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Internal Assesment Test - II

Sub:	Transmission & distribution							Code:	17EE43
Date:	16/04/2019	Duration:	90 mins	Max Marks:	50	Sem:	4	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE CO	OBE RBT
1	Each line of a 3 phase system is suspended by a string of 3 similar insulators. If the voltage across the line unit is 17.5 kV, calculate the line to neutral voltage. Assume that the shunt capacitance between each insulator and earth is 1/8 th of the capacitance of the insulator itself. Also find the string efficiency.	[10]	CO6	L3
2a	A 3 phase ,50 Hz,66kV over head line conductors are placed in a horizontal plane as shown in fig .The conductor diameter is 1.25cm.If the line length is 100 km, calculate 1) capacitance per phase 2)charging current per phase, assuming complete transposition of the line.	[5]	CO5	L3
2b	Mention different methods of increasing string efficiency	[5]	CO6	L2
3	Derive an expression for the inductance of a 3 phase over head line for symmetrical spacing and unsymmetrical spacing	[10]	CO5	L2
4	Discuss the nominal T method of a medium transmission line with appropriate circuit diagram and phasor diagram and hence obtain the expression for regulation and ABCD constants for the same.	[10]	CO5	L2
5	A 3 phase 50 Hz,16 km long overhead line supplies 1000kW at 11 kV,0.8 pf lagging. The lie resistance is 0.03Ω per phase per km and line reactance 0.219 Ω per phase per km. Calculate the sending end voltage ,voltage regulation and efficiency of transmission	[10]	CO5	L3
6	A 132 kV ,50 Hz ,3 phase transmission line delivers a load of 50 MW at 0.8 pf lagging at the receiving end. The generalized constants of the transmission line are A=D=0.9 5<1.4 ^{0} , B=96<78 ^{0}, C=0.0015<90 ^{0} .Find the regulation of the line and charging current. Use nominal T method.	[10]	CO5	L3

Solutions

1

the voltage ... capacitance between each insulator and earth is 1/8th of the ... find the string efficiency.

Solution. Fig. 8·15 shows the equivalent circuit of string insulators. If C is the self capacitance of each unit, then KC will be the shunt capacitance where $K = 1/8 = 0{\cdot}125$.

Voltage across line unit, $V_3 = 17{\cdot}5$ kV

At Junction A

$$I_2 = I_1 + i_1$$
$$V_2\,\omega C = V_1\,\omega C + V_1 K\,\omega C$$

or $V_2 = V_1(1 + K) = V_1(1 + 0.125)$

$\therefore$ $V_2 = 1{\cdot}125\,V_1$

At Junction B

$$I_3 = I_2 + i_2$$

or $V_3\,\omega C = V_2\,\omega C + (V_1 + V_2)\,K\,\omega C$

or $V_3 = V_2 + (V_1 + V_2)\,K$

$$= 1{\cdot}125\,V_1 + (V_1 + 1{\cdot}125\,V_1) \times 0.125$$

$\therefore$ $V_3 = 1{\cdot}39\,V_1$

Voltage across top unit, $V_1 = V_3/1{\cdot}39 = 17{\cdot}5/1{\cdot}39 = 12{\cdot}59$ kV

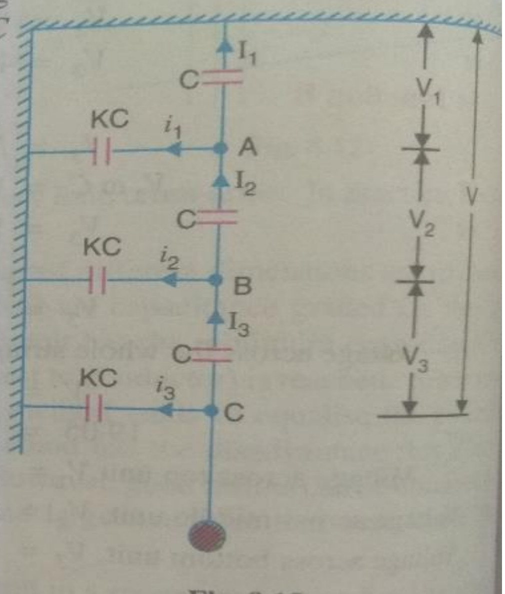


Fig. 8.15

Voltage across middle unit, $V_2 = 1{\cdot}125\,V_1 = 1{\cdot}125 \times 12{\cdot}59 = 14{\cdot}16$ kV

