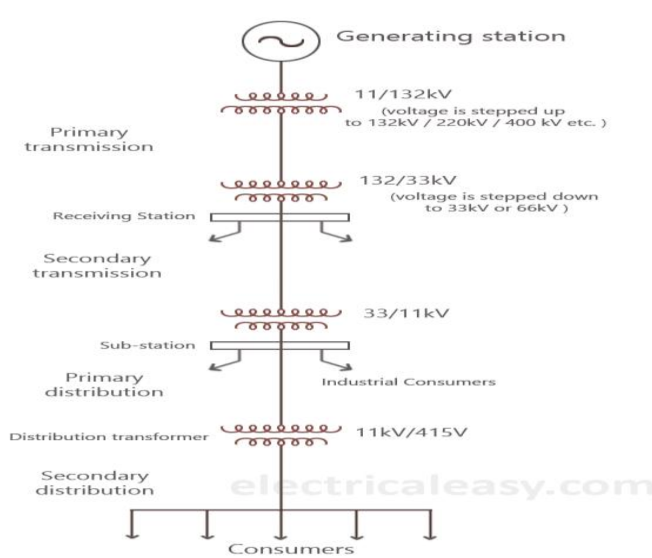
WINTER – 2018 EXAMINATION
MODEL ANSWER

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 themodel answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may tryto assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given moreImportance (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:** **Draw neat diagram of basic structure of power system network.**	**12** **4M** ***Correct Diagram 4M***



	b) **Ans**	**State the need of reactive power compensation in power system.** Power system is well designed when it gives good quality of reliable supply i.e variation of V at receiving end is within limit (+/- 5 %). If variation is more performance of equipment is affected. Variation in Voltage indicates unbalance in reactive power generated Qs & reactive power consumed by load Q_R If Qs > Q_R --- V_R increases If Qs < Q_R ----- V_R decreases If Qs = Q_R ------- V_R flat cha So to maintain balance in Qs & Q_R Reactive power compensation is needed. **OR** i. Most of the power system components are to be operated with voltage profile of 15%. But during power transfer a voltage drop of less than 10% occurs which is due to flow of reactive power. Moreover reactive currents contribute for I^2R losses in the system. ii. Most of the loads absorb lagging Vars to supply the magnetizing current of equipment such as transformers, induction motors etc. At any moment the maximum Vars which can be transferred over the line are fixed by voltage profile. iii. At peak loads the Vars demanded by the loads greatly exceeds Vars which can be transmitted over the lines. Flow of reactive power through the line causes voltage drop in the line and varies the voltage profile at important buses. Therefore additional equipment is necessary to generate lagging Vars at load centers to meet the reactive power requirements. iv. At light loads the lagging Vars produced by the lines are much larger than required by load. This surplus lagging Vars must be absorbed by additional equipment to keep voltage profile within limits. If it is not done the system voltage at some of the buses is likely to become higher then nominal value. From the above discussion it follows that it is necessary to compensate reactive power.	**4M** ***Correct explanation 4M***

	c) Ans	**"AC resistance is more than DC resistance", Justify.** 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 more than the loss when same value of DC is flowing through the conductor. Therefore AC resistance is greater than DC resistance. **OR** **AC resistance is always higher than DC resistance due to** **1) Skin effect:** The distribution of current throughout the cross section of a conductor is uniform when DC is passing through it. But when AC is flowing through a conductor, the current is non-uniformly distributed over the cross section in a manner that the current density is higher at the surface of the conductor compared to the current density at its center. This phenomenon is called skin effect. **2) Proximity effect:** When the alternating current is flowing through a conductor alternating magnetic flux is generate surrounding the conductor. This magnetic flux associates with the neighboring conductor and generate circulating currents. This circulating currents increases resistance of conductor. This phenomenon is called as, "proximity effect".	**4M** ***Skin effect 2M*** ***Proximity effect 2M***
	d) Ans	**List advantages of generalized circuit representation of transmission line.** 1. The generalized circuit equations are well suited to transmission lines. Hence for given any type of the transmission line (short, medium, long). The equation can be written by knowing the values of A B C D constants. 2. Just by knowing the total impedance and total admittance of the line the values of A B C D constants can be calculated. 3. By using the generalized circuit equations V_{RNL} $V_S = AV_R + BI_R$ i.e. when $I_R = 0$ $V_{RNL} = V_S /A$ Now the regulation of the line can be immediately calculated by % Voltage Regulation = V_S / A - V_R / V_R X 100	**4M** ***Any four advantages 1M each***

		4. Output power = $V_R I_R \cos\phi_R$ for ….1ϕ…ckt. = $3V_R I_R \cos\phi_R$ for ….3ϕ ……..ckt. Input power = $V_S I_S \cos\phi_S$…………1ϕ..ckt. = $3 V_S I_S \cos\phi_S$ …………3ϕ..ckt. losses in the line = input – output 5. By calculating input and output power efficiency can be calculated. 6. Series circuit: When two lines are connected such that the output of the first line serves as output to the second line and the output of the second line is fed to the load, the two lines behave as to parts networks in cascade. Its ABCD constants can be obtained by using following matrix: $$\begin{vmatrix} A & B \\ C & D \end{vmatrix} = \begin{vmatrix} A_1 & B_1 \\ C_1 & D_1 \end{vmatrix} \times \begin{vmatrix} A_2 & B_2 \\ C_2 & D_2 \end{vmatrix}$$ 7. When two transmission lines are connected in parallel then the resultant two part network can be easily obtained by $$A = \frac{A_1B_2 + A_2B_1}{B_1 + B_2}$$ $$B = \frac{B_1B_2}{B_1 + B_2}$$ $$D = \frac{D_1B_2 + D_2B_1}{B_1 + B_2}$$ $$C = C_1 + C_2 - \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}$$	
	B)	**Attempt any one:**	**6**
	a) **Ans**	**Draw circuit diagram for performing tests on transmission line model to measure generalized circuit constants. Also write stepwise procedure to perform the tests.** 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.	**6M** ***Explanation 1M***

