Module-5		
Distribution: Primary AC distribution systems – Radial feeders, parallel feeders, loop feeders and interconnected network system. Secondary AC distribution systems – Three phase 4 wire system and single phase 2 wire distribution, AC distributors with concentrated and uniform loads. Effect of disconnection of neutral in a 3 phase four wire system. **Reliability and Quality of Distribution system:** Introduction, definition of reliability, failure, probability concepts, limitation of distribution systems, power quality, Reliability aids.		**10**
Revised Bloom's Taxonomy Level	L_1 – Remembering, L_2 – Understanding, L_3 – Applying, L_4 – Analysing.	

Distribution Systems

8.1 Introduction

It is well known that the electrical power is now a days generated in a.c. form. It is transmitted and distributed with the help of transformers, transmission lines, feeders, distributors and service mains. The transformers are used to step up and step down the voltage levels as per the requirement at various stages. The lines which transmit an electrical power from the generating station to the different substations are feeders. There are no tappings on feeders. The electrical power is distributed from the substations with the help of distributors. The distributors can have number of tappings.

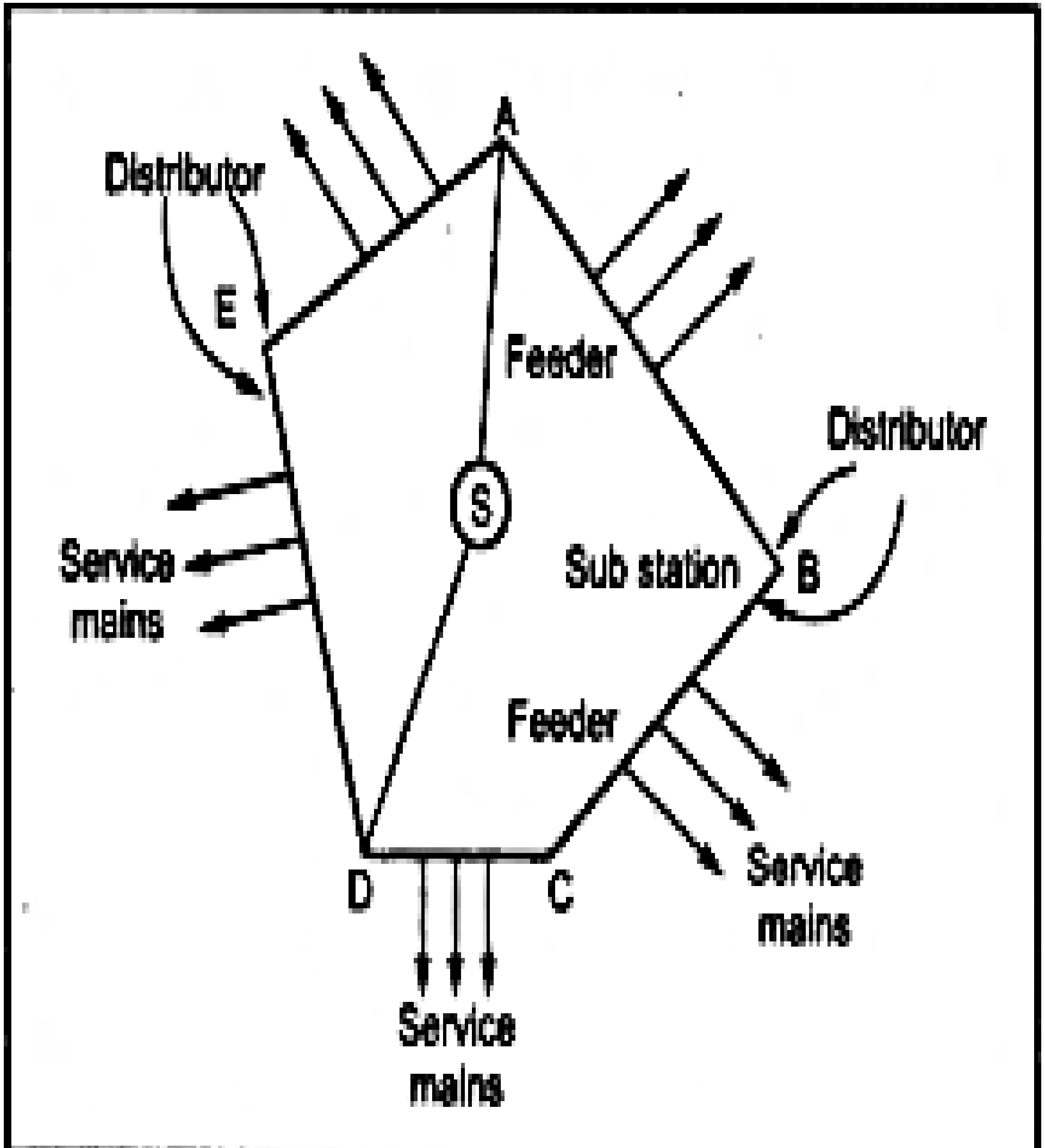


Fig. 8.1 General distribution scheme

The small cables which are used to supply consumer from the distributor are called service mains. The Fig. 8.1 shows a general distribution scheme showing feeders, distributors and service mains.

The feeders are lines of large current carrying capacity. These are feeding to the substation. The size of the feeder is determined by the required current carrying capacity of the feeder. The voltage drop along the feeder is compensated by compounding the generators.

The necessary requirements of a good distribution system are,

1. The continuity in the power supply must be ensured. Thus system should be reliable.
2. The specified consumer voltage must not vary more than the prescribed limits. As per Indian Electricity Rules, the variation must not be beyond ± 5% of the specified voltage.
3. The efficiency of the lines must be as high as possible.
4. The system should be safe from consumer point of view. There should not be leakage.
5. The lines should not be overloaded.
6. The layout should not affect the appearance of the site or locality.
7. The system should be economical.

Though the a.c. transmission and distribution is used, still for certain applications such as d.c. motors, electro-chemical work, batteries, electric traction etc. the d.c. supply is must. Hence along with a.c., d.c. distribution is also equally important. In a d.c. distribution, d.c. generators are used in the generating stations or a.c. is converted to d.c. using the converters like mercury arc rectifiers, rotary converters etc. at the substations. Then the d.c. supply is distributed to the consumers as per the requirement.

In this chapter both d.c. as well as a.c. distribution systems are discussed in detail.

8.2 General D.C. Distribution System

The Fig. 8.2 shows a general distribution system in d.c. form where d.c. generators are used at the generating stations.

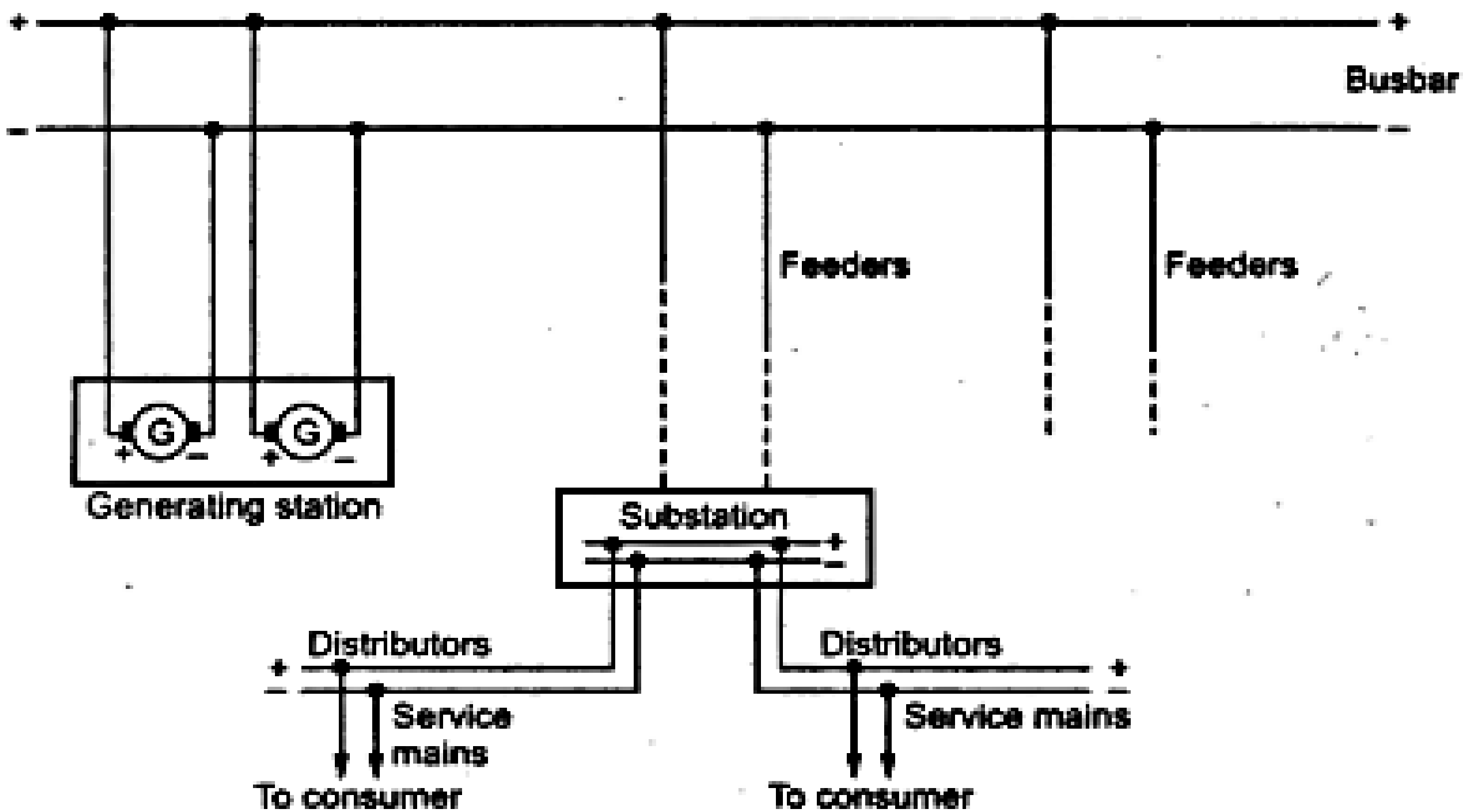


Fig. 8.2 General d.c. distribution system

As explained earlier, the feeders are used to feed the electrical power from the generating stations to the substations. The distributors are used to distribute the supply further from the substations. The service mains are connected to the distributors so as

8.3 Radial Distribution System

The Fig. 8.3 shows a radial distribution system.

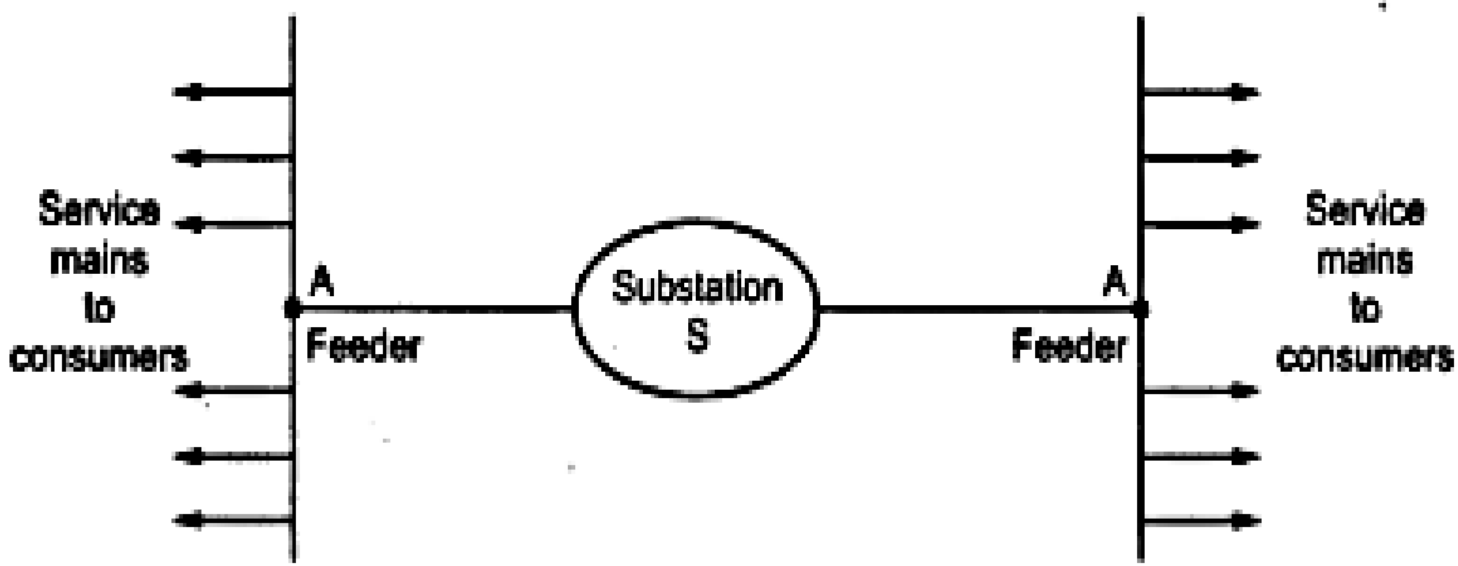


Fig. 8.3 Radial distribution system

When the distributor is connected to substation on one end only with the help of feeder, then the system is called **radial distribution system.** The feeders, distributors and service mains are radiating away from the substation hence name given as radial system. There are combinations of one distributor and one feeder, connecting that distributor to the substation. In the Fig. 8.3, distributor 1 is connected only at one end to substation through a feeder at point A. Similarly the other feeder is feeding the distributor 2, only at one point B.

