LECTURE NOTES

ON

GENERATION, TRANSMISSION DISTRIBUTION (Part III)

BRANCH- ELECTRICAL ENGINEERING

4th Semester

Department of Electrical Engineering

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Chapter5

EHV transmission

EHV AC Transmission:

NECESSITY OF EHVAC TRANSMISSION:

1. With the increase in transmission voltage, for same amount of power to be transmitted current in the line decreases which reduces I2R losses. This will lead to increase in transmission efficiency.

2. With decrease in transmission current, size of conductor required reduces which decreases the volume of conductor.

3. The transmission capacity is proportional to square of operating voltages. Thus the transmission capacity of line increases with increase in voltage.

4. With increase in level of transmission voltage, the installation cost of the transmission line per km decreases.

5. It is economical with EHV transmission to interconnect the power systems on a large scale.

6. The no. of circuits and the land requirement for transmission decreases with the use of higher transmission voltages.

ADVANTAGES :

- Reduction in the current.
- Reduction in the losses.
- Reduction in volume of conductor material required.
- Decrease in voltage drop & improvement of voltage regulation.
- Increase in Transmission Efficiency.
- Increased power handling capacity.
- The no. of circuits & the land requirement reduces as transmission voltage increases.
- The total line cost per MW per km decreases considerably with the increase in line voltage.

PROBLEMS INVOLVED IN EHV TRANSMISSION:

1. Corona loss and radio interference
2. Heavy supporting structure and erection difficulties
3. Insulation requirement
4. Suitability considerations
5. Current carrying capacity
6. Ferranti effect
7. Environmental and biological aspects
8. Equipment cost

HVDC Transmission System

We know that AC power is generated in the generating station. This should first be converted into DC. The conversion is done with the help of rectifier. The DC power will flow through the overhead lines. At the user end, this DC has to be converted into AC. For that purpose, an inverter is placed at the receiving end.
Thus, there will be a rectifier terminal in one end of HVDC substation and an inverter terminal in the other end. The power of the sending end and user end will be always equal (Input Power = Output Power).

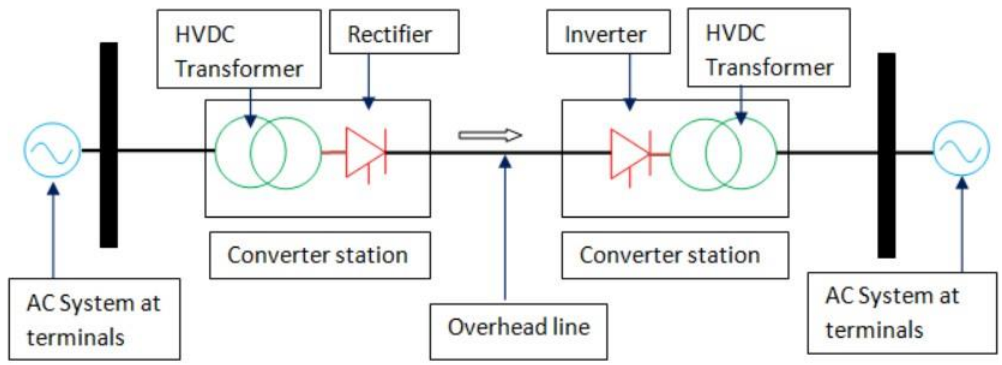

Figure 1: HVDC Substation Layout

When there are two converter stations at both ends and a single transmission line is termed as two terminal DC systems. When there are two or more converter stations and DC transmission lines is termed as multi-terminal DC substation.

Comparison of both HVAC and HVDC Transmission System

HVDC Transmission System	HVAC Transmission System
Low losses.	Losses are high due to the skin effect and corona discharge
Better Voltage regulation and Control ability.	Voltage regulation and Control ability is low.
Transmit more power over a longer distance.	Transmit less power compared to a HVDC system.
Less insulation is needed.	More insulation is required.
Reliability is high.	Low Reliability.
Asynchronous interconnection is possible.	Asynchronous interconnection is not possible.
Reduced line cost due to fewer conductors.	Line cost is high.
Towers are cheaper, simple and narrow.	Towers are bigger compared to HVDC.

