MODEL ANSWER

SUMMER - 2017 EXAMINATION

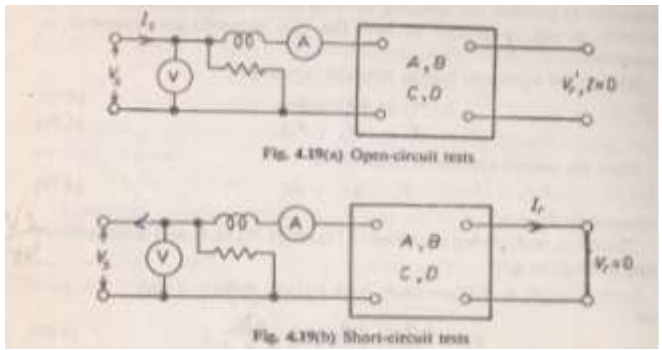
Subject: Power System Analysis **Subject Code: 17510**

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q. No.	Sub Q.N.	Answer	Marking Scheme
1.	**A)** **a)** Ans.	**Attempt any three of the following:** **State the role of power system engineer.** i. For operation of the power system he has to plan for generation of electricity where, when and by using what fuel. ii. He has to plan for expansion of the existing grid system and also for new grid system. iii. He coordinated operation of a vast and complex power network, so as to achieve a high degree of economy and reliability. iv. He has to be involved in constructional task of great magnitude both in generation and transmission. v. He has to solve problem of power shortages. vi. He has to evolve strategies for energy conservation and load management. vii. For solving the power system problems he has to develop new method.	**12** **4M** ***Any 4 point each 1M***
	b) Ans.	**Give expression for complex power, active power and reactive power at receiving end of a transmission line.** Complex power at the receiving end is given by	**4M**

		$S_R = V_R I_R^*$	***1M***
		$$P_R = \frac{\lvert V_S\rvert\lvert V_R\rvert}{\lvert B\rvert}\cos(\beta-\delta) - \frac{\lvert A\rvert\lvert V_R\rvert^2}{\lvert B\rvert}\cos(\beta-\delta)$$	***1M***
		$$Q_R = \frac{\lvert V_S\rvert\lvert V_R\rvert}{\lvert B\rvert}\sin(\beta-\delta) - \frac{\lvert A\rvert\lvert V_R\rvert^2}{\lvert B\rvert}\sin(\beta-\delta).$$	***1M***
		Where P_R= Real or active power in MW, Q_R= Reactive power in MVAR V_S = Sending end voltage per phase in KV V_R = Receiving end voltage per phase in KV δ = Power angle A, B = Generalized Circuit Constant	***1M***
	c) Ans.	**Justify "AC resistance is always higher than DC resistance".** When dc current flow in line conductor, the current is uniformly distributed across the section of the conductor whereas flow of alternating current is non uniform over the cross section in the manner that current density is higher at the surface of the conductor compared to the current density at its centre. This effect is more pronounced as frequency increases this phenomenon is called as skin effect. It causes power loss for given rms AC than the loss when same value of DC is flowing through the conductor. Therefore AC resistance is greater than DC resistance**.**	**4M** ***Explanation 4M***
	d) Ans.	**Describe stepwise procedure for measurement of generalised circuit constants.** Measurement of Generalized Circuit Constants can be done by conducting Open circuit and short circuit test. If a transmission line is already erected, the constants can be measured by conducting the open circuit and short circuit test on the two ends of the line. Consider a transmission line and determine the impedances which are complex quantities. The magnitudes are obtained by ratio of the voltages and currents and the angle with the help of wattmeter reading. The connection diagram are shown below	**4M** ***1M***



2M

The test is conducted on sending end side.

Now, $V_s = AV_R$ + BI_R------- (1)

I_s = CV_R + DI_R ------- (1)

From these = n. s. under o. c test

We to get, as I_R = CV_R

$\therefore Z_{so} = \frac{V_s}{I_s} = \frac{AV_R}{CV_R} = \frac{A}{C}$

-sending end impedance with receiving end open ckted.

From S.C. test as V_R = 0

V_s = B $I_R \times I_s$ = D I_R

$\therefore Z_{ss} = \frac{V_s}{I_s} = \frac{B}{D}$

-sending end impedance with receiving end s.c.ed

Note – These impedances $Z_{ss,}Z_{so}$are complex quantities, the magnitudes are obtained by the ratio of the voltages and currents. The angle is obtained with the help of wattmeter.

Similarly the same tests can be named out on receiving end side.

$\therefore$ From o.c. test –

Generalized = O.C can be written

As V_R = DV_s − BI_s

I_R = − CV_s + AI_s

Since the direction of sending end current according to the network whereas while performing the tests on receiving end side, the direction of the current will be leaving the network, therefore these equations become

V_R = DV_s + BI_s× (-I_R) = $-(V_s + A(-I_s)$

$\therefore -I_R = -$C$V_s - AI_s$

<table>
<tr><td></td><td></td><td>
$I_R = CV_s + AI_s$
From O. C. test, I_s = O
$Z_{ro} = \frac{V_R}{I_R} = \frac{DV_s}{CV_s} = \frac{D}{C}$
−receving end impedance with sending end open clcted.
From S.C. test, V_s=O
$Z_{rs} = \frac{V_R}{I_R} = \frac{BI_s}{AI_s} = \frac{B}{A}$
−receving end impedance with sending end s.ced
Now,
$Z_{ro} - Z_{rs} = \frac{D}{C} - \frac{B}{A} = \frac{AD-BC}{AC}$
$= \frac{1}{AC}$ $[AS\ AD - BC = 1]$
Now, $\frac{Z_{ro}-Z_{rs}}{Z_{so}} = \frac{1}{AC} \cdot \frac{C}{A} = \frac{1}{A^2}$
$\therefore \mathbf{A} = \sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$ ---------------------------(a)
$Z_{rs} = \frac{B}{A}$
or $\mathbf{B} = \mathbf{A}Z_{rs} = Z_{rs}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$ ----------------(b)
$Z_{so} = \frac{A}{C}$
$\therefore$ $\mathbf{C} = \frac{A}{Z_{so}} = \frac{1}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$ -----------------------(c)
$Z_{ro} = \frac{D}{C}$
$\therefore$ $\mathbf{D} = \mathbf{C} \cdot Z_{ro} = \frac{Z_{ro}}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$
$= Z_{ro}\sqrt{\frac{1}{(Z_{ro}-Z_{rs})Z_{so}}}$-----------(d)
If $Z_{ro} = Z_{so}$ we get A = D for symmetric network
</td><td>1M</td></tr>
<tr><td>1.</td><td>B)
a)

Ans.</td><td>
Attempt any one of the following:
Prove that AD – BC = 1 for a generalized circuit with π and T network.
i) Nominal π method:
Fig. shows medium tr line assuming total capacitance of the line divided into two parts and each half located at each end of the line
</td><td>6
6M</td></tr>
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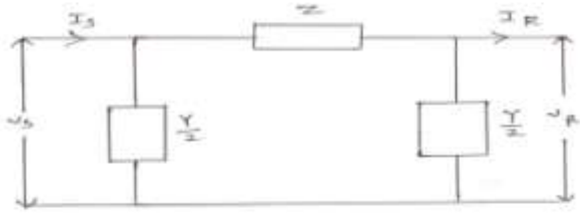


π - network.