Due to such system, if the fault occurs either on feeder or a distributor, all the consumers connected to that distributor will get affected. There would be an interruption of supply to all such consumers. Similarly the end of the distributor nearer to the substation will get heavily loaded than the end which is too far away from the substation.Similarly the consumers at the distant end of the distributor would be subjected to the voltage variations and fluctuations, as the load on the distributor changes. The system is advantageous only when the generation is at low voltage level and the substation is loaded at the centre of the load.

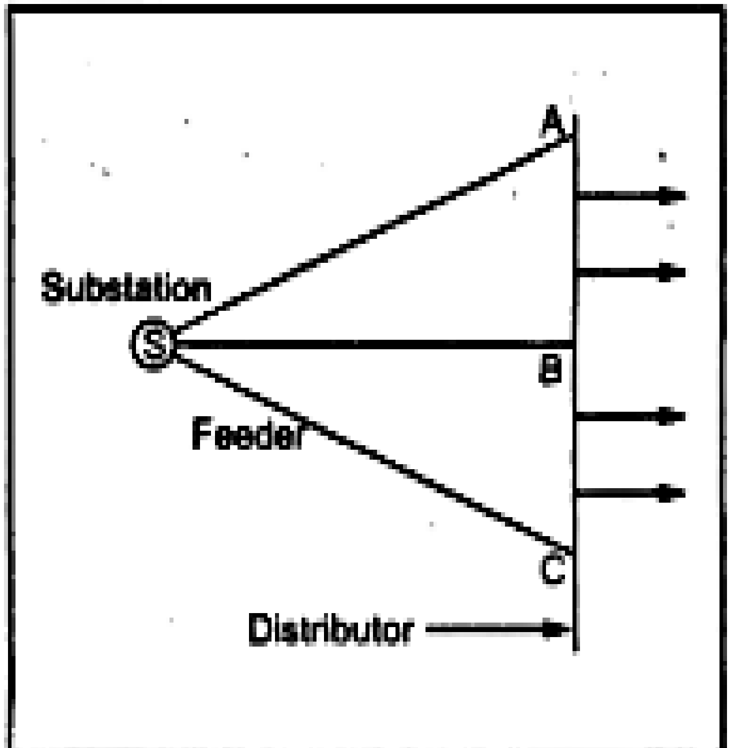


Fig. 8.4 Modified radial system

The fault on a feeder or a distributor causes interruption in supply to all the consumers connected to the distributor. This can be avoided by modifying the radial system as shown in the Fig. 8.4. In this system, the distributor is fed at number of points with the help of feeders. In Fig. 8.4, the feeders from the substation are feeding to a single distributor at points A, B and C.

8.3.1 Advantages of Radial System

The various advantages of radial system are,

1. Simplest as is fed at only one end.
2. The initial cost is low.
3. Useful when the generation is at low voltage.
4. Preferred when the station is located at the centre of the load.

8.3.2 Disadvantages of Radial System

Apart from its advantages, this system is suffered from the following disadvantages,

1. The end of distributor near to the substation gets heavily loaded.
2. When load on the distributor changes, the consumers at the distant end of the distributor face serious voltage fluctuations.
3. As consumers are dependent on single feeder and distributor, a fault on any of these two causes interruption in supply to all the consumers connected to that distributor.

8.4 Ring Main Distribution System

Another system of distribution which elliminates the disadvantages of the radial system is used in practice called **ring main distribution system.**

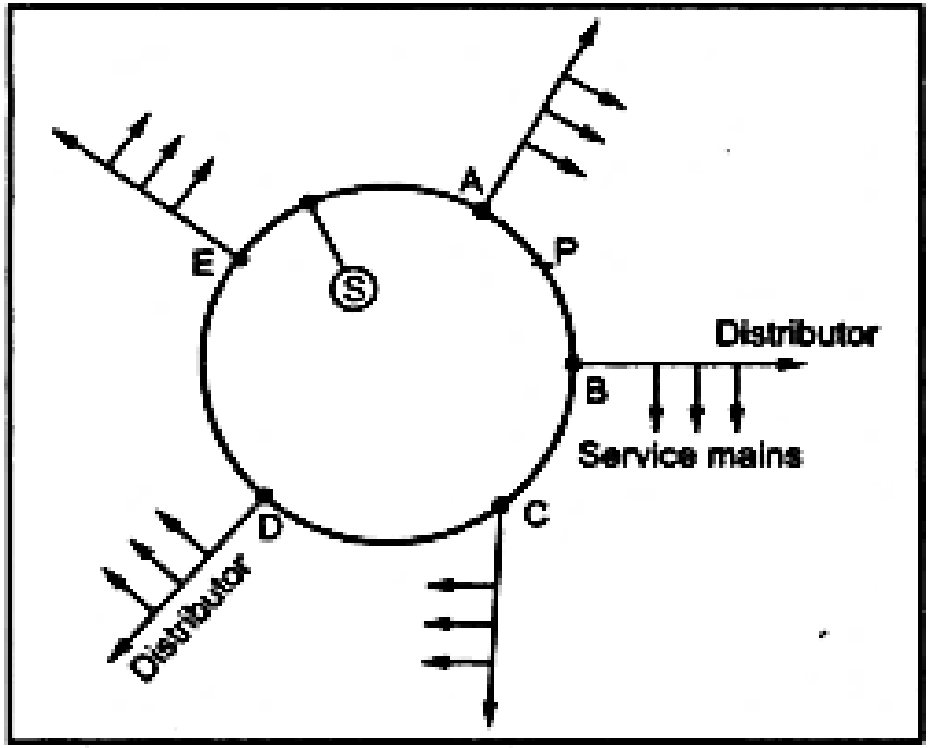


Fig. 8.5 Ring main distribution system

In such system, the feeder covers the whole area of supply in the ring fashion and finally terminates at the substation from where it is started. The feeder is in closed loop form and looks like a ring hence the name given to the system as ring main system. This is shown in the Fig. 8.5.

The feeder in the ring fashion is divided into number of sections as AB, BC, CD, DE and EA. The various distributors are connected at A, B, C, D and E. Each distributor is supplied by the two feeders and hence the design is similar to the two feeders in parallel on different paths. Hence if there is any fault on any part of the feeder, still the consumers will keep on getting the continuous supply. For example, if the fault occurs at point P in the section AB of the feeder, still the consumers connected to the distributors at A and B will get supply from the sound feeder sections AE and BC. The part AB of the feeder can be isolated and repaired. The feeder can be fed at one or more feeding points. Thus the disadvantages of radial system are eliminated in this system. The great saving in copper is another major advantage of the ring main system.

each generator is with respect to neutral which is earthed. Thus the voltage between each line and neutral is V volts while between the lines it is 2 V volts. Thus the consumers demanding higher voltage are connected to the two lines while the consumers demanding less voltage for lighting load are connected between any one line and neutral. The Fig. 8.5.1 shows the d.c. three wire distribution system.

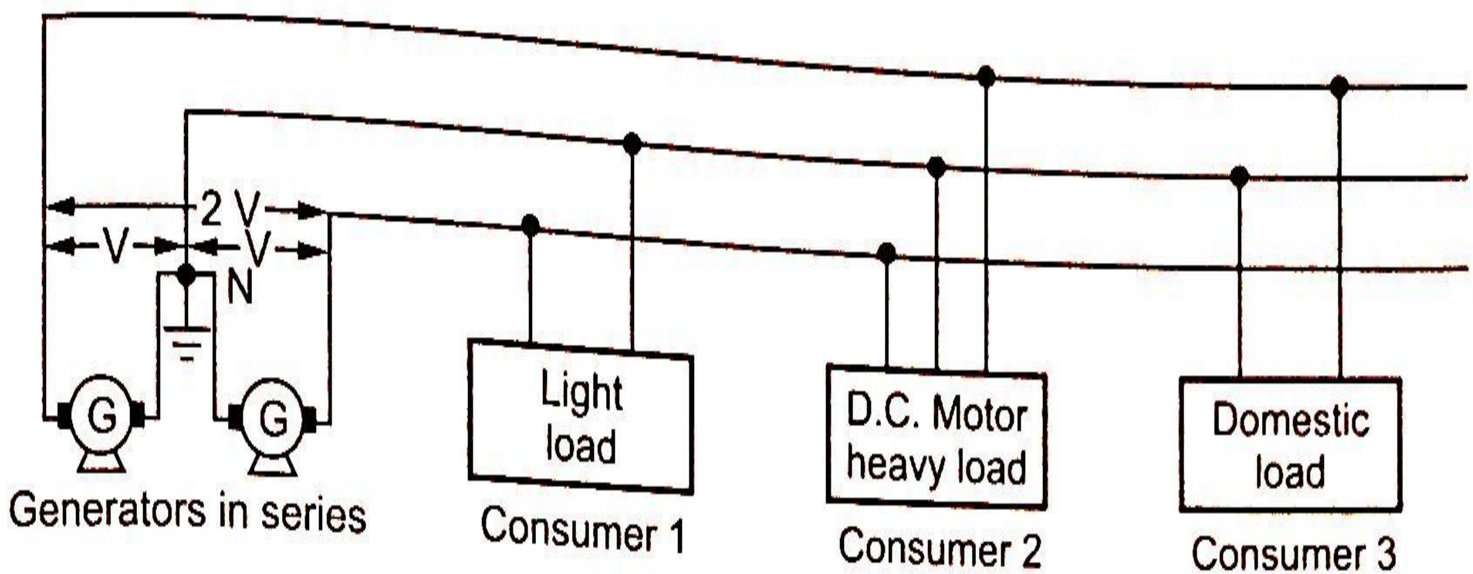


Fig. 8.5.1 Three wire d.c. system

The light loads, domestic loads are connected between any of the two lines and neutral while the d.c. motor loads requiring higher voltage are connected between the lines. The neutral is earthed.

The symbolic representation of three wire d.c. system is shown in the Fig. 8.5.2.

The Fig. 8.5.2 shows the current distribution in the system. The one line carries current I_1 while the other line carries current I_2. When the load is **balanced**, that is loads connected on either sides of the neutral wire are equal, then the neutral current is zero. And under such condition, the potential of the neutral wire is exactly half of the potential between the two outer lines. Thus the positive outer wire is at V volts above the neutral while the negative outer wire is at V volts below the neutral.

