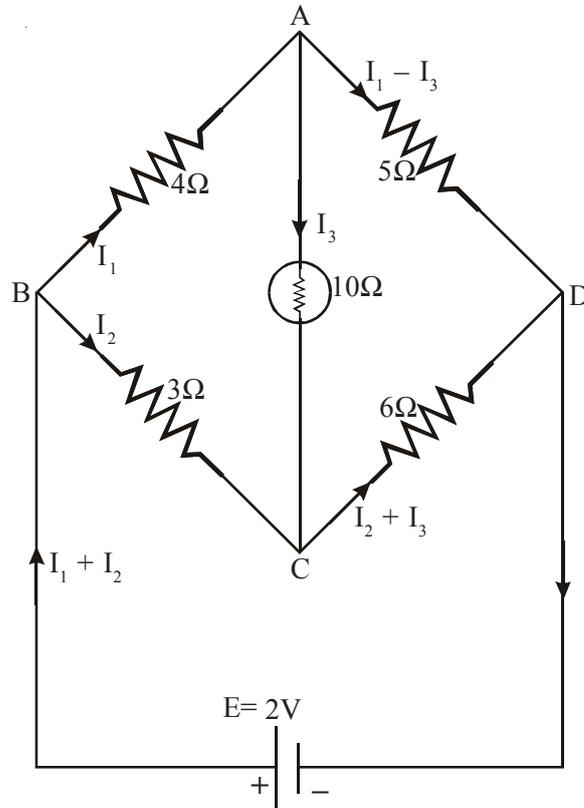
$$\text{or } 5I_1 - 6I_2 - 21I_3 = 0 \quad \dots\dots\dots (2)$$

Considering loop BADEB, we get,

$$-4I_1 - 5(I_1 - I_3) + 2 = 0$$

$$\text{or } 4I_1 - 5I_1 + 5I_3 = -2 \quad \dots\dots\dots (3)$$

$$\text{or } 9I_1 - 5I_3 = 2$$



Multiplying Eq. ( 1 ) by Eq. ( 2 ) and Subtracting from Eq. ( 2 ), we get,

$$\begin{array}{rcl}
 5I_1 - 6I_2 - 21I_3 & = & 0 \\
 8I_1 - 6I_2 + 20I_3 & = & 0 \\
 \hline
 -3I_1 & - & 41I_3 = 0
 \end{array}$$

or 
$$I_1 = -\frac{41}{3} I_3$$

Substituting the value of  $I_1$  in Eq. ( 3 ), we get,

$$9\left(-\frac{41}{3}I_3\right) - 5I_3 = 0$$

or 
$$-123I_3 - 5I_3 = 2$$

or 
$$I_3 = -\frac{1}{64} \text{ A}$$

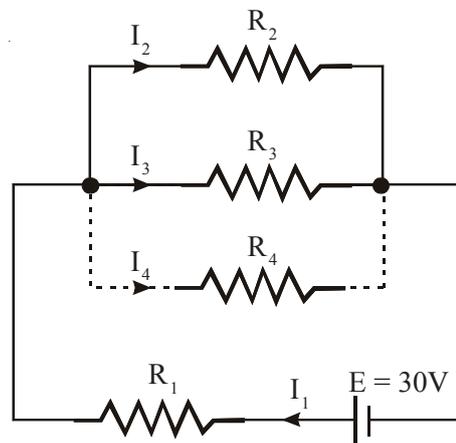
**Example 1.11:**

A resistance of  $15\Omega$  is connected in series with two resistances each of  $30\Omega$  arranged in parallel. A voltage source of  $30V$  is connected to this circuit.

- (a) What is the current drawn from the source.  
 (b) What resistance should be placed in shunt (parallel) with the parallel combination in order that the current drawn from the source is  $1.2 A$ .

**Solution:**

The circuit is as shown in the figure given below.



- (a)  $R_1$  is in series with the parallel combination of  $R_2$  and  $R_3$ .

Hence, Total Resistance  $R_t$  is,

$$R_t = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$= 15 + \frac{30 \times 30}{30 + 30}$$

$$R_t = 30\Omega$$

Hence current,

$$I_1 = \frac{E}{R_t}$$

$$I_1 = \frac{30}{30} = 1 \text{ A}$$

(b) With  $I_1 = 1.2 \text{ A}$ , Voltage across  $R_1$

$$= I_1 R_1 = 1.2 \times 15$$

$$= 18 \text{ V}$$

Voltage Drop across parallel combination of  $R_2$ ,  $R_3$  and  $R_4$  is,

$$V_p = 30 - 18$$

$$V_p = 12 \text{ V}$$

Hence, Voltage Drop across each resistor  $R_2$ ,  $R_3$ ,  $R_4$  is 12 V.

Hence,  $I_2 = \frac{V_p}{R_2} = \frac{12}{30}$

$$I_2 = 0.4 \text{ A}$$

$$I_3 = \frac{V_p}{R_3} = \frac{12}{30}$$

$$I_3 = 0.4 \text{ A}$$

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

$$= 1.2 - (0.4 + 0.4)$$

$$I_4 = 0.4 \text{ A}$$

$$I_4 = \frac{V_p}{R_4}$$

$$0.4 R_4 = 12$$

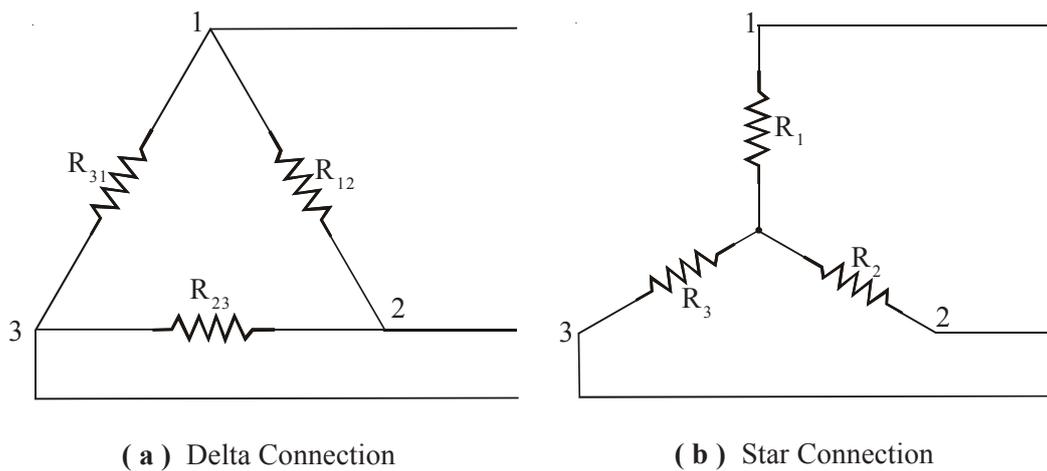
Hence,  $R_4 = \frac{12}{0.4}$

$$R_4 = 30 \Omega$$

## 1.12 RESISTANCES IN STAR OR DELTA CONNECTIONS

If the end of  $R_1$  is connected to beginning of  $R_2$ , the end of  $R_2$  is connected to beginning of  $R_3$  and the end of  $R_3$  is connected to beginning of  $R_1$  then, the resistances  $R_1, R_2, R_3$  are said to be connected in Delta ( $\Delta$ ) and the three points common to any two resistances are connected to the remaining part of the circuit as given in the Fig. 1.14 ( a ).

If one end of the resistances  $R_1, R_2, R_3$ , are all connected together and the other ends of the three resistances are connected to different points of the circuits, as given in the Fig. 1.14 ( b ), then the resistances  $R_1, R_2, R_3$  are said to be connected in Star or WYE ( Y ).



**Fig. 1.14** Resistance in Star-Delta Connection

In general, more than three resistances can be connected in Star.

In general, more than three resistances can also be connected in Mesh.

In some cases, the circuits cannot be solved by means of simple series, parallel or parallel combinations but by finding the equivalent Delta for the given Star connection or equivalent Star connection for the given Delta connection of resistances, the circuit can be resolved into simple Series, Parallel or Series-Parallel combinations.

### 1.12.1 The Equivalent Star Resistances For Given Delta Connected Resistances

Referring to Fig. 1.17 ( a ), in Delta Connection, we observe that between the terminals 1 and 2 the resistance  $R_{12}$  is in parallel with the series combination of  $R_{23}$  and  $R_{31}$ .

Referring to Fig. 1.17 ( b ), in Star Connection, we observe that between the terminals 1 and 2 the resistance  $R_1$  is in series with  $R_2$ .

Equating the resistances between terminals 1 and 2 of Star and its equivalent Delta, we have  $R_{12}$  in parallel with  $(R_{23} + R_{31})$

$$R_1 + R_2 = R_{12} + \frac{R_{23}R_{31}}{R_{23} + R_{31}}$$

Rewriting the above equation we have,

$$R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}}$$

$$R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.1 )$$

Similarly equating the resistances between terminals 2 and 3, we have,

$$R_2 + R_3 = \frac{R_{23}(R_{31} + R_{12})}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.2 )$$

Similarly equating the resistances between terminals 3 and 1, we have,

$$R_3 + R_1 = \frac{R_{31}(R_{12} + R_{23})}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.3 )$$

Subtracting Eq. ( 1.12.2 ) from Eq. ( 1.12.3 ), we have,

$$R_1 - R_2 = \frac{R_{12}(R_{31} - R_{23})}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.4 )$$

Adding Eq. ( 1.18.1 ) and Eq. ( 1.18.4 ), we have,

$$2R_1 = \frac{R_{12}(2R_{31})}{\sum R_{12}}$$

Hence, 
$$R_1 = \frac{R_{12}R_{31}}{\sum R_{12}}$$

Rewriting the above equation, we have,

$$R_1 = \frac{R_{12}R_{13}}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.5 )$$

Similarly, 
$$R_2 = \frac{R_{21}R_{23}}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.6 )$$

$$R_3 = \frac{R_{31}R_{32}}{\sum R_{12}} \quad \dots\dots\dots ( 1.12.7 )$$

Note that from Eq. ( 1.12.5 ), Eq. ( 1.12.6 ) and Eq. ( 1.12.7 ), we observe that, *the equivalent star resistance connected to a given terminal is given by the product of the two Delta resistances that are connected to that terminal divided by the sum of the three Delta connected resistances.*