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

Connection diagram 1M

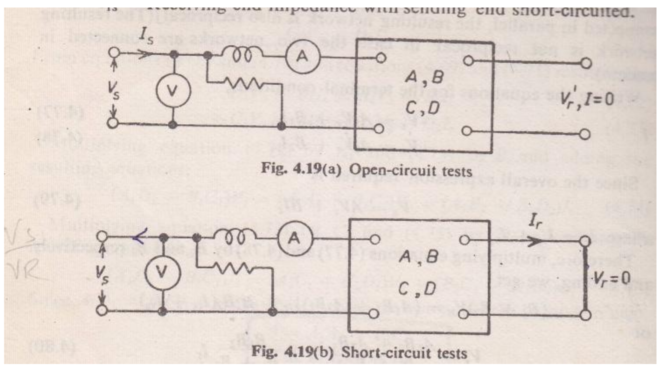


Fig. 4.19(a) Open-circuit tests

Fig. 4.19(b) Short-circuit tests

Stepwise Procedure 4M

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 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 short circuited

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 = D$V_s + BI_s \times (-I_R) = -(V_s + A(-I_s)$ $\therefore -I_R = -$C$V_s - AI_s$ I_R = C$V_s + AI_s$ 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, $\frac{Z_{ro}-Z_{rs}}{Z_{so}} = \frac{1}{AC} \cdot \frac{C}{A} = \frac{1}{A^2}$……………………2 marks $\therefore$**A** $= \sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$ -------------(a) $Z_{rs} = \frac{B}{A}$ or **B = AZ_{rs} = $Z_{rs}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$** ----------------(b) $Z_{so} = \frac{A}{C}$ $\therefore$ **C = $\frac{A}{Z_{so}} = \frac{1}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$** --------------© $Z_{ro} = \frac{D}{C}$ $\therefore$ **D = C· $Z_{ro} = \frac{Z_{ro}}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$** **= $Z_{ro}\sqrt{\frac{1}{(Z_{ro}-Z_{rs})Z_{so}}}$-----------(d)** If $Z_{ro} = Z_{so}$ we get A = D for symmetric network	

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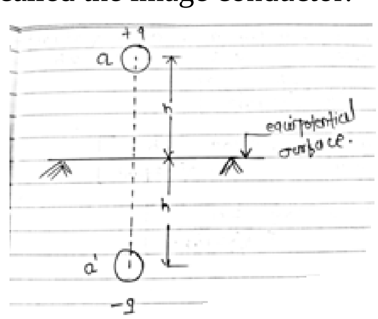
	b)	**State the effect of earth on capacitance of transmission line.**	**6M**
	Ans	As earth is also a perfect conductor its electric field affect the outside electric field i.e. capacitance of the line conductor. For example consider a circuit consisting single over head conductor with a return path through the earth. Assume the earth as a perfectly horizontal sheet of infinite extent which therefore acts like an equipotential surface. Now the earth has a charge equal in magnitude and opposite to that of the conductor. Hence potential difference exists between the conductor and the earth. And the electric flux is perpendicular to the earth's equipotential surface. Since the surface is assumed to be a perfect conductor. Imagine a fictitious conductor of the same size and shape as the over head conductor lying directly below the original conductor at a distance equal to twice the distance of the conductor above the plane of the earth by a distance equal to the distance of the overhead conductor above the earth. Suppose the earth is removed and a charge equal and opposite to that on the overhead conductor is assumed on the fictitious conductor. Now the plane midway between the original conductor and the fictitious conductor is an equipotential surface and occupies the same position as that of the earth. Now the flux between the overhead conductor and this equipotential surface is the same as that which existed between the conductor and the earth. Thus for the calculation of the capacitance, the earth may be replaced by a conductor at a distance equal to that of the overhead conductor above the earth from the earth below it. i.e. earth is replaced by a equipotential surface and a conductor. This conductor has a charge equal in magnitude and opposite in sign to that of the original conductor and is called the image conductor. 	***Explanation 4M*** ***Diagram 2M***