$V_s = V_R\left(1+\frac{YZ}{2}\right) + I_R Z - - - - - - - - (i)$

$I_S = I_R\left(1+\frac{YZ}{2}\right) + V_R Y\left(1+\frac{YZ}{4}\right) - - - - - - (ii)$

1M

comparing equation(i)and(ii)with actual equation Vs &Is then

$A = D = 1 + YZ/2,$

$B = Z,$

$C = Y(1 + YZ/4)$

1M

Therefore

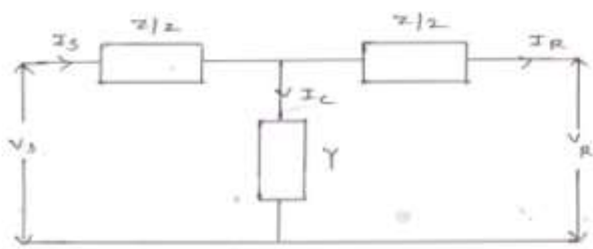
AD-BC = $\left(1+\frac{YZ}{2}\right)(1+\frac{YZ}{2}) - ZY((1+YZ/4)$

= 1

1M

ii) Nominal T method:

Figure shows the nominal T method with capacitance is connected at centre of line, the line resistance and reactance is halfly tempered on both side

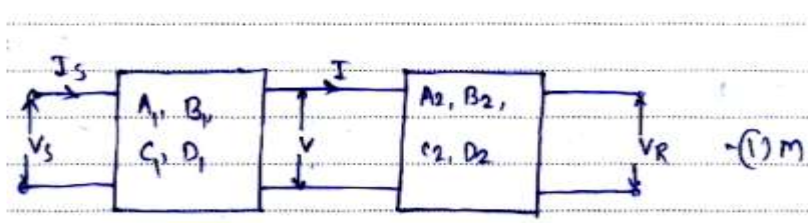


T - network.

$I_S = YV_R + I_R\left(1+\frac{YZ}{2}\right) - - - - (iii)$

$V_S = \left(1+\frac{YZ}{2}\right)V_R + \left(Z+\frac{YZ}{4}\right)I_R - - - - (iv)$

1M

		comparing equation (iii)and (ii)withactual equation V_S & I_S then $A = D = 1 + \frac{YZ}{2}$, $B = Z\left(1 + \frac{YZ}{4}\right)$, $C = Y$ Therefore AD-BC = $\left(1 + \frac{YZ}{2}\right)\left(1 + \frac{YZ}{2}\right) - YZ\left(1 + \frac{YZ}{4}\right)$ = 1	*1M* *1M*
	b) Ans.	**Give significance of inductance and resistance on performance of transmission line.** **Significance of inductance:** 1) It causes IX_L drop in transmission line which affects regulation 2) It is the only parameter which decides power transmission capacity of line i.e. if inductance decreases power transmission capacity increases. 3) It causes voltage drop which affects the voltage regulation of the line. **Significance of resistance:** 1) It causes voltage drop, so it affects regulation. 2) It causes I^2R loss which affects efficiency and temperature rise. 3) Whatever power loss occurs in transmission line is only due resistive parameter. 4) Though value of resistance is very small, it causes losses, temperature rise& poor voltage regulation so it cannot be neglected	**6M** ***Significance of inductance 3M*** ***Significance of resistance 3M***
2.	 **a)** **i)** Ans.	**Attempt any one of the following:** **Derive generalised circuit constants of two networks connected in series.**  	**16** **8M** ***1M***

		Two n/w are said to be connected in series when the o/p of one n/w is connected to the i/p of other n/w. Let the constants of these n/w be A_1, B_1, C_1, D_1 & A_2, B_2, C_2, D_2 which are connected in series as show in fig. These two n/w could be two transmission line or a transformer connected in to transmission line from equation of $V_R=DV_S-BI_S$ & $I_R=-CV_S+DI_S$ $\therefore V=D_1V_S-B_1I_S$ (1) $I= -C_1V_S+A_1I_S$ (2) & $V=A_2V_R+B_2I_R$ (3) $I=C_2V_R+D_2I_R$ (4) $D_1V_S – B_1V_S = A_2 V_R + B_2I_R$…………..(5) $-C_1V_S = A_1I_S = C_2V_R + D_2I_R$……………….(6) Multiply equation (5) by A_1 and (6) by B_1 and adding the equation $(A_1D_1-B_1C_1)V_S + (-B_1A_1+B_1A_1) I_S$ $= (A_1A_2+B_1(2)V_E + (A_1B_2+B_1B_2)IR$ $(A_1D_1-B_1C_1)V_S = (A_1A_2+B_1C_2) V_R + (A_1B_2+B_1D_2)I_R$………(7) Multiply equation (5) by G and (12) D_1 and add $(C_1D_1-D_1C_1)V_S + (-B_1C_1+A_1D_1) I_S = (A_2C_1+C_2D_1) V_R + (B_2C_1 +D_2D_1) I_R$ $(A_1D_1- B_1C_1)IS = (A_2C_1+C_2D_1) V_R + (B_2C_1+D_2D_1) I_R$…… (8) Since $A_1D_1 –B_1C_1 = 1$ from equation ………………………..(7) $V_S = (A_1A_2+B_1C_2) V_R + (A_1B_1+B_1D_2)I_R$………………………(9) From equation (8) $I_S = (A_2C_1+C_2D_1) V_R + (B_2C_1+D_2D_1) I_R$……………………..…..(10) but $V_S = AV_R+BI_R$………(11) $I_S = CV_R + DI_R$…….. (12) From equation (9), (10), (11) & (12) $A = A_1A_2+B_1C_2$ $B = A_1B_2+B_1D_2$ $C = A_2C_1 +C_2D_1$ $D = B_2C_1+D_2D_1$	***1M*** ***1M*** ***1M*** ***1M*** ***1M*** ***1M*** ***1M***

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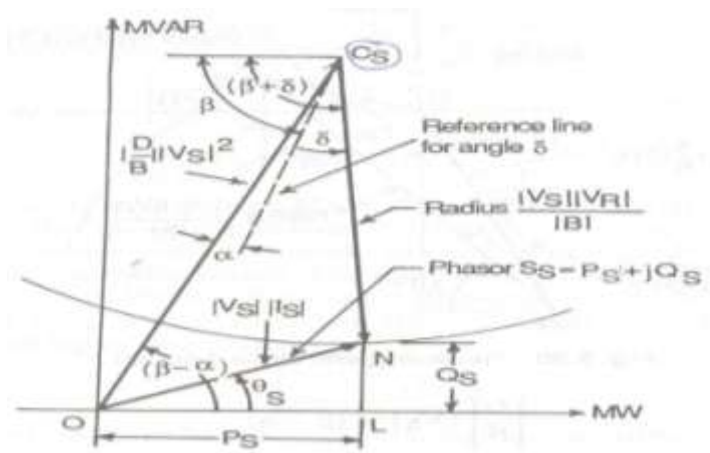
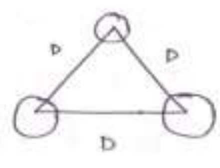
	ii) Ans.	**Describe the procedure for sending end circle diagram.** **Procedure for sending end circle diagram:** i. Step-1: Draw the X-Y plane in which plane X represents the active power (MW) & axis-y-represents the Reactive power (MVA). with proper scale. ii. Step-2: The centre of sending end circle is located at the tip of phaser $\|D/B\|\ 1V_S\|^2 < \beta - \alpha$ drawing OC_S from positive MW axis. OR locate X and Y coordinates of the centre are $\|D/B\|1V_S\|^2$ Cos $(\beta - \alpha)$ and $\|D/B\|1V_S\|^2$ Sin $(\beta - \alpha)$ and mark the point Cs. Join OCs. iii. Step-3: Radius = $\|V_S\|\|V_R\| / \|B$ Draw the Curve with the radius of sending end circle from centre Cs to the scale. iv. Step-4: Locate point Lon X axis such that OL represents Ps to the scale. Draw perpendicular at L to X axis which cuts the circle at point at N. Join NCs. N is the operating point of the system. Step-5: Complete the triangle ONL which represents power triangle at sending end.  	**8M** ***4M for procedure*** ***4M for diagram***
	b) Ans.	**A, 3 ϕ, 50Hz, OH line has regularly transposed conductors equilaterally spaced 4 m apart. Calculate the capacitance line to neutral for this arrangement. Recalculate the capacitance/km to neutral when conductors are in same horizontal plane with successive spacing of 4m, and are regularly transposed.**	**16M**

