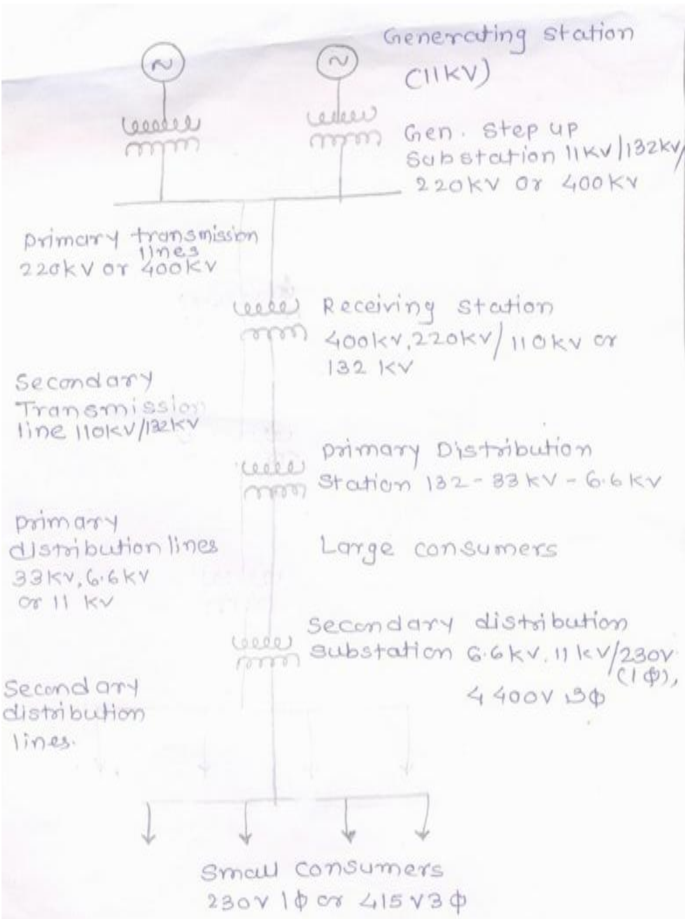
Important Instructions to examiners:

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.1.

A. Attempt any three of the following: **12**

a) Draw a single line diagram of modern power system indicating essential components.
(4-marks for Correct diagram showing all voltage levels)



b) State the expression for Complex power, Real and Reactive power at sending end of transmission line.

Let A, B, D are transmission line constants written as A = |A| < α, B = |B| < β, D= |D| <α & If VR and VS are expressed in KV line, then the 3ϕ sending end complex power can be given by

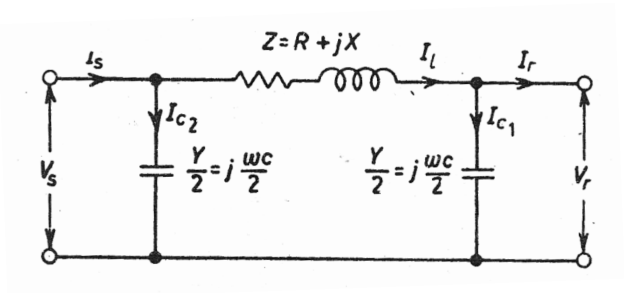
- $S_S = |D/B|\ |VS|^2 < \beta - \alpha - |V_S||V_R|\ /\ |B| < \beta + \delta$ ***[2-mark]***
- Real power Ps = $|D/B|\ |VS|^2 \mathrm{Cos}(\ \beta - \alpha) - |V_S||V_R|\ /\ |B|\ \mathrm{Cos}\ (\ \beta + \delta)$***[1-mark]***
- Reactive power Qs = $|D/B|\ |VS|^2 \mathrm{Sin}\ (\ \beta - \alpha) - |V_S||V_R|\ /\ |B|\ \mathrm{Sis}\ (\ \beta + \delta)$***[1-mark]***

c) State the difference between 'A-C resistance' and ' D.C resistance' of a conductor.
(Each 1 mark)

AC Resistance	**DC Resistance**
Rac = Resistance offered for flow of AC Current	Rdc= Resistance offered for flow of DC Current
Rac =Effective resistance =Average cu loss in conductor (watts)/ I^2rms	Rdc = Ohmic resistance = p l/a
A C resistance is higher than DC resistance	DC resistance is lower than AC resistance
Rac is higher as skin effect & proximity effect is present for AC current	Rdc is lower as DC current is uniformly distributed i.e skin effect & proximity effect is absent for DC current

d) For a generalized two port π (pi) network. Prove that AD-BC =1 where A, B, C, D are GCC.

For a nominal Pi –network



ABCD constants are given by

A = 1+YZ / 2 , B = Z

C = Y(1+ YZ / 4) D = 1 + YZ / 2 ***[2-marks]***

AD – BC = [(1+ YZ / 2)(1 + YZ / 2)] – [(Y)(Z (1+ YZ / 4))]

= [1+YZ / 2 + YZ / 2 + Y^2Z^2 / 4] – YZ + Y^2Z^2 / 4] ***[1-marks]***

= 1 + $\cancel{2}$YZ / $\cancel{2}$ + $\cancel{Y^2Z^2/2}$ – YZ – $\cancel{Y^2Z^2/4}$

= 1 + YZ – YZ

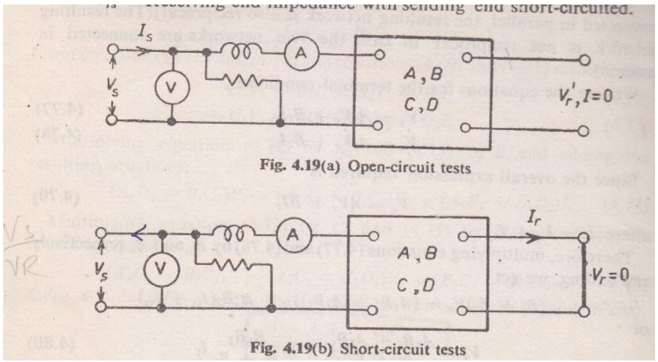
= 1

= R.H.S

Hence proved that AD – BC = 1 ***[1-mark]***

B. Attempt any one of the following: 6

a) Explain the procedure to measure GCC of erected to line.
(2-marks for Diagram, 2-marks sending end calculation, 2marks receiving end calculation, 2-marks calculation of A, B, C, D)



. To find transmission like parameters the open circuit and short circuit tests at the two ends are done. The above fig a and fig b show the connection diagrams of o.c. and s.c. respectively.
Z_{SO} = Sending end impedance with receiving end open.
Z_{SS} = Sending end impedance with receiving end short.
Z_RO = Receiving end impedance with sending end open.
Z_{RS} = Receiving end impedance with sending end short.