*The same statement can be extended to more than three resistances connected in Mesh and its equivalent Star !! ( check up )*

### 1.12.2 The Equivalent Delta Resistances For Given Star Connected Resistances

Multiplying Eq. ( 1.12.5 ) and Eq. ( 1.12.6 ), we have,

$$R_1R_2 = \frac{R_{12}^2R_{23}R_{31}}{\left(\sum R_{12}\right)^2} \quad \dots\dots\dots ( 1.12.8 )$$

Multiplying Eq. ( 1.12.6 ) and Eq. ( 1.12.7 ), we have,

$$R_2R_3 = \frac{R_{12}R_{23}^2R_{31}}{\left(\sum R_{12}\right)^2} \quad \dots\dots\dots ( 1.12.9 )$$

Multiplying Eq. ( 1.12.7 ) and Eq. ( 1.12.5 ), we have,

$$R_3 R_1 = \frac{R_{12} R_{23} R_{31}^2}{\left( \sum R_{12} \right)^2} \quad \text{..... ( 1.12.10 )}$$

Adding Eq. ( 1.12.8 ), Eq. ( 1.12.9 ) and Eq. ( 1.12.10 ), we have,

$$\begin{aligned} R_1 R_2 + R_2 R_3 + R_3 R_1 &= \frac{R_{12} R_{23} R_{31} (R_{12} + R_{23} + R_{31})}{\left( \sum R_{12} \right)^2} \\ &= ( R_{12} R_{23} R_{31} ) \frac{\left( \sum R_{12} \right)}{\left( \sum R_{12} \right)^2} \\ &= R_{12} \left[ \frac{R_{23} R_{31}}{\sum R_{12}} \right] \end{aligned}$$

$R_1 R_2 + R_2 R_3 + R_3 R_1 = R_{12} R_3$  by using  $R_3$  from eqn.1.12.7 for the term inside the bracket

Hence, 
$$R_{12} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

or 
$$R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3} \quad \text{..... ( 1.12.11 )}$$

Similarly, 
$$R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1} \quad \text{..... ( 1.12.12 )}$$

$$R_{31} = R_3 + R_1 + \frac{R_3 R_1}{R_2} \quad \text{..... ( 1.12.13 )}$$

Note that from Eq. ( 1.12.11 ), Eq. ( 1.12.12 ) and Eq. ( 1.12.13 ), we observe that, *the equivalent Delta resistance connected between any two given terminals is given by the sum of the two Star resistances that are connected between those two terminals plus the product of those two resistances connected between those two terminals divided by the third Star resistance.*

In terms of conductances the equivalent mesh element can be given in terms of the star elements for star or delta having three or more resistances as

$$G_{ij} = \frac{G_i G_j}{\sum G_i} \quad !! \text{ ( check up )} \quad \dots\dots\dots ( 1.12.14 )$$

If  $R_{12} = R_{23} = R_{31} = R$  ( say ), then, the equivalent star resistances will be,

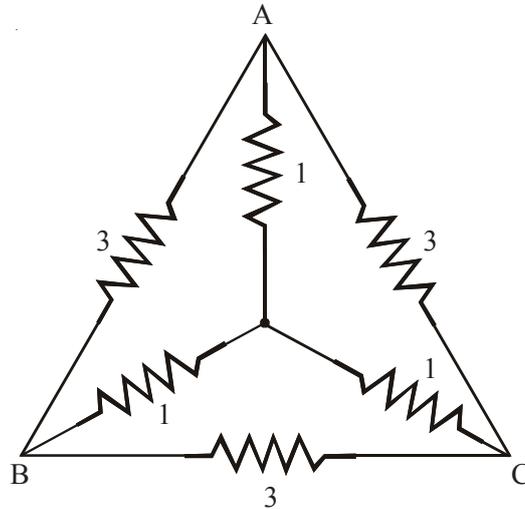
$$R_1 = R_2 = R_3 = \frac{R}{3} \quad \dots\dots\dots ( 1.12.15 )$$

If  $R_1 = R_2 = R_3 = R$  ( say ), then, the equivalent delta resistances will be,

$$R_{12} = R_{23} = R_{31} = 3R \quad \dots\dots\dots ( 1.12.16 )$$

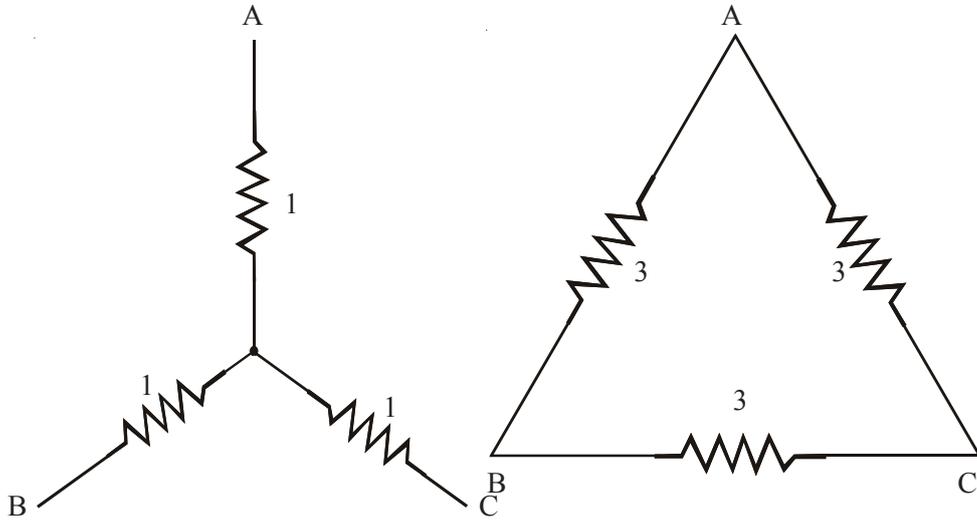
**Example 1.12:**

For the network shown in the figure below, find the equivalent resistance between the terminals B and C.

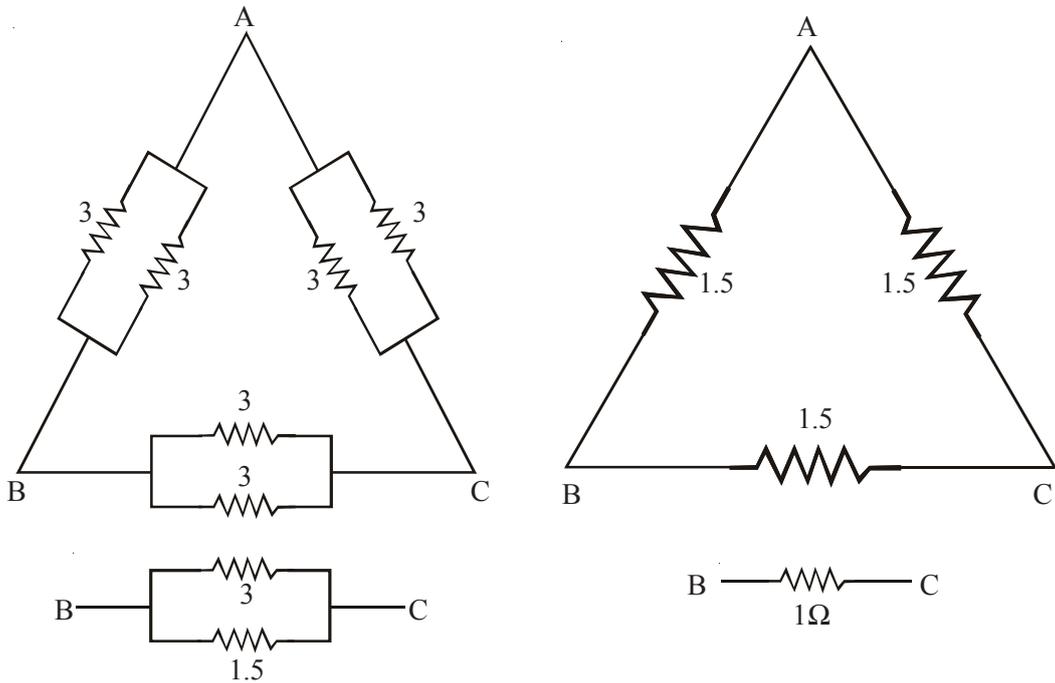


**Solution:**

The given combination of resistances between the terminals B and C is neither series combinations nor parallel combination. If, the star connection between A, B and C is converted into equivalent Delta, we will have a known combination which can be simplified by series parallel simplification.



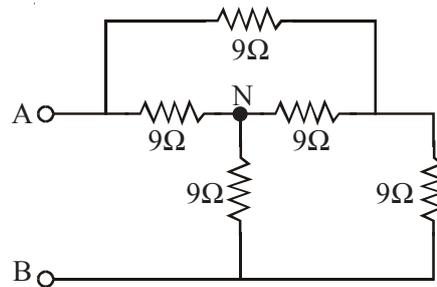
The given figure is redrawn after replacing the star by its equivalent Delta.



$$R_{BC} = \frac{3 \times 1.5}{3 + 1.5} = 1\Omega.$$

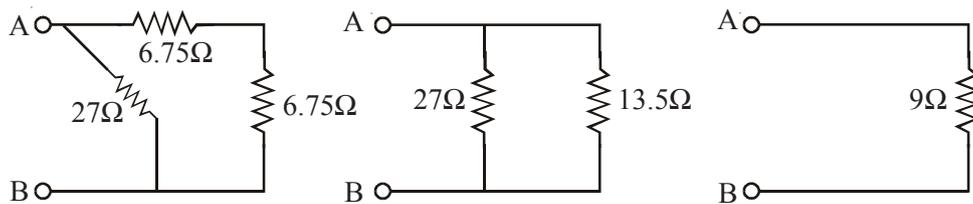
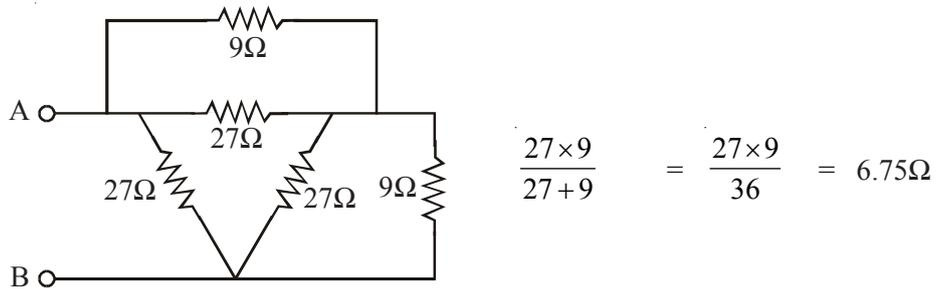
**Example 1.13:**

Determine the equivalent resistance between A and B.



