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Internal Assesment Test – III

Sub: **Transmission & Distribution**				Code: 15EE43		
Date: 29/05/2017	Duration: 90 mins	Max Marks: 50	Sem: 4th	Sections: A & B		
Answer any FIVE full questions, choosing one full question from each module. Explain your notations explicitly and clearly. Sketch figures wherever necessary.						
				Marks	OBE	
					CO	RBT
Q1a.	A suspension string insulator has three units. Each unit can withstand a maximum voltage of 11 kV. The capacitance of each joint and metal work is 20% of the capacitance of each disc. Find: (i) Maximum line voltage for which the string can be used (ii) String efficiency			[5]	C403.5	L3

1a

$C_1 = 0.2C$

$k = 0.2$

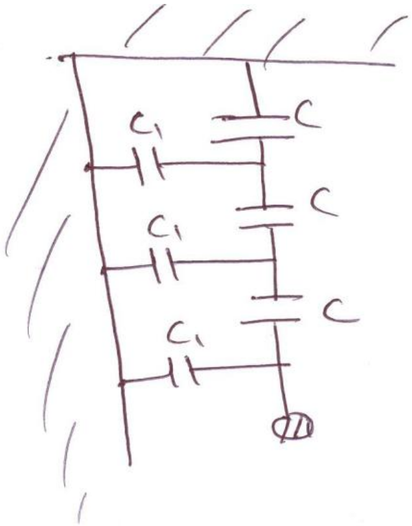
$V_3 = 11kV$

$\Rightarrow V_1 = \frac{V_3}{1+3k+k^2}$

$= 6.707$ kV

& $V_2 = V_1(1+k)$

$= 8.0487$ kV



$V = V_1 + V_2 + V_3 = 25.755$ kV

$\therefore V_{ph} = 25.755$ kV $\Rightarrow V_L = 44.61$ kV

(i) max line voltage $= V_L = 44.61$ kV

(ii) $\% \eta = \frac{V}{3.V_3} \times 100 = \frac{25.755}{3 \times 11} \times 100 = 78.04\%$

(ii) String efficiency

Q1b.	List out the advantages and disadvantages of HVDC Transmission.	[5]	C403.2	L4

Advantages of HVDC transmission.

1. These systems are economical for transmitting bulk power over long distance
2. A DC transmission line does not have any stability problem in itself and hence asynchronous operation of transmission link along with the connected machines is possible
3. There is no charging current in DC transmission systems and hence line length limitation does not arise. Also in DC system the skin effect is low and hence the current density in the DC transmission line can be higher.
4. There is greater power transmission per conductor and the DC line is cheaper as it requires two conductors instead of three and hence costs on insulator and towers are less.
5. Each conductor in DC line can be operated as an independent circuit.
6. corona loss and radio interference of HVDC lines

Q2a.	State the effect of high voltage used in transmission on: (i) Volume of copper required. (ii) Line efficiency. (iii) Line voltage drop.	[5]	C403.1	L3

7.4 Advantages of High Transmission Voltage

The transmission of electric power is carried at high voltages due to the following reasons :

***(i)* Reduces volume of conductor material.** Consider the transmission of electric power by a three-phase line.

Let P = power transmitted in watts
V = line voltage in volts
$\cos\phi$ = power factor of the load
l = length of the line in metres
R = resistance per conductor in ohms
ρ = resistivity of conductor material
a = area of X-section of conductor

$$\text{Load current, } I = \frac{P}{\sqrt{3}\, V \cos\phi}$$

$$\text{Resistance/conductor, } R = \rho l / a$$

$$\text{Total power loss, } W = 3 I^2 R = 3\left(\frac{P}{\sqrt{3}\, V \cos\phi}\right)^2 \times \frac{\rho l}{a}$$

$$= \frac{P^2 \rho l}{V^2 \cos^2\phi \, a}$$

$$\therefore \quad \text{Area of X-section, } a = \frac{P^2 \rho l}{W V^2 \cos^2\phi}$$

Total volume of conductor material required

$$= 3\, a\, l = 3\left(\frac{P^2 \rho\, l}{W V^2 \cos^2\phi}\right) l$$

$$= \frac{3 P^2 \rho l^2}{W V^2 \cos^2\phi} \qquad \ldots(i)$$

It is clear from exp. (*i*) that for given values of P, l, ρ and W, the volume of conductor material required is inversely proportional to the square of transmission voltage and power factor. In other words, the greater the transmission voltage, the lesser is the conductor material required.

***(ii)* Increases transmission efficiency**

$$\text{Input power} = P + \text{Total losses}$$

$$= P + \frac{P^2 \rho l}{V^2 \cos^2\phi \, a}$$

Assuming J to be the current density of the conductor, then,

$$a = I/J$$

$$\therefore \quad \text{Input power} = P + \frac{P^2 \rho\, l\, J}{V^2 \cos^2\phi\, I} = P + \frac{P^2 \rho\, l\, J}{V^2 \cos^2\phi} \times \frac{1}{I}$$

$$= P + \frac{P^2\, \rho\, l\, J}{V^2 \cos^2\phi} \times \frac{{}^{*}\sqrt{3}\, V \cos\phi}{P}$$

$$= P + \frac{\sqrt{3}\, P\, J\, \rho\, l}{V \cos\phi} = P\left[1 + \frac{\sqrt{3}\; J\, \rho\, l}{V \cos\phi}\right]$$

$$\text{Transmission efficiency} = \frac{\text{Output power}}{\text{Input power}} = \frac{P}{P\left[1 + \dfrac{\sqrt{3}\; J\, \rho\, l}{V \cos\phi}\right]} = \frac{1}{\left[1 + \dfrac{\sqrt{3}\; J\, \rho\, l}{V \cos\phi}\right]}$$

$$= {}^{**}\left[1 - \frac{\sqrt{3}\;J\,\rho\,l}{V\cos\phi}\right] \text{ approx.} \qquad \ldots(ii)$$

As J, ρ and l are constants, therefore, transmission efficiency increases when the line voltage is increased.

(*iii*) Decreases percentage line drop

$$\text{Line drop} = I\,R = I \times \frac{\rho\,l}{a}$$

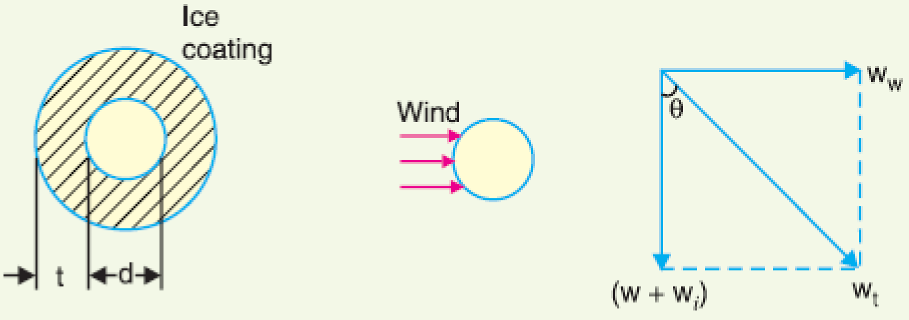
$$= I \times \rho\,l \times J/I = \rho\,l\,J \qquad [\because\ a = I/J]$$

$$\text{\%age line drop} = \frac{J\,\rho\,l}{V} \times 100 \qquad \ldots(iii)$$

As J, ρ and l are constants, therefore, percentage line drop decreases when the transmission voltage increases.

Q2b.	Derive the relevant equations for demonstrating the effect of ice covering and wind pressure on sag calculation.	[5]	C403.5	L3

Effect of wind and ice loading. The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards *i.e.*, in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally *i.e.*, at right angle to the projected surface of the conductor. Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in Fig. 8.26 (*iii*).



