Important Instructions to examiners:

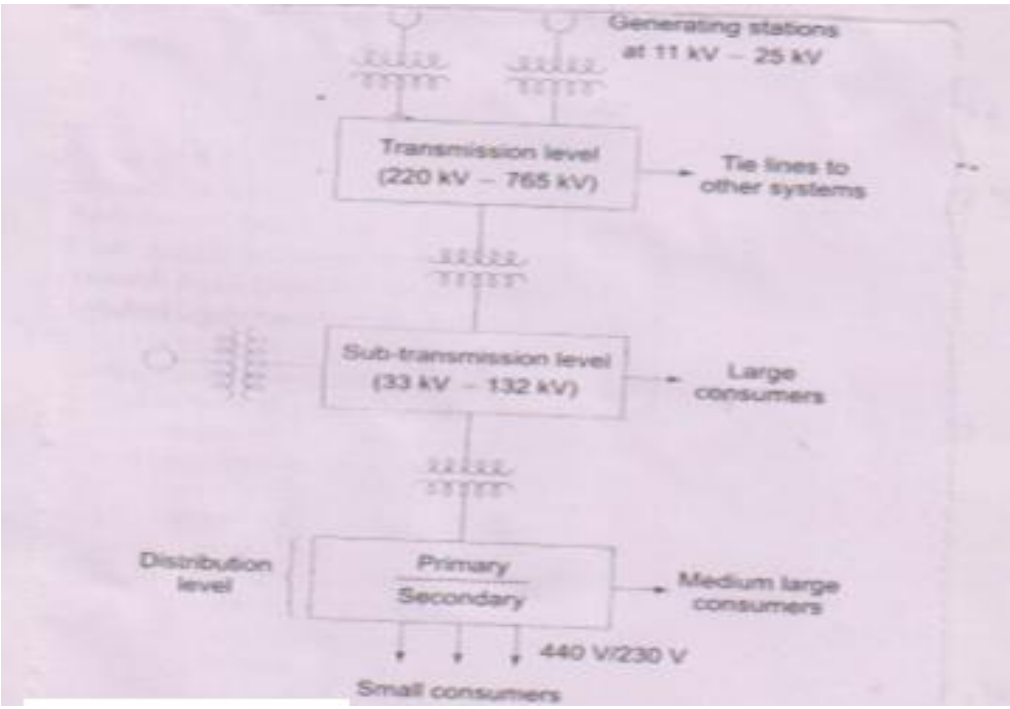
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling 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: **12**

a) Draw schematic diagram depicting power system structure.

Ans. ***(Diagram 2M, labelled 2M)***

Schematic diagram depicting power system structure.



b) Give the difference between AC resistance and DC resistance.

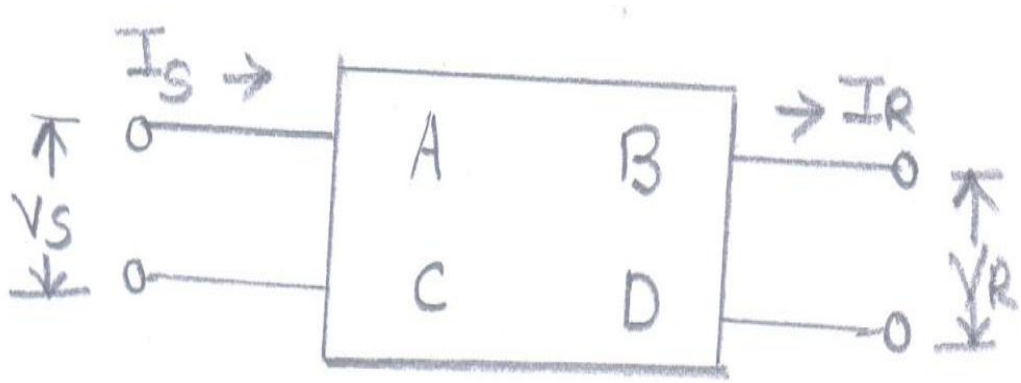
Ans. ***(1M each point)***

AC resistance	DC resistance
It is the resistance offered by the conductor when AC current flows through it.	It is the resistance offered by the conductor when DC current flows through it.
Always greater than Dc resistance	Always lesser than AC resistance
R_{AC}=Avg power loss in conductor/ I^2	$R_{dc}= \rho l/A$
Skin effect and proximity effect affects R_{ac}	Skin effect and proximity effect affects are not present in dc resistance.

c) Explain the concept of Generalized circuit constants.

Ans.

Generalized Circuit: An passive, linear, bilateral network with two port terminals is known as generalized circuit. A transmission line is a 2 port network, two input terminals where power enters & two output terminals where power leaves the network……(1 Mark)



1 Mark

Therefore the input voltage $\vec{V_s}$ and input current $\vec{I_s}$ of a 3Φ transmission line can be expressed as in generalized equation form as

$$\vec{v_S} = \vec{A}\,\vec{V_R} + \vec{B}\,\vec{I_R}$$

$\overrightarrow{I_S} = \vec{C}\,\overrightarrow{V_R} + \vec{D}\,\overrightarrow{I_R}$……..(1 Mark)

Where, $\overrightarrow{V_S}$ = sending end voltage lph

$\overrightarrow{I_S}$ = sending end current l

$\overrightarrow{V_R}$ = Receiving end voltage lph

$\overrightarrow{I_R}$ = Receiving end current

& $\vec{A}$, $\vec{B}$, $\vec{C}$ & $\vec{D}$ are the constants known as generalised ckt. constants of the line.