Disadvantages of HVDC Transmission

- Converters with small overload capacity are used.
- Circuit Breakers, Converters and AC filters are expensive especially for small distance transmission.
- No transformers for altering the voltage level.
- HVDC link is extremely complicated.
- Uncontrollable power flow.

Application of HVDC Transmission

- Undersea and underground cables
- AC network interconnections
- Interconnecting Asynchronous system

CHAPTER – 6

A.C. Distribution Calculations

A.C. distribution calculations differ from those of d.c. distribution in the following respects :

(*i*) In case of d.c. system, the voltage drop is due to resistance alone. However, in a.c. system, the voltage drops are due to the combined effects of resistance, inductance and capacitance.

(*ii*) In a d.c. system, additions and subtractions of currents or voltages are done arithmetically but in case of a.c. system, these operations are done vectorially.

(*iii*) In an a.c. system, power factor (p.f.) has to be taken into account. Loads tapped off form the distributor are generally at different power factors. There are two ways of referring power factor *viz*

(*a*) It may be referred to supply or receiving end voltage which is regarded as the reference vector.

(*b*) It may be referred to the voltage at the load point itself.

There are several ways of solving a.c. distribution problems. However, symbolic notation method has been found to be most convenient for this purpose. In this method, voltages, currents and impedances are expressed in complex notation and the calculations are made exactly as in d.c. distribution.

Methods of Solving A.C. Distribution Problems

In a.c. distribution calculations, power factors of various load currents have to be considered since currents in different sections of the distributor will be the vector sum of load currents and not the arithmetic sum. The power factors of load currents may be given (*i*) *w.r.t.* receiving or sending end voltage or (*ii*) *w.r.t.* to load voltage itself. Each case shall be discussed separately.

(*i*) **Power factors referred to receiving end voltage.** Consider an a.c. distributor AB with concentrated loads of I_1 and I_2 tapped off at points C and B as shown in Fig. 14.1. Taking the receiving end voltage V_B as the reference vector, let lagging power factors at C and B be $\cos\phi_1$ and $\cos\phi_2$ *w.r.t.* V_B. Let R_1, X_1 and R_2, X_2 be the resistance and reactance of sections AC and CB of the distributor.

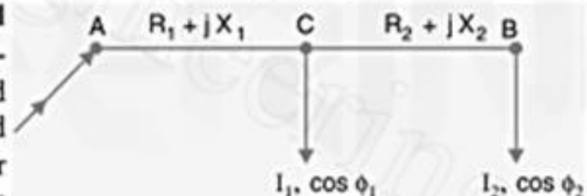

Fig. 14.1

Impedance of section AC, $\overrightarrow{Z_{AC}} = R_1 + j X_1$

Impedance of section CB, $\overrightarrow{Z_{CB}} = R_2 + j X_2$

Load current at point C, $\overrightarrow{I_1} = I_1 (\cos\phi_1 - j\sin\phi_1)$

Load current at point B, $\overrightarrow{I_2} = I_2 (\cos\phi_2 - j\sin\phi_2)$

Current in section CB, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = I_2 (\cos\phi_2 - j\sin\phi_2)$

Current in section AC, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$

$= I_1 (\cos\phi_1 - j\sin\phi_1) + I_2 (\cos\phi_2 - j\sin\phi_2)$

Voltage drop in section CB, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2 (\cos\phi_2 - j\sin\phi_2)(R_2 + j X_2)$

Voltage drop in section AC, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = \left(\overrightarrow{I_1} + \overrightarrow{I_2}\right) Z_{AC}$

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$$= [I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)][R_1 + jX_1]$$

Sending end voltage, $\qquad \overrightarrow{V_A} = \overrightarrow{V_B} + \overrightarrow{V_{CB}} + \overrightarrow{V_{AC}}$