(*i*) (*ii*) (*iii*)

Fig. 8.26

Total weight of conductor per unit length is

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

where

$$\begin{aligned} w &= \text{weight of conductor per unit length} \\ &= \text{conductor material density} \times \text{volume per unit length} \\ w_i &= \text{weight of ice per unit length} \\ &= \text{density of ice} \times \text{volume of ice per unit length} \\ &= \text{density of ice} \times \frac{\pi}{4}\,[(d + 2t)^2 - d^2] \times 1 \\ &= \text{density of ice} \times \pi\, t\, (d + t)^* \\ w_w &= \text{wind force per unit length} \\ &= \text{wind pressure per unit area} \times \text{projected area per unit length} \\ &= \text{wind pressure} \times [(d + 2t) \times 1] \end{aligned}$$

When the conductor has wind and ice loading also, the following points may be noted :

(i) The conductor sets itself in a plane at an angle θ to the vertical where

$$\tan\theta = \frac{w_w}{w + w_i}$$

(ii) The sag in the conductor is given by :

$$S = \frac{w_t\, l^2}{2T}$$

Hence S represents the slant sag in a direction making an angle θ to the vertical. *If no specific mention is made in the problem, then slant slag is calculated by using the above formula.*

(iii) The vertical sag $= S \cos\theta$

Q3a.	Write short notes on following i) Proximity effect ii) Transposition of line	[5]	C403.1	L2

(i) When two or more conductors carrying alternating current are close to each other, then distribution of current in each conductor is affected due to the varying magnetic field of each other. The varying magnetic field produced by alternating current induces eddy currents in the adjacent conductors. Due to this, when the nearby conductors carrying current in the same direction, the current is concentrated at the farthest side of the conductors. When the nearby conductors are carrying current in opposite direction to each other, the current is concentrated at the nearest parts of the conductors. This effect is called as **Proximity effect**. The proximity effect also increases with increase in the frequency. Effective resistance of the conductor is increased due to the proximity effect.

(ii) **Unsymmetrical spacing.** When 3-phase line conductors are not equidistant from each other, the conductor spacing is said to be unsymmetrical. Under such conditions, the flux linkages and inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the three phases even if the currents in the conductors are balanced. Therefore, the voltage at the receiving end will not be the same for all phases. In order that voltage drops are equal in all conductors, we generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over an equal distance. Such an exchange of positions is known as *transposition.* Fig. 9.9 shows the

transposed line. The phase conductors are designated as *A, B* and *C* and the positions occupied are numbered 1, 2 and 3. The effect of transposition is that each conductor has the same average inductance.

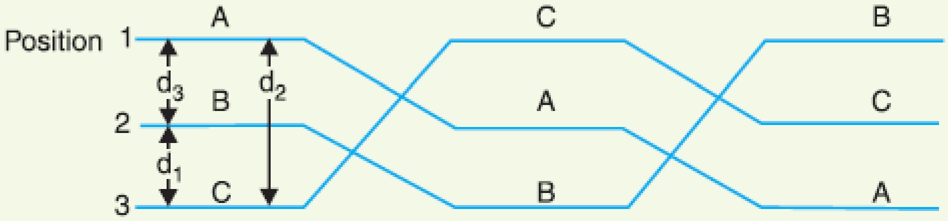


Fig. 9.9

Q3b. Obtain self GMD and mutual GMD and hence calculate inductance/km of each conductor in a 3-phase-3-wire system. Conductors are arranged at the vertices of a triangle of sides 2.5m, 3m and 5m. These are transposed at regular intervals. Diameter of each conductor is 1.5 cm.	[5]	C403.4	L3

3b

$D_1 = 2.5m$

$D_2 = 3m$

$D_3 = 5m$

$d = 1.5cm$

$r = 0.75cm$

$r' = 0.7788 \cdot r$

$= 0.5841$

Self GMD = 0.5841 cm

mutual GMD $= \sqrt[3]{(2.5)(3)(5)}$

$= 3.347 m$

$L_{ph} = 0.2 \ln\left(\frac{D_m}{D_s}\right)$

$= 1.27$ mH/km

Q4a. Write short notes on following i) Skin effect ii) GMD	[5]	C403.1	L2

9.3 Skin Effect

When a conductor is carrying steady direct current (d.c.), this current is uniformly distributed over the whole X-section of the conductor. However, an alternating current flowing through the conductor does not distribute uniformly, rather it has the tendency to concentrate near the surface of the conductor as shown in Fig. 9.3. This is known as skin effect.

The tendency of alternating current to concentrate near the surface of a conductor is known as **skin effect.**

Due to skin effect, the effective area of cross-section of the conductor through which current flows is reduced. Consequently, the resistance of the conductor is slightly increased when carrying an alternating current. The cause of skin effect can be easily explained. A solid conductor may be thought to be consisting of a large number of strands, each carrying a small part of the current. The *inductance of each strand will vary according to its position. Thus, the strands near the centre are surrounded by a greater magnetic flux and hence have larger inductance than that near the surface. The high reactance of inner strands causes the alternating current to flow near the surface of conductor. This crowding of current near the conductor surface is the skin effect. The skin effect depends upon the following factors :

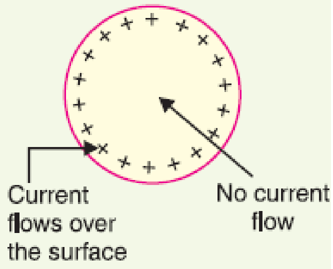


Fig. 9.3

(*i*) Nature of material
(*ii*) Diameter of wire – increases with the diameter of wire.
(*iii*) Frequency – increases with the increase in frequency.
(*iv*) Shape of wire – less for stranded conductor than the solid conductor.

It may be noted that skin effect is negligible when the supply frequency is low (< 50 Hz) and conductor diameter is small (< 1cm).

9.7 Concept of Self-GMD and Mutual-GMD

The use of *self geometrical mean distance* (abbreviated as self-GMD) and *mutual geometrical mean distance* (mutual-GMD) simplifies the inductance calculations, particularly relating to multiconductor arrangements. The symbols used for these are respectively D_s and D_m. We shall briefly discuss these terms.

(*i*) **Self-GMD (D_s).** In order to have concept of self-GMD (also sometimes called Geometrical mean radius ; GMR), consider the expression for inductance per conductor per metre already derived in Art. 9.5

$$\text{Inductance/conductor/m} = 2 \times 10^{-7}\left(\frac{1}{4} + \log_e \frac{d}{r}\right)$$

$$= 2 \times 10^{-7} \times \frac{1}{4} + 2 \times 10^{-7} \log_e \frac{d}{r} \qquad \text{...}(i)$$

In this expression, the term $2 \times 10^{-7} \times (1/4)$ is the inductance due to flux within the solid conductor. For many purposes, it is desirable to eliminate this term by the introduction of a concept called self-GMD or GMR. If we replace the original solid conductor by an equivalent hollow cylinder with extremely thin walls, the current is confined to the conductor surface and internal conductor flux linkage would be almost zero. Consequently, inductance due to internal flux would be zero and the term $2 \times 10^{-7} \times (1/4)$ shall be eliminated. The radius of this equivalent hollow cylinder must be sufficiently smaller than the physical radius of the conductor to allow room for enough additional flux to compensate for the absence of internal flux linkage. It can be proved mathematically that for a solid round conductor of radius *r*, the self-GMD or GMR = 0·7788 *r*. Using self-GMD, the eq. (*i*) becomes :

$$\text{Inductance/conductor/m} = 2 \times 10^{-7} \log_e d/D_s{}^*$$

$$\text{where} \quad D_s = \text{GMR or self-GMD} = 0{\cdot}7788\, r$$

It may be noted that self-GMD of a conductor depends upon the size and shape of the conductor and is independent of the spacing between the conductors.