equilaterally spacing.



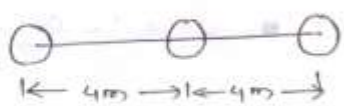
2 Marks for diagram.

$$C_{an} = \frac{2\pi \epsilon}{\log_e\left(\frac{D}{r}\right)} \quad \text{— 2 M.}$$

$$= \frac{2\pi \times 8.85 \times 10^{-12}}{\log\left(\frac{4}{r}\right)} \quad \text{— 2 M.}$$

$$C_{an} = \frac{5.56 \times 10^{-11}}{\log_e\left(\frac{4}{r}\right)} \ F/m \quad \text{— 2 M.}$$

Conductors are in same horizontal plane.



— 2 M.

$$C_{an} = \frac{2\pi \epsilon}{\log_e\left(\frac{D_{eq}}{r}\right)} \quad \text{— 2 M.}$$

$$D_{eq} = \sqrt[3]{4 \times 4 \times 8} = \sqrt[3]{128}$$

$$= 5.04 \quad \text{— 2 M.}$$

$$C_{an} = \frac{2\pi \times 8.85 \times 10^{-12}}{\log_e\left(\frac{5.04}{r}\right)} \ F/m \quad \text{— 2 M.}$$

OR

Considering or any value of r and solving by same procedure

	c)	**A line has following parameters A = D = 0.9 ∠0.4°, B = 99 ∠76.96°. The sending end and receiving end voltages are maintained at 220KV. Calculate the maximum power supplied by sending end. Also calculate sending end complex power for a load of 100MW at unity P.F. and $V_S = V_R$ = 220KV.**	**16M**
	Ans.	$A = D = 0.9\angle 0.4$ $B = 99\angle 76.96$ $\beta = 76.96$ $\alpha = 0.4$ $V_s = V_R = 220kV$ for P_{smax} $\beta + \delta = 180°$ — 1M $P_{smax} = \frac{AV_s^2}{B}\cos(\beta-\alpha) + \frac{V_sV_R}{B}$ — 2M $= \frac{0.9\times220^2}{99}\cos(76.96-0.4) + \frac{220^2}{99}$ — 1M $P_{smax} = 591.156$ MW — 1M For unity load, receiving end Q_R is zero. $Q_R = 0$ — 1M $Q_R = \frac{V_sV_R}{B}\sin(\beta-\delta) - \frac{AV_R^2}{B}\sin(\beta-\alpha)$ — 1M $0 = \frac{220^2}{99}\sin(76.96-\delta) - \frac{0.9\times220^2}{99}\sin(76.96-0.4)$ — 1M $0 = 488.88\sin(76.96-\delta) - 427.95$ $\sin(76.96-\delta) = 0.875$ $\delta = 15.92°$ — 2M To calculate S_s, substitute δ in the following express. $S_s = \frac{AV_s^2}{B}\angle\beta-\alpha - \frac{V_sV_R}{B}\angle\beta+\delta$ — 2M $= \frac{0.9\times220^2}{99}\angle 76.96-0.4 - \frac{220^2}{99}\angle 76.96+15.92$ — 2M $= 126.82 - j\,60.31$ MVA — 2M	

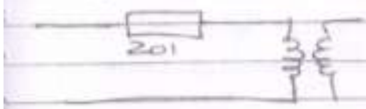
3. **Attempt any four of the following:** **16**

a) **Prove that p.u. reactance of transformer remains same referred to both sides of transformer.** **4M**

Ans.

Now Z_{pu} can be determined directly from the approximate equ. ckt on prim. side or sec side

On prim. side →



$Z_{01} = Z_1 + Z_2/k^2$

$= Z_{1pu} Z_{1B} + \frac{Z_{2pu} Z_{2B}}{k^2}$

$= Z_{1pu} Z_{1B} + Z_{2pu} Z_{1B}$ ***1M***

Per

$k = \frac{V_{2B}}{V_{1B}} = \frac{I_{2B} Z_{2B}}{I_{1B} Z_{1B}}$

$= \frac{Z_{2B}}{Z_{1B}} \cdot \frac{1}{k}$ $\quad \frac{V_2}{V_1} = \frac{I_{1B}}{I_{2B}} = k$

$\therefore \frac{Z_{2B}}{Z_{1B}} = k^2$ or $Z_{1B} = \frac{Z_{2B}}{k^2}$ ***1M***

∴ From above equn.