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.
∴ From o.c. test –
Generalized = O.C can be written
As V_R = D$V_s -$ BI_s
$I_R = -$ C$V_s +$ 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$V_s + BI_s$× (-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,

$Z_{ro} - Z_{rs} = \frac{D}{C} - \frac{B}{A} = \frac{AD-BC}{AC}$

$= \frac{1}{AC}[ASAD - BC = 1]$

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 = A**$\boldsymbol{Z_{rs}}$ = $\boldsymbol{Z_{rs}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$ ----------------(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·** $\boldsymbol{Z_{ro}} = \frac{Z_{ro}}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro}-Z_{rs}}}$

= $\boldsymbol{Z_{ro}}\sqrt{\frac{1}{(Z_{ro}-Z_{rs})Z_{so}}}$**-----------(**d)

If $Z_{ro} = Z_{so}$ we get A = D for symmetric network

b) Define 'self GMD' and 'Mutual GMD' with an example.

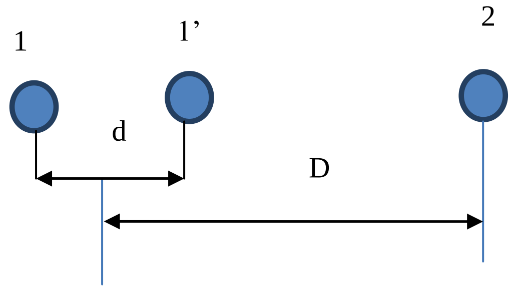
$$L_A = 2 \times 10^{-7} In \frac{[(D_{11'} \dots D_{1j'} \dots D_{1m'}) \dots (D_{i1'} \dots D_{ij'} \dots D_{im'}) \dots (D_{n1'} \dots D_{nj'} \dots D_{nm'})]^{1/m'n}}{[(D_{11} \dots D_{1i} \dots D_{1n}) \dots (D_{i1} \dots D_{ii} \dots D_{in}) \dots (D_{n1} \dots D_{ni} \dots D_{nm})]^{1/n^2}} H/m$$

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,

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 $=\sqrt[4]{D_{11}D_{1'1'}D_{11'}D_{1'1}} = \sqrt[4]{r'xr'xdxd} = \sqrt{r'xd}$

Self GMD of conductor Y = r'

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

Q.2. Attempt any two of the following: 16

a)

i. List out the advantages of generalized circuit representation in power system analysis.

Advantages of generalized circuit---- any 4 points : ***(1-mark each)***

1. The generalized circuit equation 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} can also be calculated.
   $\therefore V_S = AV_R + BI_R$
   i.e. when $I_R = 0$
   $V_{RNL} = V_S / A$
   Now the regulation of the line can be immediately calculated by
   % regu = V_S / A– V_R / V_R x 100
4. Output power = $V_R I_R \cos\phi R$ 1ϕckt.
   = # $V_R I_R \cos\phi R$ for 3 ϕckt.
   Output power = $V_S I_S \cos\phi S$ 1ϕckt.
   = # $V_S I_S \cos\phi S$ for 3ϕckt.
   $\therefore$ losses in the line = input – output
5. By calculating input and output power 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 obtain 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 to t_r lines are connected in parallel then the resultant two part network can be easily obtained by

$$A = \frac{A_1B_2 + A_2B_1}{B_1 + B_2}$$
$$B = \frac{B_1B_2}{B_1 + B_2}$$

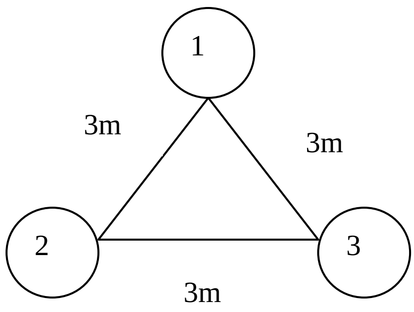
$$D = \frac{D_1B_2 + D_2B_1}{B_1 + B_2}$$
$$C = C_1 + C_2 - \frac{(A_1 - A_{2)}(D_2 - D_1)}{B_1 + B_2}$$

ii. Write expression for co-ordinates of centrean radius for sending end and receiving end circle diagram.
(Each for 2M)

1. 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.
   The X and Y coordinates of the centre are $|D/B|1V_S|^2$ Cos $(\beta - \alpha)$ and $|D/B|1V_S|^2$ Sin $(\beta - \alpha)$

2. The radius of sending end circle is drawn with $|V_S||V_R| / |B|$ from centre C_S

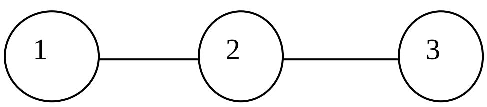
b) A three phase line with equilateral spacing of 3 mt. is to be rebuilt with horizontal spacing such that $D_{13} = 2D_{12} = 2D_{23}$. The line conductors are fully transposed. Determine the spacing between adjacent conductors so that the new tr. Line has the same inductance as the original line.



3 phase line with equilateral spacing

$L = 2X10^{-7} \log_e \frac{D}{r'} = 2X10^{-7} \log_e \frac{3}{r'}$- -----------------------Eq 1 **[1mark]**

With horizontal spacing **[1mark]**



$2X10^{-7}\log_e \frac{Deq}{r'}$ ---eq 2

$Deq = \sqrt[3]{D12}$x D23X D31

Inductance L remains same
Equating eq 1 &eq 2

$L = 2X10^{-7}\log_e \frac{D}{r'} = 2X10^{-7}\log_e \frac{Deq}{r'}$**[3 marks]**

$\frac{D}{r'} = \frac{Deq}{r'}$

D = Deq = $\sqrt[3]{(D12}$x D23X D31)

3 = $\sqrt[3]{(\ (D12)^2\ X\ (2D12))}$

3 = $\sqrt[3]{2}X(D12)^3$

D12 = $\frac{3}{\sqrt[3]{2}}$= 2.381 m **[3 marks]**

c) In a three phase line with 132kV at receiving end has A= D= 0.98∟3^0, B= 110∟75^0Ω. find the sending end power if load of 200 MW at 0.8 p.f. lagging p.f. is being delivered at receiving end. Calculate the max power demand for V_R=V_S =275kV.