Sending end current, $\qquad \overrightarrow{I_A} = \overrightarrow{I_1} + \overrightarrow{I_2}$

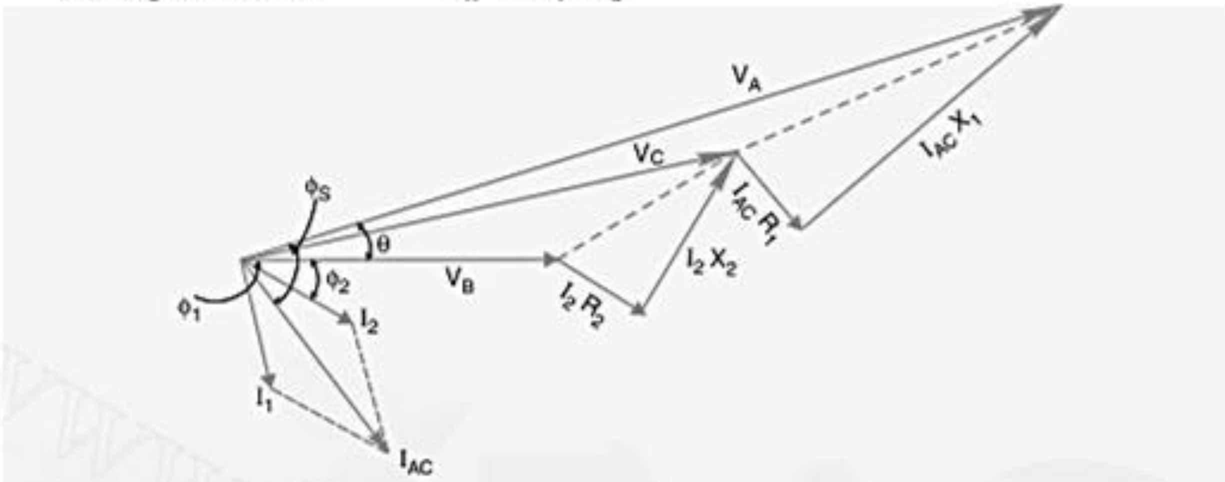

Fig. 14.2

The vector diagram of the a.c. distributor under these conditions is shown in Fig. 14.2. Here, the receiving end voltage V_B is taken as the reference vector. As power factors of loads are given *w.r.t.* V_B, therefore, I_1 and I_2 lag behind V_B by ϕ_1 and ϕ_2 respectively.

(*ii*) **Power factors referred to respective load voltages.** Suppose the power factors of loads in the previous Fig. 14.1 are referred to their respective load voltages. Then ϕ_1 is the phase angle between V_C and I_1 and ϕ_2 is the phase angle between V_B and I_2. The vector diagram under these conditions is shown in Fig. 14.3.