$\therefore$ Voltage between line and earth (*i.e.*, line to neutral)

$$= V_1 + V_2 + V_3 = 12{\cdot}59 + 14{\cdot}16 + 17{\cdot}5 = 44{\cdot}25 \text{ kV}$$

$$\text{String efficiency} = \frac{44\cdot 25}{3 \times 17\cdot 5} \times 100 = 84{\cdot}28\%$$

2A

... calculate (i) capacitance per phase, (ii) charging current per phase, assuming complete transposition of the line.

Solution. Fig 9.26 shows the arrangement of conductors of the 3-phase line. The equivalent equilateral spacing is

$$d = \sqrt[3]{d_1 d_2 d_3} = \sqrt[3]{2 \times 2\cdot 5 \times 4\cdot 5} = 2{\cdot}82 \text{ m}$$

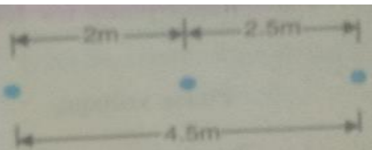


Fig. 9.26

Conductor radius, $r = 1{\cdot}25/2 = 0{\cdot}625$ cm

Conductor spacing, $d = 2{\cdot}82$ m $= 282$ cm

(*i*) Line to neutral capacitance $= \dfrac{2\pi\varepsilon_0}{\log_e d/r}$ F/m $= \dfrac{2\pi \times 8\cdot 854 \times 10^{-12}}{\log_e 282/0\cdot 625}$ F/m

$$= 0{\cdot}0091 \times 10^{-9} \text{ F/m} = 0{\cdot}0091 \times 10^{-6} \text{ F/km} = 0{\cdot}0091\ \mu\text{F/km}$$

$\therefore$ Line to neutral capacitance for 100 km line is

$$C = 0{\cdot}0091 \times 100 = 0{\cdot}91\ \mu\text{F}$$

(*ii*) Charging current per phase is

$$I_C = \frac{V_{ph}}{X_C} = \frac{66{,}000}{\sqrt{3}} \times 2\pi f C$$
$$= \frac{66{,}000}{\sqrt{3}} \times 2\pi \times 50 \times 0\cdot 91 \times 10^{-6} = 10{\cdot}9 \text{ A}$$

2B

(ii) The greater the value of K $(= C_1/C)$, the more non-uniform is the [illegible] and lesser is the string efficiency.

(iii) The inequality in voltage distribution increases with the increase of number of discs [illegible] string. Therefore, shorter string has more efficiency than the larger one.

8.8 Methods of Improving String Efficiency

It has been seen above that potential distribution in a string of suspension insulators is not uni[illegible]. The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross-arm is approached. If the insulation of the highest stressed insulator (i.e. nearest to conductor) breaks down or flash over takes place, the breakdown of other units will take place in succession. This necessitates to equalise the potential across the various units of the string i.e. to improve the string efficiency. The various methods for this purpose are :

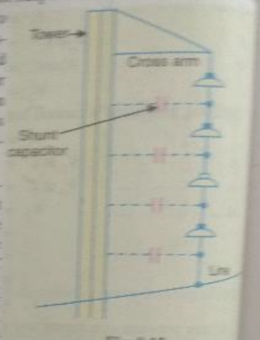
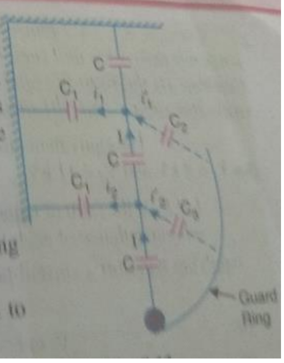


Fig. 8.12

(i) *By using longer cross-arms.* The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, $K =$ [illegible] is the limit that can be achieved by this method.

(ii) *By grading the insulators.* In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalise the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.

(iii) *By using a guard ring.* The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the Fig. 8.13. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i'_1, i'_2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.