1 Mark

OR

Generalized Circuit Constant:

1) A = $\frac{V_S}{V_R}$; I_R = O……..(1Mark)

It is the ratio of the voltage impressed at the sending end to the voltage at the receiving end when the receiving end is open circuited. It is a dimension less quantity.

2) B = $\frac{V_S}{I_R}$; V_R = O……(1Mark)

It is the volt impressed at the sending end to current of receiving end when receiving end is short circuited. It is known as Transfer impedance. It's unit is in ohms.

3) C = $\frac{I_S}{V_R}$; I_R = O…….. (1Mark)

It is defined as the ratio sending end current to the receiving end voltage when receiving end is open circuited. It is known as Transfer admittance and it's unit mho.

4) D = $\frac{I_S}{I_R}$; V_R = O……...(1Mark)

It is the ratio of amperes impressed at the sending end to the ampere at the receiving end when the receiving end is short circuited. It is a pare quantity.

d) State the expression for complex power at receiving end of transmission line. Derive the condition for maximum power at receiving end.

Ans.

Expression for complex power at the receiving end

$$P_R = \frac{|V_S||V_R|}{|B|}\cos(\beta-\delta) - \frac{|A||V_R|^2}{|B|}\cos(\beta-\alpha) - - - (2\ Mark)$$

Where, A $\angle\alpha$, B $\angle\beta$ -are GCC

V_S $\angle 0^0$ – Sending end voltage

U_R $\angle\delta$ - receiving end voltage

Condition for maximum power transfer at receiving end.

$$for\ Maximum\ power\ different\ above\ equation\ w.r.t\ \delta\ \&\ equate\ to\ Zero$$

$$\left.\begin{aligned} &\therefore i.e. \frac{dP_R}{d\delta} = 0 \\ &\therefore \frac{d}{d\delta}\left[\frac{|V_S||V_R|}{|B|}\cos(\beta-\delta) - \frac{|A||V_R|^2}{|B|}\cos(\beta-\alpha)\right. = 0 \end{aligned}\right\} \text{1 Mark}$$

$$\frac{-|V_S||V_R|}{|B|}\sin(\beta-\delta) - 0 = 0$$

$$\therefore \frac{-|V_S||V_R|}{|B|}\sin(\beta-\delta) = 0\ or\ \sin(\beta-\delta) = 0$$

$$i.e.\ \beta-\delta = 0 - - - - (sin0 = 0)$$

$$\therefore \beta = \delta - - - - - 1mark$$

$$This\ is\ the\ condition\ for\ maximum\ power.$$

Q.1)B) Attempt any one: 6

a) Describe the phenomenon of flux linkages of an isolated current carrying conductor with necessary expression.

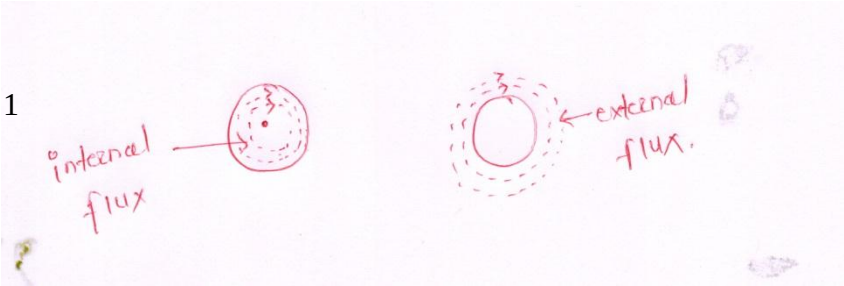
Ans. ***(1M for each point)***

1) Consider current carrying conductor as isolated i.e. return path is at infinity return path is saturated at far away so return current does not affect the magnetic field of conductor.

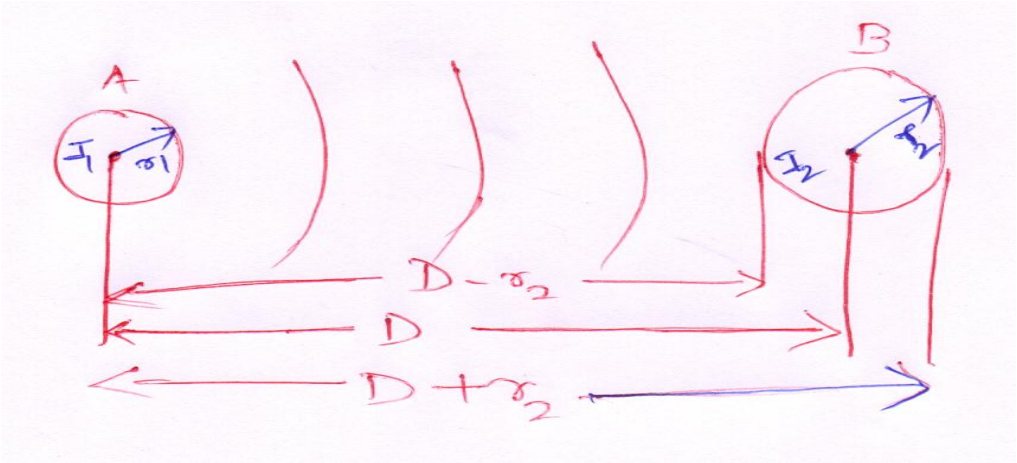
2) When current passes through conductor flux is set up which is divided in two parts:
   a) Flux inside the conductor- Internal flux
   Flux linkages due to internal flux= $\frac{I}{2} \times 10^{-7} Wb - T/m$……..1 Mark

   b) Flux outside the conductor- External flux

1



3) This division is required for calculating inductance because internal flux links small amount of current and external flux links with total current