**Solution:**

The combination is neither series nor parallel. There is Delta and Star connection. Converting the star connection for which N is the star point and redrawing the circuit, we get,



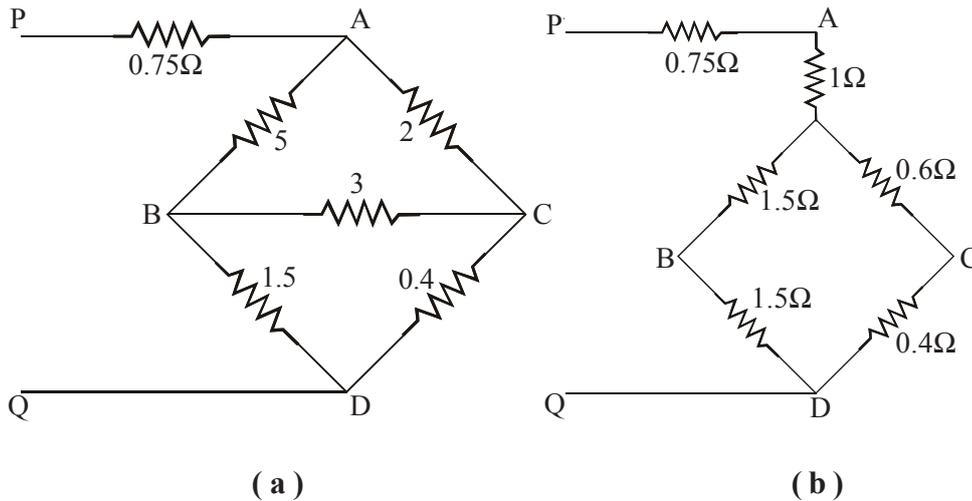
Therefore,

$$R_{AB} = 27 \parallel 13.5$$

$$= \frac{27 \times 13.5}{27 + 13.5} = 9\Omega.$$

**Example 1.14 :**

In the Wheatstone Bridge Circuit of figure ( a ) given below, find the effective resistance between PQ. Find the current supplied by a 10V Batter connected to PQ.

**Solution :**

Converting the  $\Delta$  formed by 5, 2 and  $3\Omega$  in a star of figure ( b ), we have,

$$R_A = \frac{5 \times 2}{5 + 3 + 2} = 1\Omega$$

$$R_B = \frac{5 \times 3}{10} = 1.5\Omega$$

$$R_C = \frac{3 \times 2}{10} = 0.6\Omega$$

The circuit then reduces to the following form.

The two  $1.5\Omega$  resistors are in series and this is in parallel with the  $0.6\Omega$  and  $0.4\Omega$  resistors which are in series.

Therefore, the total effective resistance between P and Q

$$\begin{aligned} &= 0.75 + 1 + \frac{3 \times 1}{3 + 1} \\ &= 2.5\Omega \end{aligned}$$

If a 10V battery is attached to PQ, current drawn,

$$= \frac{10}{2.5} = 4A.$$

*Note :* The above methods of reducing the circuit using series, parallel, series-parallel or star-delta conversions are applicable to A.C. circuit and also circuits with Unidirectional sources using instantaneous values. For steady state calculations of A.C. circuits, the R.M.S. values of voltages and currents and the impedances, all in complex form have to be used.

### 1.13 FEATURES OF A RESISTANCE

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1. Resistance is used in both D.C. & A.C. circuits and it reduces the currents.
2. The current in resistance will be in phase with the voltage i.e., at an angle  $0^\circ$ .
3. Resistance causes Power Loss and loss appears in the form of heat. Hence, sufficient provision should be made to dissipate this loss.
4. Resistance depends upon the dimensions and material of the resistance conductor.
5. In the case of resistance, the current is setup instantaneously when the voltage is applied and is cutoff instantaneously when the voltage is removed.
6. The resistance which is in the form of a coil, when used in an A.C. circuit will offer atleast some inductance and in precision work to avoid that inductance the resistance coil is split up into two halves which are wound in the opposite directions so as to have a pure resistance.
7. In precision work, the contact resistance, when the resistance is connected to a terminal should also be taken into account.
8. The resistance of the electrical transmission lines will have to be very small in order to cause negligible voltage drop across the resistance as it has to carry heavy currents. Thus, the resistance of the transmission lines is generally neglected in calculations.

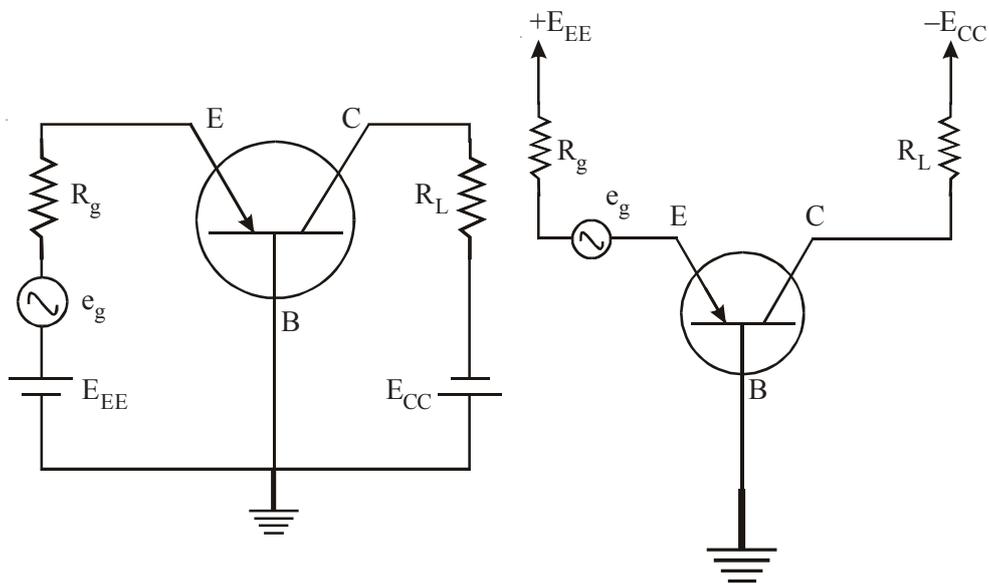
### 1.14 USES OF RESISTANCE

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1. Resistance is used in any circuit to limit the current.
2. Resistance is used in series resonance circuits to limit the currents at resonance point.
3. Resistance will be used in Wave Shaping Circuits to obtain a different wave form from a given wave form.
4. Resistance can be used in analog circuits, to solve for other systems like Mechanical Systems, Hydraulic System, etc., in terms of Electrical Systems
5. Resistance will be used in Filter Circuits to select or reject certain frequencies.
6. Change of resistances as obtained in **Resistance Strain Gauges**, which convert physical signals like temperature, strain, load, force etc., into electrical signals are used for measurement of the physical signals.
7. Resistance can also be used in Power Factor changing circuits but because it causes Power Loss and additional real power to be supplied, the power factor changing circuits generally do not employ change of resistances.
8. Resistances are used in quenching the arcs ( extinguishing the arcs ) in the case of circuit breakers, while breaking heavy current circuits in electrical transmission and distribution.
9. Resistance can be used in Measurement Circuits. For example, Variable Resistance is used to balance the bridge networks. Resistance shunt is used to extend the range of an ammeter or galvanometer, by diverting a major part of the circuit current through the shunt resistance so that only the allowable current flows through the ammeter or galvanometer. The actual current is calculated from the reading of the ammeter or galvanometer using a factor in terms of resistance of the galvanometer and the resistance of the shunt as in the case of parallel circuit. *A shunt is a very small pure resistance of the order  $1\Omega$  or less.*
10. Resistance shunt can also be used as a series resistance causing a small voltage drop across it, so that this voltage drop can be used in CRO ( Cathode Ray Oscilloscope ) to trace the current waveform which will be proportional to the voltage waveform across the resistance shunt.

1.15 DIFFERENCES BETWEEN ELECTRICAL & ELECTRONIC CIRCUITS

1. In electrical circuits, the cross over of two wires are shown as , whereas in electronic circuits, the cross over is shown as .
2. In electrical circuits, the junction of wires is shown as , whereas in electronic circuits, the junction is shown as .
3. In electrical circuits, the circuit is given completely including sources and elements whereas in electronic circuits, the circuit will not be shown completely. A pointing arrow with voltage along with its polarity marked indicates the connection to the voltage source of that polarity. The return path is assumed to be through ground by indicating the ground connections at the required places as shown in Fig. 1.15. A common ground wire will be run to which all the grounding points will be connected.

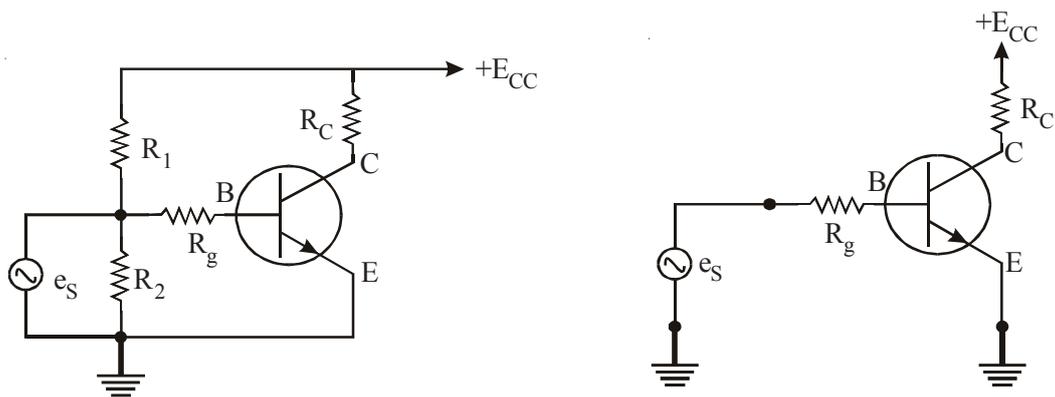


(a) As in Electrical Circuit

(b) As in Electronic Circuit

Fig. 1.15 Grounded-base Amplifier including Biasing of the PNP Transistor

4. In electronic circuits like a transistor amplifier, the biasing of the transistor will not be shown separately. Only the input signal and the output load will be shown as in Fig. 1.16. In such cases, the biasing circuit is assumed to be present. Here resistances  $R_1$  and  $R_2$  are used for biasing to fix up the operating point in the characteristics of the transistor. The signal will make an excursion about the operating point. A separate wire for power supply to which power supply points will be connected and a separate grounded earthwire to which the grounding points will be connected, while rigging up the circuit have to be provided. While connecting the circuit the biasing circuit should also be connected.
5. The direction of electron current is denoted as " $\rightarrow$ ". The direction of the conventional current will be opposite to that of electron current. Conventional current can be treated as the direction of the movement of positive ions and is denoted as " $\leftarrow$ ".