Important Points

[In] solving problems relating to string efficiency, the following [points] must be kept in mind:

(i) The maximum voltage appears across the disc nearest to

3

The term r' $(= r\,e^{-1/4})$ is called *geometric mean radius* (GMR) of the wire. Note that eq. (iii) gives the same value of inductance L_A as eq. (i). The difference is that eq. (iii) omits the term to account for internal flux but compensates for it by using an adjusted value of the radius of the conductor.

Loop inductance $= 2\,L_A = 2 \times 2 \times 10^{-7} \log_e \frac{d}{r'}$ H/m

Note that $r' = 0{\cdot}7788\,r$ is applicable to only solid round conductor.

9.6 Inductance of a 3-Phase Overhead Line

Fig. 9.8 shows the three conductors A, B and C of a 3-phase line carrying currents I_A, I_B and I_C respectively. Let d_1, d_2 and d_3 be the spacings between the conductors as shown. Let us further assume that the loads are balanced i.e. $I_A + I_B + I_C = 0$. Consider the flux linkages with conductor A. There will be flux linkages with conductor A due to its own current and also due to the mutual inductance effects of I_B and I_C.

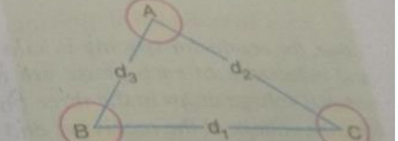


Fig. 9.8

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) \quad ...(i)$$

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi} \int_{d_3}^{\infty} \frac{dx}{x}$$

Flux linkages with conductor A due to current I_C

$$= \frac{\mu_0 I_C}{2\pi} \int_{d_2}^{\infty} \frac{dx}{x}$$

Total flux linkages with conductor A is

$$\psi_A = (i) + (ii) + (iii)$$

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi} \int_{d_3}^{\infty} \frac{dx}{x} + \frac{\mu_0 I_C}{2\pi} \int_{d_2}^{\infty} \frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) I_A + I_B \int_{d_3}^{\infty} \frac{dx}{x} + I_C \int_{d_2}^{\infty} \frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2 + \log_e \infty\,(I_A + I_B + I_C)\right]$$

As $I_A + I_B + I_C = 0$,

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

(i) Symmetrical spacing. If the three conductors A, B and C are placed symmetrically at the corners of an equilateral triangle of side d, then, $d_1 = d_2 = d_3 = d$. Under such conditions, the flux linkages with conductor A become :

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d - I_C \log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - (I_B + I_C) \log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A + I_A \log_e d\right] \qquad (\because I_B + I_C = -I_A)$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ weber-turns/m}$$

Inductance of conductor A, $L_A = \frac{\psi_A}{I_A}$ H/m $= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right]$ H/m

$$= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ H/m}$$

$$\therefore \quad L_A = 10^{-7}\left[0{\cdot}5 + 2\log_e \frac{d}{r}\right] \text{ H/m}$$

Derived in a similar way, the expressions for inductance are the same for conductors B and C.

(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.

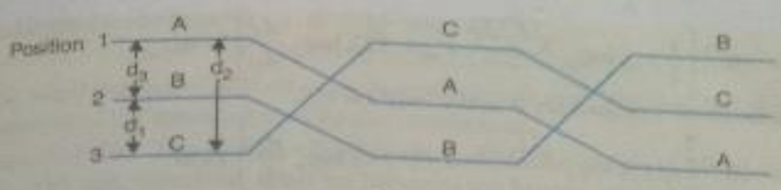


Fig. 9.9

Fig. 9.9 shows a 3-phase transposed line having unsymmetrical spacing. Let us assume that each of the three sections is 1 m in length. Let us further assume balanced conditions *i.e.*, $I_A + I_B + I_C = 0$. Let the line currents be :

$$I_A = I(1 + j\,0)$$
$$I_B = I(-0{\cdot}5 - j\,0{\cdot}866)$$
$$I_C = I(-0{\cdot}5 + j\,0{\cdot}866)$$

As proved above, the total flux linkages per metre length of conductor A is

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right)I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