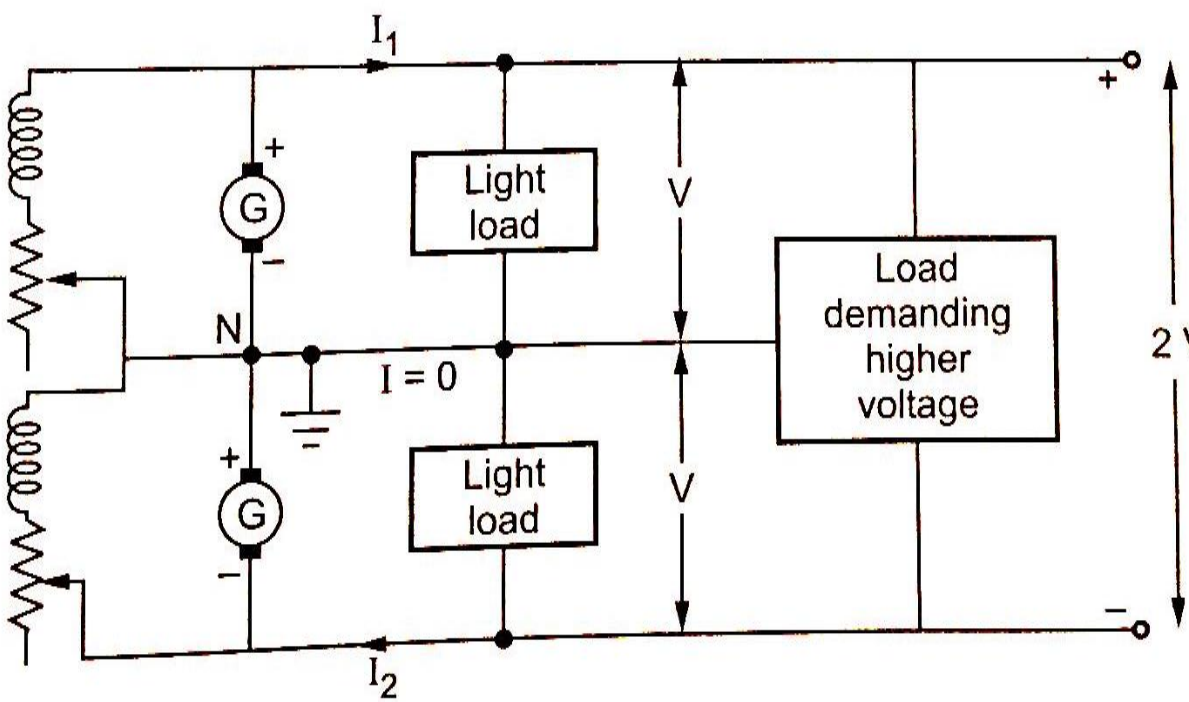
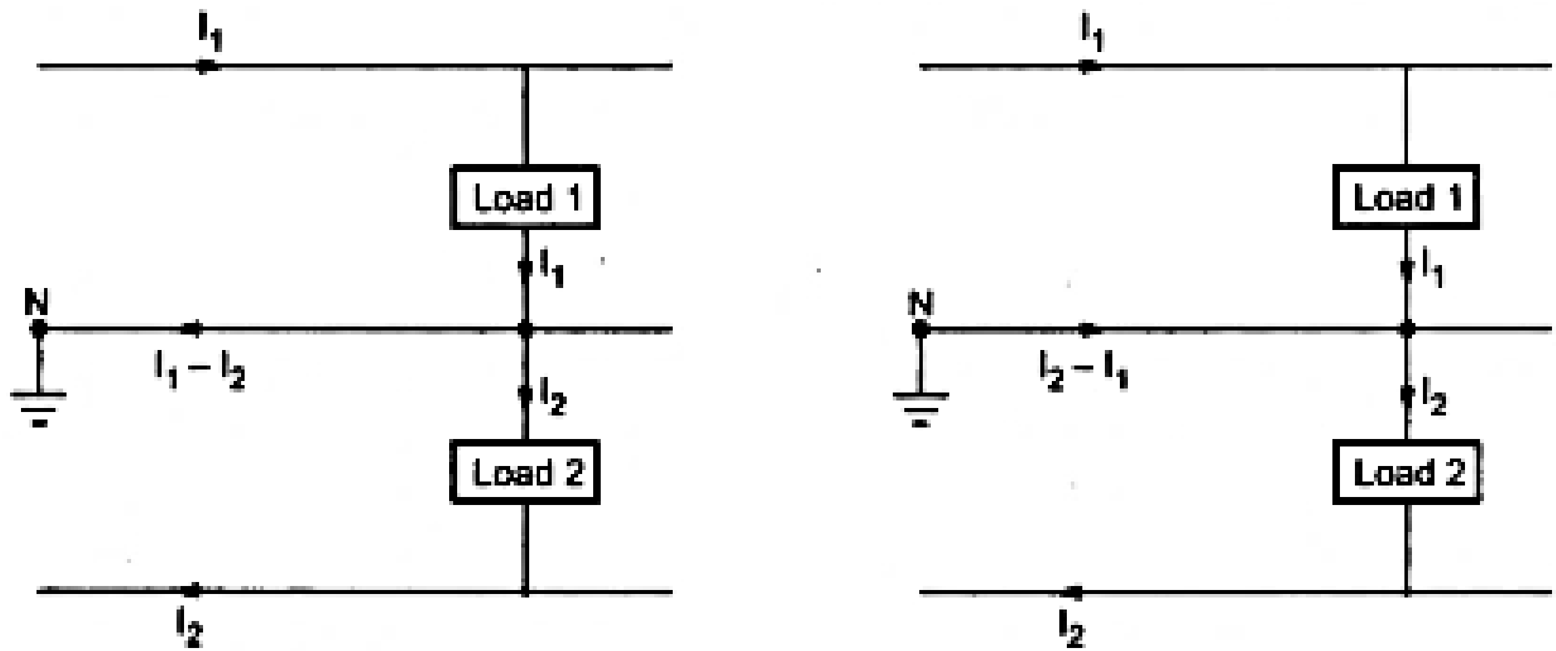


Fig. 8.5.2 Three wire d.c. system with balanced loads

If the loads are not balanced then the neutral carries the current. This current is the difference between the two line currents I_1 and I_2 and is called **out of balance current.** If the load on the positive line i.e. I_1 is greater than I_2 then neutral wire carries current equal to $I_1 - I_2$. If the load on the negative line is greater i.e. I_2 is greater than I_1 then the neutral wire carries current equal to $I_2 - I_1$. This is shown in the Fig. 8.8 (a) and (b). The direction of $I_1 - I_2$ is from load end to supply end while the direction of $I_2 - I_1$ is from supply end to load end.



(a) $I_1 > I_2$ (b) $I_1 < I_2$

Fig. 8.8 Out of balance current through neutral

In any of the two cases of out of balance current conditions, the neutral potential will not remain half of that between the two lines.

Instead of using two generators in series, a single generator having twice the line to neutral voltage rating also can be used.

This is shown in the Fig. 8.9.

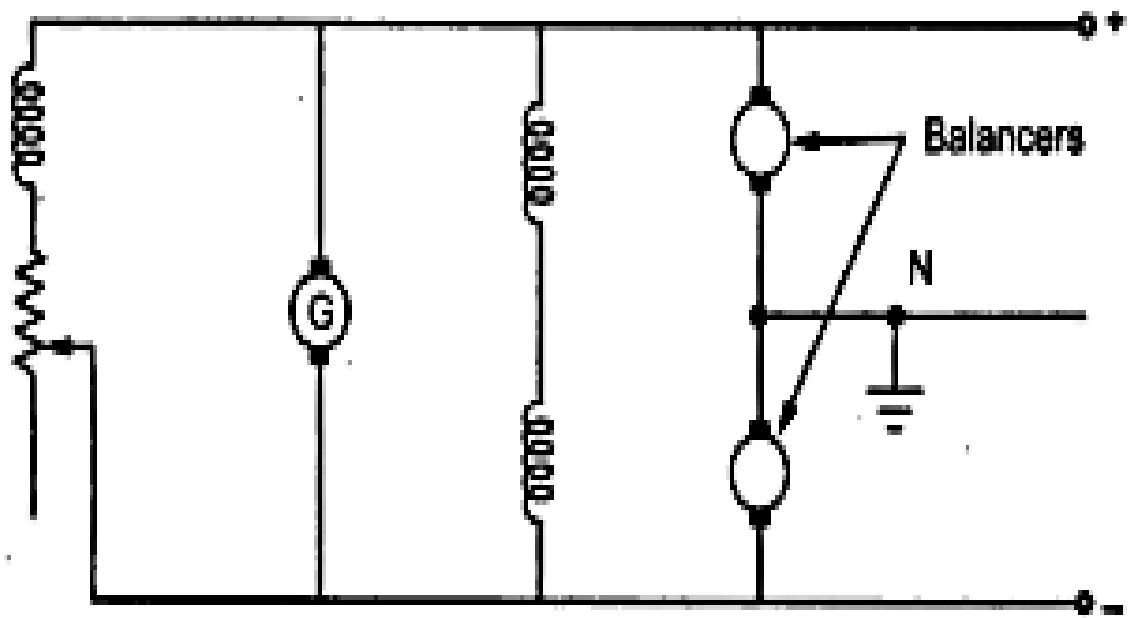


Fig. 8.9 Use of single generator in 3 wire D.C. system

8.5.1 Current Distribution in 3 Wire D.C. System

The Fig. 8.10 shows 400/200 V, 3 wire d.c. distribution system. The total current distribution can be understood by taking concrete values of load currents. The motor load connected across the lines demand 175 A while other loads requiring less voltage, are connected between line and neutral, on both the sides of neutral. The two loads connected between positive line and neutral take 35 and 25 A current respectively while the two loads connected between negative line and neutral take 50 A current each. Applying Kirchhoff's current law at various nodes, the currents in all the sections can be determined as shown in the Fig. 8.10.

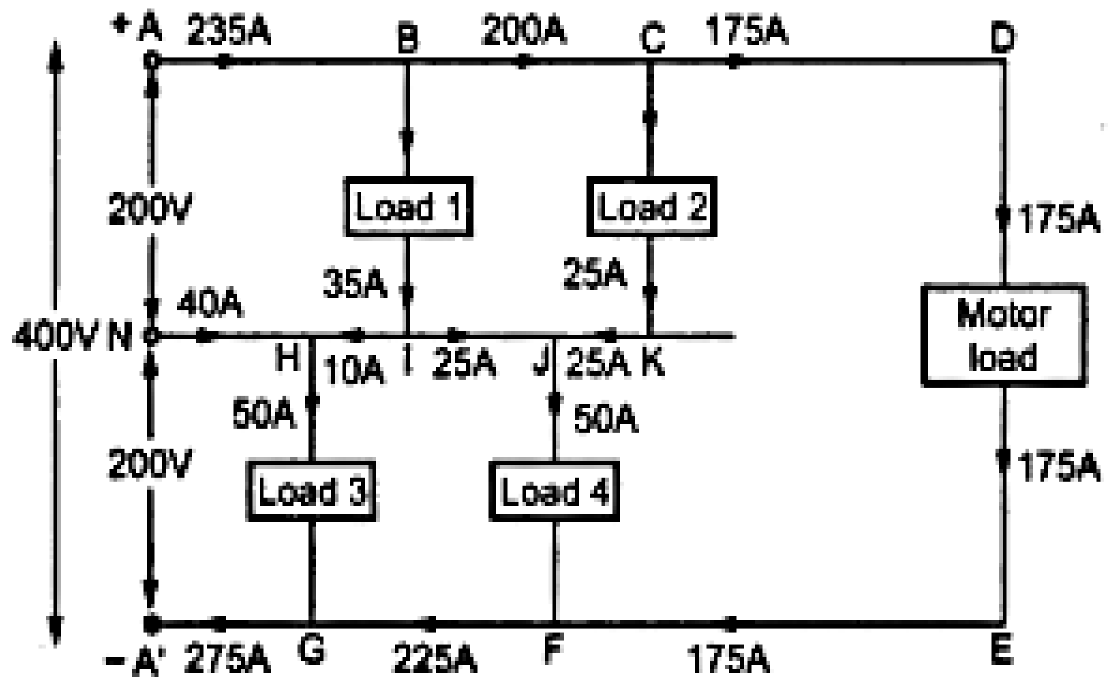


Fig. 8.10 Current distribution

8.6 Types of D.C. Distributors

It has been mentioned that the d.c. distributors are fed at one end or at both the ends. The voltages used to feed the distributors at both the ends may be equal or unequal. Such distributors fed at one end or both ends, with equal or unequal voltages are connected to the loads. In practice, the loads on the distributors may be concentrated or distributed.

The loads which are acting at particular points of the distributor are called **concentrated loads**. The domestic load tapped at a particular point of distributor is a good example of concentrated load.

The loads which spread over the particular distance of the distributor are called **distributed loads.** Practically no load is distributed in the true sense. But if number of loads having same power consumption are connected to the distributor, very close to each other then the effective load on the distributor is treated to be uniformly distributed load.

8.7 D.C. Distributor with Concentrated Loads

This distributor is further classified as,

1. Fed at one end
2. Fed at both the ends

8.7.1 Concentrated Loads Fed at One End

The Fig. 8.12 shows a distributor with concentrated loads fed at one end A – A′. The loads are connected at the points a – a′, b – b′ and c – c′.