$Z_{01} = Z_{1pu} \cdot Z_{1B} + Z_{2pu} \cdot Z_{1B}$

$= (Z_{1pu} + Z_{2pu}) Z_{1B}$

or $\frac{Z_{01}}{Z_{1B}} = Z_{1pu} + Z_{2pu}$ ***1M***

i.e. $Z_{pu} = Z_{1pu} + Z_{2pu}$

On sec side →

$Z_{02} = Z_2 + Z_1 k^2$

$= Z_{2B} \cdot Z_{2pu} + Z_{1pu} Z_{1B} k^2$

$= (Z_{2pu} + Z_{1pu}) Z_{2B}$ $\quad \because \frac{Z_{2B}}{Z_{1B}} = k^2$

$\therefore \frac{Z_{02}}{Z_{2B}} = Z_{2pu} + Z_{1pu}$

$Z_{pu} = Z_{1pu} + Z_{2pu}$ ***1M***

		Therefore it is prove that p.u. reactance of transformer remains same referred to both sides of transformer.	
	b) Ans.	**Write expression for co-ordinates of center and radius for sending end and receiving end circle diagram.** **For Sending End circle diagram:** i. The centre of sending end circle is located at the tip of phasor |D/B| $1V_S\|^2 < \beta - \alpha$ drawing OC_S from positive MW axis. The X and Y coordinates of the center are $x - co - ordinate = \frac{DIV_S^2}{B}\cos(\beta - \alpha)MW$ $Y{-}co{-}ordinate{=}\frac{DIV_S^2}{B}\sin(\beta - \alpha)MVAR$ ii. The radius of sending end circle is drawn with $\|V_S\|\|V_R\| / \|B\|$ from center $C_{S.}$ **For Receiving End:** i. The centre of receiving end circle is located at the tip of phasor |A/B| $1V_r\|^2 < \beta - \alpha$ drawing OC_S from positive MW axis The X and Y coordinates of the center are |A/B| $1V_r\|^2$ Cos $(\beta - \alpha)$ and |A/B| $1V_r\|^2$ Sin $(\beta - \alpha)$ ii. The radius of Receiving end circle is drawn with $\|V_S\|\|V_R\| / \|B\|$ from centre $C_{S.}$	**4M** ***1M*** ***1M*** ***1M*** ***1M***
	c) Ans.	**Determine the inductance of 3-phase line operating at 50 Hz and conductors are arranged at corners of symmetrical triangle with side 3.4m and diameter of each conductor is 0.8 cm.** $L_x = L_y = L_B = 2 \times 10^{-7} \log_e \frac{D}{r^1}$ $D = 3.4\, m$ $r^1 = 0.7788r = 0.7788 \times (0.8 \times 10^{-2}) = 0.00623m$ $L_x = L_y = L_B = 2 \times 10^{-7} \log_e (\frac{3.4}{0.00623})$ $= 1.2604 \times 10^{-6} \frac{H}{M} = 1.2604\, mH/KM$	**4M** ***1M*** ***1M*** ***1M*** ***1M***

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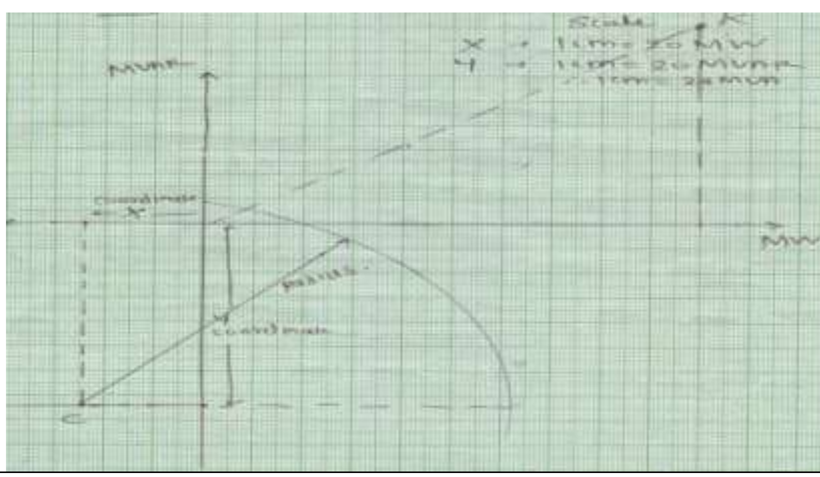
	d)	**A 132 KV, 3 phase line has constants A = 0.89 ∠3^0, B = 100 ∠75^0 ohm/ph. The line is to be operated with both end voltages at 132 KV. Draw receiving end power circle diagram for a load of 200 M W at 0.8 p.f. lagging.**	**4M**
	Ans.	$V_S = V_R = 132$ kV $A = 0.89\angle 3^\circ$, $B = 100\angle 75$ Load = 200 MW, 0.8 lag. RE circle dia → X-coordinate = $\frac{-AV_R^2}{B}\cos(\beta-\alpha)$ $= \frac{-0.89\times 132^2}{100}\cos(75-3) = -47.92$ MW → ½M Y coordinate = $\frac{-AV_R^2}{B}\sin(\beta-\alpha)$ $= \frac{-0.89\times 132^2}{100}\sin(75-3) = -147.48$ MVAR → ½M Radius = $\frac{V_S V_R}{B} = \frac{132\times 132}{100} = 174.24$ MVA → ½M Selecting scale – X axis 1cm = 20MW Y-axis 1cm = 20MVAR ∴ 1cm = 20MVA Drawing circle dia – 1M 	

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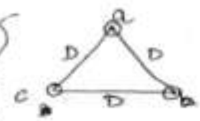
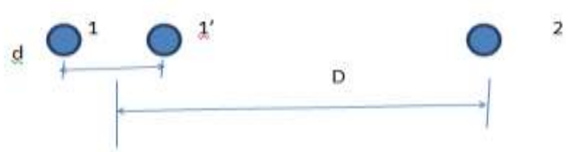
Subject: Power System Analysis **Subject Code: 17510**

	e) Ans.	**Derive an expression for capacitance of 3-ph, transmission line with equal spacing.** Capacitance of 3φ transmission line with symmetrical arrangement. 1 mark  Consider 3-phase line with symmetrical spacing. Let the radius of each conductor be r and spacing between conductors be D. We can write expressions for V_{ab} and V_{ac} as. 1 mark $V_{ab} = \frac{1}{2\pi\varepsilon}\left[q_a \ln\frac{D}{r} + q_b \ln\frac{r}{D} + q_c \ln\frac{D}{D}\right]$ — ① $V_{ac} = \frac{1}{2\pi\varepsilon}\left[q_a \ln\frac{D}{r} + q_b \ln\frac{D}{D} + q_c \ln\frac{r}{D}\right]$ — ② Adding eqn ① & ② we get 1 mark $V_{ab}+V_{ac} = \frac{1}{4\pi\varepsilon}\left[2q_a \ln\frac{D}{r} + (q_b+q_c)\ln\frac{r}{D}\right]$ — ③ If there are no other charges in vicinity $q_a+q_b+q_c=0$ or $q_b+q_c=-q_a$. $\therefore V_{ab}+V_{ac} = \frac{3q_a}{2\pi\varepsilon}\ln\frac{D}{r}$ — ④ If the three phase voltages are V_{an}, V_{bn} & V_{cn} then 1 mark $V_{an} = V\angle 0$, $V_{bn} = V\angle -120°$, $V_{cn} = V\angle +120°$ — ⑤ $V_{ab} = V_{an}-V_{bn} = V\angle 0° - V\angle -120° = \sqrt{3}V\angle 30°$ — ⑥ $V_{ac} = V_{an}-V_{cn} = V\angle 0° - V\angle +120° = \sqrt{3}V\angle -30°$ — ⑦ $V_{ab}+V_{ac} = \sqrt{3}V\angle 30° + \sqrt{3}V\angle -30° = 3V = 3V_{an}$ — ⑧ $V_{an} = \frac{q_a}{2\pi\varepsilon}\ln\frac{D}{r}$. The line to neutral capacitance is. $C_n = \frac{q_a}{V_{an}} = \frac{2\pi\varepsilon}{\ln D/r}$ F/m. $C_n = \frac{0.0242}{\log D/r}$ μF/km.	**4M** *1M* *1M* *1M* *1M*
4.	**A)** **a)** Ans.	**Attempt any three of the following:** **Define self GMD and mutual GMD.** Definition of Self & mutual GMD $L_A = 2\times10^{-7} In\frac{[(D_{11'}\ldots D_{1j'}\ldots D_{1m'})\ldots(D_{i1'}\ldots D_{ij'}\ldots D_{im'})\ldots(D_{n1'}\ldots D_{nj'}\ldots D_{nm'})]^{1/m'n}}{[(D_{11}\ldots D_{1i}\ldots D_{1n})\ldots(D_{i1}\ldots D_{ii}\ldots D_{in})\ldots(D_{n1}\ldots D_{ni}\ldots D_{nm})]^{1/n^2}} H/m$	**12** **4M**