(a) As in Electronic Circuit with Biasing Circuit    (b) As in Electronic Circuit without Biasing Circuit

*Fig. 1.16 Grounded-emitter Amplifier using NPN Transistor*

## 1.16 NETWORK THEOREMS

### 1.16.1 Introduction to Network Theorems

We have already studied the general methods of network analysis. However, in a large and complex network, these methods tend to become laborious and time-consuming. In many cases, it is advantageous to use special techniques to reduce the quantum of labour involved in circuit solution. We term such techniques as **Network Theorems**. The other important features of the theorems, besides saving labour and time, are :

- (a) they are applicable to a useful and fairly wide class of networks
- (b) their conclusion are simple
- (c) they sometimes provide good physical insight into the problems.

The theorems are useful when the problem is limited like finding the current in a single element, the value of the load for maximum power etc. In this chapter we shall study some important theorems, viz., *Reciprocity Theorem, Superposition Theorem, Substitution Theorem, Thevenin's Theorem, Norton's Theorem, Maximum Power Transfer Theorem, Compensation Theorem, Millman's Theorem and Tellegen's Theorem.*

While discussing these theorems the applicability of these theorems to certain kinds of networks only, must be clearly understood. The network elements could be classified as *Linear, Limped, Finite, Passive and Bilateral* and *Bilateral* usually abbreviated as LLFPB elements.

## 1.17 NETWORK CLASSIFICATION

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Electric Networks can be classified mainly in two ways. The first one is based on the kind of elements in the network e.g. time-invariant or non-linear or time variant etc. The second one is based on excitation (supply source) and response (output) i.e. for a given excitation the response decides the type of network.

Here we shall study classification based on the second approach.

### 1.17.1 Linear Networks

Suppose the network to be classified is under relaxed condition i.e., with no initial conditions and an excitation  $v_1(t)$  is applied for which response is  $c_1(t)$  and for excitation  $v_2(t)$  the response is  $c_2(t)$ . Then the network is classified as linear if for excitation  $v_1(t) + v_2(t)$  the response is  $c_1(t) + c_2(t)$ . This shows that a linear network follows superpositions principle.

### 1.17.2 Passive Networks

Some networks have the property of absorbing / dissipating or storing energy. These are able to return the energy previously stored to the external network. However, this energy returned is never more than the energy stored. Such networks are known as **passive networks**.

Let network N be connected to a source S. Suppose the network is initially relaxed. If  $v(t)$  is the voltage of the source and  $i(t)$  is the resulting current into the network  $N_2$  the average power delivered into the network is

$$p(t) = v(t) i(t)$$

and the energy delivered  $w(t)$  over time  $t$  is given by

$$w(t) = \int_{-\infty}^t v(t) i(t) dt \quad \dots (1.17.1)$$

This energy will always be non-negative for a passive network i.e., over time  $t$  there will be always be some energy delivered to the network or atleast there will not be any energy when the network would have returned all the energy back to the source or it would have stored some energy. It will never be a situation for a passive network when it would supply more energy what it had drawn previously. Mathematically for a passive network.

$$w(t) = \int_{-\infty}^t v(t) i(t) dt \geq 0 \quad \dots (1.17.2)$$

However, if the network has some initial energy stored equal to  $w(t_0)$  before it is switched on to the supply at  $t = t_0$  then for a passive network energy delivered to the network from the source should satisfy the inequality at any time  $t$ .

$$w(t) = \int_{-\infty}^t v(t) i(t) dt + w(t_0) \geq 0$$

A circuit which does not satisfy this condition is known as active circuit. That is for an active circuit.

$$\int_{-\infty}^t v(t) i(t) dt < 0 \quad \dots (1.17.3)$$

### 1.17.3 Lumped Networks

Many devices in electric system are distributed in space e.g. transmission lines, the windings of transformers or that of the generators, are distributed in a way.

Whenever these devices are energized, the effect is not experienced by the line length or winding lengths instantly because of finite velocity of electric signals. However, if we are interested in steady state and terminal quantities, it is sufficient to assume the parameters to be lumped rather than distributed. Sometimes when we are interested in the intermediate values and point to point variation of electric signals, we talk true nature of these devices i.e., the distributed nature. Otherwise, we assume the parameters to be lumped.

**1.17.4 Bilateral Networks**

The elements to be considered for electric network are assumed to be bilateral which means the voltage and current relations are same irrespective of direction of flow of current e.g. resistance, inductance, etc. However, for unilateral elements the voltage and current are different for two possible direction of flow of currents e.g. diodes.

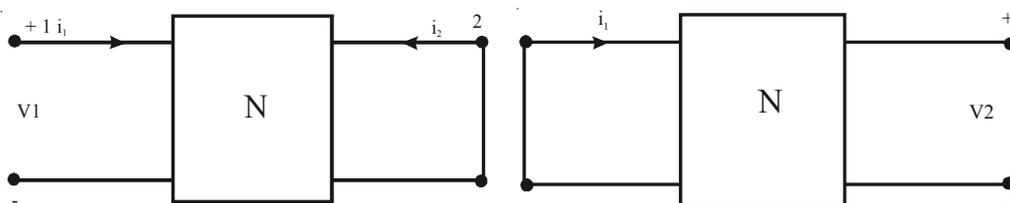
**1.17.5 Time Invariant Networks**

A network is said to be time invariant when there is some response to a certain excitation irrespective of time of application of excitation. Suppose for certain excitation  $v_1(t)$  the response is  $c_1(t)$ , if now the excitation is  $v(t + t_0)$  the response would be  $c(t + t_0)$ . Here the values of the parameters are assumed to be constant at all times and do not change with time.

**1.17.6 Reciprocity**

A network is said to be reciprocal when excitation and response terminals could be interchanged, without any change in the performance of the network.

If excitation  $v_1$  produces a response  $i_2$  and if the input and output are interchanged then with new  $v_2 = v_1$ , the new response  $i_1$  will be equal to  $i_2$ . E.g., a transmission line as shown in fig. 1.17.



*Fig.1.17 Networks to describe Reciprocity*

### 1.18 SUPERPOSITION THEOREM

This theorem is applicable to linear networks where the response is proportional to the excitation.

**Statement :**

*In a linear network if more than one number of excitations are acting, the response in a certain branch can be obtained by superimposing algebraically the responses due to various sources taking one excitation at a time of considering the remaining voltage sources, short circuited if they are ideal sources or replaced by their equivalent internal impedances and current sources are open circuited if they are ideal sources or replaced by their equivalent admittances.*

**Proof :**

In a linear network, if for an excitation  $E_1$ , the response  $I_1$  of the given network is related by

$$I_1 = CE_1 \quad \dots \text{ where 'C' is conductance}$$

with initial condition equals zero and if for an excitation  $E_2$ , the response  $I_2$  of the given network is related by

$$I_2 = CE_2$$

with initial condition equals zero then for excitation  $(E_1 + E_2)$ , the response will be  $(I_1 + I_2)$  for the given linear network. It is to be noted that if the excitation and response are related by the linear equation,

$$I_1 = CE_1 + d_1 \quad \dots \text{ where 'd}_1 \text{ is conductance}$$

the network is not linear as for double the excitation; response will not be doubled. Thus a circuit with R,L,C elements with constant values with no initial conditions.

i.e.,  $I_1(0^+) = 0$

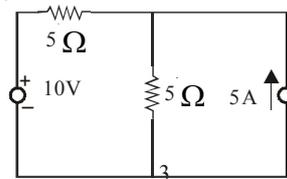
$$V_C(0^+) = 0$$

and

However, the initial conditions if any can be considered as sources or excitation and the overall response of the circuit can be obtained.

**Example 1.15 :**

Determine the current through the voltage source and the voltage across the current source in the network shown here.



**Solution :**

Since we have two sources (excitations) one voltage and another current we have to look for two circuits where in one circuit, voltage source will be short circuited and in another, current source will be open circuited.

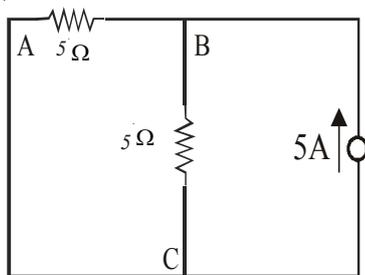
To find out current through the voltage source i.e., through branch AB we proceed as follows :

( a ) ( i ) When current source alone is acting,

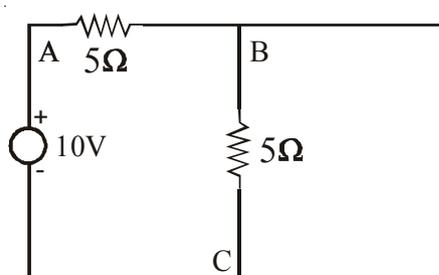
Current through AB is,

$$5 \times \frac{5}{10} = 2.5A$$

in the direction from B to A



( i ) Voltage Source Short Circuited



( ii ) Current Source Open Circuited

(ii) When voltage source alone is acting in the circuit,

Current through AB is,

$$\frac{10}{10} = 1A.$$

in the direction of A to B.



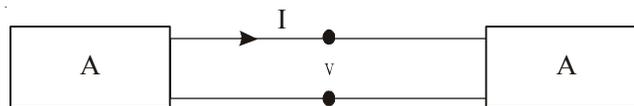
**Proof :**

In determining the  $Z_{Th}$  of the circuit, all the ideal voltage sources are short circuited. The practical voltage sources are replaced by their internal impedances. All the ideal current sources are open circuited and all the practical current sources are replaced by their internal impedance.