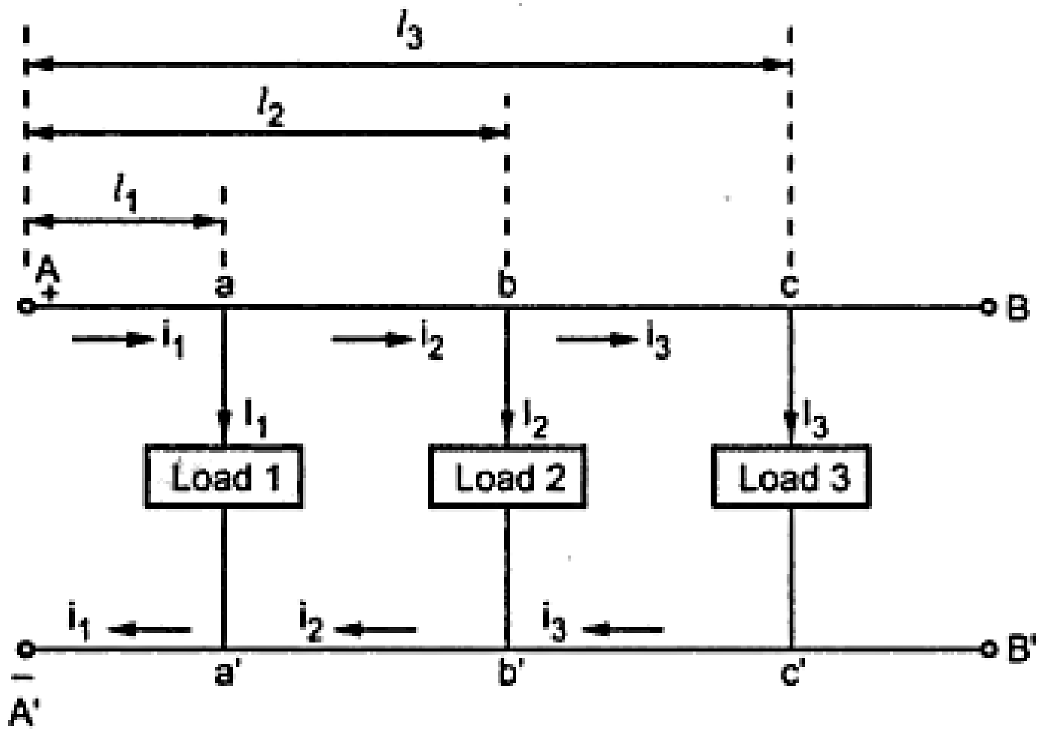


Fig. 8.12

Let l_1 , l_2 and l_3 are the lengths of the sections A – a, A – b and A – c respectively. The load currents are I_1, I_2 and I_3. The currents in various sections of the distributor are i_1, i_2 and i_3.

From the Fig. 8.12, applying KCL at various points we can write,

$$i_1 = I_1 + I_2 + I_3, \quad i_2 = I_2 + I_3 \quad \text{and } i_3 = I_3.$$

The wire A′ B′ is the return wire of the distributor.

Let $\qquad r' = $ resistance per unit length of conductor in Ω

The various voltage drops can be tabulated as,

Section	Drop	Section	Drop
Aa	$i_1\, l_1\, r'$	A′a′	$i_1\, l_1\, r'$
ab	$i_2\, (l_2 - l_1)\, r'$	a′b′	$i_2\, (l_2 - l_1)\, r'$
bc	$i_3\, (l_3 - l_2)\, r'$	b′c′	$i_3\, (l_3 - l_2)\, r'$

Applying KVL to any loop, the load point voltages can be calculated.

Now r′ is the resistance of single conductor per unit length. And it can be seen that the drops in forward and return conductors are required to be calculated separately and are equal. In practice, the resistance of **go** and **return** conductors per unit length is assumed to be $r = 2r'$ and hence two wire distributor can be represented as single wire for calculation purpose, as shown in the Fig. 8.13.

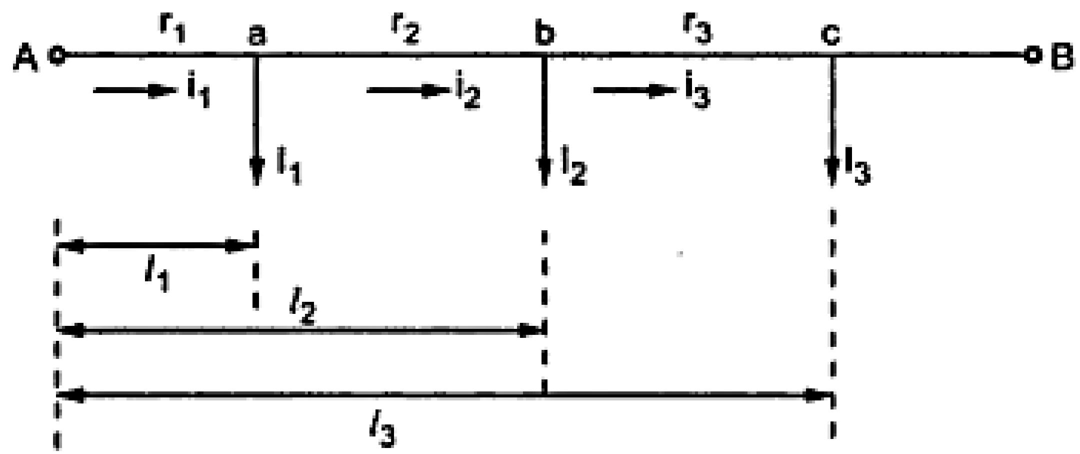


Fig. 8.13 Single wire representation

Now
$$r_1 = 2r_1'$$
$$r_2 = 2\, r_2'$$
$$r_3 = 2r_3'$$

And hence all the drop calculations and load point voltages remain same as before.

The total drop in the distributor is

$$= r_1\, i_1\, l_1 + r_2\, i_2\, (l_2 - l_1) + r_3\, i_3\, (l_3 - l_2)$$

Many times instead of specifying resistances per unit length, actual resistances are specified. The resistance values are of both go and return conductors.

The current loading and voltage drop diagrams are shown in the Fig. 8.14.

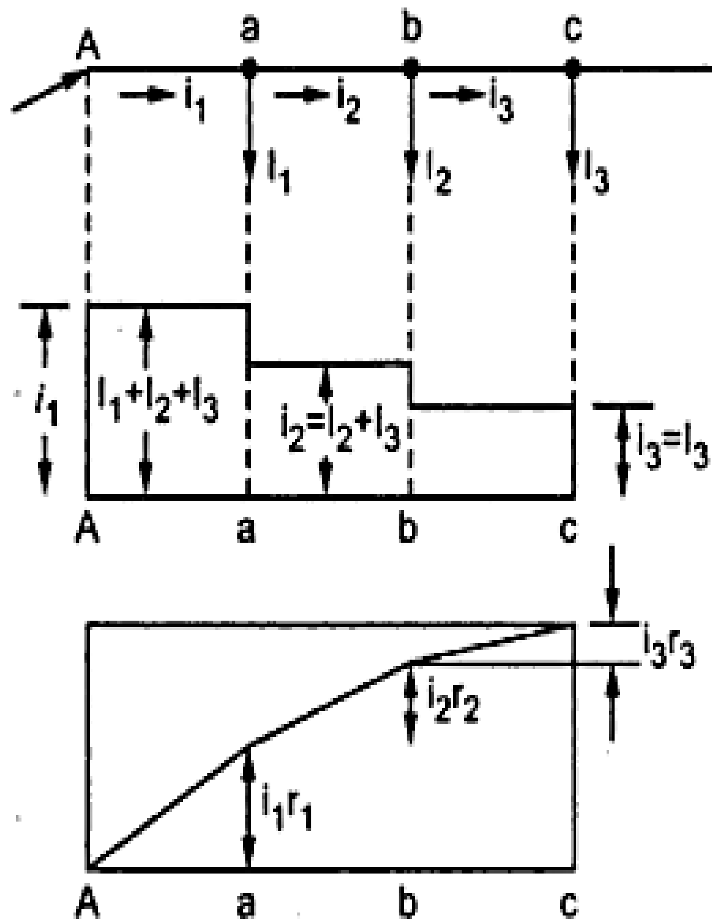


Fig. 8.14 Current loading and voltage drop diagrams

It can be seen that the minimum potential will occur at point c which is farthest from the point A where the distributor is fed at.

8.7.2 Concentrated Loads Fed at Both Ends

This type is further classified depending upon the voltage levels at the two ends.

1. Ends fed with equal voltages
2. Ends fed with unequal voltages

8.7.2.1 Ends at Equal Voltages

The Fig. 8.15 shows this type of distributor. The ends A and B are maintained at equal voltages.

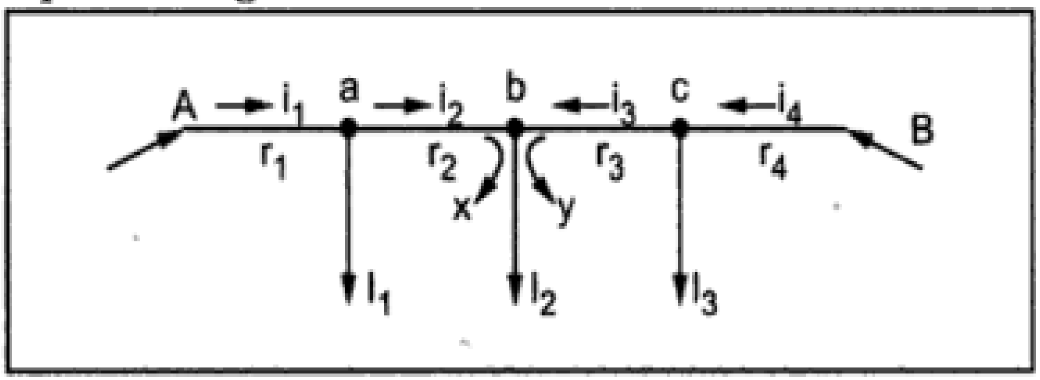


Fig. 8.15

Let r_1, r_2, r_3 and r_4 are the go and return resistances of the sections Aa, ab, bc and cB respectively.

Let point 'b' be the **point of minimum potential**.

As we move from point A towards B the potential goes on decreasing and at point b becomes minimum. All the currents between section Ab are supplied by point A. After b the voltage goes on increasing till it becomes feeding voltage at B. All the currents between Band b are supplied by the point B.

Now the current at minimum potential point b is supplied by both. Let x be supplied by point A while y be supplied by point B. It is obvious that $y = I_2 - x$.

As both the points A and B are maintained at same voltage, drop in section Aa must be equal to drop in section Bb.

$$\therefore \qquad i_1 r_1 + i_2 r_2 = i_3 r_3 + i_4 r_4$$

$$\therefore \quad (I_1 + x)\, r_1 + x r_2 = (I_2 - x)\, r_3 + (I_2 + I_3 - x)\, r_4$$

Thus knowing all the currents, x can be calculated and all the voltage drops can be obtained.

The Fig. 8.16 shows the current loading and voltage drop diagrams.

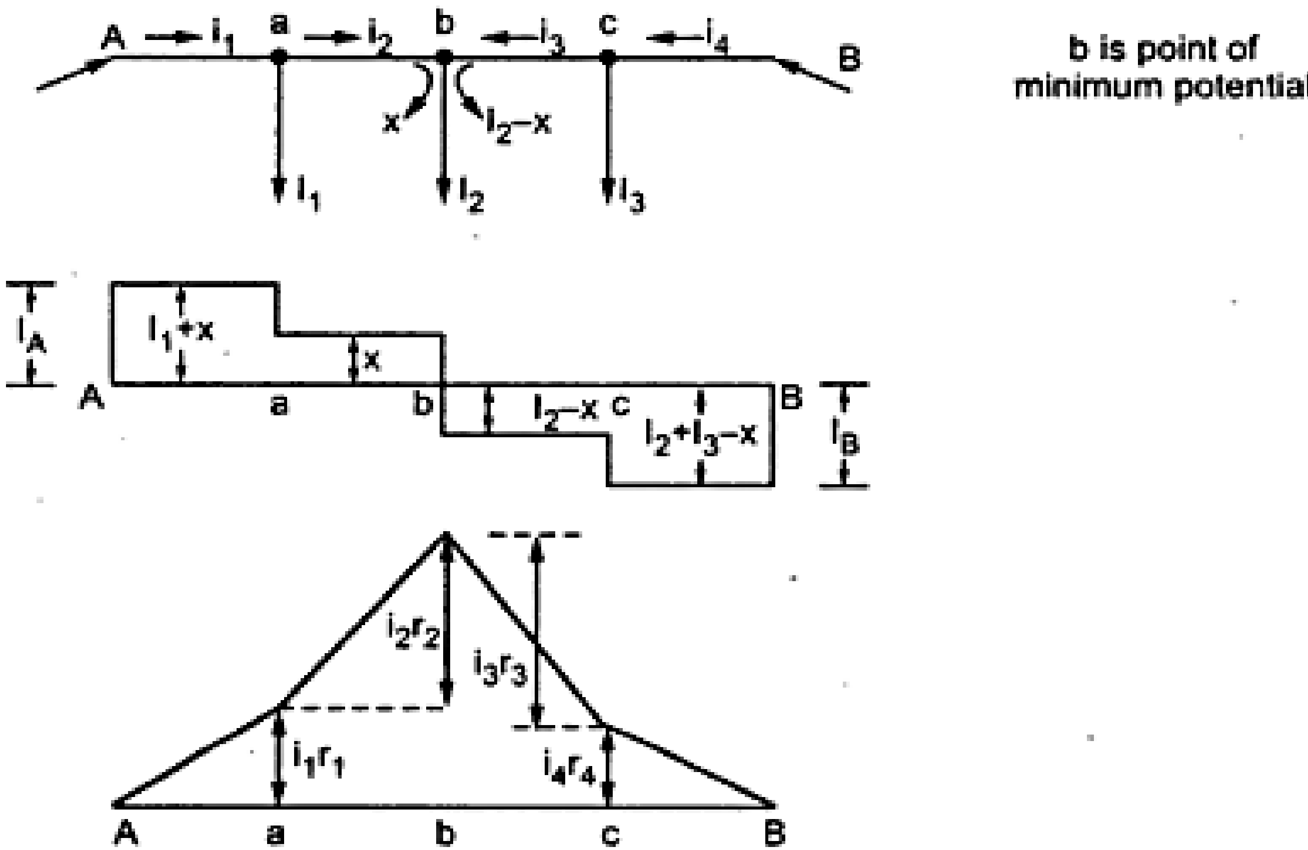


Fig. 8.16 Current loading and voltage drop diagrams

8.7.2.2 Ends at Unequal Voltages

The Fig. 8.17 shows this type of distributor. The ends A and B are maintained at different voltages.