Given data
V_R = 132KV , A=D= 0.98 ∠3 , B = 110 ∠ 75 Ω
Load 200MW, 0.8 pf lag
P_{RMAX}= ?when V_R= V_s = 275 KV

$I_R = \frac{P_R}{\sqrt{3}XV_{RX}\cos\phi_R} = \frac{200X10^6}{\sqrt{3}X\ 132X10^3X\ 0.8}$ = 1093.466∠ -36.86 **[1 mark]**
$V_S = AV_R + BI_R$

0.98 ∠3 X $\frac{132\ X10^3}{\sqrt{3}}$∠ 0 + 110 ∠75 X 1093.466 ∠ -36.86
= 186380.75 ∠24.80 V
Line voltage V_S = 186.380 /√3 = 322.8 KV **[2 Marks]**

Sending end power = Ps

Ps = |D/B| |VS|^2 Cos (β - α) - $|V_S||V_R|$ / |B| Cos (β + δ)

$$\frac{0.98}{110}\ (322.8^2\ )\cos(75-3) - \frac{322.8\ x\ 132}{110}\cos(75+24.80)$$

= 352.80 MW **[3 Marks]**

Max Power demand for $V_R = V_S$ = 275 KV

$$P_{RMAX} = \frac{V_S V_R}{B} - \frac{A}{B} VR^2 \cos(\beta - \alpha)$$

$$\frac{275\ X\ 275}{110} - \frac{0.98}{110} X (275)^2 \quad \cos(75 - 3)$$

= 479.299 MW **[2 marks]**

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

a) Draw reactance diagram for given power system as shown in Fig.1. considering generator rating as common base values.

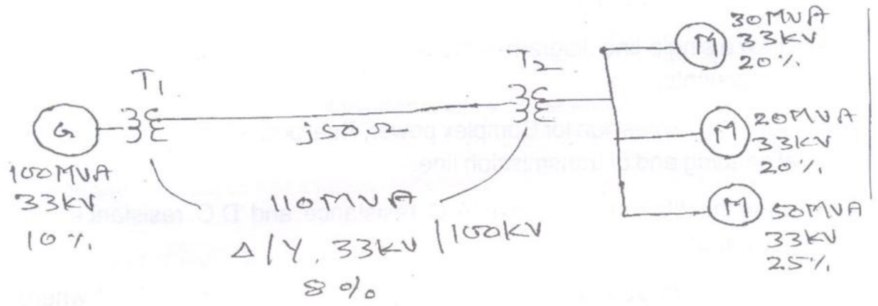
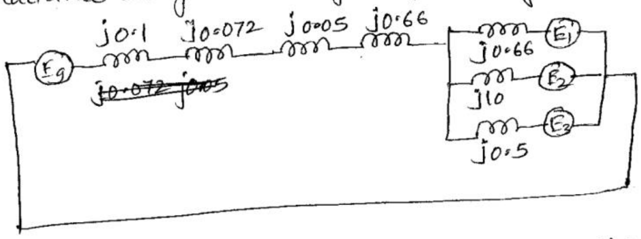


Fig. 1.

$$BaseMVA = 100MVA$$
$$BaseVoltage = 33KV$$
$$Basevoltageforline = 33 \times \frac{100}{33} = 100KV$$
$$Line - LinevoltageratioofT_2 = \sqrt{3} \times 33{:}100KV = 57.15{:}173.20$$
$$BaseVoltageformotors = 33KV ----(1M)$$
$$forabovebasevalues, thereactancesare$$
$$Reactanceofgenerator = 10\% = 0.1.p.u.$$
$$ReactanceofT_1 = 8 \times \left(\frac{33}{33}\right)^2 \left(\frac{100}{110}\right) = 7.27\% = 0.07$$
$$ReactanceofT_2 = 8 \times \left(\frac{100}{33}\right)^2 \left(\frac{100}{110}\right) = 66.78\% = 0.66$$
$$Baereactanceofline = \left(\frac{100}{100}\right)^2 = 1\Omega ----(1M)$$
$$Reactanceofline = \frac{50}{1} = 50\% = 0.05p.u.$$
$$ReactanceofMotorM_1 = 20 \times \left(\frac{33}{33}\right)^2 \left(\frac{100}{30}\right) = 66.66\% = 0.66p.u.$$
$$ReactanceofMotorM_2 = 20 \times \left(\frac{33}{33}\right)^2 \left(\frac{100}{20}\right) = 100\% = 1p.u.$$

$$Reactance of Motor M_3 = 25 \times \left(\frac{33}{33}\right)^2 \left(\frac{100}{50}\right) = 50\% = 0p.u. ---(1M)$$

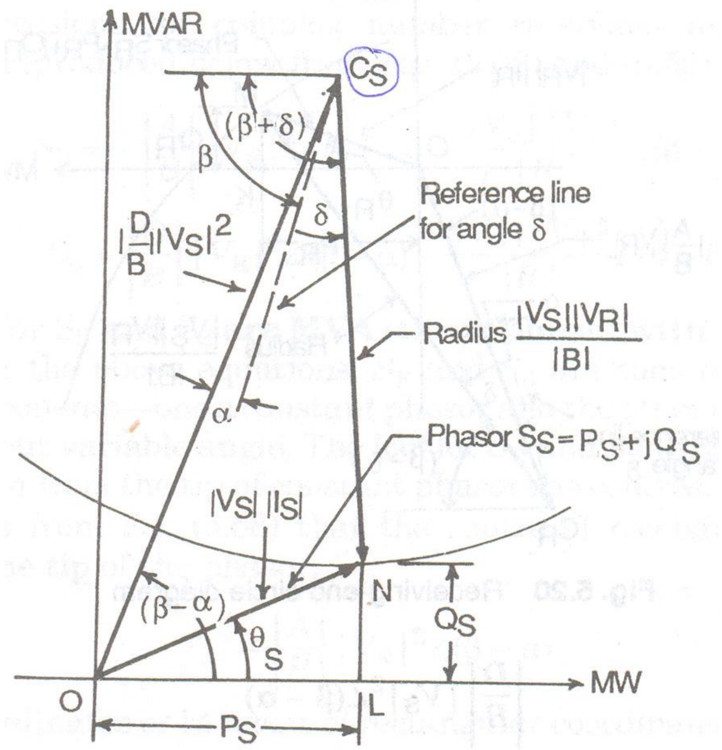
The reactance diagram for given power system



— 01 Mark

b) Explain the stepwise procedure to draw sending end circle diagram.
(2marks for step, 2 marks for 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 $|D/B|1V_S|^2\ \text{Cos}\ (\beta - \alpha)$ and $|D/B|1V_S|^2\ \text{Sin}\ (\beta - \alpha)$ 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.
v. Step-5: Complete the triangle ONL which represents power triangle at sending end.