External flux setup between A X B i.e. d-2r
Conductor links with total current I where as external flux. Between (D – r) and (D + r) Links with current which reduces from I upto zero amp.
External flux beyond (D + r) links with zero current [$I_a = I$ $I_D = -I$]
∴ Assume that external flux setup in D mts. Links with 'I' amp. ……1mark

Flux linkages due to external flux=$2 * 10^{-7} * \mathrm{I} * \log e \frac{D2}{D1} Wb/m$ …..1mark

4) So that flux linkages =
Internal flux linkages (Ψint) + External flux linkages (Ψext)……1mark

b) A132 kV, 3-phase line has the following line constants: A=0.9 $\angle 2.5^0$, B = 100 $\angle 70^0$ Ω, C = 0.0006 $\angle 80^0$ S.

Draw the receiving end power circle for a load of 40MW at 0.8 power factor lagging at receiving end and determine the sending end voltage.

Ans.

Co-ordinates of Centre 'C':

X-coordinate = $\frac{-\mathrm{AVR}^2}{\mathrm{B}} \cos(\beta - \propto)$

$= \frac{-(0.9)(132)^2}{100} \cos(70 - 2.5)$

= -156.816 cos (67.5)

= - 60.01MW……..(1 Mark)

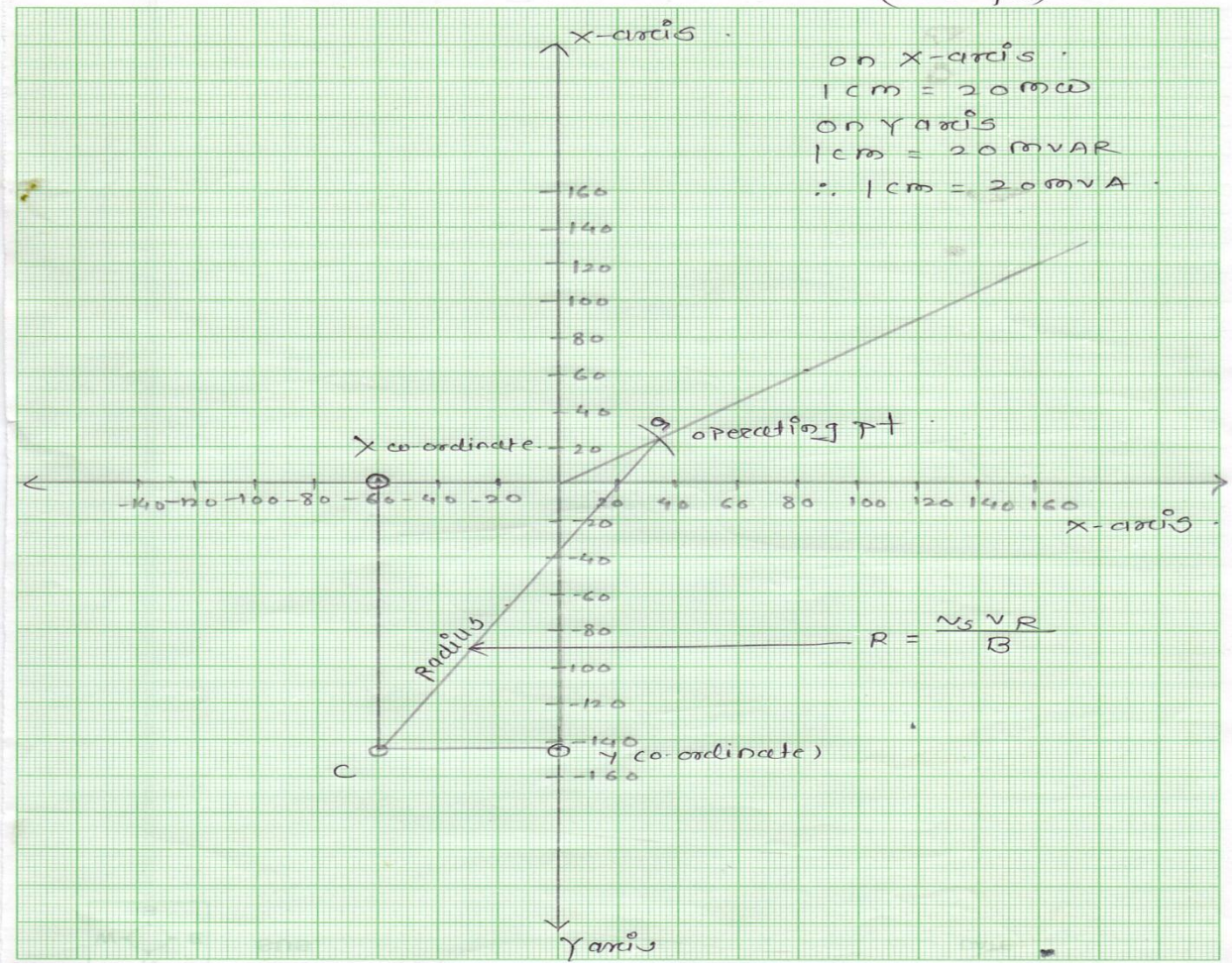
Y-coordinate = $\frac{-\mathrm{AVR}^2}{\mathrm{B}} \sin(\beta - \propto)$