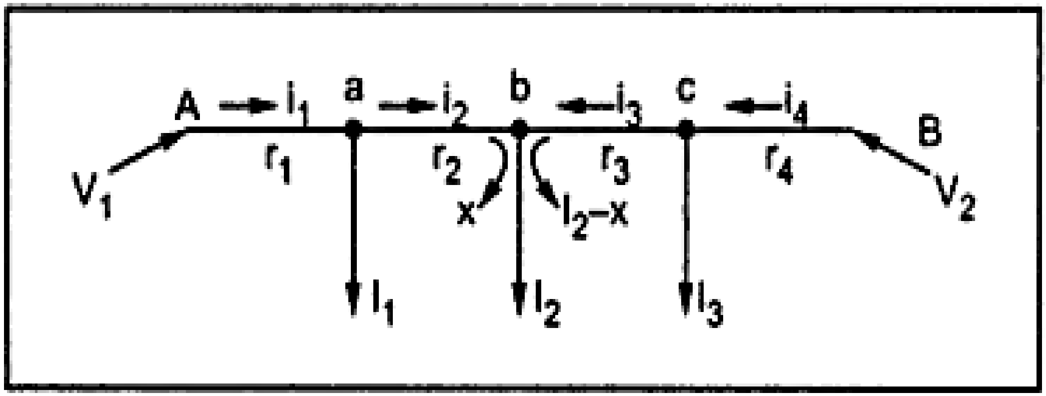


Fig. 8.17

Let the resistances of the sections Aa, ab, bc and cB are r_1, r_2, r_3 and r_4 respectively. Let point 'b' is the point of minimum potential.

In this case also the point b is fed by both the points A and B. The current from point A is x while from B it is $I_2 - x$. Now we can write the equation as,

Voltage drop between A and B = Voltage drop over AB

If voltage of A is V_1 and is greater than voltage of B which is V_2 then,

$$V_1 - V_2 = \text{drops in all the sections of AB}$$

The same equation can be written as,

$$V_1 - \text{drops over Ab} = V_2 - \text{drops over Bb}$$

$$\therefore \quad V_1 - i_1 r_1 - i_2 r_2 = V_2 - i_3 r_3 - i_4 r_4$$

$$\therefore \quad V_1 - (I_1 + x) r_1 - x r_2 = V_2 - (x_2 - x) r_3 - (I_2 + I_3 - x) r_4$$

Solving this equation, as V_1 and V_2 are known, x can be obtained.

The Fig. 8.18 shows the current loading and voltage drop diagrams.

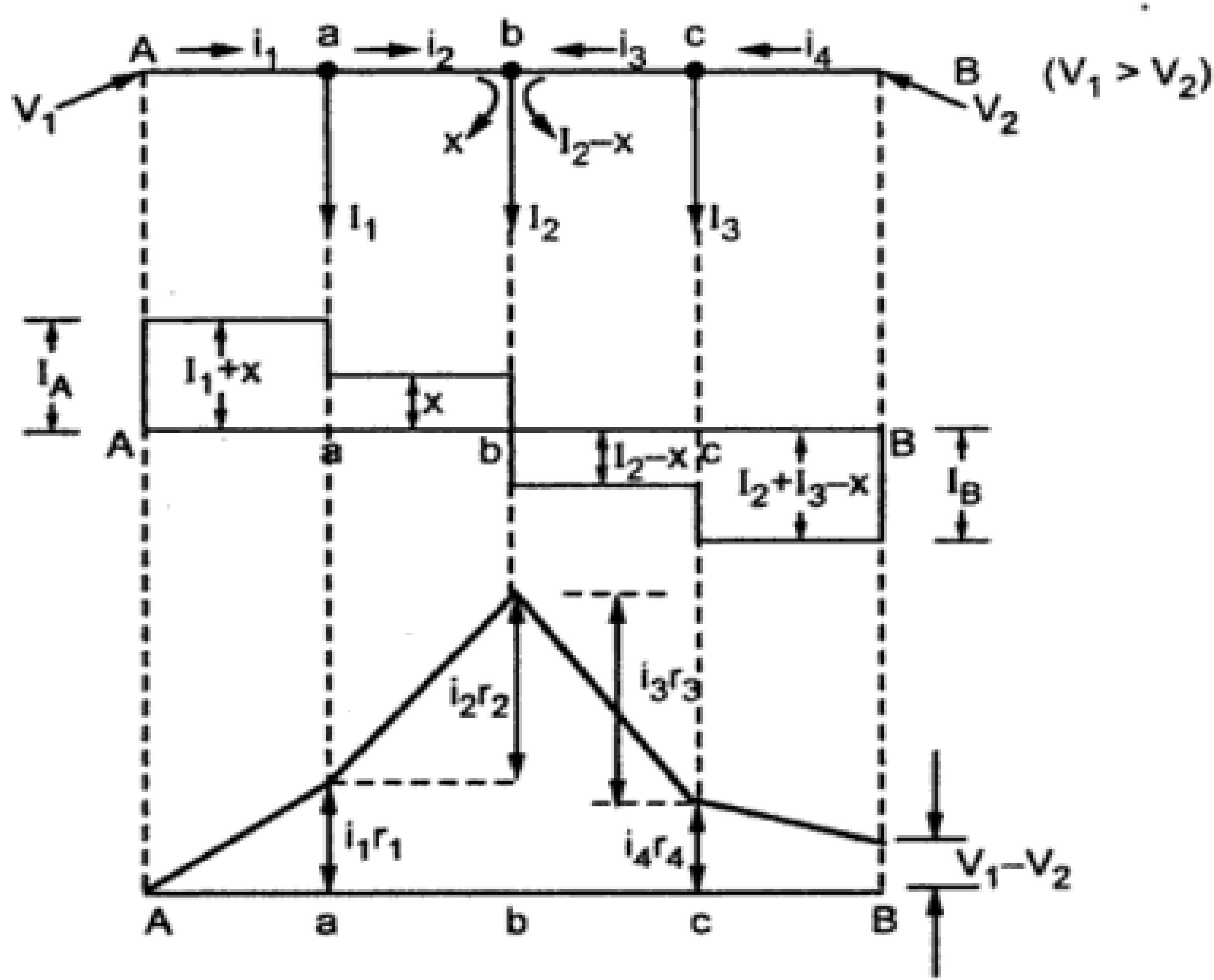


Fig. 8.18 Current loading and voltage drop diagrams

8.8 D.C. Distributor with Uniformly Distributed Load

This type of distributor is also classified as,

1. Distributor fed at one end and 2. Distributor fed at both the ends

8.8.1 Distributor Load Fed at One End

The Fig. 8.20 shows the single line diagram of uniformly distributed load on two wire distributor, fed at one end.

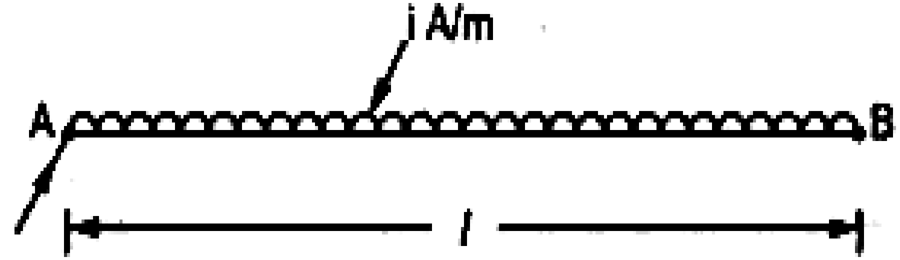


Fig. 8.20

The distributed load is of i amperes per metre.

This indicates that at every metre length i amperes load is supplied through tapping on the distributor.

Let l = length of the distributor

r = resistance per unit length in Ω

In such case, total voltage drop is to be obtained by considering a point C at a distance x from feeding end A. This is shown in the Fig. 8.8.2.

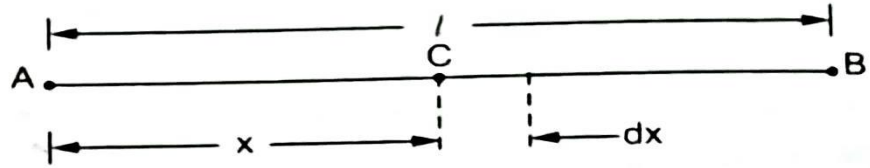


Fig. 8.8.2

The current tapped at point C is

$$= \text{Total current} - \text{Current up to point 'C'} = i \times l - i \times x = i\,(l - x)$$

Consider an elementary length dx near point C. Its resistance is r dx.

Hence the voltage drop over the length dx is

$$dV = i\,(l - x)\,r\,dx$$

Thus total voltage drop upto point C is,

$$V_{AC} = \int_0^x i\,(l-x)\,r\,dx = ir \int_0^x (l-x)\,dx = ir\left[lx - \frac{x^2}{2}\right]_0^x$$

$$\therefore \quad \boxed{V_{AC} = ir\left(lx - \frac{x^2}{2}\right) \text{volts}}$$

This is the **equation of parabola.**

Thus the voltage drop upto point B can be obtained by putting $x = l$.

$$\therefore \quad V_{AB} = ir\left(l^2 - \frac{l^2}{2}\right) = ir\,\frac{l^2}{2} = \frac{1}{2}\,(il)\,(rl)$$

$$\therefore \quad \boxed{V_{AB} = \frac{1}{2}\,I\,R}$$

where $\quad I \;=\;$ Total current fed at point A

$\quad\quad\quad R \;=\;$ Total resistance of the distributor

From this one important observation can be noted as :

Key Point *In a uniformly distributed load on the distributor fed at one end, the total voltage drop is equal to that produced by the whole of the load assumed to be concentrated at the middle point.*

This fact can be used to simplify the complicated load calculations.

The Fig. 8.8.3 shows current loading and voltage drop diagrams.

The power loss i.e. I^2R loss can be obtained from the elementary length dx.