(*ii*) **Mutual-GMD.** The mutual-GMD is the geometrical mean of the distances form one conductor to the other and, therefore, must be between the largest and smallest such distance. In fact, mutual-GMD simply represents the equivalent geometrical spacing.

(*a*) The mutual-GMD between two conductors (assuming that spacing between conductors is large compared to the diameter of each conductor) is equal to the distance between their centres *i.e.*

$$D_m = \text{spacing between conductors} = d$$

(*b*) For a single circuit 3-ϕ line, the mutual-GMD is equal to the equivalent equilateral spacing *i.e.*, $(d_1\, d_2\, d_3)^{1/3}$.

$$D_m = (d_1\, d_2\, d_3)^{1/3}$$

Q4b. A 3-phase, 50Hz, 6kV overhead line conductors are places in a horizontal plane as shown in the fig 5.6. The conductor diameter is 1.25cm. if the length is 100km, calculate the capacitance per phase and charging current per phase. Assume complete transposition of lines.

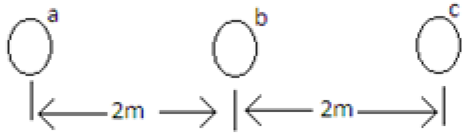


Fig 5.6

[5] C403.4 L3

4b $f = 50\,Hz$, $V_L = 6\,KV$, $d = 1.25\,cm$, $l = 100\,km$

$D_{eq} = \sqrt[3]{D_{ab} D_{bc} D_{ca}} = 2.5198\,m$

$r = \frac{d}{2} = 6.25 \times 10^{-3}\,m$

$C_{an} = 9.2728 \times 10^{-12}\,F/m$

capacitance per phase of the line $= C_{an} \times l$

$= 0.92728\ \mu F$

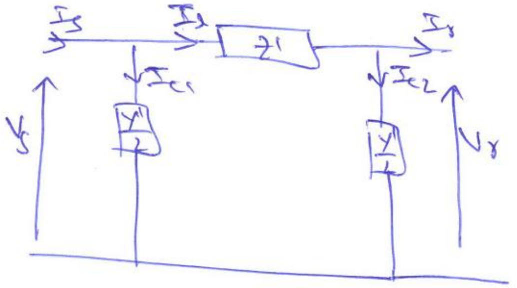
charging current $= \frac{V_{ph}}{X_c} = \frac{V_L}{\sqrt{3}} \times 2\pi f C_{line} = 1.010\,A$

Q5a. Derive the expressions for correction factors to convert Z and Y of nominal π circuit to Z^1 and Y^1 of equivalent π circuit.

[5] C403.1 L3

equivalent circuit of long transmission line:-

Consider equivalent-π circuit of long line shown in fig.



from ckt.

$I_{c2} = V_r \frac{Y'}{2}$ —— ①

$I_l = I_r + V_r \frac{Y'}{2}$

$V_s = V_r + Z'\left(V_r \frac{Y'}{2} + I_r\right)$

$V_s = V_r\left(1 + \frac{Z'Y'}{2}\right) + I_r Z'$ —— ②

$I_{c1} = V_s \frac{Y'}{2}$

$I_{c1} = V_r \frac{Y'}{2}\left(1 + \frac{Z'Y'}{2}\right) + I_r \frac{Z'Y'}{2}$

& $I_s = I_l + I_{c1}$

$I_s = I_r + V_r \frac{Y'}{2} + V_r \frac{Y'}{2}\left(1 + \frac{Z'Y'}{2}\right) + I_r \frac{Z'Y'}{2}$

$I_s = V_r Y'\left[1 + \frac{Z'Y'}{4}\right] + I_r\left[1 + \frac{Z'Y'}{2}\right]$ —— ③

but $V_s = \cosh\gamma l \cdot V_r + Z_c \sinh\gamma l \; I_r$

$I_s = \frac{\sinh\gamma l}{Z_c} V_r + \cosh\gamma l \; I_r$

comparing eqts ② & ③ with above equations

$A = 1 + \frac{Z'Y'}{2} = \cosh\gamma l = D$ —— ④

$B = Z' = Z_c \sinh\gamma l$ —— ⑤

$C = Y'\left(1 + \frac{Z'Y'}{4}\right) = \frac{\sinh\gamma l}{Z_c}$ —— ⑥

Consider eqtn. ⑤

$$Z' = Z_c \sinh \gamma l$$

$$= \sqrt{\frac{z}{y}} \sinh \gamma l$$

$$= zl \left[\sqrt{\frac{z}{y}} \frac{\sinh \gamma l}{zl} \right]$$

$$= Z \left[\frac{\sinh \gamma l}{\gamma l} \right]$$

$$Z' = Z F_1$$

where $F_1 = \frac{\sinh \gamma l}{\gamma l}$

= correction factor to convert Z from nominal π circuit to Z' in equivalent π circuit.

Consider eqtn. ④

$$1 + \frac{Z' Y'}{2} = \cosh \gamma l$$

$$\Rightarrow \frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z'}$$

Substituting Z' from eqtn ⑤ in above eqtn.

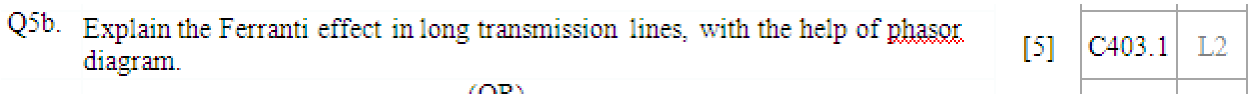
$$\frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z_c \sinh \gamma l}$$

$$= \frac{\tanh(\gamma l/2)}{\sqrt{\frac{z}{y}}}$$

$$= \frac{Y}{2} \frac{\tanh(\gamma l/2)}{\sqrt{\frac{z}{y}} \cdot y l/2}$$

$$\frac{Y'}{2} = \frac{Y}{2} \frac{\tanh(\gamma l/2)}{\sqrt{zy} \cdot l/2} = \frac{Y}{2} \frac{\tanh(\gamma l/2)}{\gamma l/2}$$

$\Rightarrow Y'/2 = \frac{Y}{2} \cdot F_2$ where $F_2 = \frac{\tanh(\gamma l/2)}{\gamma l/2}$ = correction factor to convert Y of nominal π-circuit to Y' of equivalent π-ckt



Q5b.	Explain the Ferranti effect in long transmission lines, with the help of phasor diagram.	[5]	C403.1	L2

(OR)

A long transmission line can be considered to compose a considerably high amount of capacitance and inductance distributed across the entire length of the line. Ferranti Effect occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line(during light or no load). This capacitor charging current leads to voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently the receiving end voltage tends to get larger than applied voltage leading to the phenomena called **Ferranti effect in power system**. It is illustrated with the help of a phasor diagram below.

Thus both the capacitance and inductor effect of transmission line are equally responsible for this particular phenomena to occur, and hence Ferranti effect is negligible in case of a short transmission lines as the inductor of such a line is practically considered to be nearing zero. In general for a 300 Km line operating at a frequency of 50 Hz, the no load receiving end voltage has been found to be 5% higher than the sending end voltage.

Now for analysis of Ferranti effect let us consider the phasor diagrams shown above.