$= \frac{-(0.9)(132)^2}{100} \sin(70 - 2.5)$

= -156.816 sin (67.5)

= - 144.87 MVAR……..(1 Mark)

(2 Marks)



Radius R = CA= 9.7 * power scale

= 9.7* 20

= 194 MVA……..….(1Mark)

And…….Rradius $= \frac{V_S V_R}{B}$

$194 = \frac{V_S \text{ X } 132}{100}$

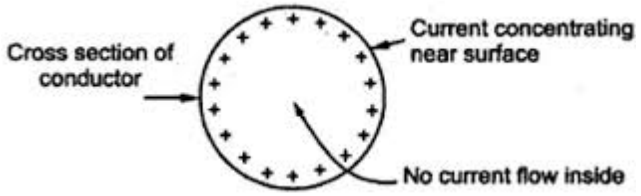
V_S = 146.96 kV……(1 Mark)

Q.2) Attempt any two: **16**

a) i) Describe the influence of skin effect and proximity effect on line conductors.

Ans.

i) Influence of skin effect: (1 Mark)



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.

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.

Skin effect depends on factors: (1 Mark)

- Current
- Permeability of material
- Frequency
- Conductor diameter

Influence of proximity effect: (1 Mark)

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”.

Factors affecting proximity effect: (1 Mark)

1. Conductor size (diameter of conductor)
2. Frequency of supply current.
3. Distance between conductors.
4. Permeability of conductor material

ii) A single phase overhead transmission line delivers 1100kW at 33kV at 0.8 p.f. lagging the total resistance and inductive reactance of line are 10 Ω and 15 Ω respectively. Determine i) sending end voltage ii) transmission efficiency.

Ans.

Given data $\longrightarrow P_R = 1100\text{kw}$

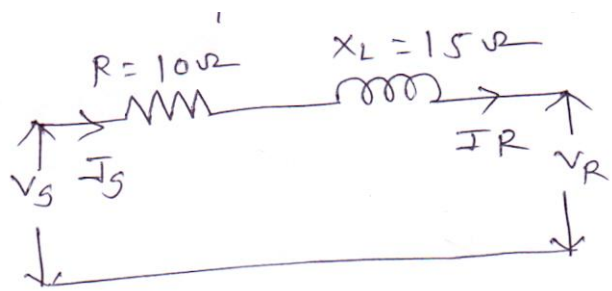
$V_R = 33\text{kv}$

$R = 10\ \Omega$

$X_L = 15\ \Omega$

Find out $\longrightarrow$ $V_S = ?$

Transmission $\eta = ?$



Z

$Z = \sqrt{(10)^2 + (15)^2} = 18.027\ \Omega$

$\phi = \cos^{-1}\left({}^{R}/_{Z}\right) = \cos^{-1}\left(\frac{10}{18.027}\right) = 56.30$

$I_R = \frac{P}{V_R \cos\phi_S} = \frac{1100 \text{ X } 10^3}{33 \text{ X } 10^3 \text{ X } 0.8} = 41.666A$

$J_S = I_R = 41.666A$……..(1Mark)

$V_S = V_R + ZI_R$

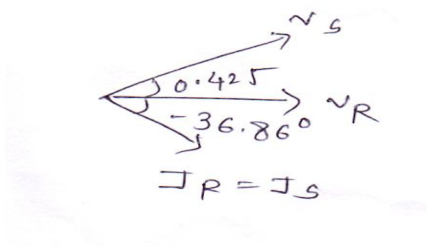
$= (33000 \angle 0^0) + (18.027 \angle 56.30^0)\ (41.666 \angle -36.86^0)$

$= (33000 \angle 0^0) + (751.112 \angle 19.44^0)$

= 33000+ j o +708.291 + j 249.98

= 33708.291 + j 249.98

= 33709.21 + $\angle 0.425^0$ ……(1 Mark)



ϕ_S = 36.86 + 0.425
= 37.285
$\cos\phi_S$ = cos(37.285)
= 0.795

I/p power= $V_S I_S \cos\phi_S$
= 33709 X 41.666 X 0.795
= 1116.59kw

(1Mark)

Transmission $\eta = \frac{o/p}{i/p}$

$= \frac{1100}{1116.59}$ X 100

= 98.51%.....(1 Mark)

b) i) Describe the phenomenon of Inductance of 1-phase line composed of bundled conductor.

Ans.

Inductance of single phase tr. Line composed of bundled conductors:

Consider a 1ϕ tr. Line composed of duplex bundled conductors x & y as shown in fig:

Let 'I' be the current through conductor 'X' which equally divides among 2 filaments 'a' & 'b' i.e. current through each filament is I/2 amp. Consider conductor 'y' forms the return path for the current.