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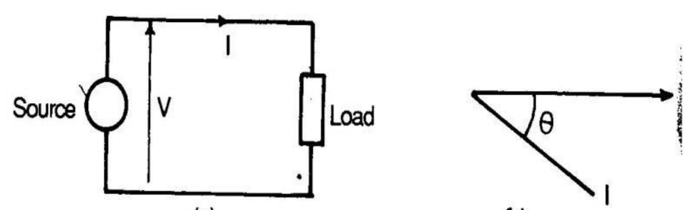
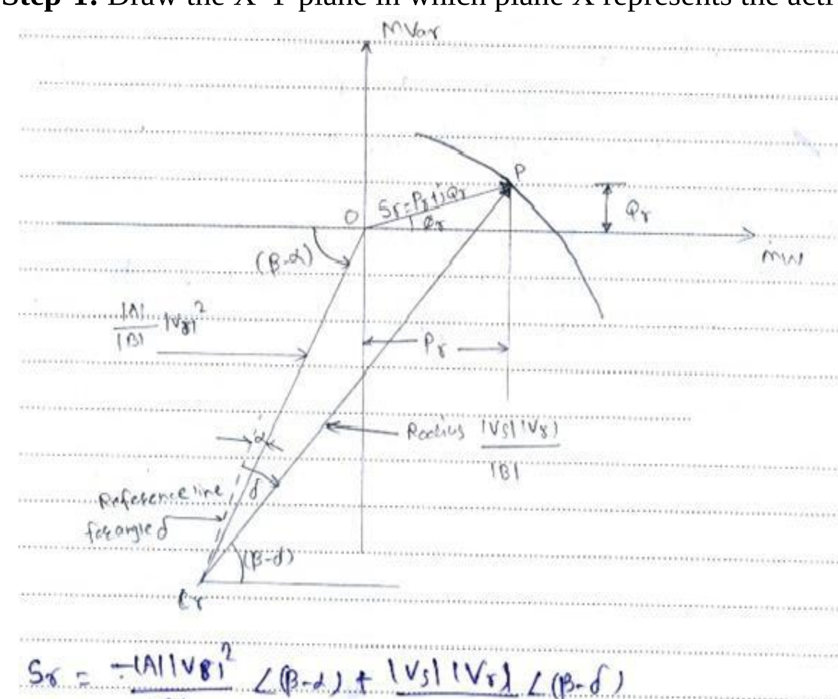
2	 **a)** **Ans**	**Attempt any two** **i) State generalised circuit constants expression for medium transmission line considering 'T' and 'π' network.** **i) Nominal T method** $A = D = 1 + \frac{YZ}{2}$, $B = Z\left(1 + \frac{YZ}{4}\right)$, $C = Y$ *Y = Total admittance/ phase* *Z = Total impedance / phase.* **Nominal π method** $A = D = 1 + YZ/2$, $B = Z$, $C = Y(1 + YZ/4)$	**16** **8M** ***T method 2M*** ***π method 2M***
	  Ans	**ii) Prove that the complex power in power system is defined as S=VI* instead of S=V*I.** Consider a single-phase load fed from a source as in Fig. . Let $V = \|V\| \angle\delta$ $I = \|I\| \angle(\delta - \theta)$  (a) (b)	

		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 $S = VI^*$ $= \|V\| \|I\| \angle\theta$ $= \|V\| \|I\| \cos\theta + j\|V\| \|I\| \sin\theta = P + jQ$ or $\|S\| = (P^2 + Q^2)^{1/2}$ Here S = complex power (VA, kVA, MVA) $\|S\|$ = apparent power (VA, kVA, MVA); it signifies rating of equipments (generators, transformers) $P = \|V\| \|I\| \cos\theta$ = real (active) power (watts, kW, MW) $Q = \|V\| \|I\| \sin\theta$ = reactive power = voltamperes reactive (VAR) = kilovoltamperes reactive (kVAR) = megavoltamperes reactive (MVAR)	2M
		It immediately follows from Eq. that Q, the reactive power, is positive for lagging current (lagging power factor load) and negative for leading current (leading power factor load). With the direction of current indicated in Fig. , $S = P + jQ$ is supplied by the source and is absorbed by the load.	2M
	b) Ans	**A 3-phase, 50Hz, 100km, 132kV overhead line has conductors placed in a horizontal plane of 4.5m apart. conductor diameter is 22.4mm, calculate capacitance per phase per km, capacitive reactance per phase, charging current per phase and total Mvars.** Given data d= 22.4mm $=22.4 \times 10^{-3}$ m r= 11.2×10^{-3}m D = 4.5m V = 132kV f = 50Hz	8M

		Capacitance (C) is given by $C = \frac{2\pi\mathcal{E}o}{Ln(\frac{D}{r})}$ --1M $= \frac{2\pi\ x\ 8.85\ x\ 10^{-2}}{Ln\ (\frac{4.5}{11.2\ x\ 10^{-3}})}$ ---1/2M = 9.275 x 10^{-12} F/m --1M = 9.275 x 10^{-6} µF/m = 9.275 x 10^{-3} µF/km = 5.35 x 10^{-3} µF/Ph/km -------------------------------------1/2M Charging current Ic = $\frac{V_{Ph}}{X_C}$ ---------------------------------1/2M $= \frac{\frac{132\ x\ 10^3}{\sqrt{3}}}{0.594\ x\ 100}$ -------------------------1/2M = 1283.0 µA -------------------------1/2M Capacitive reactance / Ph = $\frac{1}{2\pi f.C}$ -------------------------1/2M $= \frac{1}{2\pi\ x\ 50\ x\ 5.35\ x\ 10^{-3}}$ -----------1/2M = 0.594 µΩ /Ph ----------------1/2M Total Mvar = 3 x V_{pn} x I_c -------------------1M = 3 x $\frac{132\ x\ 10^3}{\sqrt{3}}\ x\ 1283$ = 3 x 76210.23 x 1283 = 293.33 Mvar-------------1M	
	c) Ans	**A 275 kV, 3-phase line has following line parameters A=0.9∠1.5°; B=110∠75°. it sending end voltage is 275kV, determine** **i) sending end power if load of 150 MW at 0.85 lagging p.f. is being delivered at receiving end.** Given data V_S =275kV V_R =275kV B = 110∠75° A = 0.9 ∠ 1.5o	8M