Here, V_r is considered to be the reference phasor, represented by OA.

$$Thus\ V_r = V_r(1 + j0)$$

$$Capacitance\ current,\ I_c = j\omega CV_r$$

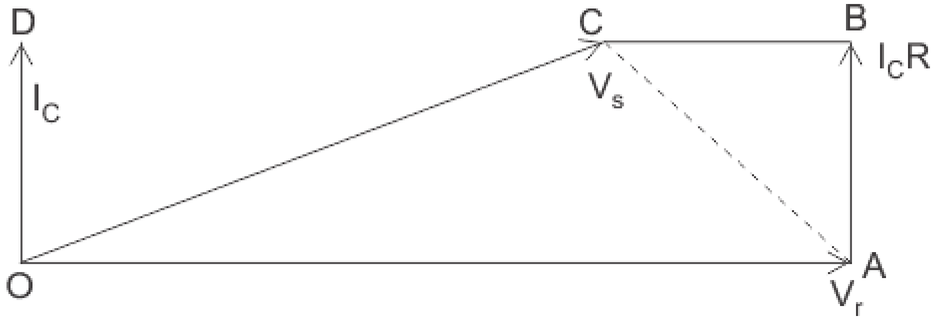
$$Now\ sending\ end\ voltage\ V_s = V_r + resistive + reactive\ drop.$$

$$= V_r + I_cR + jI_cX$$

$$= V_r + I_c(R + jX)$$

$$= V_r + j\omega CV_r(R + j\omega L)[\ Since\ X = \omega L\ ]$$

$$Now\ V_s = V_r - \omega^2 CLV_r + j\omega CRV_r$$

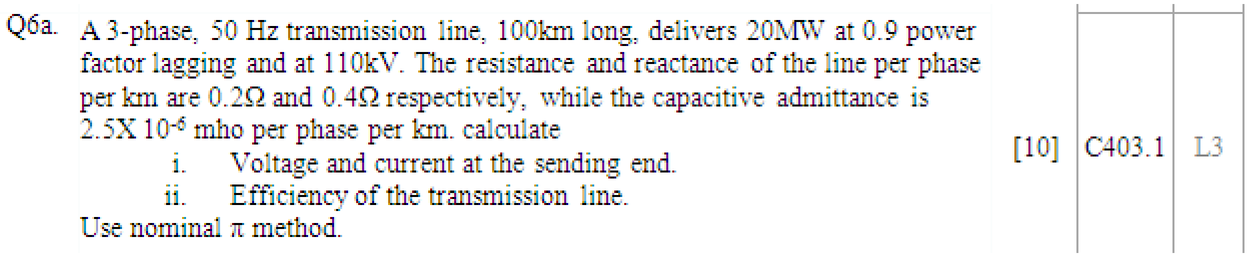


Ferranti effects in transmission line

This is represented by the phasor OC.

Now in case of a long transmission line, it has been practically observed that the line electrical resistance is negligibly small compared to the line reactance, hence we can assume the length of the phasor I_c R = 0, we can consider the rise in the voltage is only due to OA - OC = reactive drop in the line.

Now if we consider c_0 and L_0 are the values of capacitance and inductor per km of the transmission line, where l is the length of the line.



Q6a.	A 3-phase, 50 Hz transmission line, 100km long, delivers 20MW at 0.9 power factor lagging and at 110kV. The resistance and reactance of the line per phase per km are 0.2Ω and 0.4Ω respectively, while the capacitive admittance is 2.5X 10^{-6} mho per phase per km. calculate i. Voltage and current at the sending end. ii. Efficiency of the transmission line. Use nominal π method.	[10]	C403.1	L3

6a

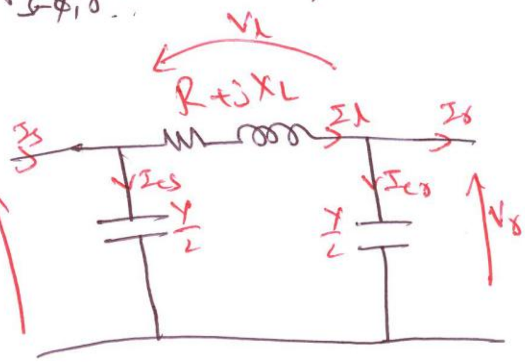
$3\text{-}\phi,\ f = 50\,\text{Hz}\ ,\ l = 100\,\text{km}\ ,\ P_{3\text{-}\phi,r} = 20\,\text{MW}\ ,\ \text{P.F}_r = 0.9$ lag.

$V_{rl} = 110\,\text{kV}$

$r = 0.2\,\Omega/\text{km}$

$x = 0.4\,\Omega/\text{km}$

$y = 2.5\times10^{-6}\ ℧/\text{km}$



(i) I_s, V_{sl}

(ii) η

$R = r.l = 20\,\Omega$

$X_L = x\,l = 40\,\Omega$

$Y = 2.5\times10^{-4}\ ℧ \Rightarrow \frac{Y}{2} = j\,1.25\times10^{-4}\ ℧$

$= 1.25\times10^{-4}\angle 90^\circ$

$|V_r| = \frac{V_{rl}}{\sqrt{3}} = 63.508\,\text{kV}$

$\overline{V}_r = 63.508\text{k}\angle 0^\circ\ \text{V}$

$$|I_r| = \frac{P_{3\text{-}\phi,r}}{3|V_r|\cos\phi_r} = \frac{20\,\text{M}}{(3)(63.508)\text{k}(0.9)} = 116.63\ \text{A}$$

$\phi_r = \cos^{-1}(0.9) = 25.84^\circ$

$\overline{I}_r = 116.63\angle 25.84^\circ\ \text{A}$

$\overline{I}_{cr} = \overline{V}_r\,\frac{\overline{Y}}{2} = 63.508\text{k}\angle 0^\circ \times (j\,1.25\times10^{-4}) = 7.938\angle 90^\circ$

$\overline{I}_l = \overline{I}_r + \overline{I}_{cr} = 120.30\angle 29.24^\circ\ \text{A}$

$\overline{V}_l = \overline{I}_l\,\overline{Z} = (120.30\angle 29.24^\circ)(20 + j40) = 5.38\text{k}\angle 92.67^\circ\ \text{V}$

$\overline{V}_s = \overline{V}_r + \overline{V}_l = 63.484\text{k}\angle 4.856^\circ\ \text{V}$

$\overline{I}_{cs} = \overline{V}_s\,\frac{Y}{2} = 7.9355\angle 94.85^\circ\ \text{A}$

$\overline{I}_s = \overline{I}_{cs} + \overline{I}_l = 123.787\angle 32.58^\circ\ \text{A}$

$|I_s| = 123.787\,\text{A}\ ,\ |V_{sl}| = \sqrt{3}|V_s| = 109.957\,\text{kV}.$

$$\eta = \frac{|V_r||I_r|\cos\phi_r}{|V_s||I_s|\cos\angle V_s I_s} = \frac{(63.508)(116.63)(0.9)}{(63.484)(123.787)\cos(32.58 - 4.856)} \simeq 95.82\%$$

Q7a. With reference to corona, derive an expression for critical disruption voltage. [5] C403.1 L2

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it is profitable to consider the following terms much used in the analysis of corona effects:

(*i*) Critical disruptive voltage. *It is the minimum phase-neutral voltage at which corona occurs.*

Consider two conductors of radii *r* cm and spaced *d* cm apart. If *V* is the phase-neutral potential, then potential gradient at the conductor surface is given by:

$$g = \frac{V}{r \log_e \frac{d}{r}} \text{ volts / cm}$$

In order that corona is formed, the value of *g* must be made equal to the breakdown strength of air. The breakdown strength of air at 76 cm pressure and temperature of 25°C is 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*) and is denoted by g_o. If V_c is the phase-neutral potential required under these conditions, then,

$$g_o = \frac{V_c}{r \log_e \frac{d}{r}}$$

where g_o = breakdown strength of air at 76 cm of mercury and 25°C
= 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*)

$$\therefore \text{ Critical disruptive voltage, } V_c = g_o \, r \log_e \frac{d}{r}$$

The above expression for disruptive voltage is under standard conditions *i.e.,* at 76 cm of Hg and 25°C. However, if these conditions vary, the air density also changes, thus altering the value of g_o. The value of g_o is directly proportional to air density. Thus the breakdown strength of air at a barometric pressure of *b* cm of mercury and temperature of *t*°C becomes $\delta \, g_o$ where

$$\delta = \text{air density factor} = \frac{3 \cdot 92b}{273 + t}$$

Under standard conditions, the value of $\delta = 1$.

$$\therefore \text{ Critical disruptive voltage, } V_c = g_o \, \delta \, r \log_e \frac{d}{r}$$

Correction must also be made for the surface condition of the conductor. This is accounted for by multiplying the above expression by irregularity factor m_o.

$$\therefore \text{ Critical disruptive voltage, } V_c = m_o \, g_o \, \delta \, r \log_e \frac{d}{r} \text{ kV/phase}$$

where m_o = 1 for polished conductors
= 0·98 to 0·92 for dirty conductors
= 0·87 to 0·8 for stranded conductors

Q7b. Show that in a single core cable the ratio of maximum to minimum stress is R/γ; R= sheath radius, γ= core radius. [5] C403.3 L3

11.9 Dielectric Stress in a Single-Core Cable

Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is infact the potential gradient (or *electric intensity) at that point.