		$$L_A = 2 \times 10^{-7} In \frac{Dm}{Ds} H/m$$ Ds --GMR: the denominator of the argument of the logarithm in above Equation is the n^2th root of n^2 product terms (n sets of n product terms each). Each set of n product term pertains to a filament and consist of r' (D_{ii}) for that filament and $(n-1)$ distances from that filament to every other filament in conductor A. The denominator is defined as the self-geometric mean distance (self GMD) of conductor A, and is abbreviated as D_{sA}. Sometimes, self GMD is also called geometric mean radius Similarly, Dm --GMD: The numerator of the argument of the logarithm in above Equation is the m'nth root of the m'n terms, which are the products of all possible mutual distances from the n filaments of conductor A to m' filaments of conductor B. It is called mutual geometric mean distance(mutual GMD) between conductor A and B and abbreviated as D_m. Example let radius of conductor X & Y is = r  Self GMD of conductor X = $\sqrt[4]{D_{11} D_{1'1'} D_{11'} D_{1'1}}$ = $\sqrt[4]{r' x\, r' x\, d\, x\, d}$ $=\sqrt{r' x d}$ Self GMD of conductor Y = r' Mutual GMD between conductor X & Y = $\sqrt{D_{12} D_{1'2}}$ = $\sqrt{\left(\frac{d}{2}+D\right) x \left(D-\frac{d}{2}\right)}$	***Self GMD 2M*** ***Mutual GMD 2M***
	b) Ans.	**A 275 KV, 3ph, transmission line has following parameters. A = 0.93 $\angle 1.5^0$, B = 115 $\angle 77^0$, if receiving end voltage is 275 KV. Draw receiving end circle diagram and determine sending end voltage required if load of 250MV at 0.85 lag p.f. is being delivered at receiving end.**	**4M**

$A = 0.93\angle 1.5$, $B = 115\angle 77$, load = 250 MW $\angle 0.85$ lag.

$V_R = 275$ kV

Receiving end circle dia →

X coordinates $= -\frac{A V_R^2}{B}\cos(\beta-\alpha)$

$= -\frac{0.93 \times 275^2}{115}\cos(77-1.5) = 153.13$ MW $= 3.06$ cm **1M**

y coordinates $= -\frac{A V_R^2}{B}\sin(\beta-\alpha)$

$= -\frac{0.93 \times 275^2}{115}\sin(77-1.5) = 592.095$ MVAR $= 11.84$ cm **1M**

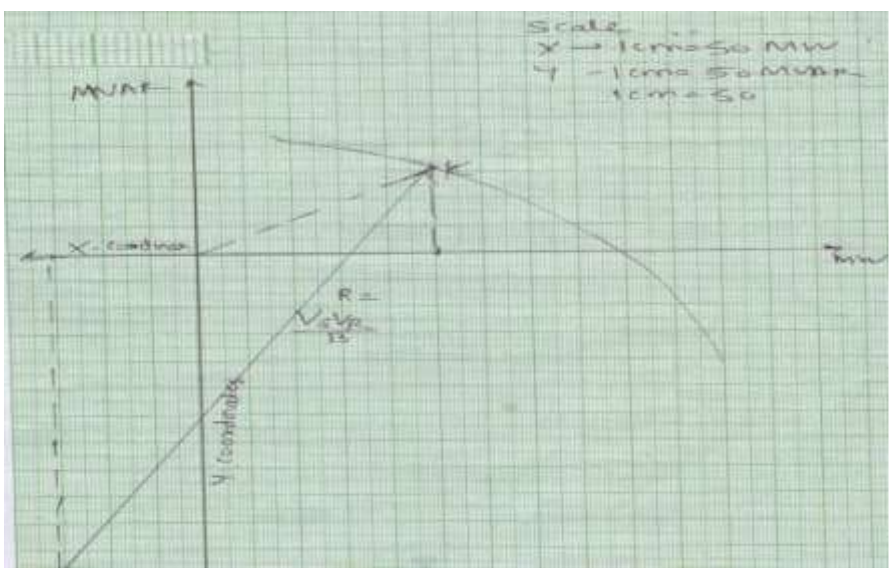
Scale - X axis 1cm = 50 MW
Y axis 1cm = 50 MVAR
1cm = 50 MVA

From graph

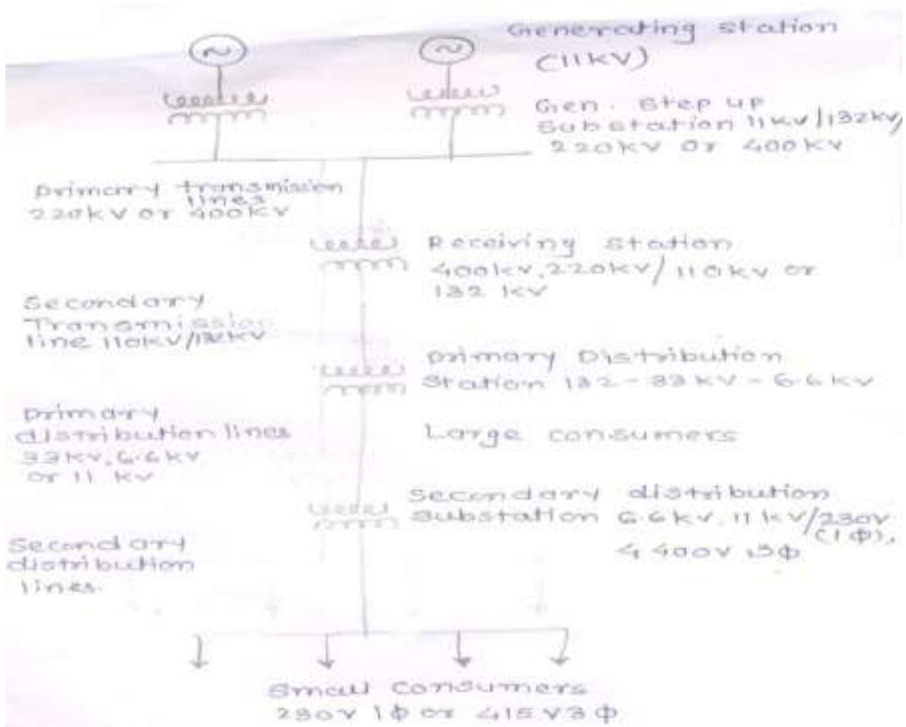
Radius = 17.1 cm = 17.1 × 50 = 855 MVA

$855 = \frac{V_S V_R}{B} = \frac{V_S \times 275}{115}$

$\therefore V_S = 357.54$ kV **1M**



1M

	c) Ans.	**Draw a basic structure of modern power system showing different voltage levels.**  	**4M** ***4M for correct diagram showing all voltage levels***
	d) Ans.	**State the field of application of reactive power compensation equipment given below:** **i) Shunt capacitor bank ii) Series inductance reactor** **iii) Synchronous condenser iv) Auto transformer** **Field of application of reactive power compensation equipment:** i) shunt capacitor bank –substation & medium Tr. Line ii) Inductance reactor bank- long HV tr. Line iii) Syn. condenser- load centre iv) Auto transformer – substations	**4M** ***1M each***
4.	**B)** **a)** Ans.	**Attempt any one of the following:** **A balanced load of 50 MVA is supplied at 132 KV, 50Hz, 0.8 p.f. lag by means of transmission line. The series impedance is 180 ∠75^0 Ω/ph and total shunt admittance is 1 x 10^{-3} ∠90^0 Siemens/ph. Calculate A, B, C, D constants using nominal π method.** $Z = 180\angle 75^o\Omega$ $Y = 1\times 10^{-3}\angle 90^0$	**6** **6M**