Putting the values of I_A, I_B and I_C, we get,

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right)I - I(-0{\cdot}5 - j\,0{\cdot}866)\log_e d_3 - I(-0{\cdot}5 + j\,0{\cdot}866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0{\cdot}5\,I\log_e d_3 + j\,0{\cdot}866\log_e d_3 + 0{\cdot}5\,I\log_e d_2 - j\,0{\cdot}866\,I\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0{\cdot}5\,I(\log_e d_3 + \log_e d_2) + j\,0{\cdot}866\,I(\log_e d_3 - \log_e d_2)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + I\,^{*}\log_e \sqrt{d_2 d_3} + j\,0{\cdot}866\,I\log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I + I\log_e \frac{\sqrt{d_2\,d_3}}{r} + j\,0{\cdot}866\,I\log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2 d_3}}{r} + j\,0{\cdot}866\log_e \frac{d_3}{d_2}\right]$$

∴ Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A} = \frac{\psi_A}{I}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\,d_3}}{r} + j\,0{\cdot}866\log_e \frac{d_3}{d_2}\right]$$

* $0{\cdot}5\,I(\log_e d_3 + \log_e d_2) = 0{\cdot}5\,I\log_e d_2 d_3 = I\log_e (d_2 d_3)^{0{\cdot}5} = I\log_e \sqrt{d_2 d_3}$

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10.8 Nominal T Method

In this method, the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on its either side as shown in Fig. 10.11. Therefore, in this arrangement, full charging current flows over half the line. In Fig. 10.11, one phase of 3-phase transmission line is shown as it is advantageous to work in phase instead of line-to-line values.

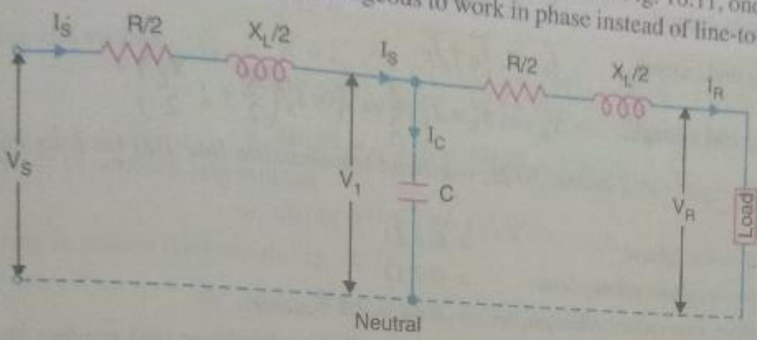

Fig. 10.11

Let I_R = load current per phase ; R = resistance per phase

X_L = inductive reactance per phase ; C = capacitance per phase

$\cos \phi_R$ = receiving end power factor (*lagging*) ; V_S = sending end voltage/phase

V_1 = voltage across capacitor C

The *phasor diagram for the circuit is shown in Fig. 10.12. Taking the receiving end voltage $\vec{V_R}$ as the reference phasor, we have,

Receiving end voltage, $\vec{V_R} = V_R + j\,0$

Load current, $\vec{I_R} = I_R(\cos \phi_R - j \sin \phi_R)$

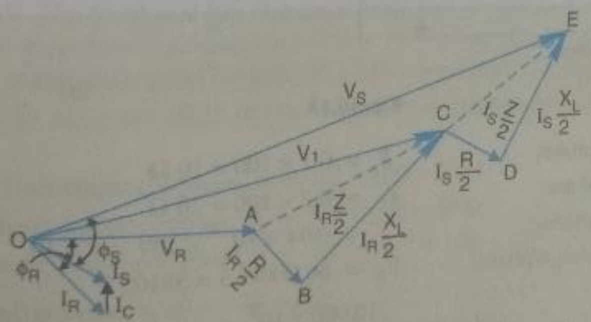

Fig. 10.12

* Note the construction of phasor diagram. $\vec{V_R}$ is taken as the reference phasor represented by OA. The load current $\vec{I_R}$ lags behind $\vec{V_R}$ by ϕ_R. The drop $AB = I_R\,R/2$ is in phase with $\vec{I_R}$ and $BC = I_R\,X_L/2$ leads $\vec{I_R}$ by 90°. The phasor OC represents the voltage $\vec{V_1}$ across condenser C. The capacitor current $\vec{I_C}$ leads $\vec{V_1}$ by 90° as shown. The phasor sum of $\vec{I_R}$ and $\vec{I_C}$ gives $\vec{I_S}$. Now $CD = I_S\,R/2$ is in phase with $\vec{I_S}$ while $DE = I_S\,X_L/2$ leads $\vec{I_S}$ by 90°. Then, OE represents the sending end voltage $\vec{V_S}$.

Voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\,\vec{Z}/2$

$$= V_R + I_R\,(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\,\frac{X_L}{2}\right)$$

Capacitive current, $\vec{I_C} = j\,\omega\,C\,\vec{V_1} = j\,2\pi\,f\,C\,\vec{V_1}$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

Sending end voltage, $\vec{V_S} = \vec{V_1} + \vec{I_S}\,\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + j\,\frac{X_L}{2}\right)$

and $AD - BC = \ldots$

Fig. 10.23

(*ii*) **Medium lines – Nominal T method.** In this method, the whole line to neutral capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on either side as shown in Fig. 10.24.

Here, $\vec{V_S} = \vec{V_1} + \vec{I_S}\,\vec{Z}/2$ ...(*v*)

and $\vec{V_1} = \vec{V_R} + \vec{I_R}\,\vec{Z}/2$

Now, $\vec{I_C} = \vec{I_S} - \vec{I_R}$

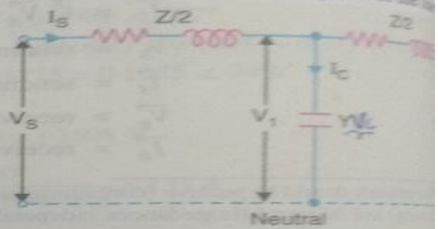

Fig. 10.24

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$$\vec{I_C} = \vec{V_1}\,\vec{Y} \quad \text{where } Y = \text{shunt admittance}$$

$$= \vec{Y}\left(\vec{V_R} + \frac{\vec{I_R}\,\vec{Z}}{2}\right)$$

$$\therefore \quad \vec{I_S} = \vec{I_R} + \vec{Y}\,\vec{V_R} + \vec{Y}\,\frac{\vec{I_R}\,\vec{Z}}{2}$$

$$= \vec{Y}\,\vec{V_R} + \vec{I_R}\left(1 + \frac{\vec{Y}\,\vec{Z}}{2}\right) \quad \text{...(vi)}$$

Substituting the value of V_1 in eq. (*v*), we get,

$$\vec{V_S} = \vec{V_R} + \frac{\vec{I_R}\,\vec{Z}}{2} + \frac{\vec{I_S}\,\vec{Z}}{2}$$

Substituing the value of I_S, we get,

$$\vec{V_S} = \left(1 + \frac{\vec{Y}\,\vec{Z}}{2}\right)\vec{V_R} + \left(\vec{Z} + \frac{\vec{Y}\,\vec{Z}^2}{4}\right)\vec{I_R} \quad \text{...(vii)}$$

Comparing eqs. (*vii*) and (*vi*) with those of (*i*) and (*ii*), we have,

$$\vec{A} = \vec{D} = 1 + \frac{\vec{Y}\,\vec{Z}}{2}\ ; \quad \vec{B} = \vec{Z}\left(1 + \frac{\vec{Y}\,\vec{Z}}{4}\right)\ ; \ \vec{C} = \vec{Y}$$

Incidentally :

$$\vec{A}\,\vec{D} - \vec{B}\,\vec{C} = \left(1 + \frac{YZ}{2}\right)^2 - Z\left(1 + \frac{YZ}{4}\right)Y$$

$$= 1 + \frac{Y^2Z^2}{4} + YZ - ZY - \frac{Z^2Y^2}{4} = 1$$

Example 10.8. *A 3-phase, 50 Hz, 16 km long overhead line supplies 1000 kW at 11kV, 0.8 lagging. The line resistance is 0·03 Ω per phase per km and line inductance is 0·7 mH per phase per km. Calculate the sending end voltage, voltage regulation and efficiency of transmission.*

Solution.