Consider a single core cable with core diameter d and internal sheath diameter D. As proved in Art 11.8, the electric intensity at a point x metres from the centre of the cable is

$$E_x = \frac{Q}{2\pi \varepsilon_o \varepsilon_r x} \text{ volts/m}$$

By definition, electric intensity is equal to potential gradient. Therefore, potential gradient g at a point x metres from the centre of cable is

$$g = E_x$$

or $$g = \frac{Q}{2\pi \varepsilon_o \varepsilon_r x} \text{ volts/m} \quad \ldots(i)$$

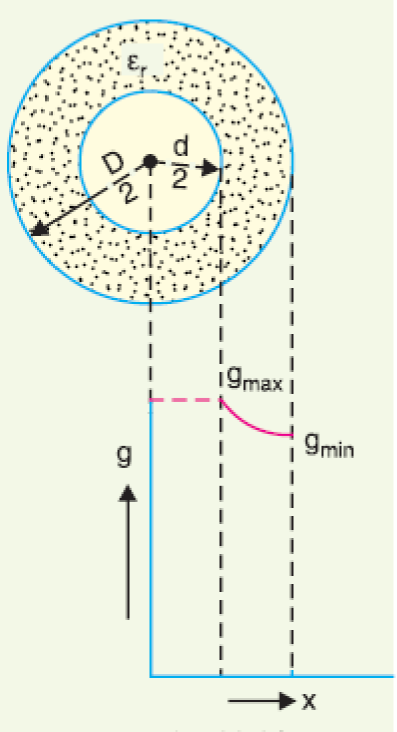


Fig. 11.14

As proved in Art. 11.8, potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi \varepsilon_o \varepsilon_r} \log_e \frac{D}{d} \text{ volts}$$

or $$Q = \frac{2\pi \varepsilon_o \varepsilon_r V}{\log_e \frac{D}{d}} \quad \ldots(ii)$$

Substituting the value of Q from exp. (*ii*) in exp. (*i*), we get,

$$g = \frac{\dfrac{2\pi \varepsilon_o \varepsilon_r V}{\log_e D/d}}{2\pi \varepsilon_o \varepsilon_r x} = \frac{V}{x \log_e \frac{D}{d}} \text{ volts/m} \quad \ldots(iii)$$

It is clear from exp. (*iii*) that potential gradient varies inversely as the distance x. Therefore, potential gradient will be maximum when x is minimum *i.e.*, when $x = d/2$ or at the surface of the conductor. On the other hand, potential gradient will be minimum at $x = D/2$ or at sheath surface.

∴ Maximum potential gradient is

$$g_{max} = \frac{2V}{d \log_e \frac{D}{d}} \text{ volts/m} \quad [\text{Putting } x = d/2 \text{ in exp. } (iii)]$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D \log_e \frac{D}{d}} \text{ volts/m} \quad [\text{Putting } x = D/2 \text{ in exp. } (iii)]$$

$$\therefore \qquad \frac{g_{max}}{g_{min}} = \frac{\dfrac{2V}{d\log_e D/d}}{\dfrac{2V}{D\log_e D/d}} = \frac{D}{d}$$

The variation of stress in the dielectric is shown in Fig. 11.14. It is clear that dielectric stress is maximum at the conductor surface and its value goes on decreasing as we move away from the conductor. It may be noted that maximum stress is an important consideration in the design of a cable. For instance, if a cable is to be operated at such a voltage that *maximum stress is 5 kV/mm, then the insulation used must have a dielectric strength of atleast 5 kV/mm, otherwise breakdown of the cable will become inevitable.

Q8a. Write a short notes on methods of reducing Corona.	[5]	C403.1	L3

8.14 Methods of Reducing Corona Effect

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus-bars rated for 33 kV and higher voltages otherwise highly ionised air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment. The corona effects can be reduced by the following methods :

(*i*) *By increasing conductor size.* By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that *ACSR* conductors which have a larger cross-sectional area are used in transmission lines.

(*ii*) *By increasing conductor spacing.* By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated. However, spacing cannot be increased too much otherwise the cost of supporting structure (*e.g.*, bigger cross arms and supports) may increase to a considerable extent.

Q8b. Derive an expression for current rating of a cable in terms of the maximum permissible temperature of the core and ambient temperature.	[5]	C403.3	L3

calculation of current rating:-

let

θ_m = maximum permissible temperature of the core of the cable.

θ_s = sheath temperature

θ_a = ambient temperature.

The heat generated in the core of the cable will pass through the dielectric medium where as through the bedding, serving and the ground.

The heat flow is sum of the heat generated in the core and the sheath.

ie $$nI^2R = \frac{\theta_m - \theta_s}{S_1}$$

n = no. of cores

R = resistance of each core

I = current in each core, expression of which is required here

S_1 = Thermal resistance of dielectric.

If the ratio of sheath loss to core loss is λ, the heat flowing through bedding, serving and the ground will be $(1+\lambda)nI^2R$ and the following relation will hold good.

$$(1+\lambda)nI^2R = \frac{\theta_s - \theta_a}{S_4 + S_5 + G}$$

Since normally θ_s is not known, eliminating it from the two equations.

$$\theta_m - \theta_s = nI^2RS_1$$

$$\theta_s - \theta_a = (1+\lambda)\, nI^2R\,(S_4 + S_5 + G)$$

$$\therefore\; I = \sqrt{\frac{\theta_m - \theta_a}{nR\left\{S_1 + (1+\lambda)(S_4 + S_5 + G)\right\}}}$$

Q9a. Write short notes on Loop feeder. [2] C403.5 L2

A similar level of system reliability to that of the parallel arrangement can be achieved by using **ring main feeders**. This usually results from the growth of load supplied by a parallel feeder where the cabling has been installed along different routes. These are most common in urban and industrial environments.

Whilst the start and finish ends of the ring are at the same location, power is delivered by both pathways of the ring into substations located around the ring.

> In typical urban / suburban ring main arrangements, the open ring is operated manually and loss of supply restored by manual switching.

In typical urban / suburban ring main arrangements, the open ring is operated manually and loss of supply restored by manual switching.