In the case of D.C. networks, we use the notation  $V_{Th}$  and  $R_{Th}$  instead of  $V_{Th}$  and  $Z_{Th}$ .

The current through any branch in the circuit can be calculated using Thevenin's Theorem, denoting that branch as the load branch  $Z_L$  ( or  $R_L$  in the case of D.C. networks) and finding the Thevenin's Equivalent Network for the remaining part of the network.

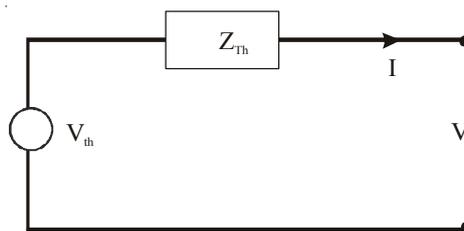
Thevenin's Theorem can be explained with the help of two networks A and B connected as shown in Fig.1.18



**Fig : 1.18** Two networks "A and B connected

The original network can be considered as a combination and connection of networks A and B. Network A contains linear elements which may have initial condition. It may also have an independent and dependent sources. However, there is no mutual magnetic source in A couple to B.

For network B, the elements need not necessarily be linear. These could be non-linear or time varying or both. However, in our analysis we will assume that the network elements are linear and many a times this will be a single branch (load) of the network.

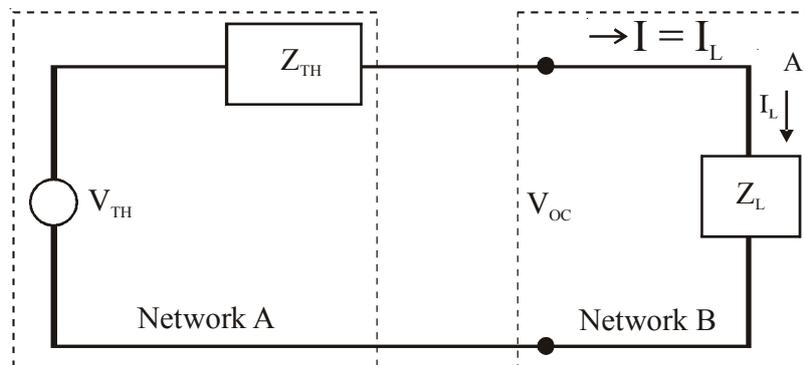


**Fig. 1.19** Thevenin Equivalent of the circuit in Fig.1.18

Network A is to be replaced by an equivalent network under the condition that the current  $I$  and voltage  $V$  identified in the figure remain invariant when the replacement is made. This amounts to replacing network A by an equivalent Thevenin's Voltage source and an equivalent Thevenin's series impedance (resistance) as shown in Fig.1.19

The following procedure is followed to find Thevenin's equivalent circuit.

To determine  $V_{TH}$  we remove the network B (could be a load resistor or the element through which current is required) and solve the network A to find out voltage across the open circuited terminal. This voltage is the Thevenin's Equivalent Voltage Source  $V_{TH}$ . Also  $Z_{Eq}$  is the impedance as seen in the network between the two open circuited terminals replacing the voltage sources by their equivalent admittances. The impedance as seen is known as Thevenin's Equivalent series impedance. While finding Thevenin's Equivalent, dependent sources continue to operate in the network.



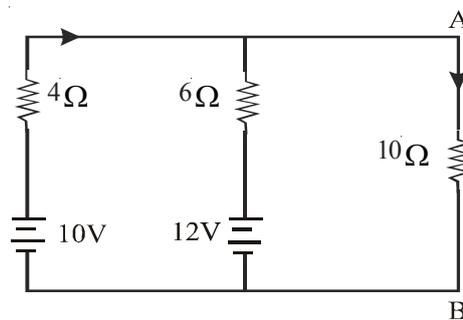
**Fig : 1.20** Complete Thevenin Equivalent circuit of Fig. 1.19

If  $Z_L$  is the load impedance and  $Z_{Eq}$  the Thevenin's Equivalent series impedance Fig. 1.20 the current through the load impedance is given by.

$$I = \frac{V_{TH}}{Z_{TH} + Z_L} \quad \dots\dots\dots ( 1.19.1 )$$

**Example 1.16 :**

Determine the current  $I$  in the network by using Thevenin's Theorem.

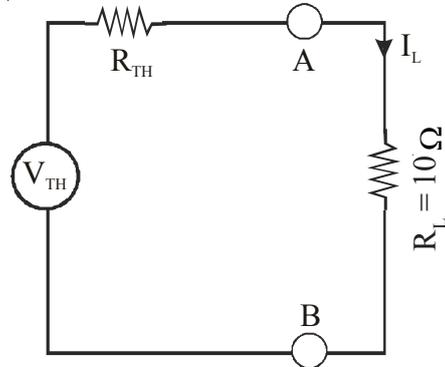


**Solution :**

**Step 1 :**

The Thevinin's equivalent circuit is,

$$I = \frac{V_{TH}}{Z_{TH} + Z_i} = \frac{V_{TH}}{R_{TH} + R_L}$$



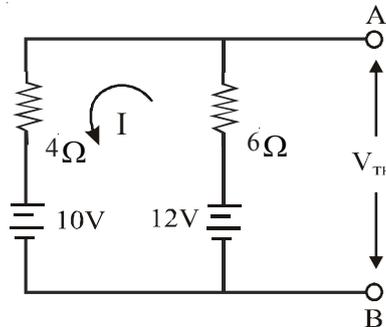
**Step 2 : To find V<sub>TH</sub> :**

From the given circuit, disconnect

$$R_L = 10 \Omega$$

$$I = \frac{12 - 10}{4 + 6} = 0.2 A$$

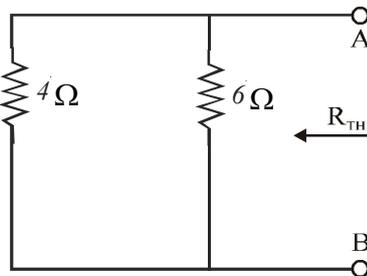
$$\begin{aligned} V_{TH} = V_{AB} &= 61 - 12 \\ &= 6 \times 0.2 - 12 \\ &= -10.8 V \end{aligned}$$



B is negative polarity and A is positive polarity.

**Step 3 : To Calculate R<sub>TH</sub> :**

From the given circuit, kill the sources. The resultant circuit is,



**Circuit to find R<sub>TH</sub>**

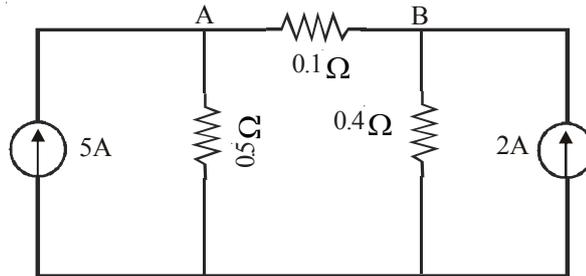
$$R_{TH} = R_{AB} = 4 \parallel 6 = \frac{4 \times 6}{4 + 6} = 2.4 \Omega$$

**Step 4 :**

$$I_L = \frac{V_{TH}}{R_{TH} + R_L} = \frac{10.8}{2.4 + 10} = 0.871 A$$

**Example 1.17 :**

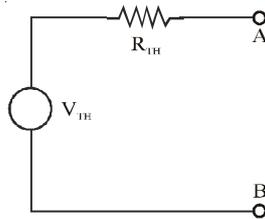
It is required to find current through the  $0.1\ \Omega$  resistor in the figure, using Thevenin's Method.



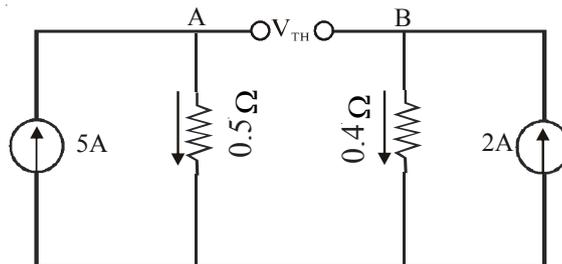
**Solution :**

**Step 1 :**

The Thevenin's equivalent circuit is,

**Step 2 : To find  $V_{TH}$  :**

From the given circuit, disconnect  $R_L = 0.1\ \Omega$



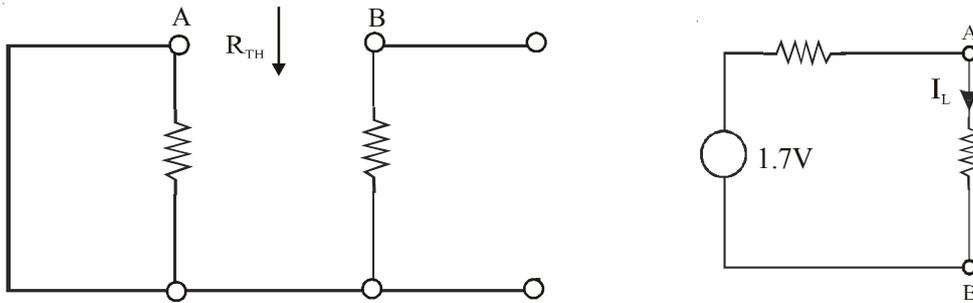
**Circuit to find  $V_{TH}$  :**

$$\begin{aligned} V_{TH} = V_{AB} &= -5 \times 0.5 + 2 \times 0.4 \\ &= -1.7\ \text{V} \end{aligned}$$

B is negative polarity and A is positive polarity.

**Step 3 : To calculate  $R_{TH}$  :**

From the given circuit, kill the current. The resultant circuit is,

**Circuit to find  $R_{TH}$** 

$$\begin{aligned} R_{TH} &= R_{AB} \\ &= 0.5 + 0.4 = 0.9 \Omega \end{aligned}$$

**Step 4 :**

$$I_L = \frac{V_{TH}}{R_{TH} + R_L} = \frac{1.7}{0.9 + 0.1} = 1.7 A$$

**1.20. NORTON'S THEOREM**

Norton's Theorem is the dual of Thevenin's Theorem and similar to Thevenin's Theorem, it is used in finding out the current through any particular branch of the network instead of solving the entire network. Norton's Theorem is also frequently used in electronic circuits.