c) Determine the loop inductance of single phase tr. Line comprised of solid conductors of diameter 1.5 cm. and spacing between two conductors as 7 mt.
Given Data:

$$\text{diameter}1.5\text{cm}, \quad D = 7\text{m}, ----------(1\text{M})$$
$$\text{radius}r = 1.\frac{5}{2} = 0.75\text{cm} = \text{o}.75 \times 10^{-2}\text{m}$$
$$r' = 0.7788 \times 0.75 = 0.584 \times 10^{-2} ------(1\text{M})$$
$$\text{loopinductance}L = 4 \times 10^{-7}\ln(\frac{D}{r'})(1\text{M})$$
$$\text{loopinductance}L = 4 \times 10^{-7}\ln\left(\frac{7}{0.584 \times 10^{-2}}\right)$$
$$L = 28.\frac{3510^{-7}\text{H}}{\text{m}} = 28.35 \times 10^{-4}\frac{\text{H}}{\text{Km}} ----(1\text{M})$$

d) A 200 kV transmission line base GCC $A = 0.86\llcorner 75^0 B = 300\llcorner 75^0\Omega$. determine real power at unity p.f. that can be received if voltage at both end are maintained at 200 kV.
Given data:
$\boldsymbol{A = 0.86\angle 7^0}$
$\boldsymbol{B = 300\angle 75^0\Omega}$
$\boldsymbol{V_r = 200kV = V_s}$
$\boldsymbol{for unity p.f.}\, Q_r = 0 ---------- (\boldsymbol{1M})$

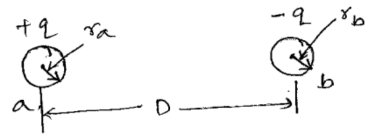
$$Q_r = \frac{|V_s||V_r|}{|B|}\sin(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\sin(\beta - \propto) ----(1M)$$
$$0 = \frac{(200)(200)}{300}\sin(\beta - \delta) - \frac{0.86}{300}(200)^2\sin(75 - 7)$$
$$0 = 133.33\sin(\beta - \delta) - 114.66$$
$$\sin(\beta - \delta) = \frac{114.66}{133.33} = 0.86$$
$$(\beta - \delta) = 59.31 ----(1M)$$

$$Subsituting in expression of P_r$$

$$P_r = \frac{|V_s||V_r|}{|B|}\cos(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\cos(\beta - \propto) ----$$

$$P_r = 133.33cos(59.31) - 42.95$$
$$P_r = \boldsymbol{68.05 - 42.95 = 25.10MW} ----(\boldsymbol{1M})$$

e) Derive an expression for capacitance of single phase tr. Line comprised of solid conductors.



The above figure shows two conductors of a single phase line having solid conductors. If charge per unit length on conductors a is q, then the charge per unit length on conductor b is –q -----------------------------**(1M)**

The potential difference between conductors a and b is

If $r_a = r_b = r$ then.

$$V_{ab} = \frac{1}{2\pi r}\left(q ln\frac{D}{r_a} - q ln\frac{V_b}{D}\right)$$

$$= \frac{q}{2\pi r} ln\frac{D^2}{r_a r_b} - - - - (\boldsymbol{1M})$$

The capacitance per unit length between the conductors i.e. C_{ab} is the ratio of charge to potential difference per unit length.

$$C_{ab} = \frac{q}{V_{ab}} = \frac{2\pi r}{ln\frac{D^2}{r_a r_b}} = \frac{\pi r}{ln(\frac{D}{\sqrt{r_a r_b}})}\frac{F}{M} - - - (\boldsymbol{1M})$$

$$if\ r_a = r_b = r\ then$$

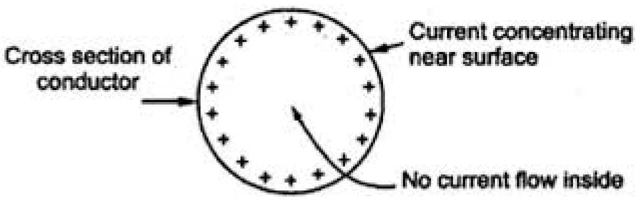
$$\boldsymbol{C_{ab}} = \frac{\boldsymbol{0.01206}}{\boldsymbol{\log\frac{D}{r}}}\frac{\boldsymbol{\mu F}}{\boldsymbol{Km}} - - - - (\boldsymbol{1M})$$

Q.4.

A. Attempt any three of the following: **12**

i. Define skin effect. State the factors on which skin effect depends?

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. **(2M ark)**



Effects of Skin Effect:
It causes larger power loss for a given rms AC than the loss when same value of DC is flowing through the conductor. Consequently the effective conductor Skin effect depends on following resistance is more for AC then for DC. **(1 Mark)**

Skin effect depends on factors: **(1 Mark)**

- Current
- Permeability of material
- Frequency
- Conductor diameter

ii. A 50 Hz, 3Φ, 27kV line has following GCC$A = 0.896 \llcorner 0.7^0, B = 138.7 \llcorner 84.2^0$. if line is supplied at 275 kV determine the MVA rating of shunt reactor that would be required to maintain 275 kV at receiving end when line is delivering no load.

$\boldsymbol{A = 0.896\angle 0.7^0}$
$\boldsymbol{B = 138.7\angle 84.2^0 \Omega}$
$\boldsymbol{Assume\ = V_s = 275KV}$
$\boldsymbol{V_r = 275kV}(\boldsymbol{inpaperpreintedas27KV})$
Line delivers number of load,$\boldsymbol{P_r = 0}$

$$P_r = \frac{|V_s||V_r|}{|B|}\cos(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\cos(\beta{-}\propto) - - - - (\boldsymbol{1M})$$
$$0 = \frac{(275)(275)}{138.7\cos(\beta - \delta)} - \frac{0.896}{138.7\cos(84.2 - 0.7)}$$
$$= 545.24\cos(\beta - \delta) - 645.99\cos(83.5)$$
$$0 = 545.24\cos(\beta - \delta) - 73.12$$
$$\cos(\beta - \delta) = 0.13$$
$$\beta - \delta = 82.29 - - - - - - (1M)$$

Substituting in equation of

$$Q_r = \frac{|V_s||V_r|}{|B|}\sin(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\sin(\beta{-}\propto) - - - - (\boldsymbol{1M})$$
$$Q_r = 545.24\sin(82.29) - 645.99\sin(83.5)$$
$$Q_r = 540.31 - 641.83$$
$$Q_r = -101.52MVar$$
$$atnoloadQ_r = 0Mvar, henceMVAratingofshuntreactoris\ 101.52MVar - -(\boldsymbol{1M})$$

iii. State advantages of P.U system in power system analysis.
[Each 1 mark]

1. Manufacturers: Usually specify the impedance of a piece of apparatus in percent or per unit on the bases of the nameplate rating.
2. The Zpu of machine of the same type but having widely different ratings usually lie within a narrow range. Although the value differ with the ratings. Hence, when the

impedance of the machine is not known, the table in which a values for different machines given.