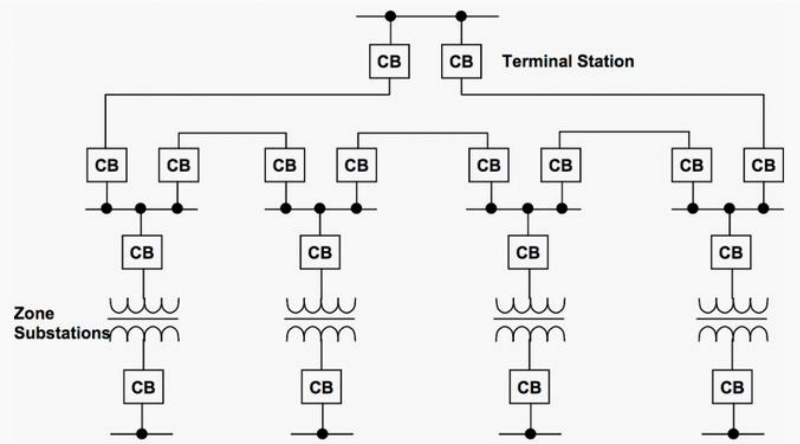
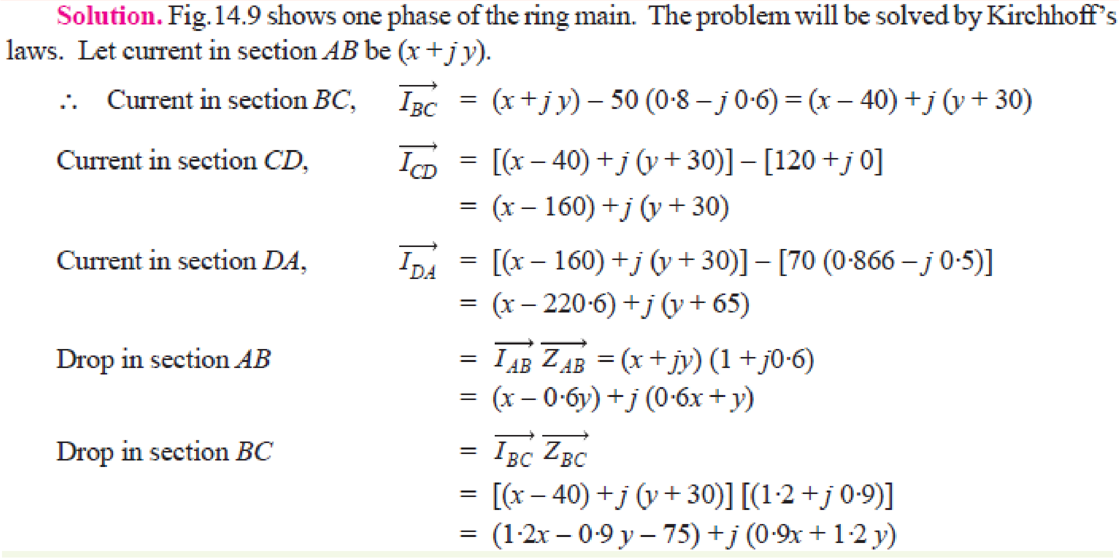


Figure 4 – A ring main feeder system

Current practice is to use distribution automation, where operation and supply restoration in the feeder rings is done automatically by centrally controlled supervisory systems.

This gives the advantages of ring main systems as line voltage drops are reduced at the various load substations there is a ‘firm’ supply (i.e. an alternative path is available if the primary one fails) to each load substation.

Q9b.	A 3-phase ring distributor ABCD, fed at A at 11KV supplies balanced loads of 50A at 0.8pf lagging at B, 120 A at unity pf at C and 70A at 0.866 lagging at D, the load currents being referred to the supply voltage at A. the impedances of the various sections are: Section AB: (1+j0.6) Ω ; section BC: (1.2+j0.9)Ω Section CD: (0.8+j0.5) Ω ; section DA: (3+j2)Ω Calculate the currents in various sections and station bus-bar voltages at B, C and D	[8]	C403.3	L4



Solution. Fig.14.9 shows one phase of the ring main. The problem will be solved by Kirchhoff’s laws. Let current in section *AB* be $(x + j\,y)$.

$\therefore$ Current in section *BC*, $\overrightarrow{I_{BC}} = (x + j\,y) - 50\,(0{\cdot}8 - j\,0{\cdot}6) = (x - 40) + j\,(y + 30)$

Current in section *CD*, $\overrightarrow{I_{CD}} = [(x - 40) + j\,(y + 30)] - [120 + j\,0]$

$= (x - 160) + j\,(y + 30)$

Current in section *DA*, $\overrightarrow{I_{DA}} = [(x - 160) + j\,(y + 30)] - [70\,(0{\cdot}866 - j\,0{\cdot}5)]$

$= (x - 220{\cdot}6) + j\,(y + 65)$

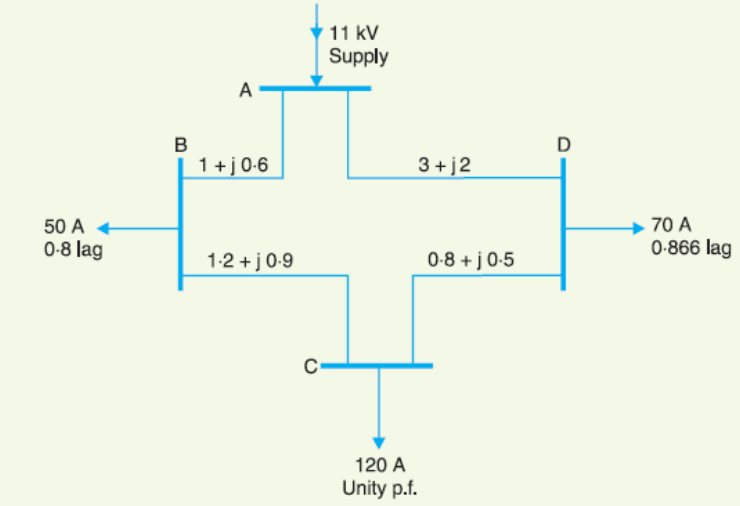
Drop in section *AB* $= \overrightarrow{I_{AB}}\,\overrightarrow{Z_{AB}} = (x + jy)\,(1 + j0{\cdot}6)$

$= (x - 0{\cdot}6y) + j\,(0{\cdot}6x + y)$

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

$= [(x - 40) + j\,(y + 30)]\,[(1{\cdot}2 + j\,0{\cdot}9)]$

$= (1{\cdot}2x - 0{\cdot}9\,y - 75) + j\,(0{\cdot}9x + 1{\cdot}2\,y)$



$$\begin{aligned}\text{Drop in section } CD &= \overrightarrow{I_{CD}}\,\overrightarrow{Z_{CD}}\\ &= [(x-160)+j\,(y+30)]\,[(0{\cdot}8+j\,0{\cdot}5)]\\ &= (0{\cdot}8x-0{\cdot}5y-143)+j\,(0{\cdot}5x+0{\cdot}8y-56)\end{aligned}$$

$$\begin{aligned}\text{Drop in section } DA &= \overrightarrow{I_{DA}}\,\overrightarrow{Z_{DA}}\\ &= [(x-220{\cdot}6)+j\,(y+65)]\,[(3+j\,2)]\\ &= (3x-2y-791{\cdot}8)+j\,(2x+3y-246{\cdot}2)\end{aligned}$$