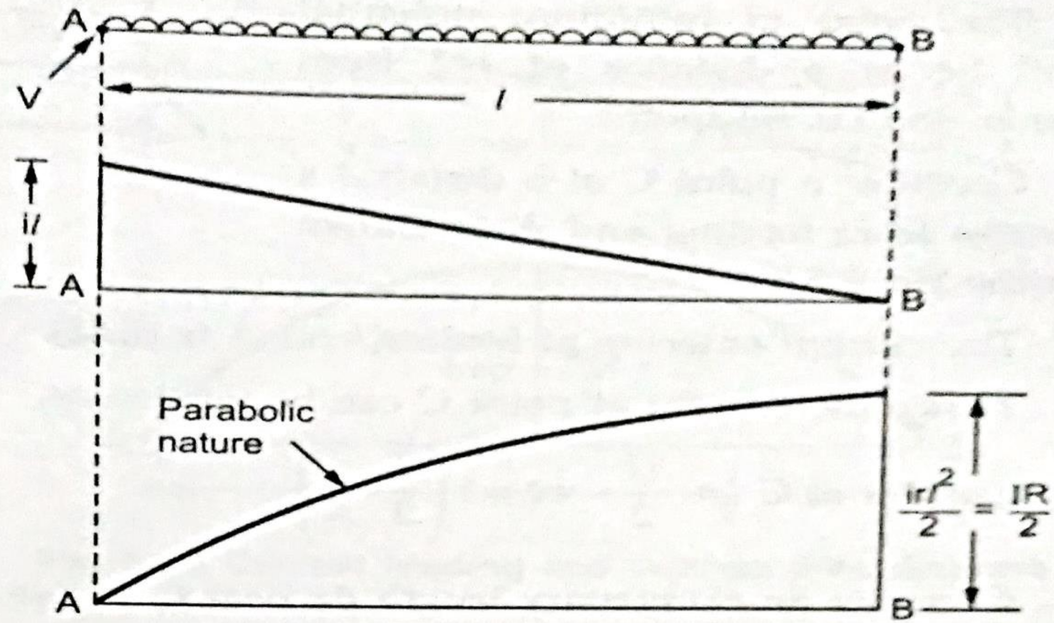


Fig. 8.8.3 Current loading and voltage drop diagram

The current at any point C at distance x is i $(l - x)$. Hence the power loss over the elementary length dx is,

$$dP = [i\,(l - x)]^2\, r\, dx$$

$$\therefore \quad P = \int_0^l i^2\,[l^2 - 2lx + x^2]\, r\, dx = i^2 r \left[l^3 x - \frac{2l^3 x^2}{2} + \frac{l^3}{3} \right]_0^l = i^2 r \left[l^3 - \frac{2l^3}{2} + \frac{l^3}{3} \right]$$

$$\therefore \quad \boxed{P = \frac{i^2 r l^3}{3} \text{ watts}}$$

8.8.2 Distributed Load Fed at Both Ends

This is type is further classified as,

1. Ends maintained at equal voltages and 2. Ends maintained at unequal voltages

8.8.2.1 Ends at Equal Voltages

The Fig. 8.8.4 shows a distributor of length l with uniform load of i amperes per metre. The resistance of the conductor is r ohms per metre. It is fed at the points A and B which are maintained at equal voltages.

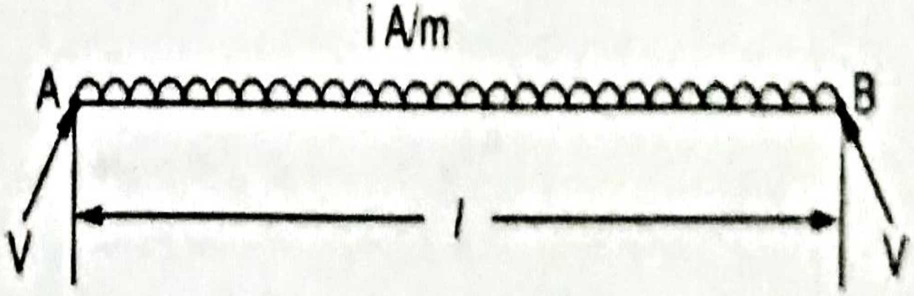


Fig. 8.8.4

The total current to be supplied is il amperes.

As two end voltages are equal, each end will supply half the required current i.e. $\frac{il}{2}$.

The point of minimum potential will be at a distance of $l/2$ from either end i.e. midpoint.

Consider a point C at a distance x metres from feeding end A as shown in the Fig. 8.8.5.

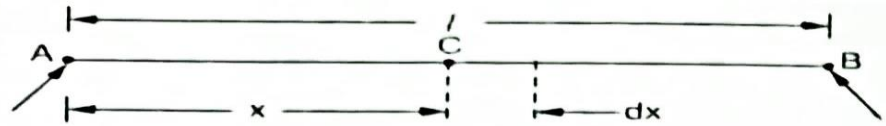


Fig. 8.8.5

The current entering at feeding end A is $(il/2)$.

Hence the current at point C can be written as,

$$\text{Current at C} = \frac{il}{2} - ix = i\left(\frac{l}{2} - x\right)$$

Consider an elementary length dx near C whose resistance is rdx.

So voltage drop over length dx is,

$$dv = i\left(\frac{l}{2} - x\right) r\,dx$$

Hence voltage drop upto point C is,

$$V_{AC} = \int_0^x i\left(\frac{l}{2} - x\right) r\,dx = ir\left[\frac{lx}{2} - \frac{x^2}{2}\right] = \frac{ir}{2}\left[lx - x^2\right]$$

Now maximum voltage drop is at midpoint i.e. $x = \frac{l}{2}$ as the midpoint is the point of minimum potential.

$$\therefore \quad \text{Maximum drop} = ir\left[\frac{l}{2}\left(\frac{l}{2}\right) - \frac{(l/2)^2}{2}\right] = ir\left[\frac{l^2}{4} - \frac{l^2}{8}\right] = \frac{irl^2}{8} = \frac{1}{8}(il)(rl)$$

$$\therefore \quad \boxed{\text{Maximum drop} = \frac{IR}{8}}$$

where I is total current and R is the total resistance.

The Fig. 8.25 shows current loading and voltage drop diagrams.

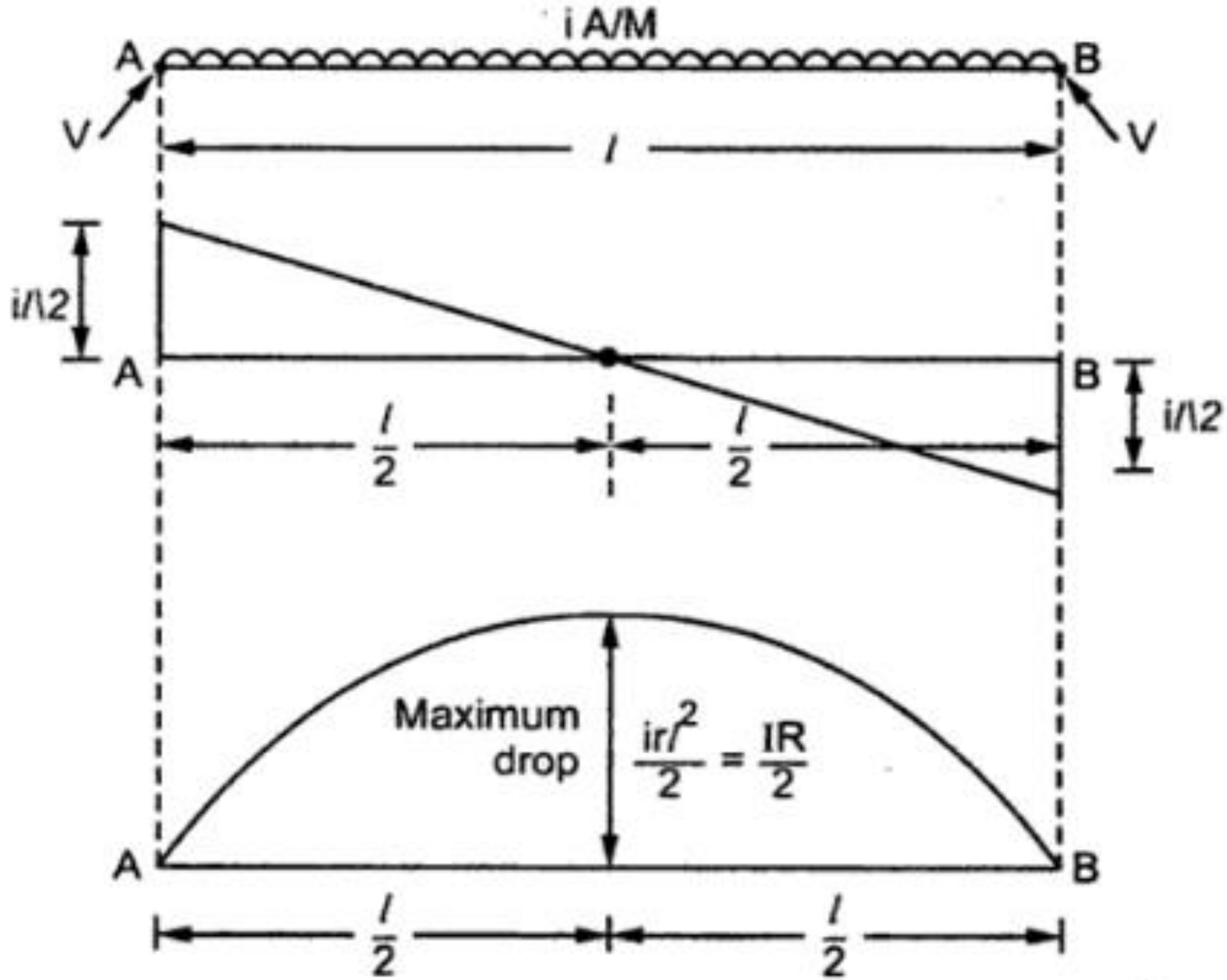


Fig. 8.25 Current loading and voltage drop diagram

8.8.2.2 Ends at Unequal Voltages

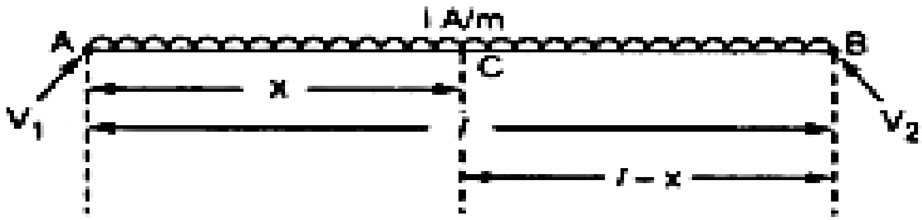


Fig. 8.26

The Fig. 8.26 shows the uniformly distributed load on the distributor of length l. The load is i amperes/m while the distributor is fed at both the ends which are maintained at different voltages.

To find the location of point of minimum potential :

Let point C be the point of minimum potential which is at a distance x from feeding point A.

The current supplied by the feeding point A is ix. While the current supplied by the feeding point B is i $(l - x)$.

Now, V_1 - drop in section AC = V_2 - drop in section BC.

Let r be the resistance per metre length.

In case of distributed load the drop is given by $\frac{i\,r\,l^2}{2}$ for a length of 'l'. Considering section AC as separate section fed at one end the drop in section AC can be written as,

$$V_{AC} = \frac{i\,r\,x^2}{2} \text{ volts}$$

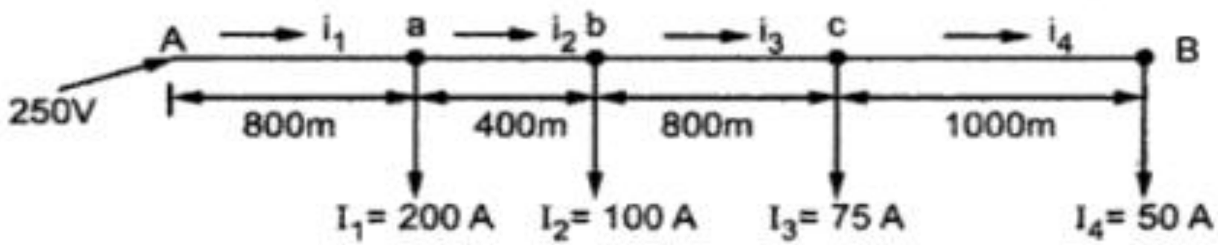
Similarly, $$V_{BC} = \frac{i\,r\,(l-x)^2}{2} \text{ volts}$$

$$\therefore \quad V_1 - \frac{i\,r\,x^2}{2} = V_2 - \frac{i\,r\,(l-x)^2}{2}$$

Knowing V_1, V_2, i, r and l, the above equation can be solved for x which gives the point of minimum potential.

Example 1.2 : *A two wire d.c. distributor system is 3 km long and it supplies loads of 200A, 100A, 75A and 50A at 800 m, 1200m, 2000m and 3000m from the feeding point A. Each conductor has go and return resistance of 0.004 Ω per 100m. Calculate the voltage at each load point if voltage at feeding point is 250 V.*

Solution : The distributor is shown in the Fig. 1.37.



Resistance of various sections are,

$$R_{Aa} = 0.004 \times 8 = 0.032\ \Omega$$

$$R_{ab} = 0.004 \times 4 = 0.016\ \Omega$$

$$R_{bc} = 0.004 \times 8 = 0.032\ \Omega$$

$$R_{cB} = 0.004 \times 10 = 0.04\ \Omega$$

The currents in various sections are,

$$i_1 = 200 + 100 + 75 + 50 = 425\ A$$

$$i_2 = 425 - 200 = 225\ A$$

$$i_3 = 225 - 100 = 125\ A$$

$$i_4 = 125 - 75 = 50\ A$$

$\therefore$ $$V_a = V_A - i_1 R_{Aa} = 250 - 425 \times 0.032 = 236.4\ V$$

$\therefore$ $$V_b = V_a - i_2 R_{ab} = 236.4 - 225 \times 0.016 = 232.8\ V$$

$\therefore$ $$V_c = V_b - i_3 R_{bc} = 232.8 - 125 \times 0.032 = 228.8\ V$$

and $$V_B = V_c - i_4 R_{cB} = 228.8 - 50 \times 0.04 = 226.8\ V$$

These are the voltage at the various load points a, b, c and B.