$for\ Nominal\ \pi - circuit$

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

$A = D = \frac{1+yz}{2} = 1 + [\frac{(1\times10^{-3}\angle 90^0).(180\angle 75^o)}{2}]$ ***1M***

$A = 1 + \frac{0.18\angle 165}{2}$

$A = 1 + 0.09\angle 165$

$A = 0.913 + j0.02329 = 0.913\angle 1.46 = D$ ***2M***

$B = Z = 180\angle 75^o\Omega$ ***1M***

$C = Y\left(1 + \frac{yz}{4}\right) = 1\times10^{-3}\angle 90^0\left[1 + \frac{\left(1\times10^{-3}\angle 90^0\right)(180\angle 75^o)}{4}\right] =$

$= 1\times10^{-3}\angle 90^0 x 0.9566\angle 0.697$

$= 9.566\ \times 10^{-4}\angle 90.697 siemens)$ ***2M***

b) Find self GMD for following arrangement **6M**

Fig. i Fig. ii

Ans.

Fig. i:

Self GMD $D_S = \sqrt[9]{(D_{11}D_{12}D_{13})(D_{21}D_{22}D_{23})(D_{31}D_{32}\ D_{33})}$ ***1M***

$D_{11} = D_{22} = D_{33} = 0.7788$ r

$D_{12} = D_{23} = D_{32} = D_{21} = 2r\ (D_{11}D_{12}D_{13})^2$

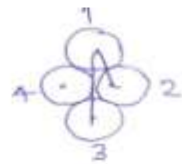
$D_{13} = D_{31} = 4r$ ***1M***

Self GMD DS = $\sqrt[9]{(D_{11}D_{12}D_{13})^2(D_{21}D_{22}D_{23})}$

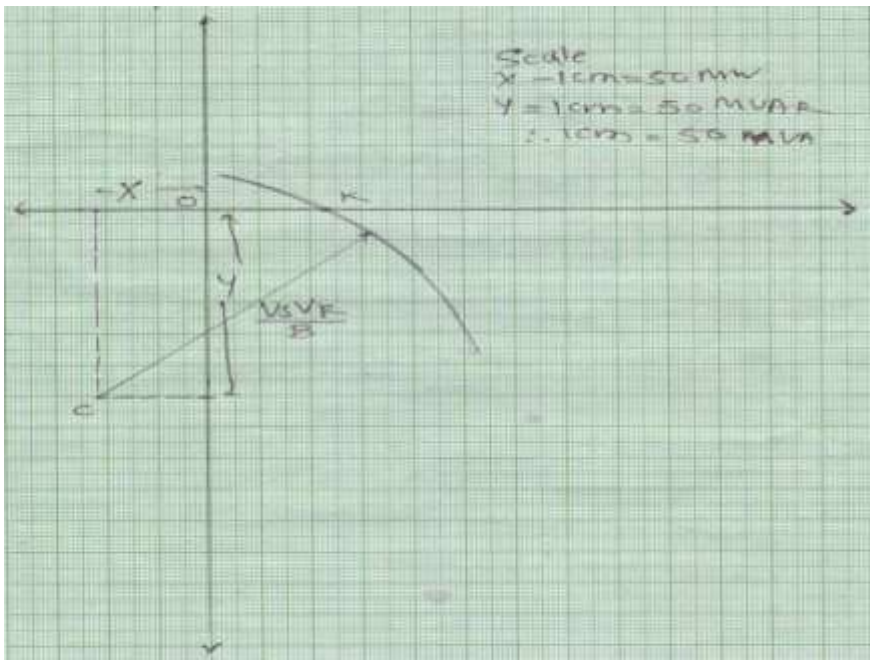
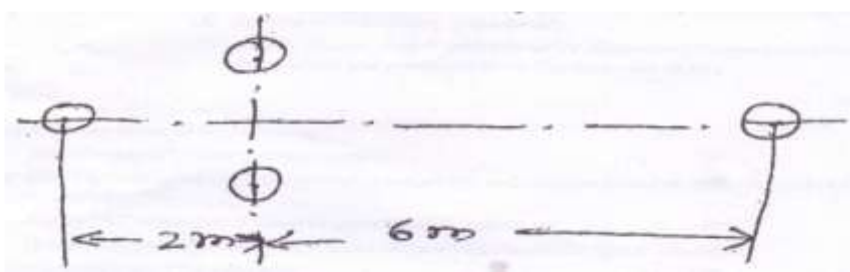
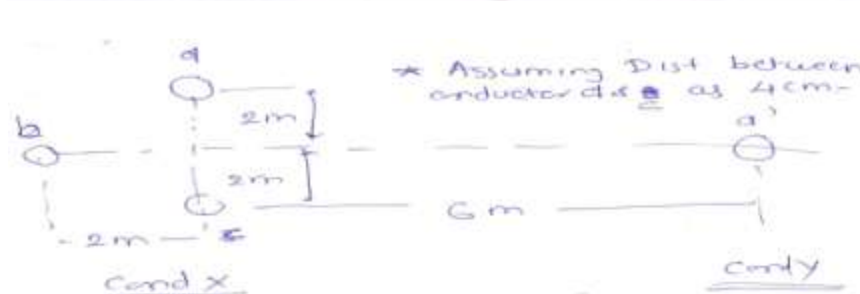
$= \sqrt[9]{(0.7788r\ X\ 2R\ X\ 4r\ )^2(2r\ X\ 0.7788\ r\ X\ 2r)}$

$= \sqrt[9]{(r\ )^9(120.92)}$

Self GMD = 1,70 r cm ***1M***

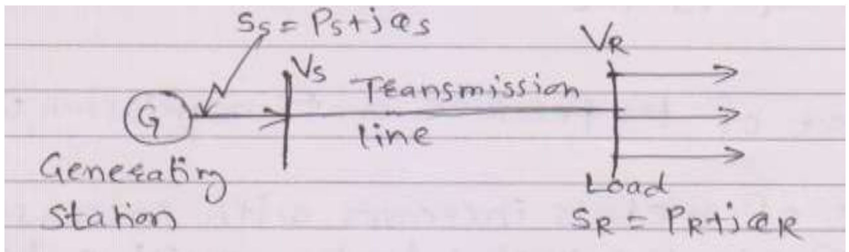
		Fig. ii:  $D_{13} = 2\sqrt{(2r)^2 - r^2} = 2\sqrt{3}r$ $D_S = \sqrt[16]{(D_{11}D_{12}D_{13}D_{14})^2 (D_{21}D_{22}D_{23}D_{24})^2}$ $D_{11} = r'$ $D_{21} = 2r$ $D_{12} = 2r$ $D_{22} = r'$ $D_{13} = 2\sqrt{3}r$ $D_{23} = 2r$ $D_{14} = 2r$ $D_{24} = 2r$ $D_S = \sqrt[8]{(D_{11}D_{12}D_{13}D_{14})(D_{21}D_{22}D_{23}D_{24})}$ $= \sqrt[8]{(r' \times 2r \times 2\sqrt{3}r \times 2r)(2r \times r' \times 2r \times 2r)}$ $= \sqrt[8]{(0.7788^2 \times 32 \times 2\sqrt{3}) \times r^8}$ $= 1.69 r$	*1M* *1M* *1M*
5.	**a)** Ans.	**Attempt any two of the following:** **A 132 KV, 50Hz, 3-phase line delivers load at 40 MW, 0.8 p.f. lag, at receiving end. The GCC of line are, A = 0.95 $\angle 1.4^0$, B = 96 $\angle 78^0$, C = 0.0015 $\angle 90^0$. Calculate sending end voltage, sending end current and voltage regulation. Use nominal T-method.** $given: V_R = 132KV, \quad A = 0.95\angle 1.4, \quad B = 96\angle 78$ $load = 40Mw, 0.8lag$ $load = \sqrt{3}V_R I_R \cos\emptyset_R = 40 \times 10^6$ $= \sqrt{3}\, X132 \times 10^3 \times I_R \times 0.8$ $\therefore I_R = 218.69\ Amp \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{1M})$ $\emptyset_R = \cos^{-1} 0.8 = 36.86$	**16** **8M**