Applying Kirchhoff's voltage law to mesh *ABCDA*, we have,

Drop in *AB* + Drop in *BC* + Drop in *CD* + Drop in *DA* = 0

or
$$\begin{aligned}&[(x-0{\cdot}6y)+j\,(0{\cdot}6x+y)]+[(1{\cdot}2x-0{\cdot}9y-75)+j\,(0{\cdot}9x+1{\cdot}2y)]\\ &\quad+[(0{\cdot}8x-0{\cdot}5y-143)+j\,(0{\cdot}5x+0{\cdot}8y-56)]\\ &\quad+[(3x-2y-791{\cdot}8)+j\,(2x+3y-246{\cdot}2)]=0\end{aligned}$$

or
$$(6x-4y-1009{\cdot}8)+j\,(4x+6y-302{\cdot}2)=0$$

As the real (or active) and imaginary (or reactive) parts have to be separately zero,

$$\therefore \quad 6x-4y-1009{\cdot}8 = 0$$

$$\text{and} \quad 4x+6y-302{\cdot}2 = 0$$

Solving for x and y, we have,

$$x = 139{\cdot}7\text{ A} \quad ; \quad y = -\,42{\cdot}8\text{ A}$$

$$\text{Current in section } AB = \mathbf{(139{\cdot}7-j\,42{\cdot}8)\ A}$$

$$\begin{aligned}\text{Current in section } BC &= (x-40)+j\,(y+30)\\ &= (139{\cdot}7-40)+j\,(-\,42{\cdot}8+30) = \mathbf{(99{\cdot}7-j\,12{\cdot}8)\ A}\end{aligned}$$

$$\begin{aligned}\text{Current in section } CD &= (x-160)+j\,(y+30)\\ &= (139{\cdot}7-160)+j\,(-\,42{\cdot}8+30)\\ &= \mathbf{(-20{\cdot}3-j\,12{\cdot}8)\ A}\end{aligned}$$

$$\begin{aligned}\text{Current in section } DA &= (x-220{\cdot}6)+j\,(y+65)\\ &= (139{\cdot}7-220{\cdot}6)+j\,(-\,42{\cdot}8+65)\\ &= \mathbf{(-80{\cdot}9+j\,22{\cdot}2)\ A}\end{aligned}$$

$$\text{Voltage at supply end } A, \quad V_A = 11000/\sqrt{3} = 6351\text{ V/phase}$$

$$\begin{aligned}\therefore\ \text{Voltage at station } B, \quad \overrightarrow{V_B} &= \overrightarrow{V_A}-\overrightarrow{I_{AB}}\,\overrightarrow{Z_{AB}}\\ &= (6351+j\,0)-(139{\cdot}7-j\,42{\cdot}8)\,(1+j\,0{\cdot}6)\\ &= \mathbf{(6185{\cdot}62-j\,41{\cdot}02)\ volts/phase}\end{aligned}$$

$$\begin{aligned}\text{Voltage at station } C, \quad \overrightarrow{V_C} &= \overrightarrow{V_B}-\overrightarrow{I_{BC}}\,\overrightarrow{Z_{BC}}\\ &= (6185{\cdot}62-j\,41{\cdot}02)-(99{\cdot}7-j\,12{\cdot}8)\,(1{\cdot}2+j\,0{\cdot}9)\\ &= \mathbf{(6054{\cdot}46-j\,115{\cdot}39)\ volts/phase}\end{aligned}$$

$$\begin{aligned}\text{Voltage at station } D, \quad \overrightarrow{V_D} &= \vec{V}_C-\overrightarrow{I_{CD}}\,\overrightarrow{Z_{CD}}\\ &= (6054{\cdot}46-j\,115{\cdot}39)-(-20{\cdot}3-j\,12{\cdot}8)\times(0{\cdot}8+j\,0{\cdot}5)\\ &= \mathbf{(6064{\cdot}3-j\,95)\ volts/phase}\end{aligned}$$

Q10a. Write short notes on reliability aids. [2] C403.1 L2

7.9 Reliability Aids

7.9.1 Mastering Information

Every thing in this universe is energy and information. The data is always aggregated into information in order to make decisions, e.g., a decision to replace a substation transformer will be based on an aggregation of loading data. Asset and operational data reside in the GIS and SCADA as information. Information is a resource that can be utilized to use all other resources in the best possible manner. The power systems are expanding and the activities becoming complex and diversified. New tools for handling data are word processors/personal computers, optical scanners, microfilm storage, computer networks and Internet are aimed to lighten the information overload. This is a cycle: more diversity and change equals more information equals more technologies to handle information and may lead to still more diversity and change. That is the dynamics driving the information revolution. Furthermore, as we organize the information, we deepen our scientific understanding of the system and use information for transforming the processes of production and services. The successful deployment of information technology will make the enterprise dynamic, integrated, effective and responsible. Managing information (see Fig. 7.12) successfully mean processing information to add value in at least one of three ways by increasing:

- Productivity,
- Competency,
- Innovation.

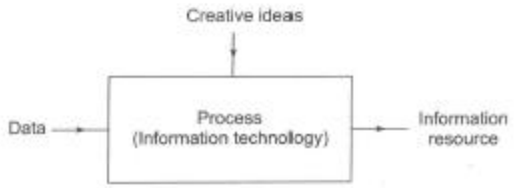


Fig. 7.12 *Information process*

The following points must be checked for the useful deployment of information technology:

- Does the information system unify the whole organisation, connecting various activities?
- Is the information system centrally managed and compatible throughout?
- Has the information system been designed by people who are going to use it?
- Is the information network widely accessible?
- Does it capture the information you need?
- Does it provide the support you need to make rapid, fact-based, accurate decisions?
- Does your information system allow you to know your consumers well: Track record regarding defaults, theft of energy, energy conservation, load profile, metering history etc.?

To avoid information overload, it is necessary to keep redefining the context in which knowledge is required so as to avoid storing everything and then not having any use for it. The significance of the information is only realised when it is used.

7.9.2 System Configuration

System configuration plays a very important part in reliability. For service continuity taking into account both long outages and momentary interruptions, the better system reliabilities are rated in the following order of merit (see Fig. 1.3):

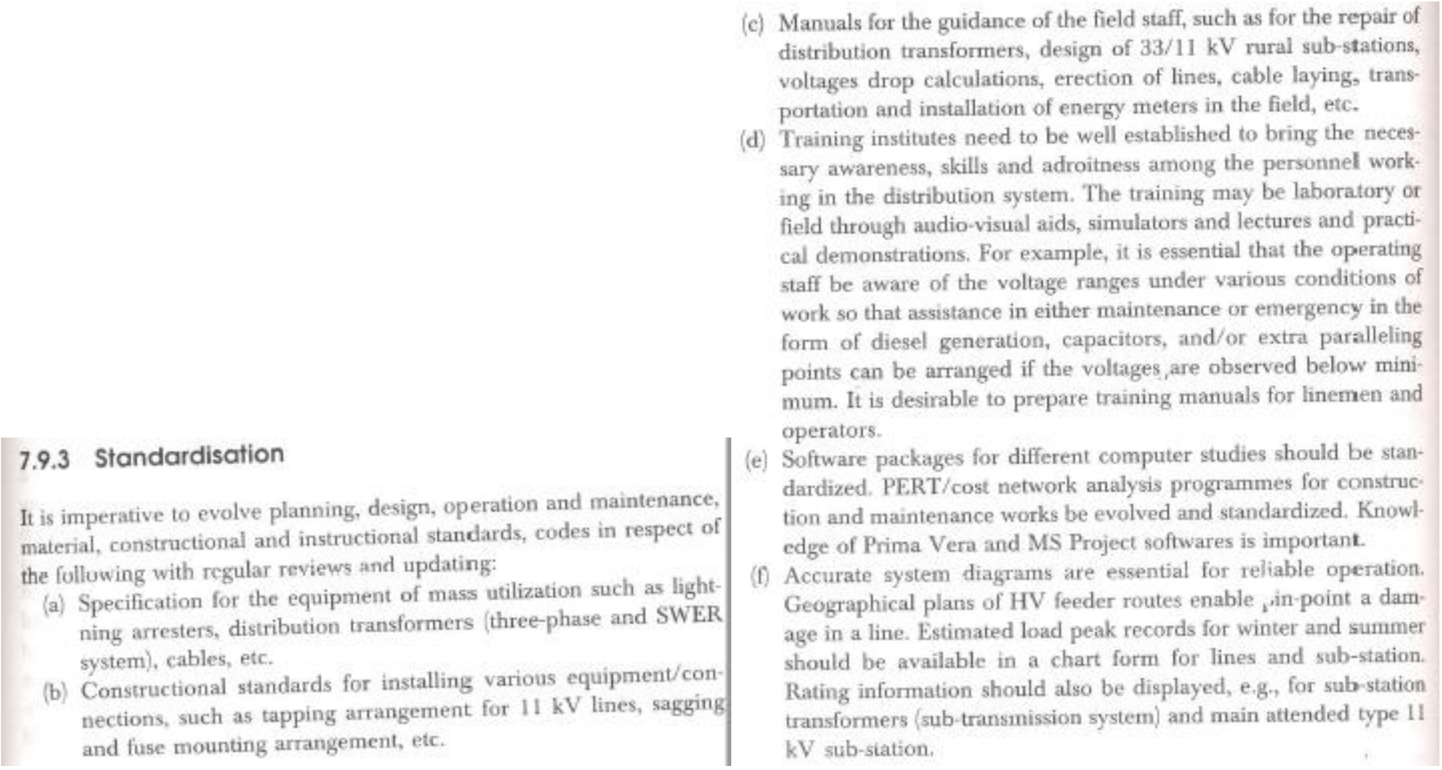
1. Grid network
2. Spot network
3. Secondary selective
4. Primary selective
5. Primary loop
6. Radial