**Statement :**

*Any two terminal linear network can be replaced by an equivalent network consisting of a current source  $I_{SC}$  in parallel with a network of impedance  $Z_{SC}$ . The impedance is the same as the Thevenin's Impedance as defined earlier and  $I_{SC}$  is the current between the two terminals when these terminals are short circuited.*

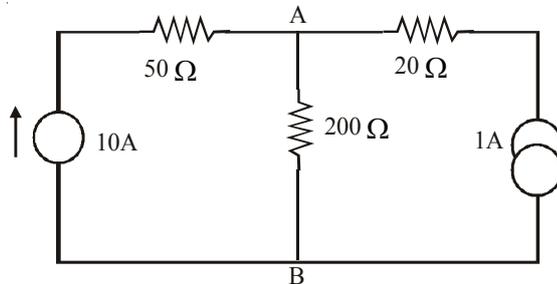
**Proof :** In Fig. 1.20 of the Thevenin's Theorem, the voltage supply  $V_{OC} = V_{TH} - I R_{TH}$  can be replaced with a current source of  $I = I_{SC}$ . This current  $I_{SC}$  is obtained by short circuiting  $V_{OC}$ . This leads to the development of Norton's Theorem.

The circuit of fig. 1.18 can be represented as given in fig. by using Norton's theorem which is a dual of Thevenin's theorem.

In determining the load current  $I_L$ , use is made of the formula for current division in any parallel branch knowing the total current for the parallel combination.

**Example 1.18 :**

Determine the voltage across  $200\ \Omega$  resistor in circuit by Norton's Theorem.



**Solution :**

**Step 1 :**

To find the short circuit current  $I_{SC}$ , replace the  $200\ \Omega$  by short-circuit. The current through short circuited A, B is  $I_{SC}$ .

The modified circuit is shown below.

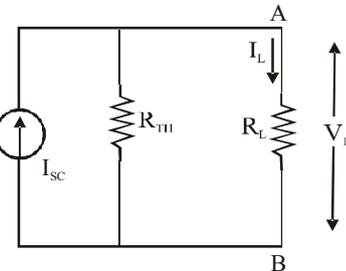
The voltage source will drive a current of  $10/50 = 0.2\text{A}$ , which flows through short-circuited A, B only.

Similarly, the current of  $1\text{A}$  flows through  $20\ \Omega$  and then through short-circuited A, B only.  $0.2\text{A}$  will not flow through  $20\ \Omega$  and  $1\text{A}$  will not flow through  $50\ \Omega$ . It is because of short-circuit. So,

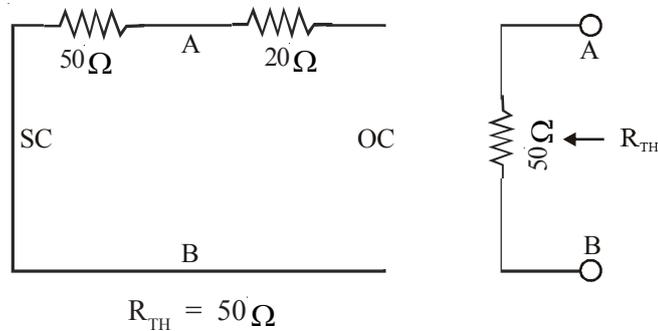
$$I_{SC} = 0.2 + 1 = 1.2\text{A}$$

**Step 2 : To find  $R_{TH}$  :**

From the given circuit, disconnect  $R_L = 200\ \Omega$  between A and B and also kill the sources. The resultant circuit becomes as follows.



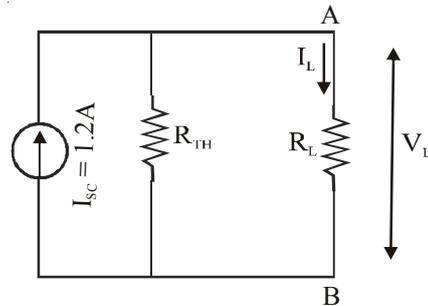
**Fig : 1.21** Norton's equivalent circuit



Step 3 :

Drawing Norton's equivalent circuit and showing the load resistance  $R_L$  we get the following circuit.

$$\begin{aligned}
 I_L &= \frac{I_{SC} R_{TH}}{R_{TH} + R_L} \\
 &= \frac{1.2 \times 50}{50 + 200} \\
 &= 0.24 \text{ A} \\
 V_1 &= I_L R_L \\
 &= 0.24 \times 200 = 48 \text{ V}
 \end{aligned}$$



### 1.21. MAXIMUM POWER TRANSFER THEOREM

In electronic circuits, it is desirable to transfer maximum power through a source to a load or from one stage to another stage in the case of multi-stage amplifiers because the currents and also the currents and power in the circuits will be very small of the order of milli-Amperes ( mA ) and milli-watts ( mW ). This is what is done by matching the load impedance with the source impedance. But in the case of electrical power circuits, maximum power transfer is not tried because the power is in the order of mega-watts ( MW ).

**Statement :**

*In an electric circuit maximum power is transferred to the load when the Load Resistance is equal to the Thevenin's Resistance in the case of D.C. circuits. In the case of A.C. circuits maximum power is transferred to the load when the load impedance is equal to the complex conjugate of the Thevenin's Impedance. The maximum power that can be transferred to the load will be 50% of the Power supplied to the circuit.*

An ideal voltage source  $V_s$  will give the full voltage to a load connected to it. However, if the source has an internal resistance  $R_s$  then the voltage across the load  $R_L$  falls short of  $V_s$ . As it is desirable to get as much power from  $V_s$  as possible the problem that arises is one of optimising the load for maximum transfer of power. Depending on the parameters of the load the relation between  $R_s$  and  $R_L$  for maximising the power to the load will differ. There are three situations which are of significance. When the internal resistance  $R_s$  is purely resistive the  $R_L$  should be  $R_L = R_{TH}$  since any circuit upto the load can be represented by Thevenin's voltage  $V_{Th}$  in series with Thevenin's resistance  $R_{Th}$ . This  $V_{Th}$  is similar to  $V_s$  and  $R_{Th}$  is similar to  $R_s$ .

$$\text{For the Circuit, } I = \left( \frac{V_{Th}}{R_{Th} + R_L} \right)$$

and power in the load

$$P_L = I^2 R_L = \left( \frac{V_{Th}}{R_{Th} + R_L} \right)^2 R_L$$

For maximising  $P_L$  obtain  $\frac{dP_L}{dR_L}$  and equate it to zero.

$$\begin{aligned} \frac{dP_L}{dR_L} &= \frac{d}{dR_L} \left( \frac{V_{Th}}{R_{Th} + R_L} \right)^2 R_L = 0 \\ &= V_{Th}^2 \left[ \frac{1}{(R_{Th} + R_L)^2} - \frac{2R_L}{(R_{Th} + R_L)^3} \right] = 0 \\ &= V_{Th}^2 \left[ \frac{R_{Th} + R_L - 2R_L}{(R_{Th} + R_L)^3} \right] = 0 \end{aligned}$$

Hence equating the numerator to zero we get

$$\begin{aligned} V_{Th}^2 [(R_{Th} + R_L - 2R_L)] &= 0 \\ = V_{Th}^2 [(R_{Th} - R_L)] &= 0 \end{aligned}$$

Hence for maximum power to be transferred to the load  $R_L$  we have the condition that

$$R_L = R_{Th}$$

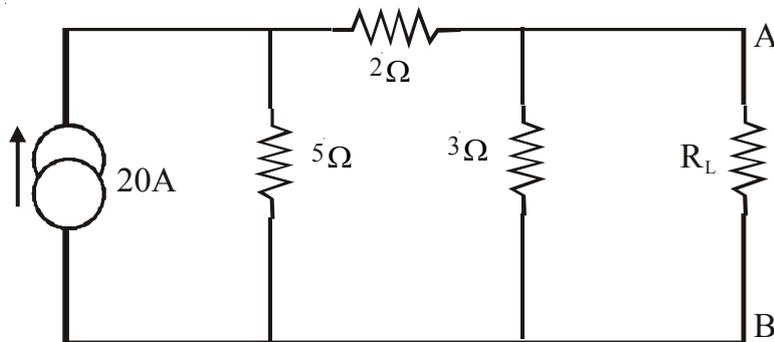
The load resistance should be equal to the Thevenin's Resistance for maximum power transfer to the load in the case of D.C. circuit.

In the case of A.C. circuits for maximum to be transferred to the load impedance  $Z_L$  we have the condition that the load impedance should be the complex conjugate of the Thevenin's Impedance.

$$Z_L = Z_{Th}^*$$

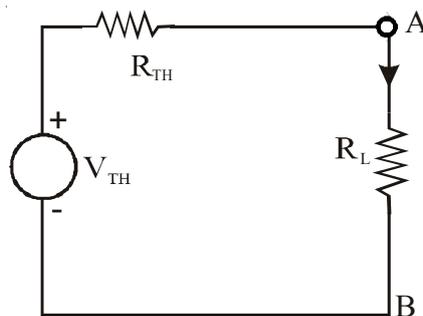
**Example 1.19 :**

The circuit shown in the figure R, absorbs maximum power. Compute the value of R and maximum power.



**Solution :**

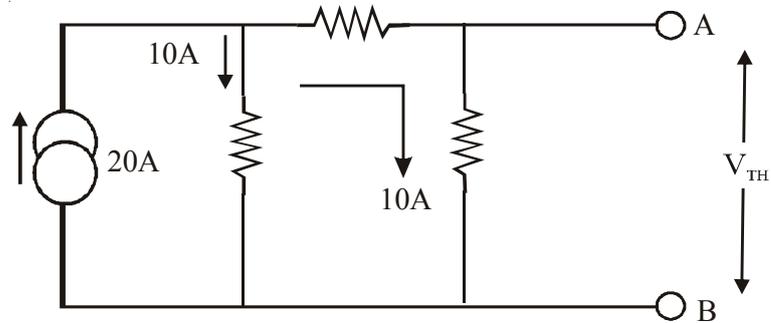
Thevenin's equivalent circuit is drawn as below.