		$V_S = AV_R + BI_R$ $= 0.95\angle 1.4 \times 132 \times 10^3\angle 0 + 96\angle 78$ $\times 218.69\angle -36.86 \ldots.(\mathbf{1M})$ $V_s = 142.178\angle 6.816\ KV \ldots\ldots\ldots\ldots\ldots(\mathbf{1M})$ $I_S = CV_R + DI_R$ $= 0.0015\angle 90 \times 132 \times 10^3\angle 0 + 0.95\angle 1.4 \times 218.69\angle -36.86$ $\ldots.(\mathbf{1M})$ = 186.11 ∠ 24.599 Amp $\ldots.(\mathbf{1M})$ Voltage regulation = $\dfrac{\frac{Vs}{A} - -V_{RFL}}{V_{RFL}}$ X 100 $\ldots.(\mathbf{1M})$ $= \dfrac{\frac{142.178}{0.95} - 132}{132}$ x 100 $\ldots.(\mathbf{1M})$ = 19.68% $\ldots.(\mathbf{1M})$	
	b) Ans.	**With the help of receiving end circle diagram, determine complex power delivered at unity p.f. if voltage at each end of line is maintained at 275 KV. Given that A = 0.85 ∠5^0, B = 200 ∠75^0.** $V_S = V_R = 275$ KV $A = 0.85\angle 5$, $B = 200\angle 75$ RE circle dia — X-coordinates $= \frac{-AV_R^2}{B}\cos(\beta-\alpha)$ $= -\frac{0.85\times 275^2}{200}\cos(75-5) = 109.93$ MW $= \underline{2.198}$ cm → 2M Y coordinates $= \frac{-AV_R^2}{B}\sin(\beta-\alpha)$ $= \frac{-0.85\times 275^2}{200}\sin(75-5) = 302.02$ MVAR $= \underline{6.04}$ cm → 2M Radius $= \frac{V_S V_R}{B} = \frac{275\times 275}{200} = 378.125$ MVA $= \underline{7.56}$ cm → 2M scale X → 1cm = 50MW Y → 1cm = 50MVAR 1cm = 50 From graph — power delivered at unity PF OK = 2.3 cm = 2.3 × 50 = $\underline{115}$ MW → 2M	**8M**

			
	c)	**Determine inductance of line for arrangement shown in figure. Diameter of each conductor is 1cm.** 	**8M**
	Ans.		

		$d_{1a} = 1cm.$ $L_x = 2\times10^{-7}\log_e \frac{D_m}{D_{sx}}$ & $L_y = 2\times10^{-7}\log_e \frac{D_m}{D_{sy}}$ → 1M $D_m = \sqrt[3]{D_{aa'} D_{ba'} D_{ca'}}$ $D_{aa'} = \sqrt{2^2+6^2} = 6.32m$ $D_{ba'} = -{''}- = 6.32m$ $D_{ca'} = 2+6 = 8m$ $\therefore D_m = \sqrt[3]{6.32\times6.32\times8} = 6.84\ m$ → $1\frac{1}{2}$M $D_{sx} = \sqrt[9]{(D_{aa} D_{ab} D_{ac})^2 (D_{ca} D_{cb} D_{cc})}$ $D_{aa} = D_{cc} = r' = 0.7788\times0.5\times10^{-2}$ $= 3.894\times10^{-3}\ m$ $D_{ab} = 2+2 = 4m.$ $D_{ac} = D_{ca} = D_{cb} = \sqrt{2^2+2^2} = 2.83\ m.$ $\therefore D_{sx} = \sqrt[9]{(3.894\times10^{-3}\times4\times2.83)^2(2.83^2\times3.894\times10^{-3})}$ $= 0.3399$ → $1\frac{1}{2}$M $\therefore L_x = 2\times10^{-7}\log_e \frac{6.84}{0.3399} = 6.0038\times10^{-7}\ H/m$ → $1\frac{1}{2}$M $0.60038\ mH/km$ $D_{sy} = D_{aa'} = 0.7788r = 0.7788\times0.5\times10^{-2} = 3.894\times10^{-3}$ → 1M $\therefore L_y = 2\times10^{-7}\log_e \frac{6.84}{3.894\times10^{-3}} = 1.494\times10^{-6}\ H/m$ $= 1.494\ mH/km$ → $\frac{1}{2}$M	

6.		**Attempt any four of the following:**	**16**
	a)	**Derive the expression for complex power at sending end of transmission line.**	**4M**
	Ans.		



1M

Figure shows the single line diagram of a 3Ø transmission line.

- In the figure two bus system having the sending end bus which is fed by the generator and the receiving end bus which feeds the load.
- S_R is the complex power of the receiving end and S_S is the complex power at the sending end.
- Using the current I_S can be expressed in terms of V_R and V_S as:

$$I_S = \frac{D}{B}V_S - \frac{1}{B}V_R = \frac{A}{B}V_S - \frac{1}{B}V_R \text{.......(i)}$$

Let, $V_R = |V_R| \angle 0, V_S = |V_S| \angle 0$, D = A = |A| $\angle \propto$, B = |B| $\angle B$

1M

Then $I_S = \frac{|A||V_S|}{B}(\angle \propto + \delta - \beta) - \frac{|V_R|}{B} - \angle B$

The conjugates of I_S are

1M

$$Is^* = \frac{|A||V_S|}{B}(\angle \beta - \propto - \delta) - \frac{|V_R|}{B} \quad \angle B$$

The complex power/phase at the sending end are

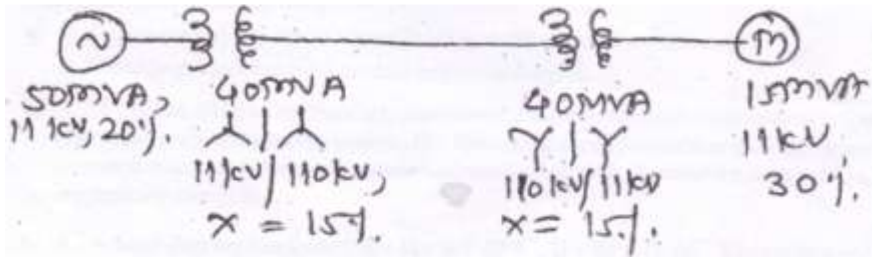
$$S_S = P_S + jas = V_S {I_S}^*$$

$$S_S = |V_S| \delta \left[\frac{|A||V_S|}{|B|}(\beta \angle \propto - \delta) - \frac{|V_R|}{|B|} \angle B\right]$$

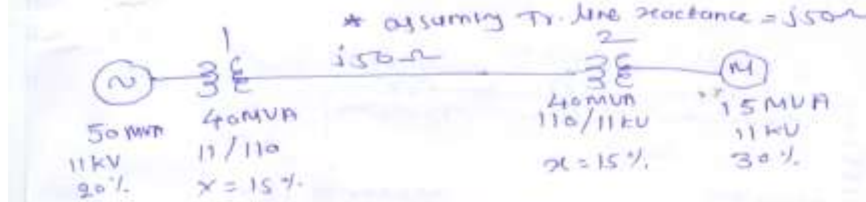
$$S_S = \frac{|A||V_S|^2}{|B|} (\angle \beta - \propto) - \frac{|V_R||v_S|}{|B|}(\angle \beta + \delta)$$

The above equation is the sending end side complex power. ***1M***

b) **Draw reactance diagram for following power system.** **4M**



Ans.