		$\cos\phi_R$ = 0.85 lagging **To obtain δ we use receiving end Power** $P_R = \frac{V_S V_R}{B} Cos\,(\beta - \delta) - \frac{A{V_R}^2}{B} Cos\,(\beta - \alpha)$------------ 1/2 M $150 = \frac{275\,x\,275}{110} Cos\,(75 - \delta) - \frac{0.9\,x\,275^2}{B} Cos\,(75 - 1.5)$ -----1/2M **150= 687.5 Cos(75 - δ) – 618.75 Cos(73.5)** **150= 687.5 Cos(75 - δ) – 175 - 73** **0.473 = Cos(75 - δ)** **75 - δ = Cos $^{-1}$ (0.473)** **75 - δ = 61.719** ------------1/2M **δ = 75 - 61.719** **δ = 13.281°** ------------1/2M **Sending end power is given by** $P_s = \frac{A{V_S}^2}{B} Cos\,(\beta - \alpha) - \frac{V_S V_R}{B} Cos\,(\beta + \delta)$ -----------1/2M $\frac{0.9\,x\,275^2}{110}$ **Cos (75 - 1.5) -** $\frac{275^2}{110}$**Cos (75 + 13.281)** -----------1/2M **= 618.75 Cos(73.5) – 687.5 x 0.03** ------------------1/2 M **= 175.73 – 20.63** **P_s = 155.1 MW** -----------------------------1/2M **ii)Maximum power at receiving end that can be delivered if sending end voltage is 295kV with receiving end voltage at 275kV.** For max receiving end power condition is $B - \delta = 0$ … … … … (1M)	
	Ans	$P_{R_{max}} = \frac{V_S V_R}{B} - \frac{AV_R^2}{B}\cos(\beta - \alpha)$ … … … . (1M) $= \frac{295 \times 275}{100} - \frac{0.9 \times (275)^2}{100}\cos(75 - 1.5)$ … … . (1M) $P_{R_{max}} = 561.77 Mw$ … … … … … … (1M)	

3	 **a)** **Ans**	**Attempt any four:** **Describe the importance of impedance diagram and reactance diagram of power system.** **Importance of impedance diagram:** 1. Each component of power system is represented by its equivalent circuit Impedance diagram. So it is simple representation of power system. 2. Impedance diagram is useful to calculate performance of system under load condition or after occurrence of fault. **Importance of reactance diagram** 1. In Impedance diagram resistances and capacitances, no load branch of transformer are neglected to obtain Reactance diagram. So it gives simplified diagram of power system. 2. Reactance diagram is useful for Fault calculation parameters.	**16** **4M** ***Each point 1M***
	b) **Ans**	**Describe stepwise procedure to draw receiving end circle diagram along with diagram.** **Step-1:** Draw the X-Y plane in which plane X represents the active  $S_r = \frac{-\lvert A\rvert \lvert V_r\rvert^2}{\lvert B\rvert} \angle(\beta-\alpha) + \frac{\lvert V_s\rvert \lvert V_r\rvert}{\lvert B\rvert} \angle(\beta-\delta)$	**4M** ***Diagram 1M*** ***Each step ½ M***

		power (MW) & axis-y-represents the Reactive power (MVA). $\frac{\lvert A \rvert}{\lvert B \rvert} \lvert V_r \rvert^2$ **Step-2:** To draw the center of the circle take the distance equal to & angle equal to (β-α) & draw the line in third quadrant & locate the point 'n'. **Step-3:** To draw the circle the radius is taken equal to |Vs| |Vr| & draw a circle in 1st quadrant. **Step-4:** The operating point p on the circle is located by the amount of real power delivered to the load i.e.pr **Step-5:** Joint the 'op'& draw the line parallel from point P to Y-axis. 'op' represents the true power Sr=Pr+jQr& the corresponding value of Qr can be read from the diagram. **Step-6:** Draw the reference line w.r.t. 'on'at an angle α. The power angle is the angle between the ref. line shown & phasor 'np'.	
	c) **Ans**	**A 20km single phase line has two parallel conductors separated by 1.5meters. the diameter of each conductor is 0.823cm. if the conductor has resistance of 0.311 Ω/km, find loop impedance of the line at 50Hz.** $L = 2 \times 10^{-7} \log_e \frac{D}{r^1}$ ------ **1M** $r^1 = 0.7788r = 0.7788 \times (0.823/2 \times 10^{-2}) = 0.003205m$ $L = 2 \times 10^{-7} \log_e (\frac{1.5}{0.003205})$ ----**1M** $= 1.2297 \times 10^{-6} \frac{H}{M} = 1.2297\ mH/KM$ -----**1M** Loop inductance= 2Xl = 1.2297x2 = 2.4594 mH/KM -----**1M**	**4M**

d) **A 220kV transmission line has following GCC:A=0.85∠73°, B=300∠78°. Determine receiving end active power if voltage at each end is maintained at 220kV and unity p.f.** **4M**

Ans

Given data

$V_S = V_R = 220$ KV, A = 0.85 <73 °, B = 300 < 78 °

Note : Given α value is not in range

If students assumed other value ,it should be considered

Then for unity power factor $Q_R = 0$

$\therefore Q_R = |V_S||V_R| / |B| \sin(\beta - \delta) - |A| / |B| |V_R|^2 \sin(\beta - \alpha)$

Substituting all values we get

$0 = (220)X(220)/ 300 \sin(\beta - \delta) – (0.85)(220)^2 / 300 \sin(78 – 73)$
$0 = 161.33 \sin(\beta - \delta) -11.95$
$\sin(\beta - \delta) =0.0740$
$\beta - \delta = 4.2478$ -----------2M

Substituting this is in equation of P_R we get
$P_R = |V_S||V_R| / |B| \cos(\beta - \delta) - |A| / |B| |V_R|^2 \cos(\beta - \alpha)$
$= (220)(220) / 300 \cos(4.247) – 0.85 \times (220)^2 / 300 \cos(78 -73)$
$= 160.89 - (137.133)(0.996)$
$= 160.89 – 136.58$
$P_R = 24.31$ MW.
Unity power at receiving end is24.31MW -------------2M

e) **Describe concept of self GMR and self GMD in calculation of transmission line inductance with an example.** **4M**