**To find  $V_{TH}$  :**

Disconnect R from the original circuit

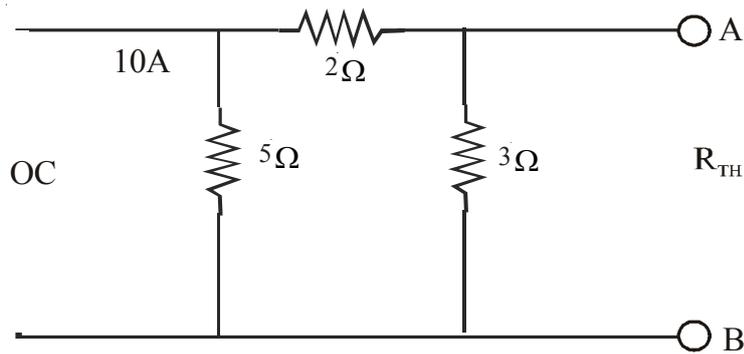
$$\begin{aligned} V_{TH} &= V_{AB} \\ &= -10 \times 3 = -30V \\ &= 30V \end{aligned}$$



B is negative polarity and A is positive polarity.

To find  $R_{TH}$  :

From the above circuit, open circuit the current source. Thus,



$$R_{TH} = \frac{7 \times 3}{7 + 3} = 2.1\Omega$$

According to the statement of Maximum Power Transfer Theorem, the value of R for maximum power transfer to it.

$$R_{TH} = 2.1 \text{ W}$$

and the maximum power transferred

$$\begin{aligned} &= \frac{V_{TH}^2}{4R_L} = \frac{V_{TH}^2}{4R_{TH}} = \frac{30^2}{4 \times 2.1} \\ &= 107\text{W} \end{aligned}$$

\*\*\*\*\*

**COMPREHENSION - 1**

**Note :** By answering all the questions given in this comprehension one can answer any objective type of questions easily whatever be the form of the question. Answers for these questions can be obtained by going through the topics in this chapter carefully.

1. State the difference between Electrical and Electronic Currents.
2. State Coulomb's Law.
3. What is meant by Absolute Permittivity and Relative Permittivity? Give the value for Absolute Permittivity of Free Space or Vacuum.
4. What are the values of Relative Permittivity for Air and Mica?
5. Define the terms
  - ( a ) Electric Field Intensity
  - ( b ) Electric Flux Density
  - ( c ) Potential
  - ( d ) Potential Differenceand mention their units.
6. Define the term Current and mention its unit.
7. What is Steady State Current?
8. What is the relationship between the Current and the Charge?
9. Define the unit of Current.
10. What is meant by Resistance Parameter? What are its Units?
11. How are Mega-Ohms, Kilo-Ohms, Milli-Ohms and Micro-Ohms denoted?
12. Explain the Color Code for Resistors used in Electronic Circuits.
13. What are the factors that affect a Resistance?
14. Given an expression for the Resistance?
15. Explain the different ways of connecting a Rheostat.
16. What will be the output in the case of a Potential Divider connection?
17. What is meant by Temperature Coefficient of Resistance?
18. Discuss the effect of Temperature on Resistance. Mention materials having negative temperature coefficients. What is meant by Negative Temperature Coefficient?
19. What is meant by Electrical Conductance? What are its Units?

20. Explain the differences between Ideal and Practical Sources of Voltage and Current.
21. What should be the nature of the Internal Resistance for
  - ( a ) Voltage Source?
  - ( b ) Current Source?
22. Distinguish between D.C. and A.C. Sources giving their waveforms with respect to time.
23. State and Explain Ohm's Law.
24. Explain the difference between Potential Rise and Potential Drop.
25. What is the difference between Linear and Non-Linear Resistances? Draw their  $v-i$  Characteristics. Give examples.
26. What is meant by Electrical Power? Give different forms of expression for Electrical Power. Give its Units.
27. Give expressions for Instantaneous Value of Power Loss and Power Supplied.
28. State and Explain Kirchoff's Voltage Law ( KVL ).
29. State and Explain Kirchoff's Current Law ( KCL ).
30. Give KVL and KCL in Point Form.
31. Explain the different methods of connecting Resistances.
32. Derive the Equivalent Series Resistance for a number of Resistances which are connected in Series.
33. Derive the Equivalent Parallel Resistance for a number of Resistances which are connected in Parallel.
34. Explain the nature of the Division of Currents in Parallel Circuits.
35. What are the Salient Features of Series and Parallel Connections of Resistances?
36. How do you reduce Series-Parallel Resistances into a Single Equivalent Resistance?
37. How are the Voltages and Currents measured in a circuit?
38. What should be the Resistance of a Voltmeter and an Ammeter? Why? How should they be connected in a circuit?
39. In D.C. circuits, What should be the nature & Polarities of the Voltmeter and Ammeter while connecting?
40. Explain Star and Delta Connection of Resistances.

41. Give the connection diagram for Mesh or Star connection using three and more than three resistances. How are their equivalent resistances obtained?
42. Give expressions for the Equivalent Star Resistances for a given Delta connected Resistances.
43. Give expressions for the Equivalent Delta Resistances for a given Star connected Resistances.
44. Explain the features of resistances.
45. Explain the uses of resistances.
46. Explain the differences between Electrical and Electronic Circuits.
47. What are the important features of Network Theorems?
48. What are the different classifications of Networks?
49. State & Prove Superposition Theorem.
50. When & How is the Superposition Theorem used?
51. State & Prove Thevenin's Theorem.
52. Explain the terms Thevenin's Voltage and Thevenin's Impedance. How do you obtain them?
53. What is the importance of Thevenin's Theorem? Where is it used generally?
54. Is the Thevenin's Theorem applicable for AC and for Transients?
55. What is the Dual of Thevenin's Theorem?
56. State and Prove Norton's Theorem.
57. Explain the terms Norton's Short-circuit Current. How do you obtain it?
58. What is the importance of Norton's Theorem? Where is it used generally?
59. Is the Norton's Theorem applicable for AC and for Transients?
60. How is the remaining part of the circuit other than the load represented in Norton's Theorem?
61. State & Prove Maximum Power Transfer Theorem.
62. What is the condition for Maximum Power Transfer to take place in
  - (i) DC Circuits
  - (ii) AC Circuits?
63. What is the importance of Maximum Power Transfer? Where is it used?

\* \* \* \* \*

<b>EXERCISE - 1</b>
---------------------

**Note :** By answering all the questions given in this exercise one can answer subjective type of questions easily including problems. The worked examples in the chapter may help in solving these questions.

1. ( a ) Distinguish between potential difference between two points and the potential gradient.  
 ( b ) Find the potential difference and the potential gradient between two points A and B when the potential of point A is 30V and the potential of point B is -20V if they are separated by a distance of 2mts.

**[ Ans:  $V_{AB} = 50\text{Volts}$ ;  $E = 25\text{V/mts}$  ]**

2. ( a ) What is meant by electric current? What is its units?  
 ( b ) If a charge of 25C passes a given point in a circuit in a time of 125ms, determine the current in the circuit.

**[ Ans:  $I = 200\text{A}$  ]**

3. ( a ) What is meant by resistance? Give an expression for resistance in terms of its dimensions.  
 ( b ) An aluminium wire 400mts long has a resistance of  $0.25\Omega$ . Find its area of cross-section. Find the area of cross-section required if the wire is of copper ( specific resistances of copper and aluminium are  $1.73 \times 10^{-8}$  and  $2.83 \times 10^{-8}\Omega\text{-m}$  )

**[ Ans:  $a = 0.4528\text{Sq-cm}$ ;  $0.2768\text{Sq-cm}$  ]**

4. ( a ) What are the factors that effect a resistance and How?  
 ( b ) Give the color code for the resistors used in electronic circuits.  
 ( c ) A conductor of 10mts long and with  $2\text{mm}^2$  cross-sectional area has resistance of  $0.4\Omega$ . Calculate the specific resistance of the conductor material. What is its conductance?

**[ Ans:  $\rho = 0.8 \times 10^{-7} \Omega\text{-m}$ ;  $G = 2.5\text{Siemens}$  ]**

5. ( a ) What is the effect of temperature on resistance?  
 ( b ) Define temperature coefficient of resistance.  
 ( c ) The resistance of the armature of a D.C. generator is  $0.92\Omega$  at  $25^\circ\text{C}$ . After working for 6Hrs on full load, the resistance increases to  $1\Omega$ . Calculate the temperature rise of the armature, if the temperature coefficient of resistance is 0.0040 at  $0^\circ\text{C}$ .

**[ Ans:  $23.9^\circ\text{C}$  ]**

6. ( a ) How does the temperature coefficient of a resistance vary with respect to temperature?  
( b ) What is meant by Negative Temperature Coefficient of Resistance? Mention some materials having Negative Temperature Coefficient of Resistance.  
( c ) A coil has resistance of  $20\Omega$  when its mean temperature is  $30^\circ\text{C}$  and  $24\Omega$  when its mean temperature is  $50^\circ\text{C}$ . Find the temperature coefficient of resistance at  $0^\circ\text{C}$ . Also find the mean temperature rise when its resistance is  $26\Omega$  and the surrounding temperature is  $20^\circ\text{C}$ .
- [ Ans:  $\alpha_0 = 0.0143/^\circ\text{C}$ ;  $40^\circ\text{C}$  ]**
7. ( a ) What is meant by EMF of a source?  
( b ) Distinguish between ideal and practical voltage sources drawing the V-I characteristics.  
( c ) Distinguish between ideal and practical current sources drawing the V-I characteristics.  
( d ) The internal resistance of a 12V battery is  $0.9\Omega$ . What will be its terminal voltage when the current drawn from the battery is 2A?
- [ Ans: V = 10.2Volts ]**
8. ( a ) Distinguish between DC and AC sources of voltage and current drawing the waveforms with respect to time.  
( b ) What is meant by Instantaneous Voltage and Instantaneous Current? How are they represented?  
( c ) What is meant by Polarity of a source? When do you generally use it? Can you use the polarities for AC sources?
9. ( a ) State and explain Ohm's Law.  
( b ) State Ohm's Law in Point Form.  
( c ) A lamp takes 2.5A at 230V when switched on at room temperature ( $25^\circ\text{C}$ ). At the normal working temperature the current drops to 0.2A. What is the cold resistance and hot resistance of the filament at the operating temperature?
- [ Ans:  $92\Omega$ ;  $1150\Omega$  ]**
10. ( a ) What is meant by electrical power and electrical energy?  
( b ) Twenty lamps of 60W are used each for 4Hrs in a building. Calculate the current drawn when all the lamps are working and the monthly electricity charge at Rs. 1.20 per unit. Assume supply at 240V.
- [ Ans: 0.25A; Rs. 172.8 ]**

11. A factory has a 220V supply and has the following loads:

**Lighting:** Five Hundred 100W and Five Hundred 60W lamps:  
5Hrs per day.

**Heating:** 120KW: 10Hrs per day.

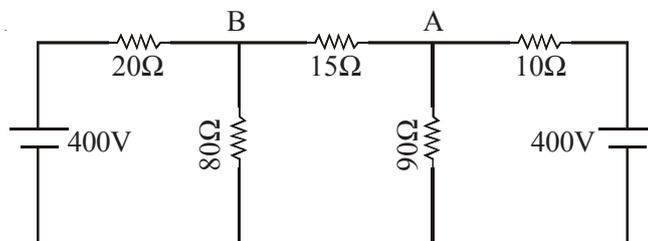
**Motors:** 48KW with average efficiency of 80%: 4Hrs  
per day.