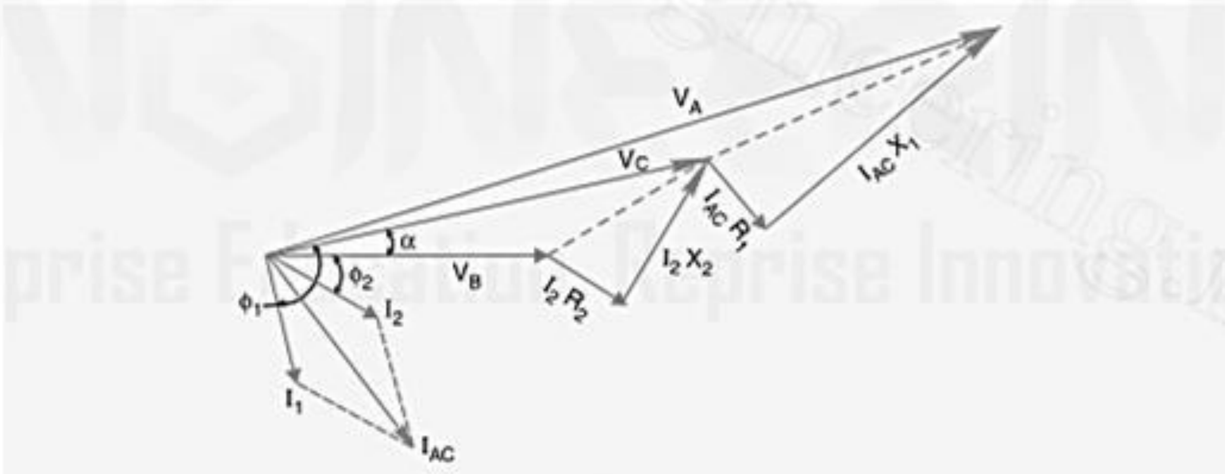

Fig. 14.3

Voltage drop in section $CB = \overrightarrow{I_2}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$

Voltage at point $C = \overrightarrow{V_B}$ + Drop in section $CB = V_C \angle \alpha$ (say)

Now $\qquad \overrightarrow{I_1} = I_1 \angle -\phi_1$ *w.r.t.* voltage V_C

$\therefore \qquad \overrightarrow{I_1} = I_1 \angle -(\phi_1 - \alpha)$ *w.r.t.* voltage V_B

i.e. $\qquad \overrightarrow{I_1} = I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)]$

Now $\qquad \overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$

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

Voltage drop in section AC $= \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}}$

$\therefore$ Voltage at point A $= V_B$ + Drop in CB + Drop in AC

Example *A single phase a.c. distributor AB 300 metres long is fed from end A and is loaded as under :*

(i) 100 A at 0·707 p.f. lagging 200 m from point A

(ii) 200 A at 0·8 p.f. lagging 300 m from point A

The load resistance and reactance of the distributor is 0·2 Ω and 0·1 Ω per kilometre. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end.

Solution. Fig. 14.4 shows the single line diagram of the distributor.

Impedance of distributor/km $= (0{\cdot}2 + j\,0{\cdot}1)\,\Omega$

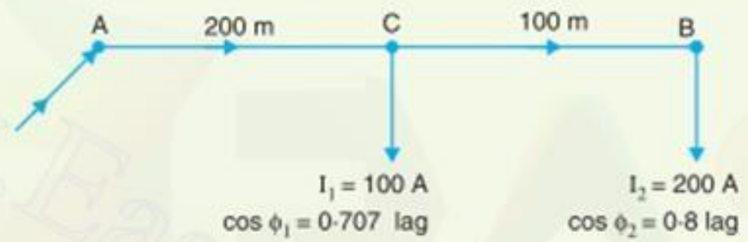

Fig. 14.4

Impedance of section AC, $\overrightarrow{Z_{AC}} = (0{\cdot}2 + j\,0{\cdot}1) \times 200/1000 = (0{\cdot}04 + j\,0{\cdot}02)\,\Omega$

Impedance of section CB, $\overrightarrow{Z_{CB}} = (0{\cdot}2 + j\,0{\cdot}1) \times 100/1000 = (0{\cdot}02 + j\,0{\cdot}01)\,\Omega$

Taking voltage at the far end B as the reference vector, we have,

Load current at point B, $\overrightarrow{I_2} = I_2 (\cos\phi_2 - j\sin\phi_2) = 200\,(0{\cdot}8 - j\,0{\cdot}6)$
$= (160 - j\,120)$ A

Load current at point C, $\overrightarrow{I_1} = I_1 (\cos\phi_1 - j\sin\phi_1) = 100\,(0{\cdot}707 - j\,0{\cdot}707)$
$= (70{\cdot}7 - j\,70{\cdot}7)$ A

Current in section CB, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = (160 - j\,120)$ A

Current in section AC, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2} = (70{\cdot}7 - j\,70{\cdot}7) + (160 - j\,120)$
$= (230{\cdot}7 - j\,190{\cdot}7)$ A