Ans Definition of Self & mutual GMD

Each term with example 2M

$$L_A = 2 \times 10^{-7} In \frac{[(D_{11'} \dots D_{1j'} \dots D_{1m'}) \dots (D_{i1'} \dots D_{ij'} \dots D_{im'}) \dots (D_{n1'} \dots D_{nj'} \dots}{[(D_{11} \dots D_{1i} \dots D_{1n}) \dots (D_{i1} \dots D_{ii} \dots D_{in}) \dots (D_{n1} \dots D_{ni} \dots D} /m$$

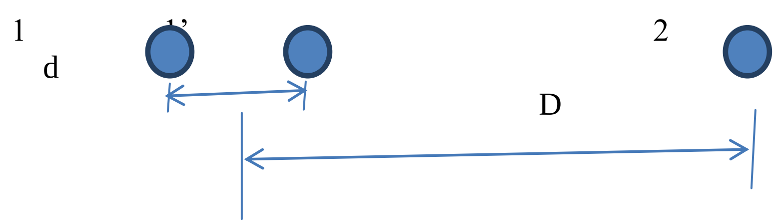
$$L_A = 2 \times 10^{-7} In \frac{Dm}{Ds} H/m$$

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 meandistance*** **(self GMD)** of conductor A, and is abbreviated as D_{sA}. Sometimes, self GMD is also called *geometric mean radius* ----*[2 MARK]*

Similarly,

Dm --GMD: The numerator of the argument of the logarithm in above Equation is the *m'n*th 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 $D_{m.}$ ----*[2 MARK]*

Example let radius of conductor X & Y is = r



Self GMD of conductor X = $\sqrt[4]{D_{11}D_{1'1'}D_{11'}D_{1'1}}$ = $\sqrt[4]{r'x\,r'x\,d\,x\,d}$ $=\sqrt{r'xd}$

Self GMD of conductor Y = r'

Mutual GMD between conductor X & Y = $\sqrt{D_{12}D_{1'2}}$ = $\sqrt{\left(\frac{d}{2}+D\right)x\,(D-\frac{d}{2})}$

4	A) a) Ans	**Attempt any three:** **State factors that influence skin effect** **Skin effect depends on factors:** • Current • Permeability of material • Frequency	**12** **4M** ***Any four factors 1M each***

		• Conductor diameter • Diameter • Material of conductor	
	b) **Ans**	**A 3-phase 132kV transmission line delivers 40MVA at 0.8 p.f. lagging. Draw receiving end circle diagram and determine sending end voltage for A=0.98∠3°, B=140∠78°.** **Given data** $V_R = 132kV$ **Load 40MVA, 0-8pf** **A= 0.9∠3** **B=140∠78** **X coordinates =** $\frac{-AV_R{}^2}{B}$ **Cos (β – α)** $= \frac{-0.98 \; x \; 132^2}{140} \; Cos(78-3)$ **= 31.57 MW ------------------------1M** **X coordinates =** $\frac{-AV_R{}^2}{B}$ **Sin (β – α)** $= \frac{-0.98 \; x \; 132^2}{140} \; Sin(78-3)$ **= 117.81 MVAR------------------------1M** **Selecting scale on X-axis 1cm=10MW** **Y-axis 1cm = 10MVAR** **∴ 1cm = 10MVA** **For Graph Radius = CQ = 15.5 cm** **=155MVA -------------------1M** $= \frac{V_S V_R}{B}$ $155 = \frac{V_S \; x \; 132}{140}$ $\therefore V_S = 164.39 \; kV$ **--------------1M**	**4M**

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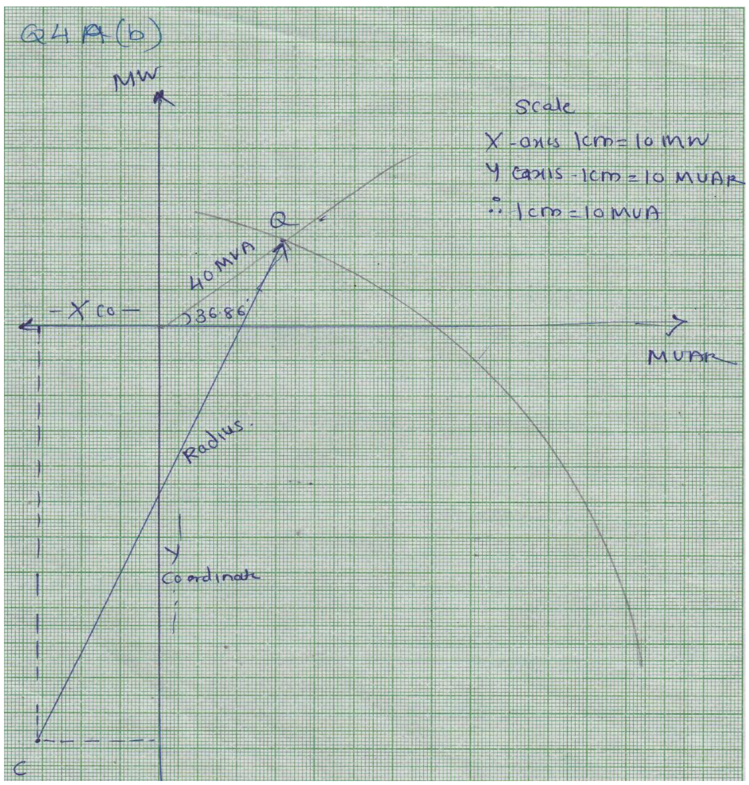
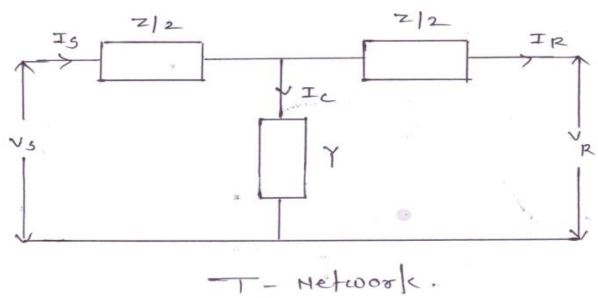
<tr><td></td><td></td><td>
</td><td></td></tr>
<tr><td></td><td>c)
Ans</td><td>List the advantages of p.u. system.
Advantages of PU calculations:

Manufacturers specify impedance of apparatus in % or P.U. values on basis of name plate rating.
P.U. impedance of machine of same type having different ratings usually lay within narrow range though actual values differs with rating. Hence if impedance is not known, we can consider value from table in which avg. value for different type of machine are given.
P.U values are same referred to either side of transformer.
Type of connection of 3Φ transformer in 3Φcircuit does not affect p.u. values.
</td><td>4M

Any four advantages 1M each</td></tr>
</table>

	d) Ans	**Derive the condition for maximum power transferred (P_{RMAX}) at receiving end for a two port network.** As the receive end side active power is given by, $P_R = \frac{\lvert V_S \rvert \lvert V_R \rvert}{\lvert B \rvert}\cos(\beta-\delta) - \frac{\lvert A \rvert \lvert V_R \rvert^2}{\lvert B \rvert}\cos(\beta-\alpha)$ -----------1M **For max value differentiate above eq. w.r.t. 'δ'** as $V_S, V_R, A, B \& \alpha$ are constant. $\therefore \frac{dP_R}{d\delta} = \frac{d}{d\delta}[\frac{\lvert V_S \rvert \lvert V_R \rvert}{\lvert B \rvert}\cos(\beta-\delta) - \frac{\lvert A \rvert \lvert V_R \rvert^2}{\lvert B \rvert}\cos(\beta-\alpha)]$ ----1M **Equate this equation w.r.t. zero** $\frac{dP_R}{d\delta} = \frac{\lvert V_S \rvert \lvert V_R \rvert}{\lvert B \rvert}\frac{d}{d\delta}\cos(\beta-\delta) = 0$ ----------------1M $\sin(\beta-\delta) = 0$ $\beta - \delta = \sin^{-1}(0) = 0$ ---------------------------1M $\boldsymbol{\beta = \delta}$**condition ----**	4M
	B) a) Ans	**Attempt any one of the following:** **Prove that AD – BC = 1 for a generalized circuit with π and T network.** **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  	6 6M *Diagram 2M*

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

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

comparing equation (iii)and (ii)withactual equationV_S&$I_S$then

$$A = D = 1+\frac{YZ}{2},$$

$$B = Z\left(1+\frac{YZ}{4}\right),$$

$$C = Y$$ --------------------**2M**

Therefore

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

= 1 2M

b) **Find self GMD for following arrangement of conductors with radius of each conductor as 'r' in Fig 01.** **6M**

Ans

Each Case 3M

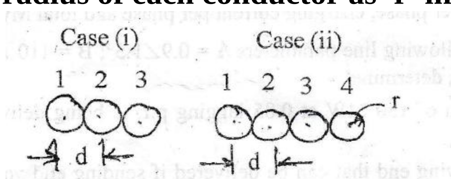


Fig. 01

Case (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

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

$D_{13} = D_{31} = 4r$

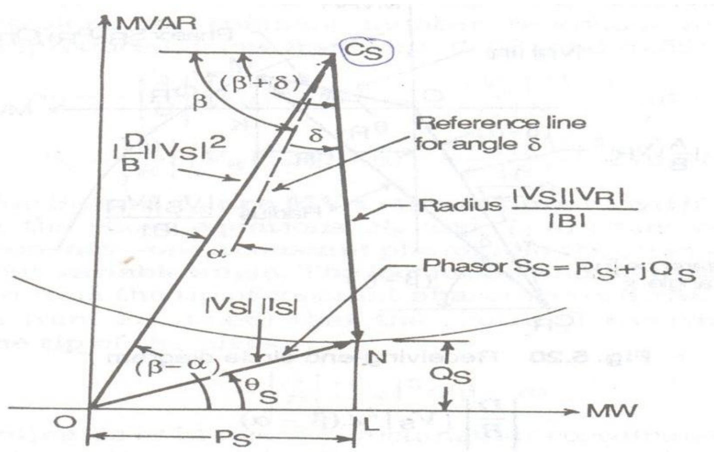
Self GMD DS = $\sqrt[9]{(D_{11}D_{12}D_{13})^2(D_{21}D_{22}D_{23})}$

= $\sqrt[9]{(0.7788r\ X\ 2R\ X\ 4r\ )^2(2r\ X\ 0.7788\ r\ X\ 2r)}$ -----------*1M*