3. The per unit impedance once expressed on the proper base, is same referred to either side of any transformers, because Base KV is selected in the same ratio as the transformer ratio.
4. The way in which transformers are connected in 3-phase circuits of the transformer, although it determine the relation between the base voltages on the two sides of the transformer.
5. Per unit values of quantities simplifies the calculations to greater extent. More over since system data is available in per unit values hence it is always convenient to adopt per unit calculations.

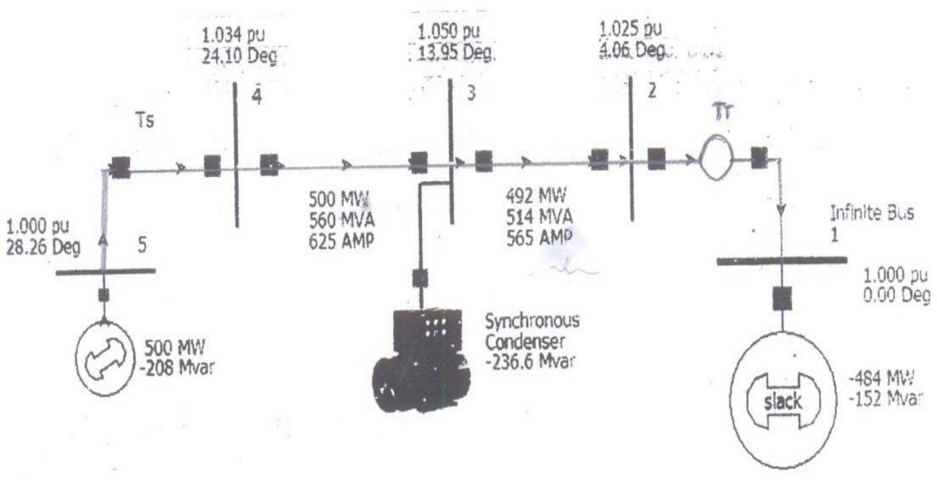
iv. State the necessity of reactive power compensation. Explain any one method of the reactive power compensation.

Need of reactive power compensation.[2mark]

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.

Method of reactive power compensation [Any One method ,2 mark]



1) Synchronous Condenser:

- A synchronous condenser is a synchronous motor running under no-load condition, which delivers inductive or absorbs capacitive reactive power.
- Synchronous condenser Can supply lagging as well as leading VARs
- Synchronous condensers have been used at both distribution and transmission voltage levels to improve stability and to maintain voltages within desired limits under varying load conditions and contingency situations
- The control of synchronous condenser is fast and continuous
- No switching problems present in synchronous condenser
- For large VAR requirement synchronous condenser is economical
- Their losses are much higher than those associated with static compensators, and the cost is much higher compared with static compensators. Their advantage lies in their high temporary overload capability.

2) **Capacitor Bank--**

- Capacitor Bank can supply only leading VARs
- The control of Capacitor Bank is slow
- The failure of one unit of capacitor bank affects that unit only for small VAR requirement capacitor banks are economical.
- Capacitor bank cannot be overloaded

B. Attempt any one of the following: **6**

a) A **3Φ, 50 Hz line has resistance of 20 Ω, inductance 0.2 H and capacitance 1 µ F. all parameters are per km. length of line is 150km and delivers a load of 50 MW at 132 kV, 0.8 lag p.f. determine ABCD constants of the line (considering π model).**

Given Data:

$$R = 20\Omega\,, L = 0.2H, \quad C = 1\mu F, \quad l = 150km, Vr = 132KV, 0.8\, pflagging$$

The line parameters

$$R = 20 \times 150 = 300\Omega$$
$$L = 0.2 \times 150 = 30H$$
$$C = 1 \times 150 = 150\mu F$$
$$Z = (300 + j2\pi \times 50 \times 30) = 300 + j9420\Omega$$
$$Y = (j2\pi \times 50 \times 150 \times 10^{-6}) = j942 \times 10^{-6} = 942 \times 10^{-6}\angle 90^0 - - - (\mathbf{1M})$$
$$Considering \pi model:$$
$$D = A = 1 + \frac{YZ}{2} = 1 + \frac{(9424.77\angle 88.77^0)(942 \times 10^{-6}\angle 90^0)}{2}$$
$$= 1 + 4.439\angle 178.77^0$$
$$= 1 - 4.437 + j0.095$$
$$= A = D = -344\angle 178.4^0 - - - -(\mathbf{2M})$$
$$B = Z = 9424.77\angle 88.77\Omega - - - (\mathbf{1M})$$

$$C = Y = 1 + \frac{YZ}{2} = 1 + \frac{(942 \times 10^{-6}\angle 90^0)(1 + 2.2195\angle 178.77^0))}{2}$$
$$= 942 \times 10^{-6}\angle 90^0(1 - 2.2189 + j0.0476)$$
$$= 942 \times 10^{-6}\angle 90^0(-1.2189 + j0.0476)$$

$$= 942 \times 10^{-6}\angle 90^0(1.2198 + \angle 177.76^0)$$
$$= 1.14 \times 10^{-6}\angle 267.76\ siemens. -----(\mathbf{2M})$$

b) Determine the self G.M.D. of conductors shown in Fig. 2 assume r=0.1cm:

i) ii)

Fig. 2.