Voltage drop in section CB, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\ \overrightarrow{Z_{CB}} = (160 - j\,120)\,(0{\cdot}02 + j\,0{\cdot}01)$
$= (4{\cdot}4 - j\,0{\cdot}8)$ volts

Voltage drop in section AC, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}} = (230{\cdot}7 - j\,190{\cdot}7)\,(0{\cdot}04 + j\,0{\cdot}02)$
$= (13{\cdot}04 - j\,3{\cdot}01)$ volts

Voltage drop in the distributor $= \overrightarrow{V_{AC}} + \overrightarrow{V_{CB}} = (13{\cdot}04 - j\,3{\cdot}01) + (4{\cdot}4 - j\,0{\cdot}8)$
$= (17{\cdot}44 - j\,3{\cdot}81)$ volts

Magnitude of drop $= \sqrt{(17{\cdot}44)^2 + (3{\cdot}81)^2} =$ **17·85 V**

Example *A single phase distributor 2 kilometres long supplies a load of 120 A at 0·8 p.f. lagging at its far end and a load of 80 A at 0·9 p.f. lagging at its mid-point. Both power factors are*

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referred to the voltage at the far end. The resistance and reactance per km (go and return) are 0·05 Ω and 0·1 Ω respectively. If the voltage at the far end is maintained at 230 V, calculate :

(*i*) *voltage at the sending end*

(*ii*) *phase angle between voltages at the two ends.*

Solution. Fig. 14.5 shows the distributor *AB* with *C* as the mid-point

Impedance of distributor/km $= (0{\cdot}05 + j\,0{\cdot}1)\,\Omega$

Impedance of section *AC*, $\vec{Z}_{AC} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\,\Omega$

Impedance of section *CB*, $\vec{Z}_{CB} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\,\Omega$

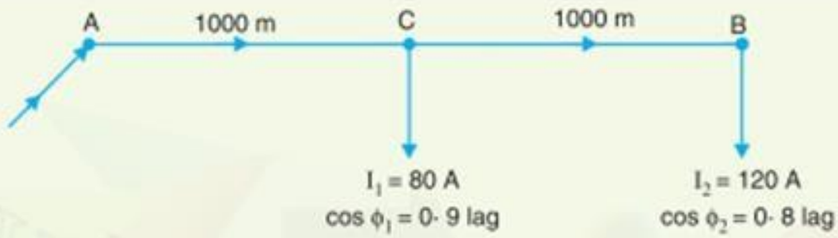

Fig. 14.5

Let the voltage V_B at point *B* be taken as the reference vector.

Then, $\vec{V_B} = 230 + j\,0$

(*i*) Load current at point *B*, $\vec{I_2} = 120\,(0{\cdot}8 - j\,0{\cdot}6) = 96 - j\,72$

Load current at point *C*, $\vec{I_1} = 80\,(0{\cdot}9 - j\,0{\cdot}436) = 72 - j\,34{\cdot}88$

Current in section *CB*, $\overrightarrow{I_{CB}} = \vec{I_2} = 96 - j\,72$

Current in section *AC*, $\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2} = (72 - j\,34{\cdot}88) + (96 - j\,72)$

$= 168 - j\,106{\cdot}88$

Drop in section *CB*, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = (96 - j\,72)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 12 + j\,6$

Drop in section *AC*, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = (168 - j\,106{\cdot}88)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 19{\cdot}08 + j\,11{\cdot}45$

∴ Sending end voltage, $\vec{V_A} = \vec{V_B} + \overrightarrow{V_{CB}} + \overrightarrow{V_{AC}}$