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

Self GMD = 1.70 r -------------1M

		Case ii) Self GMD $D_S = \sqrt[16]{(D11D12D13D14)^2(D21D22D23D24)^2}$ ---1M $D_{11} = r^1$, D_{12} = 2r, D_{13} = 4r, D_{14} = 6r D_{21} =2r, $D_{22} = r^1$, D_{23} = 2r, D_{24} = 4r $\sqrt[8]{(0.7788r\ X\ 2rX\ 4r\ x\ 6r)\ \ (2r\ X\ 0.7788\ r\ X\ 2r\ x\ 4r)}$ ----1M D_s = 2.155r -------------1M	
5	a) Ans	**Attempt any two** **A 3 phase single circuit transmission line delivering a load of 50MVA at 110kV at 0.8 lagging p.f. with GCC A=D=0.98∠3°, B=110∠75°Ω, C=0.0005∠80° siemens. Determine sending end voltage, sending end current, sending p.f. and sending end power.** $given: load = 50MVA, \quad V_R = 110KV,$ $p.f = 0.8, \quad A = 0.98∠3, \quad B = 110∠75$ C=0.0005∠80 $I_R = \frac{50\ x\ 10^6}{\sqrt{3}\ x\ 110\ x\ 10^3\ x\ 0.8}$ = 328.0399 Amp ϕ_R = Cos $^{-1}$ 0.8 = 36.86 I_R = 328.0399∠ -36.86 ---------1M $V_S = AV_R + BI_R$ ------------1M = 0.98∠3 x $\frac{110\ x\ 10^3}{\sqrt{3}}$∠0 + 0.98 ∠3 x 328.0399 ∠ -36.86 $V_{S_{ph}}$ = 94067.78 ∠ 15.75 volt/ph ---------------2M $V_{S_{line}}$ = 162.93kV $I_{S=} CV_R + DI_R$ -------------------------------------1M = 0.0005∠80 x $\frac{110\ x\ 10^3}{\sqrt{3}}$ ∠0 + 0.98 ∠3 x 328.0399 ∠ -36.86 = 309.999 ∠ -28.48 Amp ------------ 2M ϕ_S = 15.75 – (-28.48) = 44.23	16 8M

		Sending end pf = Cos ϕ_S = Cos 44.23 = 0.7165 lag -------1M	
	b) **Ans**	**Along with diagram write stepwise procedure to draw sending end circle diagram. Also state data required to draw 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. **data required to draw sending end circle diagram:** **Vs ,Vr A ,B,** α,β & -------------------------------------2M 	**8M** ***1M for each step*** ***Diagram 2M***

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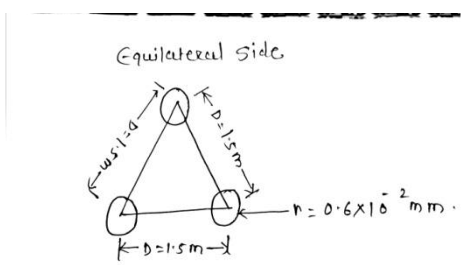
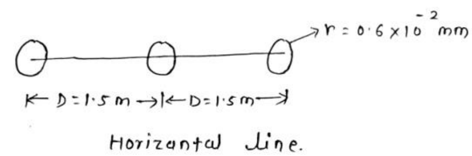
Subject: Power System Analysis **Subject Code** 17510

	c)	**Calculate capacitance per phase and charging of 3-phase system where conductors are placed at the corners of an equilateral triangle of sides 1.5m each. The diameter of each conductor is 1.2cm. Also calculate the capacitance per phase and charging current of conductors are rearranged in horizontal line with spacing of 3m between each conductor.**	**8M**
	Ans	C & Icn = ? D=1.5m, r=1.2 x 10^{-2}/2 = 0.6 x 10^{-2} mm  C=$\frac{\pi \in}{\log_c \frac{D}{r}}$ = $\frac{\pi \text{ x } 8.854 \text{ x } 10^{-12}}{\log_c \frac{1.5}{0.6 \text{ x } 10^{33}}}$π x 8.854 x 10^{-12} ----------------1M = 5.0377 x 10^{-12} F/M = 5.0377 µF/Km Can = 2 x 5.0377 = 1.0075 x 10^{-11} F/m -----------------2M $I_{charging} = \frac{V_{ph}}{X_c}$ Assuming voltage as 132KV. Students can assume any voltage. $I_{charging} = \frac{132 \text{ x } 10^3 / \sqrt{3}}{1 / 2\pi f c}$ $= \frac{132 \text{ x } 10^3}{\sqrt{3}}$ x 2 π x 50 x 1.0075 x 10^{-11} = 2.41 x 10^{-4} Amp If conductors in horizontal line ---------------------------1M	



Deq = $\sqrt[3]{(3\ x\ 3\ x\ 6)}$ = 3.78 m ---------------1M

C= $\frac{\pi\ x\ 8.854\ x\ 10^{-12}}{\log_c \frac{3.78}{0.6\ x\ 10^{-2}}}$

= 4.315 x 10^{-12}

= 4.315 µF / Km. ----------------2M

$I_{charging}$ = $\frac{132\ x\ 10^3}{\sqrt{3}}$ x 2 x π x 50 x 4.315x 10^{-12}

=1.033 x 10^{-4} *Amp* ------------------1M

6 **Attempt any four:** **16**

a) **A 132kV, 50Hz, 3 phase transmission line delivers no load at receiving end. Determine MVA rating of shunt reactor having negligible losses to maintain 132kV at both ends of line. GCE for line are A=0.95∠1.4°, B=96∠78°, C=0.0015∠90°.** **4M**

Ans

Given Data : $V_R = 132KV,\ V_s = 132KV$

$A = 0.95\angle 1.4, \quad B = 96\angle 78$

C = 1.0015∠90

$No\ load\ \therefore Q_R = 0$

MVA rating of shunt Reactor = $Q_s - Q_R$-----------1M

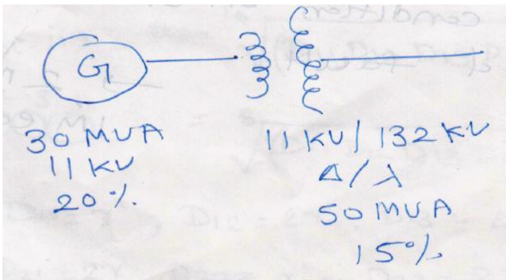
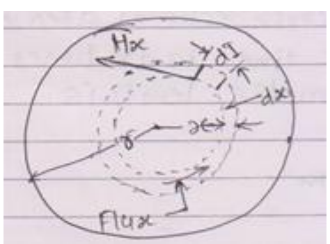
$Q_S = \frac{AV_s^2}{B}$ Cos (β – α) - $\frac{V_S V_R}{B}$ Cos (β + δ) ----1M

$$\frac{-0.95\ x\ 132^2}{96} Cos(78 - 1.4) - \frac{132\ x\ 132}{96}\ x\ Cos(78 + 0)$$