For fig (i)

The result self GMD is given by

$$\boldsymbol{D_s = \sqrt[9]{(D_{11}D_{12}D_{13})(D_{21}D_{22}D_{23})(D_{31}D_{32}D_{33})}}$$

$$\boldsymbol{D_{12} = D_{21} = D_{23} = D_{31} = 2r}$$
$$\boldsymbol{D_{13} = D_{31} = 4r ------1M}$$
$$\boldsymbol{D_{11} = D_{22} = D_{33} = 0.7788r}$$
$$\boldsymbol{DS = \sqrt[9]{(r^1)^3(2r)^4(4r)^2} --- (1M)}$$
$$\boldsymbol{= \sqrt[9]{(0.7788)^3(r)^3(2r)^4(4r)^2} ---}$$

$$\boldsymbol{Ds = 1.703r = 1.703 \times 0.1 = 0.17cm --- (1M)}$$

For fig (ii)

The result self GMD is given by

$$\boldsymbol{D_s = \sqrt[16]{(D_{11}D_{12}D_{13}D_{14})(D_{21}D_{22}D_{23}D_{24})(D_{31}D_{32}D_{33}D_{34})(D_{41}D_{42}D_{43}D_{44})}}$$

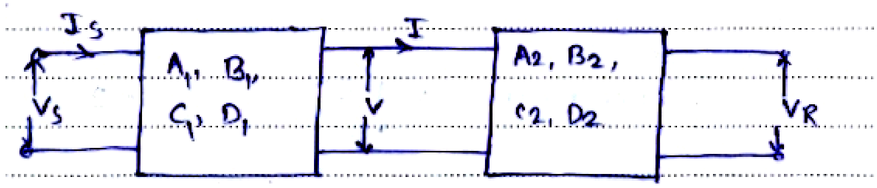
$$\boldsymbol{D_{11} = D_{22} = D_{33} = D_{44} = 0.7788r}$$

$$\boldsymbol{D_{12} = D_{23} = D_{34} = D_{41} = D_{21} = D_{32} = D_{43} = D_{44} = 2r}$$
$$\boldsymbol{D_{13} = D_{24} = D_{31} = D_{42} = 2\sqrt{2}r ------1M}$$

$$\boldsymbol{Ds = \sqrt[16]{(0.7788)^4(2r)^8\left(2\sqrt{2}r\right)^4} --- (1M)}$$
$$\boldsymbol{Ds = \sqrt[16]{(0.7788)^4(2)^8\left(2\sqrt{2}r\right)^4}\, r^{16}}$$
$$\boldsymbol{= Ds = 1.799r = 1.799 \times 0.1 = 0.1799cm ----(1M)}$$

Q.5. Attempt any two of the following: 16

a) Two transmission line networks are connected in series. Determine A, B, C, D constants of overall network.



-(1) m

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 A1, B1, C1, D1 & A2, B2, C2, D2 which are connected in series as show in fig. **(1M)**

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

∴ $V=D_1V_S-B_1I_S$ (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)

From equation (1) & (3) & equation (2) & (4) respectively.**(1M)**

$A_1 V_S - B_1 I_S = A_2 V_R + B_2 I_R$ -(5)

$-C_1 V_S + A_1 I_S = C_2 V_R + D_2 I_R$ -(6) -(1)m

multiply eqn (5) by A_1 & (6) by B_1 & adding the eqn.

$(A_1 D_1 - B_1 C_1) V_S + (-B_1 A_1 + B_1 A_1) I_S$
$= (A_1 A_2 + B_1 C_2) V_R + (A_1 B_2 + B_1 D_2) I_R$

$(A_1 D_1 - B_1 C_1) V_S = (A_1 A_2 + B_1 C_2) V_R + (A_1 B_2 + B_1 D_2) I_R$ -(7) -(1)m

multiply eqn (5) by C_1 & (6) by D_1 & add

$(C_1 D_1 - D_1 C_1) V_S + (-B_1 C_1 + A_1 D_1) I_S = (A_2 C_1 + C_2 D_1) V_R +$
$(B_2 C_1 + D_2 D_1) I_R$

$(A_1 D_1 - B_1 C_1) I_S = (A_2 C_1 + C_2 D_1) V_R + (B_2 C_1 + D_2 D_1) I_R$ -(8) (1)m

Since $A_1 D_1 - B_1 C_1 = 1$ ∴ from eqn (7)

∴ $V_S = (A_1 A_2 + B_1 C_2) V_R + (A_1 B_2 + B_1 D_2) I_R$ -(9)

from eqn (8) -(1)m

$I_S = (A_2 C_1 + C_2 D_1) V_R + (B_2 C_1 + D_2 D_1) I_R$ -(10)

but $V_S = A V_R + B I_R$ & -(11)

$I_S = C V_R + D I_R$ -(12)

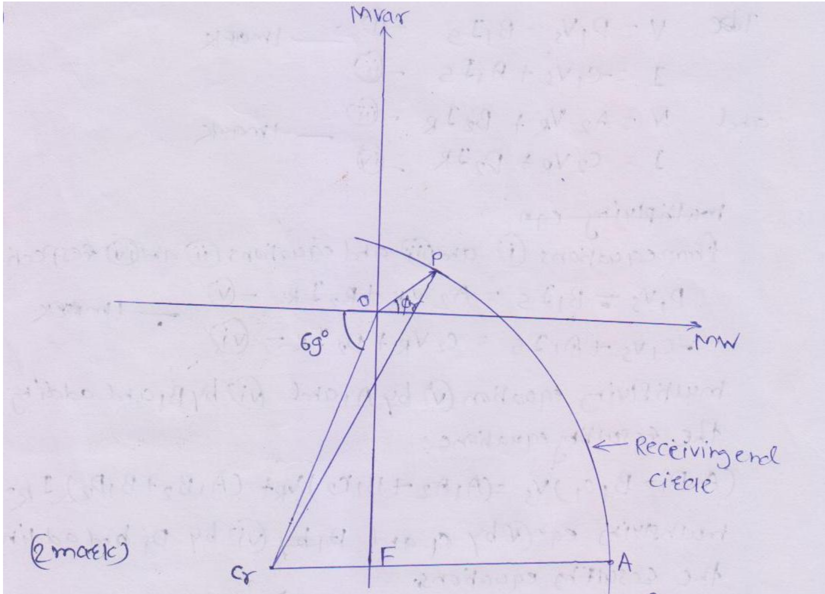
from eqn (9), (10), (11) & (12) (1)m

$A = A_1 A_2 + B_1 C_2$

$B = A_1 B_2 + B_1 D_2$ $D = B_2 C_1 + D_2 D_1$.

$C = A_2 C_1 + C_2 D_1$

b) A3Φ, 132 kV tr. Line delivers 40 MVA at 0.8 p.f. lagging. Determine sending end voltage with the help of circle diagram. Given that $A = 0.98\llcorner 3^0$ $B = 110\llcorner 72^0\Omega$. Also find max delivered at receiving end.



The distance of centre of circle $OC_r = \frac{|A||V_R|^2}{|B|}$

$= \frac{0.98 \times 132^2}{110}$

$= 155.23$ MVA —(1 mark)

$\angle B-\alpha = 72-3 = 69°$

Select a scale of 1 cm = 25 MVA and draw OC_r equal to $\frac{155.23}{25} = 6.2$ cm inclined at 68° to the negative real axis. —(1 mark)

1. OP is the 0.8 lagging p.f. line inclined at $\cos^{-1} 0.8$, i.e. 36.87 to positive x-axis. Take OP=40/25=1.6cm with Cr as entre and Crp as radius draw the receiving end circle.