$= (230 + j\,0) + (12 + j\,6) + (19.08 + j\,11.45)$

$= 261.08 + j\,17.45$

Its magnitude is $= \sqrt{(261{\cdot}08)^2 + (17{\cdot}45)^2} =$ **261·67 V**

(*ii*) The phase difference θ between V_A and V_B is given by :

$$\tan\theta = \frac{17{\cdot}45}{261{\cdot}08} = 0{\cdot}0668$$

∴ $\theta = \tan^{-1} 0{\cdot}0668 = \mathbf{3{\cdot}82^\circ}$

Example *A single phase distributor one km long has resistance and reactance per conductor of 0·1 Ω and 0·15 Ω respectively. At the far end, the voltage V_B = 200 V and the current is 100 A at a p.f. of 0·8 lagging. At the mid-point M of the distributor, a current of 100 A is tapped at a p.f.*

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of 0·6 lagging with reference to the voltage V_M at the mid-point. Calculate :

(*i*) *voltage at mid-point*

(*ii*) *sending end voltage V_A*

(*iii*) *phase angle between V_A and V_B*

Solution. Fig. 14.6 shows the single line diagram of the distributor *AB* with *M* as the mid-point.

Total impedance of distributor $= 2(0\cdot1 + j\,0\cdot15) = (0\cdot2 + j\,0\cdot3)\,\Omega$

Impedance of section *AM*, $\overrightarrow{Z_{AM}} = (0\cdot1 + j\,0\cdot15)\,\Omega$

Impedance of section *MB*, $\overrightarrow{Z_{MB}} = (0\cdot1 + j\,0\cdot15)\,\Omega$

Let the voltage V_B at point *B* be taken as the reference vector.

Then, $\overrightarrow{V_B} = 200 + j\,0$

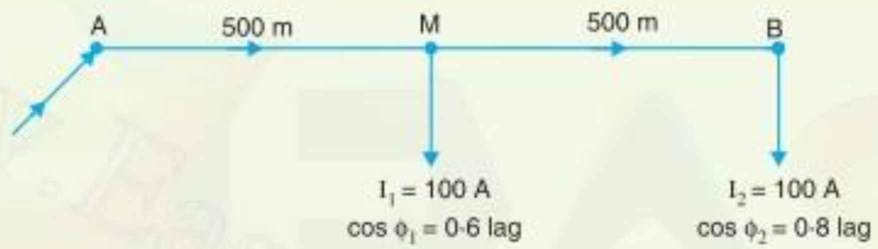

Fig. 14.6

(*i*) Load current at point *B*, $\overrightarrow{I_2} = 100\,(0\cdot8 - j\,0\cdot6) = 80 - j\,60$

Current in section *MB*, $\overrightarrow{I_{MB}} = \overrightarrow{I_2} = 80 - j\,60$

Drop in section *MB*, $\overrightarrow{V_{MB}} = \overrightarrow{I_{MB}}\,\overrightarrow{Z_{MB}}$

$= (80 - j\,60)\,(0\cdot1 + j\,0\cdot15) = 17 + j\,6$

∴ Voltage at point *M*, $\overrightarrow{V_M} = \overrightarrow{V_B} + \overrightarrow{V_{MB}} = (200 + j\,0) + (17 + j\,6)$

$= 217 + j\,6$

Its magnitude is $= \sqrt{(217)^2 + (6)^2} =$ **217·1 V**

Phase angle between V_M and V_B, $\alpha = \tan^{-1} 6/217 = \tan^{-1} 0\cdot0276 = 1\cdot58^\circ$

(*ii*) The load current I_1 has a lagging p.f. of 0·6 *w.r.t.* V_M. It lags behind V_M by an angle $\phi_1 = \cos^{-1} 0\cdot6 = 53\cdot13^\circ$

∴ Phase angle between I_1 and V_B, $\phi'_1 = \phi_1 - \alpha = 53\cdot13^\circ - 1\cdot58 = 51\cdot55^\circ$

Load current at *M*, $\overrightarrow{I_1} = I_1\,(\cos\phi_1' - j\sin\phi_1') = 100\,(\cos 51\cdot55^\circ - j\sin 51\cdot55^\circ)$