=39.959 – 37.73 -------------------2M

=2.229MVAR

∴ MVA rating of shunt reactor = 2.229 MVAR

	b) Ans	**A generator rated at 30MVA, 11KV has a reactance of 20% connected to a 3-phase, 50MVA, 11/132kV, Δ-Y transformer with X=15%. calculate its p.u. reactance of generator and transformer for a base of 50MVA and 10kV.**  **Given Base MVA = 50MVA** **Base KV = 10KVfor Gen. and transformer∠V** $X_{pu\,new} = X_{pu\,old} \times \frac{MVA\,new}{MVA\,old} \times \left(\frac{KV\,old}{KV\,new}\right)^2$ **2M** $X_{pu\,Gen} = 0.2 \times \frac{50}{30} \times \left(\frac{11}{10}\right)^2$ **= 0.403 pu -------------------------------1M** $X_{pu\,tranformer} = 0.15 \times \frac{50}{50} \times \left(\frac{11}{10}\right)^2$ **= 0.1815 pu -------------------------------1M**	
	c) Ans	**Derive the expression for flux linkages at an isolated current carrying conductor due to internal flux only**  Figure Shows the cross-section of a long cylindrical conductor of radius r carrying a Sinusoidal current of r.m.s. value I. The magnetic lines of flux are concentric with the Conductor.	

		Let, the field intensity at a distance x meters from the centre of the conductor be Hx. Since the field is symmetrical, Hx is constant for all point equi distant from the centre. If Ix is the current enclosed upto distances x, then……………………………….***(1M)*** $\oint H_x . dl = I_x$ ……………………………….(i) or $2\pi x\ H_x = I_x$ ……………………………(ii) For finding the value of Ix, the current is assumed to be uniformly distributed over the cross-section of the conductor. Then $I_x = \left(\frac{\pi x^2}{\pi r^2}\right)$ I = $\left(\frac{x^2}{r^2}\right)$ I …………..(iii) ……………..***(1M)*** From equation (ii) & (iii) $H_x = \frac{Ix}{2\pi r^2}$ AT/m………………(iv) The flux density B$x$at a distance x from the centre is Bx = $\mu H_x = \frac{\mu I_x}{2\pi r^2}$ ωb/m^2………(v)………………..***(1M)*** For finding flux linkages, a tabular element of thickness dx may be considered. The cross-sectional area of the element, normal to the flux line is dx times the axial length. The flux per meter length is $d\emptyset = \frac{\mu I_x}{2\pi r^2} dx$ ωb/m A flux line positioned at x links with $\frac{\pi x^2}{\pi r^2}$ of the total current. Thus the flux linkage for flux d∅ is given by $d\Psi = \frac{\pi x^2}{\pi r^2} . d\emptyset$ $= \frac{\mu I_x{}^3}{2\pi r^4}$ d$x\omega$b-T/m………………(vi) For computing the total internal flux linkages Ψ int we integrate equation (vi) from The centre to surface of the conductor. r Ψ int $= \int \frac{\mu I x^3}{2\pi r^4} dx = \frac{\mu I}{8\pi}$ ωb-T/m…………***(1M)***	

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	d) **Ans**	**State the importance of real power and reactive power in modern power system.** 1Rating of generator, transformer depends on Real power flow in transmission line. 2. Transmission line performance is calculated by complex power flow. 3. Power loss in system is considered in terms of real power. 4. Voltage profile at receiving end depends on reactive power flow. If reactive power is balance, $Q_S = Q_R$, receiving voltage remains constant.	**4M** ***Each point 1M***
	e) **Ans**	**A medium transmission line of 3ϕ, 132kV, 50Hz have series impedance of (20 +j50)Ω and shunt admittance of 3.14 x 10-4 siemens per phase. Determine A,B,C,D constants of the line considering nominal 'π' network.** $Z = (20 + \ j\,50)\,\Omega$ $Y = 3.14 \times 10^{-4}\angle 90^0$ $for\ Nominal\ \pi - circuit$ $A = D = 1 + \frac{YZ}{2}, B = Z, C = Y\left(1 + \frac{YZ}{4}\right)$ $A = D = \frac{1+YZ}{2} = 1 + [\frac{(3.14\times10^{-4}\angle 90^0)(20+\ j\,50))}{2}]$ $A = 1 + \frac{0.18\angle 165}{2}$ $A = 1 + 0.00854\ \angle 158$ $A = 0.99215 + j0.00314 = 0.99215\ \ \angle 0.181 = D$ $B = Z = (20 + \ j\,50) = 53.85\ \angle 68.198\,\Omega$ $C = Y\left(1 + \frac{YZ}{4}\right) = 3.14 \times 10^{-4}\angle 90^0\left[1 + \frac{\left(\left(3.14 \times 10^{-4}\angle 90^0\right)(20 + \ j\,50)\right)}{4}\right]$ $= 3.14 \times 10^{-4}\angle 90^0 x\ 0.9960\angle 0.090$ $= 3.1276\ \times 10^{-4}\angle 90.09 siemens)$	**4M** ***Each constant 1M***