Typical figures of various types of feeders are given below:

	SAIFI	*MAIFI*
Simple radial	0.3 to 1.3	5 to 10
Primary auto-loop	0.4 to 0.7	10 to 15
Underground residential	0.4 to 0.7	4 to 8
Primary selective	0.1 to 0.5	4 to 8
Secondary selective	0.1 to 0.5	2 to 4
Spot network	0.02 to 0.1	0 to 1
Grid network	0.005 to 0.02	0

Annual SAIDI in minutes in various countries is as below [22,23]:

South Korea(2007)	17.2
USA(2003)	88
UK (2003)	61
France(2004)	51
Singapore (FY 2007-08)	1.1
Thailand(2006)	98
Malaysia(2006)	148
Tokyo (2006)	3
Hong Kong(2006)	6
New York (2006)	12
Melbourne (2006)	21
Jakarta Metropolitan(2004)	300



7.9.3 Standardisation

It is imperative to evolve planning, design, operation and maintenance, material, constructional and instructional standards, codes in respect of the following with regular reviews and updating:

(a) Specification for the equipment of mass utilization such as lightning arresters, distribution transformers (three-phase and SWER system), cables, etc.

(b) Constructional standards for installing various equipment/connections, such as tapping arrangement for 11 kV lines, sagging and fuse mounting arrangement, etc.

(c) Manuals for the guidance of the field staff, such as for the repair of distribution transformers, design of 33/11 kV rural sub-stations, voltages drop calculations, erection of lines, cable laying, transportation and installation of energy meters in the field, etc.

(d) Training institutes need to be well established to bring the necessary awareness, skills and adroitness among the personnel working in the distribution system. The training may be laboratory or field through audio-visual aids, simulators and lectures and practical demonstrations. For example, it is essential that the operating staff be aware of the voltage ranges under various conditions of work so that assistance in either maintenance or emergency in the form of diesel generation, capacitors, and/or extra paralleling points can be arranged if the voltages are observed below minimum. It is desirable to prepare training manuals for linemen and operators.

(e) Software packages for different computer studies should be standardized. PERT/cost network analysis programmes for construction and maintenance works be evolved and standardized. Knowledge of Prima Vera and MS Project softwares is important.

(f) Accurate system diagrams are essential for reliable operation. Geographical plans of HV feeder routes enable pin-point a damage in a line. Estimated load peak records for winter and summer should be available in a chart form for lines and sub-station. Rating information should also be displayed, e.g., for sub-station transformers (sub-transmission system) and main attended type 11 kV sub-station.

Q10b.	The three line leads of a 400/230 V, 3-phase, 4-wire supply are designated as R, Y and B respectively. The fourth wire or neutral wire is designated as N. The phase sequence is RYB. Compute the currents in the four wires when the following loads are connected to this supply : From R to N : 20 kW, unity power factor From Y to N : 28·75 kVA, 0·866 lag From B to N : 28·75 kVA, 0·866 lead If the load from B to N is removed, what will be the value of currents in the four wires ?	[8]	C403.3	L4

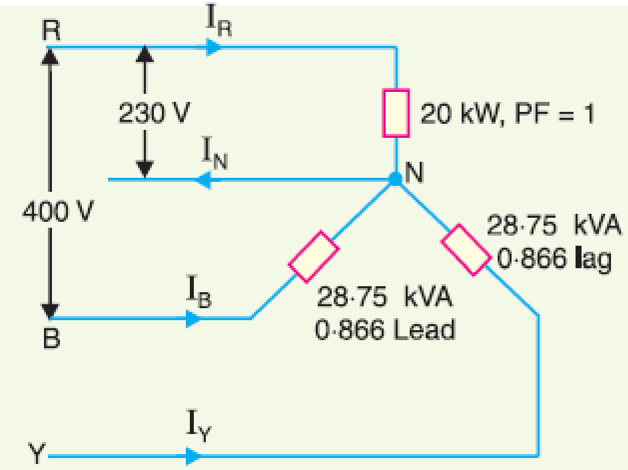


Fig. 14.17

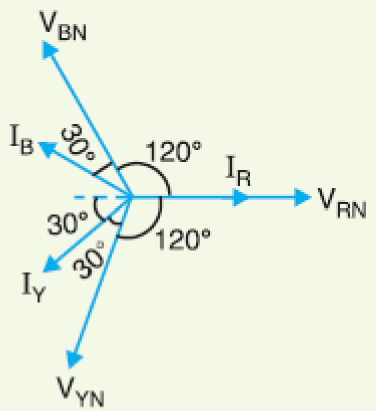


Fig. 14.18

Solution. Fig. 14.17 shows the circuit diagram whereas Fig.14.18 shows its phasor diagram. The current I_R is in phase with V_{RN}, current I_Y lags behind its phase voltage V_{YN} by $\cos^{-1} 0{\cdot}866 = 30^\circ$ and the current I_B leads its phase voltage V_{BN} by $\cos^{-1} 0{\cdot}866 = 30^\circ$.

$$I_R = 20 \times 10^3/230 = \mathbf{89{\cdot}96\ A}$$

$$I_Y = 28{\cdot}75 \times 10^3/230 = \mathbf{125\ A}$$

$$I_B = 28{\cdot}75 \times 10^3/230 = \mathbf{125\ A}$$

The current in the neutral wire will be equal to the phasor sum of the three line currents I_R, I_Y and I_B. Referring to the phasor diagram in Fig.14.18 and resolving these currents along *x*-axis and *y*-axis, we have,

Resultant *X*-component $= 86{\cdot}96 - 125 \cos 30^\circ - 125 \cos 30^\circ$

$= 86{\cdot}96 - 108{\cdot}25 - 108{\cdot}25 = -\ 129{\cdot}54$ A

Resultant *Y*-component $= 0 + 125 \sin 30^\circ - 125 \sin 30^\circ = 0$

$\therefore$ Neutral current, $I_N = \sqrt{(-129\cdot 54)^2 + (0)^2} = \mathbf{129{\cdot}54A}$

When load from *B* to *N* removed. When the load from *B* to *N* is removed, the various line currents are :

$I_R =$ **86·96A** in phase with V_{RN} ; $I_Y =$ **125A** lagging V_{YN} by 30° ; $I_B =$ **0 A**

The current in the neutral wire is equal to the phasor sum of these three line currents. Resolving the currents along *x*-axis and *y*-axis, we have,

Resultant *X*-component $= 86{\cdot}96 - 125 \cos 30^\circ = 86{\cdot}96 - 108{\cdot}25 = -\ 21{\cdot}29$ A

Resultant *Y*-component $= 0 - 125 \sin 30^\circ = 0 - 125 \times 0{\cdot}5 = -\ 62{\cdot}5$ A

$\therefore$ Neutral current, $I_N = \sqrt{(-\ 21\cdot 29)^2 + (-\ 62\cdot 5)^2} = \mathbf{66{\cdot}03\ A}$