Now crp=7.6cm=190MVA but radius of receiving rnd circle is radius=$\frac{|V_S||V_R|}{|B|} = 190$

$$\therefore \frac{|V_S|132}{110} = 190$$
$$\therefore |V_S| = 158.33KV --- (3M)$$

2. Draw the line parallel to MW axis from centre Cr which will touch the circle at point A.

$$\therefore maxpower = FA = 5.4cm = 135MVA(1M)$$

(NOTE: the answer may vary depending upon the accuracy of the diagram give mark by for procedure of the problem the scale also can change)

c) Determine inductive reactance of 1Φ tr. Line with the arrangement as shown in fig 3. The diameter of each conductor is 1cm. and current is equally shared by two parallel conductors.

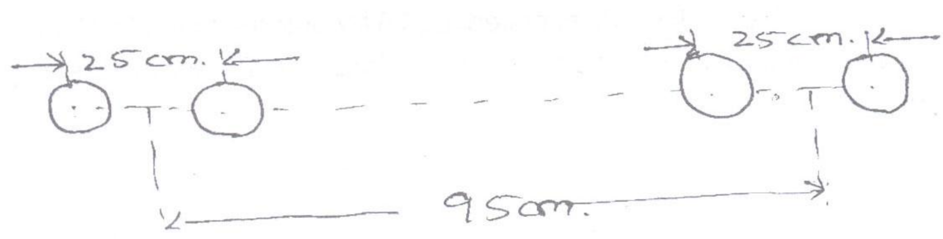


Fig. 3.

$d = 1cm \therefore r = 0.5cm = 0.5 \times 10^{-2}m$

$\frac{L}{M} = 2 \times 10^{-7} ln \frac{D_m}{D_S} ----(1M)$

Self GMR=0.7788r=0.7788× $0.5 \times 10^{-2} = 0.00389gm --- (2M)$

$\therefore D_{aa} = D_{a'a'} = D_{bb} = D_{b'b'} = 0.00389GM$

$\therefore D_S = \left(D_{aa} \times D_{a'a'} \times D_{aa'} \times D_{a'a}\right)^{1/4}$

$= (0.003894 \times 0.003894 \times 0.25 \times 0.25)^{1/4}$

$= (0.003894 \times 0.25)^{\frac{1}{2}} = 0.03120m --- (1M)$

$D_m = 0.95m --(1M)$

$\frac{L}{m} = 2 \times 10^{-7} ln \frac{0.95}{0.03120} = 683.20 \times 10^{-9} --- (1M)$

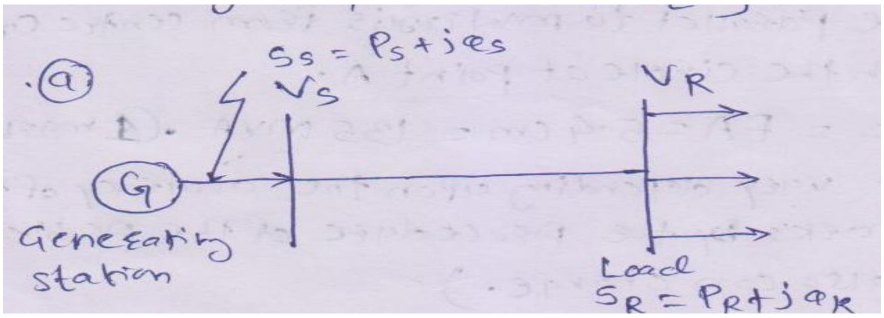
$\frac{L}{Km} = 689.20 \times 10^{-9} \times 1000 = 689.20 \times 10^{-6}H --- (1M)$

$\therefore X_L = 2\pi FL = 2 \times 3.14 \times 50 \times 689.20 \times 10^{-6} = 0.\frac{2164\Omega}{km} --- (2M)$

Note: Formula for calculation may be change check according to step.

Q.6. Attempt any four: 16

a) Derive the expression for complex power at receiving end of the line with generalized circuit.



The above diagram is a 2bus system having the sending end bus which is fed by the generator and the receiving end bus which is feed the load. S_R is a complex power at receiving end and $S_S$is complex power at sending end**-----------------------(1M)**

$$V_S = AV_R + BI_R - - - (a)$$
$$I_S = CV_R + DI_R - - - (b)$$

The current I_R can be expressed in terms of V_R , V_S as

$$I_R = \frac{1}{B}V_S - \frac{A}{B}V_R - - - - - - (i) - - - (\mathbf{1M})$$
$$Let, V_R = |V_R|\angle 0,, V_S = |V_S|\angle\delta$$
$$D = A = |A|\angle \propto, B = |B|\angle\beta,$$
$$then, I_R = \frac{|V_S|\angle\delta}{|B|\angle\beta} - \frac{|A|\angle\delta}{|B|\angle\beta}|V_R|\angle 0$$
$$I_R = \frac{|V_S|}{|B|}\angle\delta - \beta - \frac{|A|\angle\delta}{|B|}|V_R|\angle \propto -\beta - - - (ii)$$

The conjuguate of I_R is

$$I_R^* = \frac{|V_S|}{|B|}\angle\beta - \delta - \frac{|A|\angle\delta}{|B|}|V_R|\angle\beta{-}\propto - - -(iii) - - - (\mathbf{1M})$$

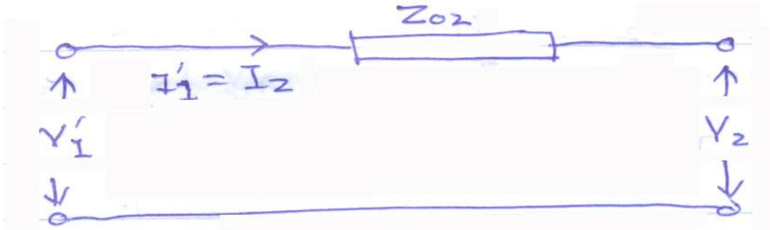
The complex power ph at the receiving end is

$$S_R = P_R + j_{QR} = V_R I_R = |V_R|\angle 0\left[\frac{|V_S|}{|B|}\angle\beta - \delta - \frac{|A||V_R|}{|B|}\angle\beta{-}\propto\right]$$

$$S_R = \frac{|V_S||V_R|}{|B|}\angle\beta - \delta - \frac{|A||V_R|}{|B|}\angle\beta{-}\propto - - - - (iv) - - - (\mathbf{1M})$$

b) Prove that p.u. reactance of transformer remains same refer to both side of the transformer.(each steps ½ M)

i. The approximate equivalent ckt sides.X_{mer} can be represented as



Approximate equivalent ckt referred to secondary.

ii. $Z_{o2} = Z_2 + Z_{1'}$

$Z_{o2} = Z_2 + Z_1.K$

iii. $Z_{o2} = Z_{2pu}.Z_{2b} + Z_{1pu}.Z_{1b}K^2 - - - -(i)$

$now, K = \frac{V_{2b}}{V_{1b}} = \frac{I_{1b}}{I_{2b}}$

iv. Because the base KV_s are selected in same transformation ratios & base KVA is same on both side of transformer.