Inductance of conductor 'x', L_x

$= \frac{1}{x} L_{ax}$

$= \frac{1}{2} X L_a$

Where L_a inductance of filament 'a'

$L_a = L_b$

n – no. of filament

= 2…. For duplex butid conductor

Net flux linkage with filament 'a' due to current through a, b, a^1, b^1 filaments

$$\psi = 2 \times 10^{-7} \left\{ \frac{I}{2} \left(\log_e \frac{1}{r^1} + \log_e \frac{1}{D_{ab}} \right) - \frac{I}{2} \left(\log_e \frac{1}{D_{aa^1}} + \log_e \frac{1}{D_{ab^1}} \right) \right\}$$

$= 2 \times 10^{-7} I \log_e \frac{\sqrt{Daa^1 \cdot Dab^1}}{\sqrt{D_{aa} . D_{ab}}}$ where $D_{aa} = r^1$

$$\therefore L_a = \frac{y_a}{I/2} = 2 X 10^{-7} \log_e \frac{Da a^1 . Dab^1}{D_{aa} . D_{ab}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots H/mt$$

$$III\ l_y\ L\ b = 2 X 10^{-7} \log_e \frac{Db a^1 . Dbb^1}{D_{ba} . D_{bb}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots H/mt$$

$$\therefore L_{ax} = \frac{L_a + L_b}{2}$$

$$= 2 X 10^{-7} \log_e \frac{\sqrt{Da a^1 .\ Dab^1 . Dbb^1 .\ Dba^1}}{\sqrt{Da a .\ Dab . Dbb .\ Dba}}$$

$$\therefore L_x = \frac{1}{2} L_{ax}$$

$$= 2 \times 10^{-7} \log_e \frac{4\sqrt{Da a^1 .\ Dab^1 .Dbb^1 .\ Dba^1}}{4\sqrt{Da a .\ Dab .Dbb .\ Dba}}$$

$$= 2 \times 10^{-7} \log_e \frac{D_m}{Ds_x} \ldots\ldots\ldots\ldots\ldots {}^{H}/_{mt} \ldots\ldots\ldots\ldots (1\ Mark)$$

lll l_y $L_y = 2 \times 10^{-7} \log_e \frac{Dm}{Ds_y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots {}^{H}/_{mt}$

where $Ds_{y=} 4\sqrt{Da^1 a^1 .Db^1\ b^1 .Da^1 b^1\ .Db^1 a^1}$ ……(1 Mark)

∴ L_{loop} - Total inductance of 1ϕ line

$= L_x + L_y$ (1 Mark)

$$= 2 \times 10^{-7} \left[\log_e \frac{Dm}{Ds_x} + \log_e \frac{Dm}{Ds_y} \right]$$

$$= 2 \times 10^{-7} \log_e \frac{Dm^2}{Ds_x . Ds_y}$$

$= 2 \times 10^{-7} \log_e \frac{Dm^2}{Ds^2}$ where $D_s = Ds_x = Ds_y$ for duplex bundelled

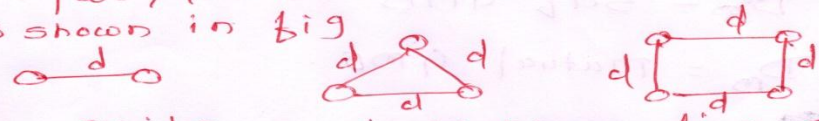
$= 4 \times 10^{-7} \log_e D_m/D_s$…….H/mt

$L_{loop} = 4 \times 10^{-7} \log_e D_m/D_s$……H/mt

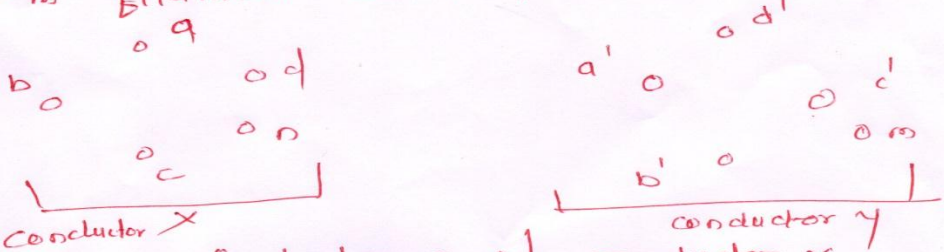
OR

Bundle conductor —

Bundle of conductor comprises two, three or four conductor arranged as shown in fig



Consider a single phase line of bundled conductor. let conductor x is composed of 'n' identical parallel filaments carrying equal current. conductor y is composed of 'm' filament carrying equal current



let L_x be inductance of conductor x.

$= \frac{1}{n} \times$ inductance of any one subconductor.

have same inductance value.

$= \frac{1}{n} \times$ avg value of inductance.

$$L_{avg} = \frac{L_a + L_b + L_c + \cdots + L_n}{n}$$

putting value of L_a, L_b, L_c eqn is

$$L_x = \frac{1}{n} \times L_{avg}$$

$$= 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

$D_m = \sqrt[mn]{mn \text{ terms}}$ $D_m = \sqrt[4]{4}$

because $\therefore m = 2$ $n = 2$

$D_s = \sqrt[m^2]{m^2 \text{ terms}}$.