Example 1.3 : *A two conductor cable 1 km long is loaded as shown in the Fig. 1.45. Both ends are supplied at 250 V. If the minimum allowable voltage to the consumer is 245 V, calculate the cross-section of each conductor. The resistivity of the material is 1.7 $\mu\Omega$-cm.*

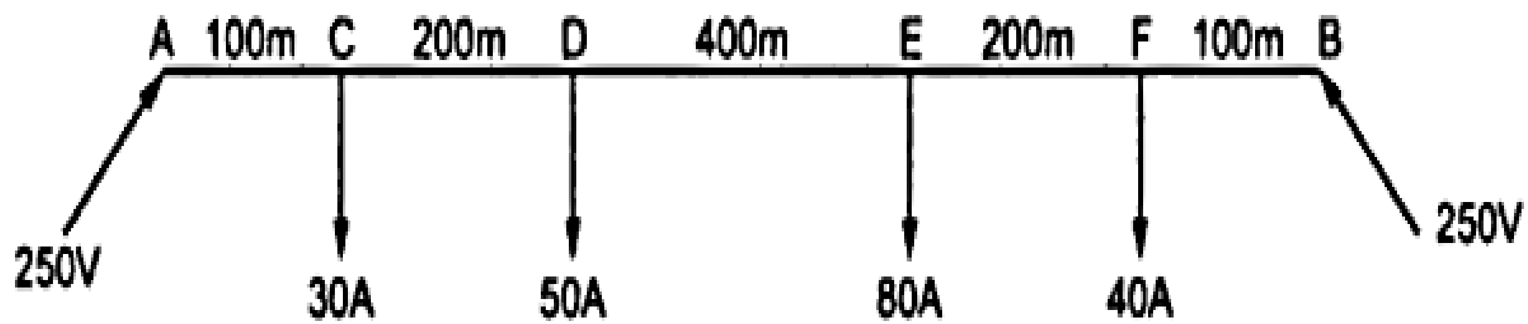


Fig. 1.45

Solution : Let r be the resistance for both go and return per unit length. Let D be the point of minimum potential. So point A supplies xA current to D while 50 – x is supplied by end B. The other current distribution is shown in the Fig. 1.46.

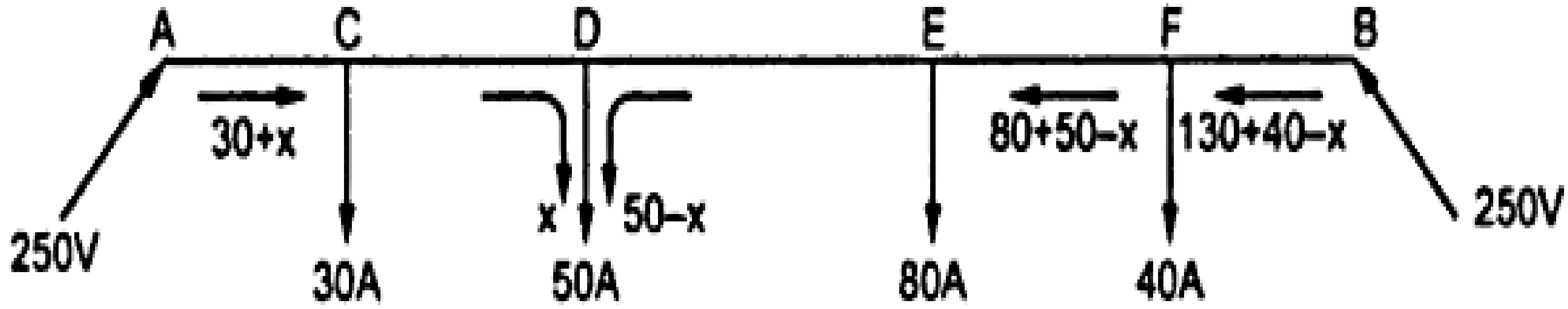


Fig. 1.46

Now as two ends are at equal voltages,

$$\text{Drop (A – D)} = \text{Drop (B – D)}$$

$$\therefore (30 + x)\, r \times 100 + (x)\,(r)\, 200 = (50 - x)\, r \times 400 + (130 - x)\, r \times 200 + (170 - x)\, r \times 100$$

Cancelling r we get,

$$(30 + x)\, 100 + 200\, x = (50 - x)\, 400 + (130 - x)\, 200 + (170 - x)\, 100$$

$$\therefore \quad 3000 + 300\, x = 63000 - 700\, x$$

$$\therefore \quad 1000\, x = 60000$$

$$\therefore \quad x = 60 \text{ A}$$

But as x is more than that required at D, point D is not the point of minimum potential, but it lies to the right of D. Hence point E is the point of minimum potential.

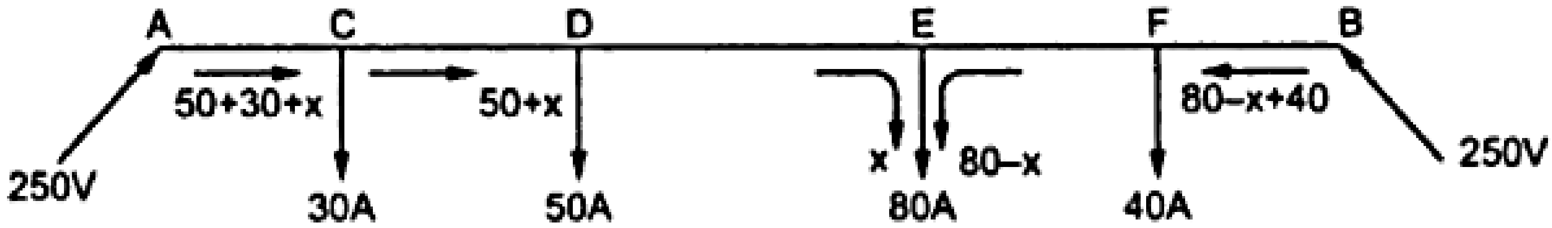


Fig. 1.47

$$\text{Drop (A} - \text{E)} = \text{Drop (BE)}$$

$$\therefore (80 + x)\, r\, 100 + (50 + x)\, r\, 200 + x\, r\, 400 = (80 - x)\, r\, 200 + (120 - x)\, r\, 100$$

$$\therefore \quad 18000 + 700\,x = 28000 - 300\,x$$

$$\therefore \quad 1000\,x = 10000$$

$$\therefore \quad x = 10\text{ A}$$

Hence the current distribution is,

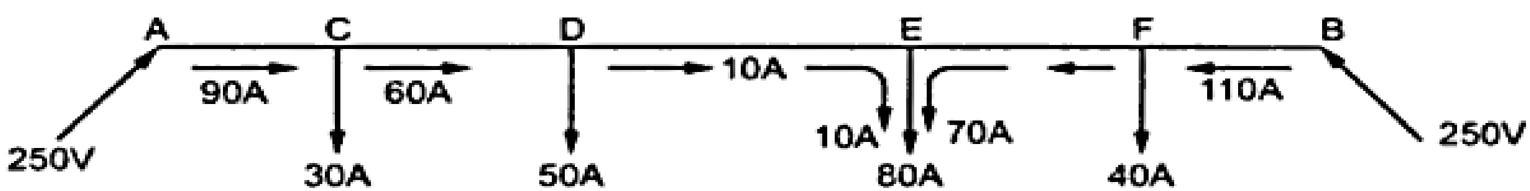


Fig. 1.48

Now the allowable voltage is 245 V hence maximum permissible voltage drop is 250 – 245 = 5V at E which is point of minimum potential.

$$\therefore \qquad \text{Drop (AE)} = 5\text{ V}$$

$$\therefore \qquad 90\times r\times 100+60\times r\times 200+10\times r\times 400 = 5$$

$$\therefore \qquad r = 2\times 10^{-4}\ \Omega/\text{m}$$

$$\text{Now} \qquad r = \frac{\rho l}{A}\times 2 \qquad \text{... go and return path}$$

$$\therefore \qquad 2\times 10^{-4} = \frac{1.7\times 10^{-6}\times 10^{-2}\times 1\times 2}{A} \qquad \text{... as } l = 1\text{m}$$

$$\therefore \qquad A = \frac{1.7\times 10^{-8}\times 2}{2\times 10^{-4}}$$

$$= 1.7\times 10^{-4}\ \text{m}^2 = 1.7\ \text{cm}^2$$

Example 1.4 : *A two wire D.C. distributor AB, 600 m long is loaded as under :*

Distance from A (metres)	150	300	350	450
Load in amperes	100	200	250	300

The feeding point A is maintained at 440 V while B maintained at 430 V. If each conductor has a resistance of 0.01 Ω per 100 m, calculate :

1. *The current supplied from A and B*
2. *The power dissipated in the distributor.*

8.9 Ring Main Distributor with Interconnector

It has been mentioned that in ring main system, the cable is arranged in the loop or ring fashion. In most simple case, the ring distributor is fed at only one point.

But sometimes the ring main system is used to supply a large area and hence voltage drop across the various sections may become large in such case. Hence to compensate for such excessive voltage drops, the distant points of ring distributor are joined together by a conductor. This is called an interconnector. The Fig. 8.35 shows a ring main system with an interconnector.

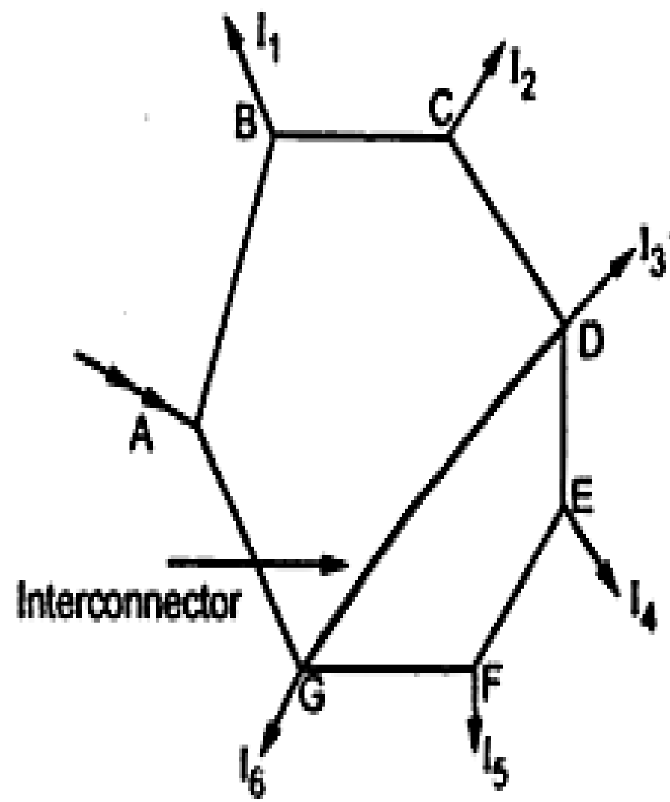


Fig. 8.35

The points D and G are joined by an interconnector.

Such a case is generally analysed using Thevenin's theorem.

Let us briefly revise the steps to use the Thevenin's theorem.

The steps to use Thevenin's theorem :

1. Remove an interconnector DG.
2. Find the voltage V_{DG} without an interconnector, which is Thevenin's voltage denoted as E_0.
3. Determine the equivalent resistance as viewed through the terminals D and G, i.e. where an interconnector is to be connected. This is Thevenin's equivalent resistance denoted as R_{TH}.
4. Knowing the resistance of an interconnector DG, the Thevenin's equivalent can be drawn as shown in the Fig. 8.36.
5. The current I through an interconnector then can be obtained as,

$$I = \frac{E_0}{R_{TH} + R_{DG}} \text{ Amp}$$

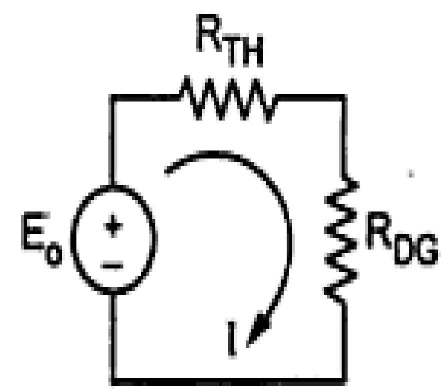


Fig. 8.36

Once this current is known, current in all the sections and the voltages at load points can be determined.