$= 62\cdot2 - j\,78\cdot3$

Current in section *AM*, $\overrightarrow{I_{AM}} = \overrightarrow{I_1} + \overrightarrow{I_2} = (62\cdot2 - j\,78\cdot3) + (80 - j\,60)$

$= 142\cdot2 - j\,138\cdot3$

Drop in section *AM*, $\overrightarrow{V_{AM}} = \overrightarrow{I_{AM}}\,\overrightarrow{Z_{AM}} = (142\cdot2 - j\,138\cdot3)\,(0\cdot1 + j\,0\cdot15)$

$= 34\cdot96 + j\,7\cdot5$

Sending end voltage, $\overrightarrow{V_A} = \overrightarrow{V_M} + \overrightarrow{V_{AM}} = (217 + j\,6) + (34\cdot96 + j\,7\cdot5)$

$$= 251{\cdot}96 + j\,13{\cdot}5$$

Its magnitude is $= \sqrt{(251\cdot96)^2 + (13\cdot5)^2} = \mathbf{252{\cdot}32\ V}$

(iii) The phase difference θ between V_A and V_B is given by :

$$\tan\theta = 13{\cdot}5/251{\cdot}96 = 0{\cdot}05358$$

$$\therefore \quad \theta = \tan^{-1} 0{\cdot}05358 = \mathbf{3{\cdot}07^{\circ}}$$

Hence supply voltage is 252·32 V and leads V_B by 3·07°.

Four-Wire Star-Connected Unbalanced Loads

We can obtain this type of load in two ways. First, we may connect a 3-phase, 4-wire unbalanced load to a 3-phase, 4-wire supply as shown in Fig. 14.10. Note that star point *N* of the supply is connected to the load star point *N'*. Secondly, we may connect single phase loads between any line and the neutral wire as shown in Fig.14.11. This will also result in a 3-phase, 4-wire **unbalanced load because it is rarely possible that single phase loads on all the three phases have the same magnitude and power factor. Since the load is unbalanced, the line currents will be different in magnitude and displaced from one another by unequal angles. The current in the neutral wire will be the phasor sum of the three line currents *i.e.*

Current in neutral wire, $I_N = I_R + I_Y + I_B$ ...*phasor sum*

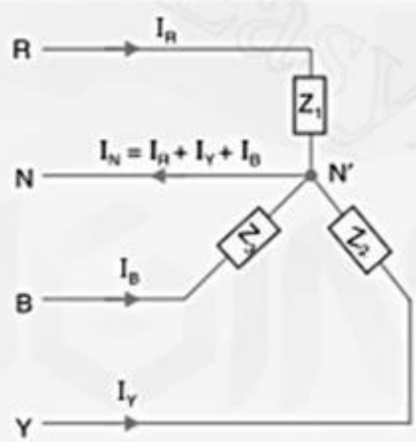

Fig. 14.10

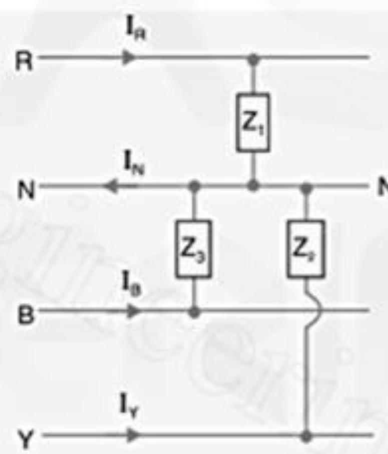

Fig. 14.11

The following points may be noted carefully :

(*i*) Since the neutral wire has negligible resistance, supply neutral *N* and load neutral *N'* will be at the same potential. It means that voltage across each impedance is equal to the phase voltage of the supply. However, current in each phase (or line) will be different due to unequal impedances.

(*ii*) The amount of current flowing in the neutral wire will depend upon the magnitudes of line currents and their phasor relations. In most circuits encountered in practice, the neutral current is equal to or smaller than one of the line currents. The exceptions are those circuits having severe unbalance.