D_s – self GMD

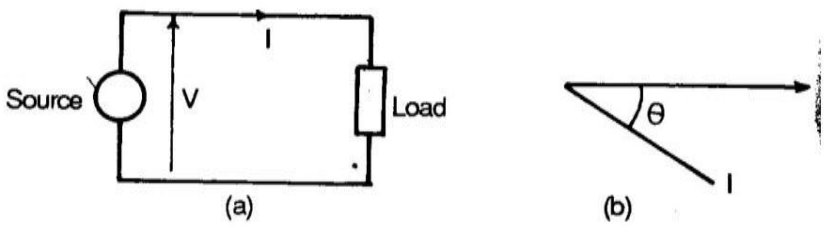
D_m = Mutual GMD.

ii) Prove that the complex power in power system is S = VI*.

Ans.

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

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



1 mark

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

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

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)

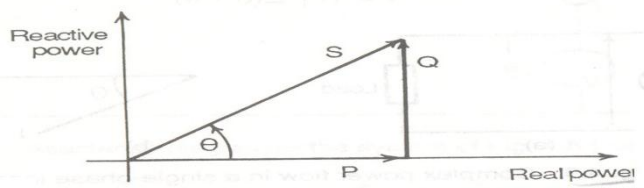
= kilovoltamperes reactive (kVAR)

= megavoltamperes reactive (MVAR)

2 marks

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.

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



Phasor representation of complex power (lagging pf load)

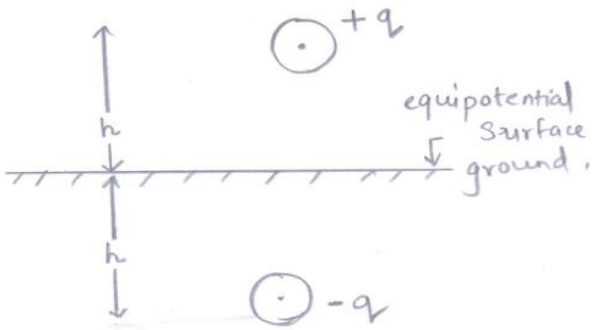
1 mark

c) i) Explain the effect of earth field on transmission line capacitance.

Ans. ***(1M for diagram & 3M for explanation)***

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.



ii) Write the stepwise procedure for drawing sending end circle diagram.

Ans. ***(2M for step, 2M for diagram)***

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.

Step-2: The center 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. 1 Mark

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.

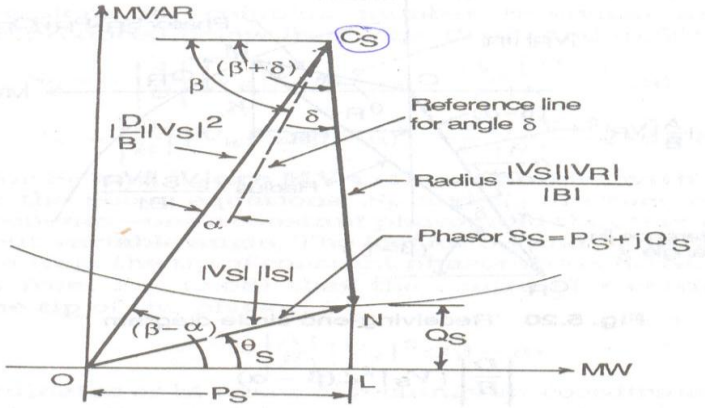
Step-3: Radius = $|V_S||V_R| / |B$

Draw the Curve with the radius of sending end circle from center

C' to the scale.

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. 1 Mark

Step-5: Complete the triangle ONL which represents power triangle at sending end.