**Others:** 15KW: 4Hrs per day

Assume 6 day week, calculate the daily and weekly consumption of the factory. Calculate the current drawn with only the lighting load, lighting and heating.

[ Ans: 1900KWH; 11400KWH; 363.6A; 909A ]

12. ( a ) Explain Kirchoff's Voltage Law ( giving an example of a circuit with atleast two sources of different polarities and two or three resistances in series )
- ( b ) Explain Kirchoff's Current Law ( for a junction with two or three source currents of opposite directions and two or three load currents )
- ( c ) Using Kirchoff's Laws, find the magnitude and direction of current flowing through the  $15\Omega$  resistance in the given circuit.



[ Ans: 1A from A to B ]

13. ( a ) Explain how the total resistance of a circuit having more than one resistance in series is calculated.
- ( b ) A 60W, 240V lamp is connected in series with a 40W, 200V lamp across 250V supply. Calculate the current taken, voltage across each lamp and power given by each lamp. Assume that the resistance of the lamps remain constant.

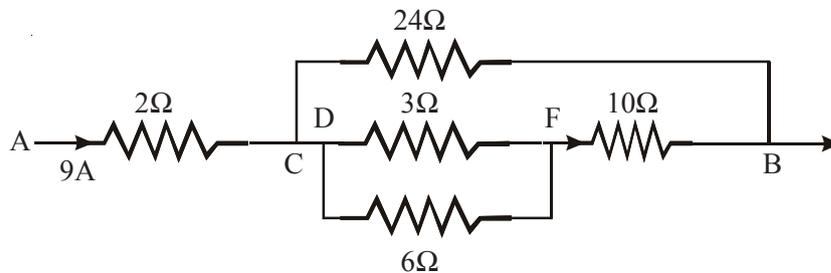
[ Ans: 0.12755A; 127.45V; 15.62W, 16.27W ]



17. (a) How do you reduce the circuit and obtain the total resistance in the case of a circuit with series and parallel resistances?  
 (b) A  $10\Omega$  resistor is connected in series with a group of two resistances of  $15\Omega$  each connected in parallel. Draw the circuit diagram and find out what resistance  $R$  must be shunted across this parallel combination so that the total current taken from  $20V$  supply is  $1.5A$ .

[ Ans:  $R = 6\Omega$  ]

18. Determine the effective resistance between terminals A and B in the circuit of the given figure. If the current drawn at A is  $9A$ , find the current in and the voltage drop across each element.



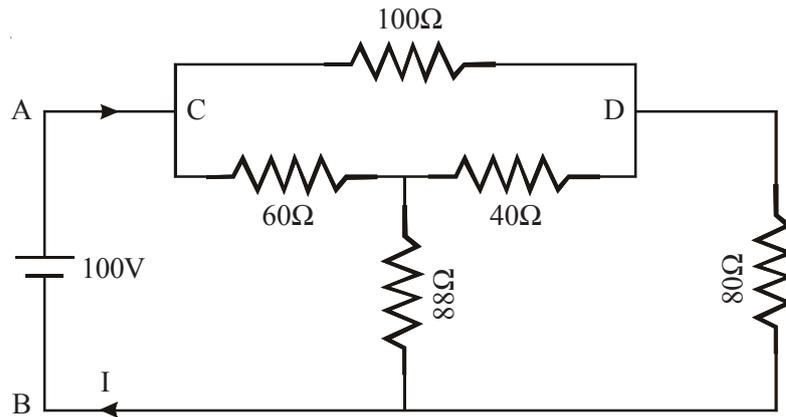
[ Ans:  $9A, 18V; 3A, 72V; 4A, 12V; 2A, 12V; 6A, 60V$  ]

19. (a) Explain the Potential Divider connection of a Rheostat.  
 (b) A direct voltage of  $240V$  is applied to a uniform  $200\Omega$  resistor connected between A and C. A load  $40\Omega$  resistance is connected between the terminal A and the tapping B ( between the terminals A and C ) Draw the circuit diagram and find the resistance AB in order that  $1A$  flows in the  $40\Omega$  resistor.

[ Ans:  $R = 71.65\Omega$  ]

20. (a) Explain how three resistances can be connected in Star and Delta.  
 (b) How do you extend Star-Mesh connection to more than three resistances?  
 (c) Derive expressions for equivalent star resistances for given delta and equivalent delta resistances for given star.  
 (d) How do you extend the finding out the equivalent resistances in the case of Star-Mesh connections having more than three resistances?

21. In the given figure, 160V are applied to the terminals AB. Determine the resistance between the terminals A & B and the current.



[ Ans:  $R_{AB} = 80\Omega$ ;  $I = 2A$  ]

22. ( a ) Enumerate the features and uses of resistance.  
 ( b ) Enumerate the differences between Electrical Circuits and Electronic Circuits.
23. Using Superposition Theorem, determine the current through the branch AB in Fig 1. .

[ Ans:  $0.8A$  ]

24. Using Superposition Theorem, determine the current through the  $3\Omega$  resistor and the power loss in it in Fig. 2.

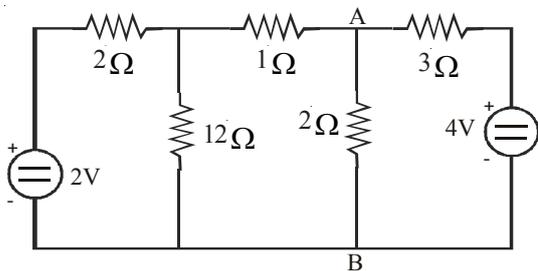


Fig. 1

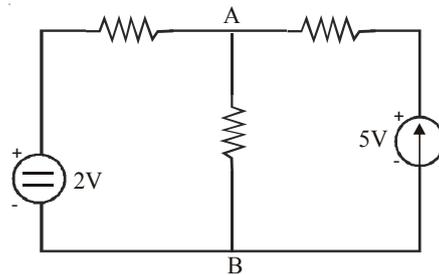


Fig. 2

[ Ans.  $5.62A$ ;  $94.92W$  ]

25. Using Superposition Theorem, determine current through the branch AB in the circuit given in Fig. 2.
26. Using Thevenin's Theorem, determine the current through  $2\ \Omega$  resistor connected between A and B in the circuit of Fig.3.

[ Ans:  $0.82\text{A}$  ]

27. Determine the Thevenin's Equivalent across the Terminals A, B, in Fig. 4.

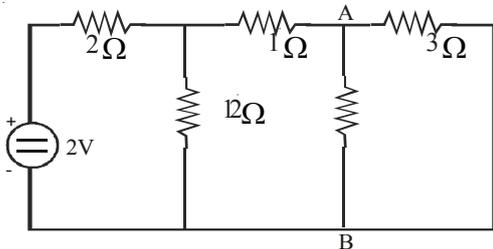


Fig. 3

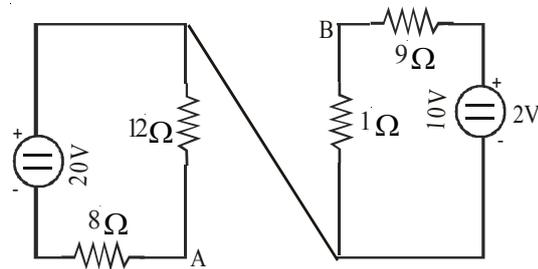


Fig. 4

[ Ans :  $V_{TH} = 11\text{V}$ ;  $R_{TH} = 5.7\ \Omega$  ]

28. Using Thevenin's Theorem, determine the current through the ammeter of  $2\ \Omega$  connected in unbalanced Wheat Stone Bridge of Fig.5.

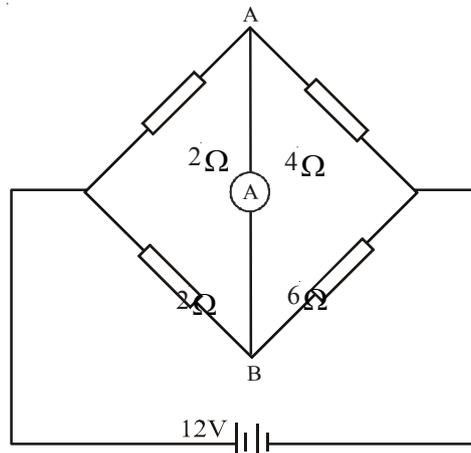
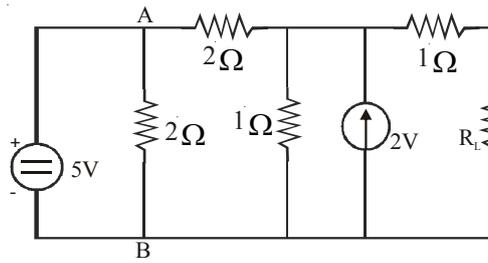


Fig. 5

29. Using Norton's Theorem, Solve Problem No.26
30. Using Norton's Theorem, Solve Problem No. 27

31. Using Norton's Theorem, Solve Problem No.28.
32. Using Maximum Power Transfer Theorem, find the resistance  $R_L$  for the maximum power transfer in the circuit shown in Fig.6. Calculate the Maximum Power also. (Hint : AB is a redundant element).

**Fig. 6**

[ Ans:  $R_L = 1.75\Omega$  ;  $P_L = 1.08V$  ]

\* \* \* \* \*