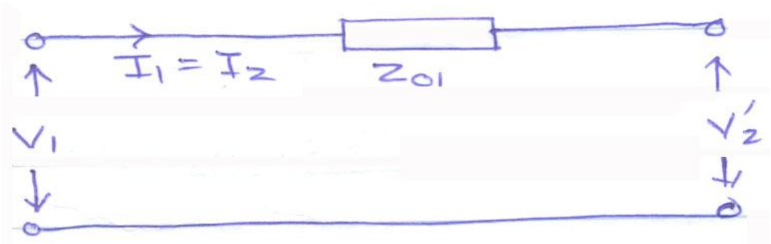
v. Also, $\frac{V_{2b}}{V_{1b}} = \frac{I_{1b}.Z_{2b}}{I_{2b}.Z_{1b}}$

$$\therefore K = \frac{Z_{2b}}{Z_{1b}} \times \left(\frac{I_{1b}}{I_{2b}}\right)$$
$$\therefore K = \frac{Z_{2b}}{Z_{1b}} \times \frac{1}{K}$$
$$\therefore Z_{2b} = Z_{1b}.K^2$$

vi. Substituting the relation in (i), we get

$$Z_{o2} = Z_{2pu}.Z_b + Z_{1pu}.Z_{2b}$$
$$Z_{o2} = Z_{2b}(Z_{1pu} + Z_{2pu})$$
$$\therefore \frac{Z_{o2}}{Z_{2b}} = Z_{1pu} + Z_{2pu}$$
$$\therefore Z_{pu} = Z_{1pu} + Z_{2pu}$$

vii. Considering the approximate equivalent ckt of transformer reffered to primary side.



viii. $Z_{o1} = Z_1 + Z_{2'}$

$$Z_{o1} = Z_1 + \frac{Z_2}{K^2} = Z_{1pu}.Z_{1b} + \frac{Z_{2pu}.Z_{2b}}{K^2}$$
$$Z_{o1} = Z_{1pu}.Z_{1b} + Z_{2pu}.Z_{1b}$$
$$= Z_{1b}(Z_{1pu}.Z_{2pu})$$
$$\therefore \frac{Z_{o1}}{Z_{1b}} = Z_{1pu} + Z_{2pu}$$
$$\therefore Z_{pu} = Z_{1pu} + Z_{2pu}$$

ix. Impedance calculated at primary and secondary side is same.

c) Give significance of inductance, resistance and capacitance parameters of tr. Line.

Significance of inductance in transmission line :[2mark]

- inductance causes voltage drop (IXl) which affect regulation
- due to lagging p.f. V_S is always greater than $V_{R,}$, hence regulation is always positive.Asp.f. increases regulation also increases.
- Transmission line capacity depends on inductance

Significance of resistance: [1mark]

- Resistance causes voltage drop IR, which affects regulation
- Resistance causes I^2R losses, which affects efficiency.
- Temperature of line increases due to resistance

Significance of capacitance in performance of transmission line [1mark]

- The capacitance is uniformly distributed along the whole length of the line and may be regarded as a uniform series of capacitors connected between the conductors.
- When an alternating voltage is applied sinusoidal current called the charging current which is drawn even when the line is open circuit at the far end.
- The line capacitance being proportional to its length, the charging current is negligible for lines less than 100km long. For longer lines the capacitance becomes increasingly important and significant for performance of 1 transmission line.
- Line capacitance creates a voltage drop in the line due to its reactance value.
- In EHV lines line capacitance is responsible for boosting the voltage level under no load condition.

d) State the field of applications of following reactive power compensators.

i. Shunt capacitor bank
ii. Series inductor bank
iii. Synchronous condenser
iv. Auto transformer.
(Each point 1M, consider also any other location)

i. shunt capacitor bank –substation & medium Tr. Line, busbar, tertiary wdg of main x'mer
ii. Inductance reactor bank- long HV tr. Line, middle of line, rear substation switching substation
iii. Syn. condenser- load centre, high voltage system, HVDC system
iv. Auto transformer – substations, at the both line.

e) A 3 phase, 50 Hz, line is 250 km long. It has series impedance 35+j40Ω and shunt admittance 930x 10^{-4} Ω. It delivers 40 MW at 220kV with 0.9 lag. P.f. determine ABCD constant considering medium line having nominal Tcircuit.

$$f = 50HZ, l = 250Km, Z = 35 + j40\Omega, = 53.15\angle 48.81$$
$$Y = j930 \times 10^{-4} = 930 \times 10^{-4}S, P_R = 40MW\ ,$$
$$V_R = 220KV\ \ , cosQ_R = 0910g - - - (\mathbf{1M})$$
$$A = 1 + \frac{ZY}{2} = 1 + \frac{(53.15 < 48.81)(930 \times 10^{-4} < 90)}{2}$$
$$= 1 + 2.471 < 138.81$$
$$= 1 + (-1.859 + j1.627)$$
$$= -0.859 + j1.627$$
$$= 1.839 + j117.83 = D - - - -(\mathbf{1M})$$
$$A = 1 + \frac{YZ}{2} = 53.15 < 48.81[1 + \frac{(930 \times 10^{-4} < 90)(53.15 < 48.81)}{4}$$
$$= 53.15 < 48.81[1 + \frac{4.942 < 138.81}{4}$$
$$= 53.15 < 48.81[1 + 1.2355 < 138.81]$$
$$= 53.15 < 48.81[1 + (-0.9297 + j0.8136)]$$
$$= 53.15 < 48.81[0.0703 + j0.8136]$$
$$= (53.15 < 48.81)(0.8166 < 85.06)$$
$$= 43.40 < 133.87 - - - (\mathbf{1M})$$
$$= C = Y = 930 \times 10^{-4} < 90^0 - - - -(\mathbf{1M})$$