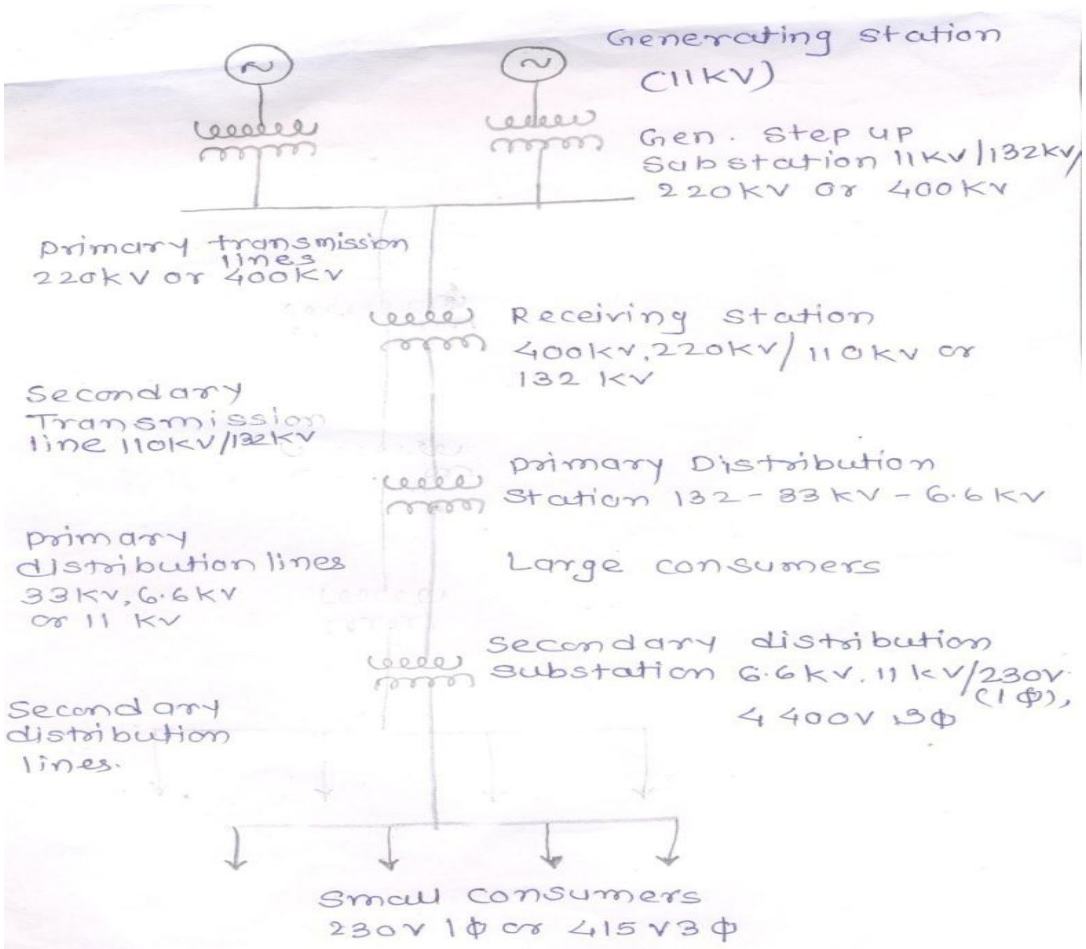


2 Mark

Q.3) Attempt any four: **16**

a) Draw a single line representation of a simple power system.

Ans. ***(1M-- voltage levels & 3M -- line diagram diagram)***



b) Describe the effect of temperature on transmission line resistance.

Ans.

(1M for each point)

The effect of temperature on transmission line resistance:

- Transmission line is made up of conducting material i.e. metal Cu /Al
- Metal has positive temperature coefficient.
- Due to positive temperature coefficient , as temperature increases resistance of transmission line also increases
- Resistance at any t temperature is given by Rt = Ro (1+ ∝ot) where Ro is resistance at zero temperature , ∝o is temperature coefficient of material at zero temperature & t is temperature

c) Determine the receiving end voltage of a 3-phase, 100km, 50Hz, transmission line delivering 20MW at a p.f. of 0.8 lagging and 66 kV to a balanced load. The conductors are of copper, each having resistance 0.1 ohm per km, 1.5cm outside diameter, spaced equilaterally 2 meters between centres. Neglect leakage. Use nominal T method.

Ans. (4M)

3 phase transmission line delivering 20MW at a p.f. of 0.8 lagging & '**66 Kv to a balanced load'** This indicates that receiving end voltage =66kV

Students have been asked to determine the same so if student writes V_R = 66KV …….(4 Marks).

Note: If student has attempted this question 4 marks should be given .

d) A 50 Hz, 3-phase, 275 kV, 400km transmission line has the following parameters:
Resistance = 0.035 Ω/km per phase
Inductance = 1.1 mH/km per phase
Capacitance = 0.012 μ F/km per phase.
If the line is supplied at 275 kV, determine the MVA rating of a shunt reactor having Negligible losses that would be required to maintain 275 kV at the receiving end when the line is delivering no load. Use nomimal – π method.

Ans.

Given data:
f=50Hz, V_s=275kv, L=400 km, V_R=275kv,
R=0.035Ω/km/ph,

L=1.1mH/km/ph=1.1X10^{-3}H/km/ph,
C=0.012μF/km/ph=0.012X10^{-6} F/km/ph
At no load condition i.e Pr=0 MVA
For nominal π circuit model,

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

$$Z = R + jX_L = \sqrt{R^2 + {X_L}^2}$$

$$X_L = 2\pi FL = 2 \times \pi \times 50 \times 1.1 \times 10^{-3} \times 400 = 138.23$$
$$R = 0.5 \times 400 = 200\Omega$$
$$Z = 200 + j138.23 = 243.12 < 34.65\Omega \ldots$$
$$Y = jwc = j \times 2\pi \times 50 \times 0.012 \times 10^{-6} \times 400$$
$$= 1.5079 \times 10^{-3} = j1.5079 \times 10^{-3} = 1.5079 \times 10^{-3} < 90^0 \quad \ldots\ldots..(1\ mark)$$

$$\therefore A = 1 + (1.5079 \times 10^{-3} < 90\ x\ 243.12 < 34.65)/2$$

$$= 1 + 0.1833 < 124.65 = 1 + (-0.1042 + j0.1508)$$

$$= 0.8958 + j0.1508 = 0.908 < 9.55$$

$$B = Z = 243.12 < 34.65\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1\ mark)$$

$$\therefore |A| = 0.908, \alpha = 9.55, |B| = 243.12, \beta = 34.65$$

At no load Power at R. E. is zero.

$$\therefore P_r = \frac{|V_S||V_r|}{|B|}\cos(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\cos(\beta - \alpha) = 0$$

$$\therefore O = \frac{275 \times 275}{243.12}\cos(\beta - \delta) - \frac{0.908 \times 275}{243.12}\cos(34.65 - 9.55)$$

$$(\beta - \delta) = 89.82^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1\ Mark)$$

Substituting in expression of Q_r

$$\therefore Q_r = \frac{|V_s||V_r|}{|B|}\sin(\beta - \delta) - \frac{|A||V_r|^2}{|B|}\sin(\beta - \alpha)$$

$$= \frac{275 \times 275}{243.12}\sin(89.82) - \frac{0.9988 \times 275}{243.12}\sin(34.65 - 9.55)$$

$$311.057 - 0.479$$

$$Q_r = 310.577MVAR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1\ mark)$$

Thus the line supplies $310.577MVAR$ logging at no load, thus the rating of shunt reactor $310.577MVAR$

e) A 3-phase transmission line has a resistance 10 Ω per phase and a reactance of 30 Ω per phase. Determine the maximum power which may be transmitted if 132 kV were maintained at each end.