Resistance of each conductor, $R = 0{\cdot}03 \times 16 = 0{\cdot}48\ \Omega$

Reactance of each conductor, $X_L = 2\pi f L \times 16 = 2\pi \times 50 \times 0{\cdot}7 \times 10^{-3} \times 16 = 3{\cdot}52\ \Omega$

Receiving end voltage/phase, $V_R = \dfrac{11 \times 10^3}{\sqrt{3}} = 6351\ \text{V}$

Load power factor, $\cos \phi_R = 0{\cdot}8$ lagging

Line current, $I = \dfrac{1000 \times 10^3}{3 \times V_R \times \cos\phi} = \dfrac{1000 \times 10^3}{3 \times 6351 \times 0{\cdot}8} = 65{\cdot}6\text{A}$

Sending end voltage/phase, $V_S = V_R + I R \cos \phi_R + I X_L \sin \phi_R$

$= 6351 + 65{\cdot}6 \times 0{\cdot}48 \times 0{\cdot}8 + 65{\cdot}6 \times 3{\cdot}52 \times 0{\cdot}6 = 6515\ \text{V}$

$\therefore$ %age Voltage regulation $= \dfrac{V_S - V_R}{V_R} \times 100 = \dfrac{6515 - 6351}{6351} \times 100 = 2{\cdot}58\%$

Line losses $= 3 I^2 R = 3 \times (65{\cdot}6)^2 \times 0{\cdot}48 = 6{\cdot}2 \times 10^3\ \text{W} = 6{\cdot}2\ \text{kW}$

Input power $=$ Output power + Line losses $= 1000 + 6{\cdot}2 = 1006{\cdot}2$ kW

$\therefore$ Transmission efficiency $= \dfrac{\text{Output power}}{\text{Input power}} \times 100 = \dfrac{1000}{1006{\cdot}2} \times 100 = 99{\cdot}38\%$

Solution.

Receiving end voltage/phase, $V_R = 132 \times 10^3/\sqrt{3} = 76210$ V

Receiving end current, $I_R = \dfrac{50 \times 10^6}{\sqrt{3} \times 132 \times 10^3 \times 0.8} = 273$ A

$\cos \phi_R = 0.8; \quad \sin \phi_R = 0.6$

Taking receiving end voltage as the reference phasor, we have,

$$\vec{V_R} = V_R + j\,0 = 76210 \angle 0°$$

$$\vec{I_R} = I_R \angle -\phi_R = 273 \angle -36.9°$$

Sending end voltage per phase is

$$\begin{aligned}
\vec{V_S} &= \vec{A}\,\vec{V_R} + \vec{B}\,\vec{I_R} \\
&= 0.95 \angle 1.4° \times 76210 \angle 0° + 96 \angle 78° \times 273 \angle -36.9° \\
&= 72400 \angle 1.4° + 26208 \angle 41.1° \\
&= 72400 (\cos 1.4° + j \sin 1.4°) + 26208 (\cos 41.1° + j \sin 41.1°) \\
&= 72400 (0.9997 + j\,0.0244) + 26208 (0.7536 + j\,0.6574) \\
&= (72378 + j\,1767) + (19750 + j\,17229) \\
&= 92128 + j\,18996 = 94066 \angle 11.65° \text{ V}
\end{aligned}$$

Sending end current,

$$\begin{aligned}
\vec{I_S} &= \vec{C}\,\vec{V_R} + \vec{D}\,\vec{I_R} \\
&= 0.0015 \angle 90° \times 76210 \angle 0° + 0.95 \angle 1.4° \times 273 \angle -36.9° \\
&= 114 \angle 90° + 260 \angle -35.5° \\
&= 114 (\cos 90° + j \sin 90°) + 260 (\cos 35.5° - j \sin 35.5°) \\
&= 114 (0 + j) + 260 (0.814 - j\,0.58) \\
&= j\,114 + 211 - j\,150 = 211 - j\,36
\end{aligned}$$

Charging current,

$$\begin{aligned}
\vec{I_C} &= \vec{I_S} - \vec{I_R} = (211 - j36) - 273 \angle -36.9° \\
&= (211 - j\,36) - (218 - j\,164) = -7 + j\,128 = 128.2 \angle 93.1° \text{ A}
\end{aligned}$$

$$\% \text{ Regulation} = \frac{(V_S/A) - V_R}{V_R} \times 100 = \frac{94066/0.95 - 76210}{76210} \times 100 = 30\%$$

Example 10.18. *Find the following for a single circuit ...*