8.10 A.C. Distribution

In earlier days, d.c. system was used for the generation, transmission and distribution of electrical energy. But in case of d.c. system the voltage level cannot be changed easily unless we used rotating machinary which may not prove to be economical in many cases. This is the major disadvantage while working with d.c.

Later on with the development of transformer, a.c. system has become predominant. Now a days large power systems in the world are using a.c. system rather than d.c. because of many advantages of a.c. system.

The transmission of electrical energy generated in the power station is at very high voltage with the use of 3 phase, 3 wire system. These voltages are stepped down for distribution at the substations. There are mainly two parts of the distribution system. They are primary distribution and secondary distribution. The voltage level of primary distribution system is higher than general utilisation level. The secondary distribution systems receive power from primary distribution systems through distribution transformers. By distribution transformer voltage is stepped down to the normal working level and the consumers get the power with the voltage 400/230 V. The very commonly used a.c. distribution system is three phase four wire system as studied earlier..

8.11 A.C. Distribution Calculations

The A.C. distribution calculations and d.c. distribution calculations are different in the following respects :

1. In case of d.c. system, the voltage drop is due to resistance only which in a.c. system it is due to combined effect of resistance, inductance and capacitance.
2. The voltages or currents are added or subtracted arithmetically in case of d.c. system whereas they are added or subtracted vectorially in case of a.c. system.
3. It is required to take into account the power factor while making calculations in a.c. system which is absent in d.c. system. The distributors are normally tapped at different points with the loads having different power factors.

There are two ways of referring the power factor.

a) The p.f. may be referred to receiving end voltage which is reference vector.

b) The p.f. may be referred to the voltage at load point itself.

By different methods the a.c. distribution problems can be solved.

The most convenient method is the symbolic notation method wherein voltages, currents and impedances are expressed in the complex notation and the calculations are similar to those in case of d.c. distribution.In a.c. calculations, addition and subtraction must be done by expressing various quantities in the rectangular form while the multiplication and the division must be done by expressing the various quantities in the polar form.

8.12 Methods of Solving A.C. Distribution Problems

As discussed in earlier section in case of a.c. distribution system we have to take into account the power factor. This power factor can be either considered with respect to receiving end voltage or with respect to load voltage itself. Let us consider each case separately.

8.12.1 Power Factors Referred to Receiving End Voltage

Consider an A.C. distribution PQ having concentrated loads of I_1 and I_2 tapped off at point Q and R respectively. This is shown in the Fig. 8.42.

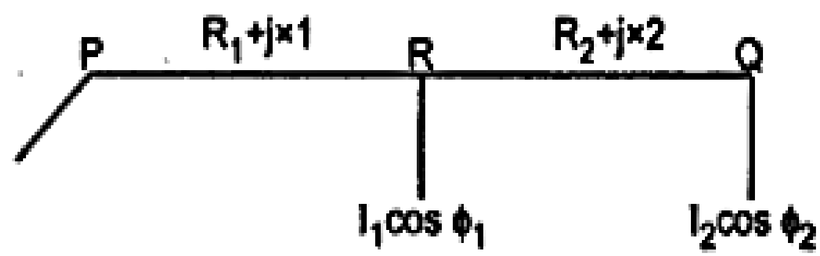


Fig. 8.42

Let voltage V_Q which is the voltage at the receiving end be taken as reference vector. The power factors at R and Q are $\cos \phi_1$ and $\cos \phi_2$ with respect to V_Q and they are lagging.

Let R_1 = Resistance of section PR

X_1 = Reactance of section PR

R_2 = Resistance of section RQ

X_2 = Reactance of section RQ

Impedance of section PR is given by,

$$\bar{Z}_{PR} = R_1 + j X_1$$

Impedance of section RQ is given by

$$\bar{Z}_{RQ} = R_2 + j X_2$$

The load current at point R is $\bar{I}_1$,

$$\bar{I}_1 = I_1 \angle -\phi_1 = I_1 (\cos \phi_1 - j \sin \phi_1)$$

Similarly the load current at point Q is $\bar{I}_2$

$$\bar{I}_2 = I_2 \angle -\phi_2 = I_2 (\cos \phi_2 - j \sin \phi_2)$$

The current in section RQ is nothing but $\bar{I}_2$,

$$\therefore \quad \bar{I}_{RQ} = \bar{I}_2 = I_2 (\cos \phi_2 - j \sin \phi_2)$$

The current in section PR is given by,

$$\bar{I}_{PR} = \bar{I}_1 + \bar{I}_2 = I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)$$

The voltage drop in section RQ is given by,

$$\bar{V}_{RQ} = \bar{I}_{RQ} \bar{Z}_{RQ}$$

$$\therefore \quad \bar{V}_{RQ} = [I_2 (\cos \phi_2 - j \sin \phi_2)] \cdot [R_2 + j X_2]$$

The voltage drop in section PR is given by,

$$\overline{V}_{PR} = \overline{I}_{PR}\,\overline{Z}_{PR}$$

$$= [I_1 (\cos\phi_1 - j \sin\phi_1) + I_2 (\cos\phi_2 - j \sin\phi_2)]\,[R_1 + j X_1]$$

Thus the sending end voltage V_A is given as,

$$\overline{V}_P = \overline{V}_Q + \overline{V}_{RQ} + \overline{V}_{PQ}$$

The sending end current is given as,

$$\overline{I}_P = \overline{I}_1 + \overline{I}_2$$

The corresponding phasor diagram is shown in the Fig. 8.43.

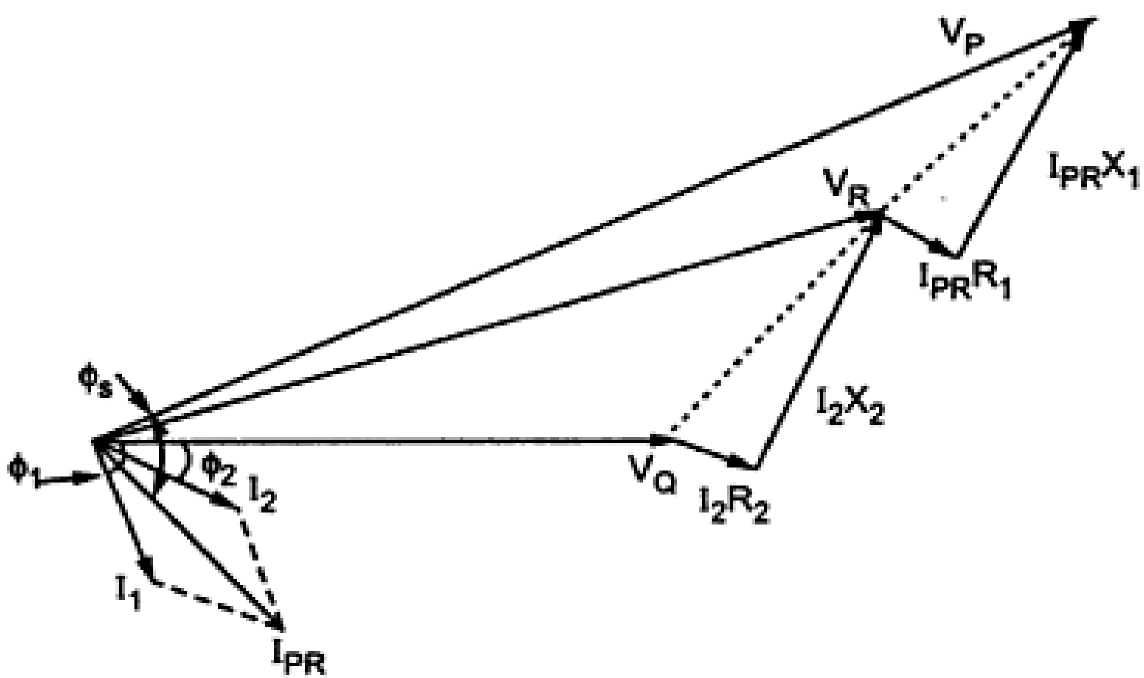


Fig. 8.43

As shown in the Fig. 8.43 the receiving end voltage V_Q is taken as reference vector. The currents I_1 and I_2 are lagging from V_Q by angles of ϕ_1 and ϕ_2 respectively. The vector sum of I_1 and I_2 gives current I_{PR}. The drop $I_2 R_2$ is in phase with I_2 while $I_2 X_2$ is leading by 90°. The vector sum of V_Q, $I_2 R_2$ and $I_2 X_2$ gives V_R. The drop $I_{PR} R_1$ is in phase with current I_{PR} while $I_{PR} X_1$ is leading by 90°. The vector sum of V_R, $I_{PR} R_1$ and $I_{PR} X_1$ gives the sending end voltage V_P.

8.12.2 Power Factors Referred to Respective Load Voltages

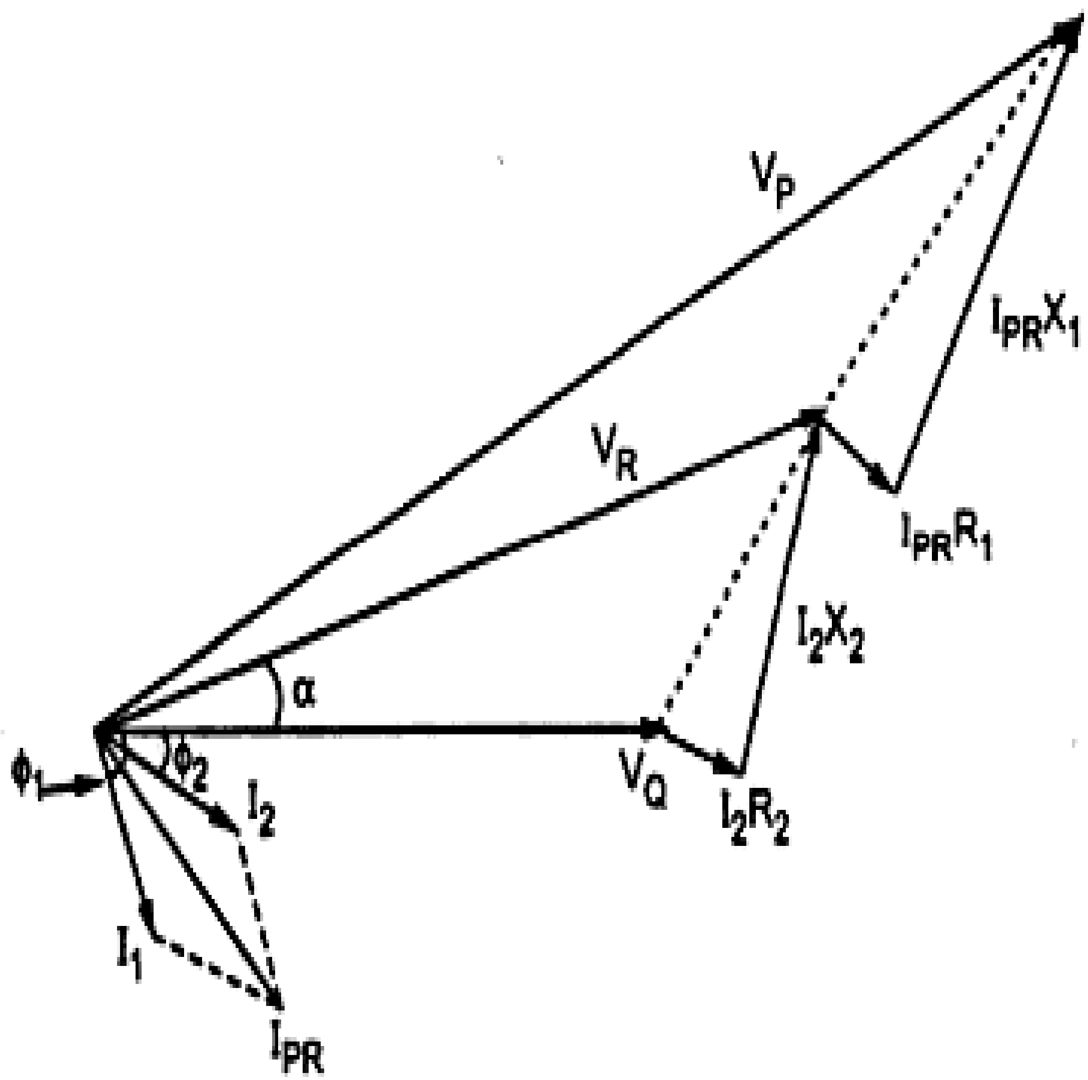


Fig. 8.44

In previous section we have considered the load power factors with respect to receiving end voltage. Here we will consider these power factors with respect to their respective load voltages. Now ϕ_1 is the phase angle between V_R and I_1 while the angle ϕ_2 is the phase angle between V_Q and I_2.

The phasor diagram under this condition will be as shown in the Fig. 8.44.