Considering 50MVA as base MVA.

Base V → Generator side – 11KV
Tr line — 110KV
Motor side – 11KV

Calculation of Xpu =

① Generator

$X_{pu\,new} = X_{pu\,old} = 20\% = 0.2\,PU$

② Transformer 1 & 2

$X_{pu\,new} = X_{pu\,old} \times \left(\frac{MVA_{B\,new}}{MVA_{B\,old}}\right) \times \left(\frac{KV^2_{B\,old}}{KV^2_{B\,new}}\right)$

$= 0.15 \times \frac{50}{40} \times \left(\frac{110}{110}\right)^2 = 0.187\,PU$

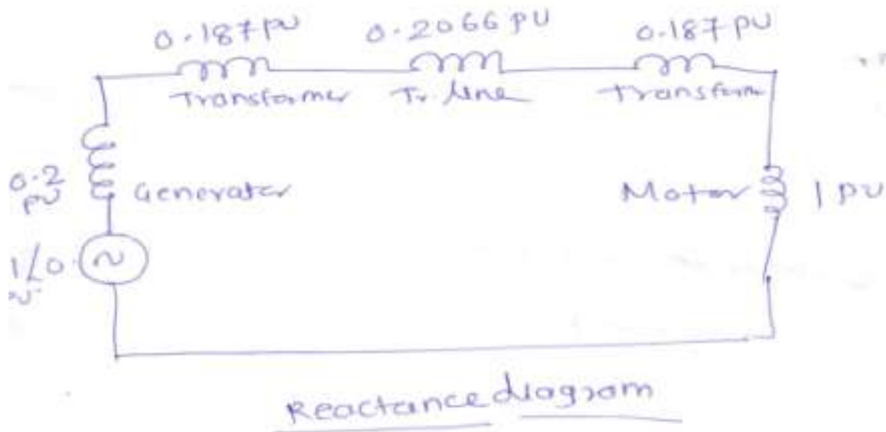
③ Motor

$X_{pu\,new} = 0.3 \times \frac{50}{15} \times \left(\frac{11}{11}\right)^2 = 1\,PU$

④ Tr Line

$X_{pu} = \frac{X_{actual} \times MVA_B}{kV^2_B}$

$= \frac{50 \times 50}{(110)^2} = 0.2066\,PU$



c) Ans.

What is transposition of 3ph line, state its advantages. **4M**

Transposition of conductors means exchanging the positions of the conductors at regular intervals along the line such that each conductor occupies the original position of every other conductor over equal distance *2M*

Advantages of transposition:

Unsymmetrical Spacing in the transmission line causes the flux linkages and therefore the inductance of each phase to be different resulting in unbalanced receiving end voltages even when sending end voltages and line currents are balanced.

Any 2 advantages 2M

1) The transposition causes each conductor to have the same average inductance over the transposition cycle. Over the length of one transposition cycle the total flux linkages is zero.
2) Transposition results in balanced receiving end voltages when sending end voltages and line currents are balanced.
3) Voltages induced in the adjacent communication lines will be zero

d) Ans.

Prove that complex power in power system is S = VI*. **4M**

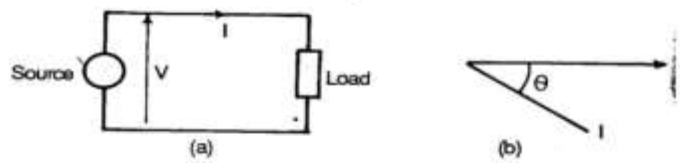
MODEL ANSWER

SUMMER - 2017 EXAMINATION

Subject: Power System Analysis **Subject Code: 17510**

Consider a single-phase load fed from a source as in Fig. Let

$$V = |V| \angle \delta$$
$$I = |I| \angle(\delta - \theta)$$



Complex power flow in a single-phase load

When θ is positive, the current lags behind voltage. This is a convenient choice of sign of θ in power systems where loads have mostly lagging power factors.

Complex power flow in the direction of current indicated is given by

$$S = VI^*$$
$$= |V|\,|I| \angle\theta$$
$$= |V|\,|I| \cos\theta + j|V|\,|I| \sin\theta = P + jQ$$

In electrical engineering Q is positive when load is inducting and negative when load is capacitive. In order to get the proper sign for Q it is necessary to find out VI* instead of V*I which will reverse sign for Q.

As if S= V*I = VI $\angle -\theta_1 + \theta_2$

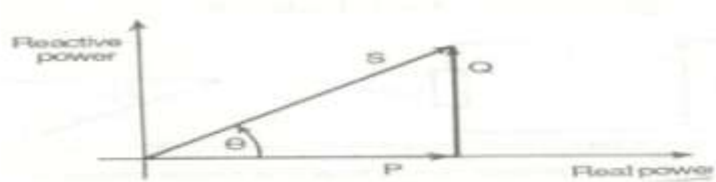
$= \text{VI} \angle -(\theta_1 - \theta_2)$

$= \text{VI}\cos(\theta_1 - \theta_2) - \text{jVI}\sin(\theta_1 - \theta_2)$

= P – jQ

$\theta = \tan^{-1}\frac{Q}{P}$ – positive for lagging current

– negative for leading current



Phasor representation of complex power (lagging pf load)

	e)	**A 50 Hz, 3 ϕ transmission line is 250km. long. It has a total series impedance of 35 + j40Ω and shunt admittance of 930 X 10^{-4} Ω. It delivers 40000 KW at 220 KV with 0.9 p.f. lagging. Find ABCD constants considering nominal T-circuit.**	**4M**
	Ans.	$Z = 35 + j\,40\,\Omega$ $Y = 930 \times 10^{-4} \angle 90^0$ $for\ Nominal\ T - circuit$ $A = D = 1 + \frac{YZ}{2}, \quad B = Z\left(1 + \frac{yz}{4}\right), \quad C = Y$ $A = D = \frac{1+YZ}{2} = 1 + [\frac{(930\times10^{-4}\angle90^0)X(35+j\,40)}{2}]$ $A = 1 + (-1.85 + j1.627)$ $A = 1.84\angle117.85$ = D ... $(2M)$ $B = Z\left(1 + \frac{yz}{4}\right)$ $(35 + j\,40)\left[1 + \frac{(930\times10^{-4}\angle90^0)(35+j\,40)}{4}\right]$ B = 43.41∠133.89 $C = Y = 930 \times 10^{-4} \angle 90^0 siemens$	***2M*** ***1M*** ***1M***