Ans.

Maximum power that can be transmitted if sending end voltage and receiving end voltage is 132 kV. , R= 10 ohm/phase, X= 30 ohm/phase
For max receiving end power condition is $B - \delta = 0 \ldots\ldots\ldots\ldots(1M)$

B= Z = 10 +j 30 = 31.6227< 71.56

$$P_{R_{max}} = \frac{V_S V_R}{B} - \frac{AV_R^2}{B}\cos(\beta - \alpha) \ldots\ldots\ldots.(1M)$$

$$= \frac{132x\ 132}{31.6227} - \frac{1 \times (132)^2}{31.6227}\cos(71.56 - 0) \ldots\ldots.(1M)$$

$$P_{R_{max}} = 408.388\ Mw \ldots\ldots\ldots\ldots\ldots\ldots(1M)$$

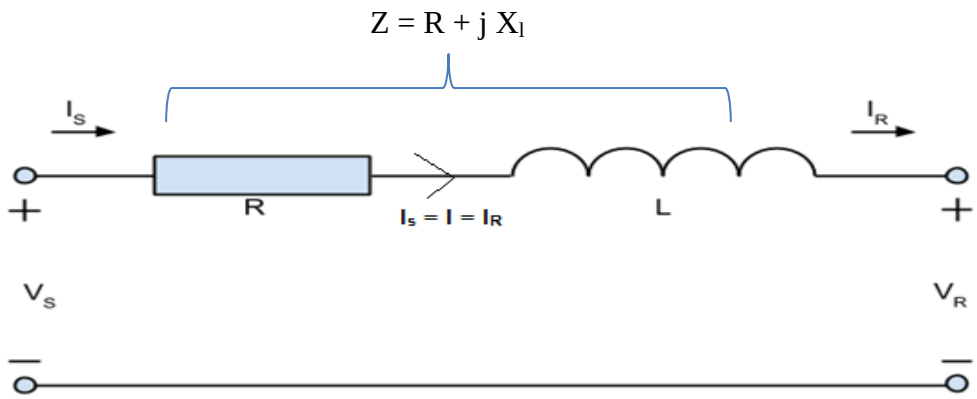
Q.4) A) Attempt any three: 12

a) Draw an equivalent circuit representation of short transmission line

Ans . ***(Diagram 3 mark, label- 1M)***

Short tr. Line –voltage up to 20 Kv and length up to 80 Km

Line parameters uniformly distributed along the length of the line. In short tr. Line because of low voltage and shorter length effect of line capacitance on performance of line is negligible. Also conductance is also negligible. Hence these two parameters are neglected. Now short tr. Line has two parameter i.e. R & L , which forms a series element. Therefore equivivelent ckt. can be drawn as



R – Total resistance

X_l = Total inductive reactance = $2\pi f L X_l$

b) Explain the concept of self GMD and mutual GMD.

Ans. ***(2M for each definition)***

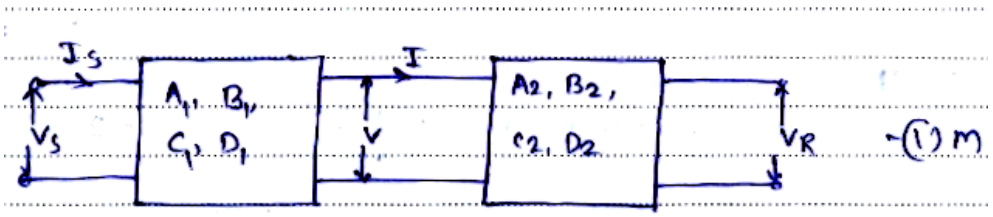
The concept of Mutual GMD and self GMD in transmission line.

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

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 $D_{m.}$
Similarly,
GMR :the denominator of the argument of the logarithm in above Equation is the $n^2 th$ 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* (GMR).

c) Derive the generalised circuit constants of two network connected in series.

Ans.



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. 1 Mark

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.

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)

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

$D_1V_S – B_1V_S = A_2 V_R + B_2I_R$……..(5)

$-C_1V_S = A_1I_S = C_2V_R + D_2I_R$…….(6) 1 Mark

Multiply equation (5) by A_1 and (6) by B_1 and adding the equation

$(A_1D_1-B_1C_1)V_S +(-B_1A_1+B_1A_1)I_S$

$=(A_1A_2+B_1(2)V_E + (A_1B_2+B_1B_2)I_R$

$(A_1D_1-B_1C_1)V_S = (A_1A_2+B_1C_2)V_R +(A_1B_2+B_1D_2)I_R$……(7)

Multiply equation (5) by G and (12) D_1 and add

$(C_1D_1-D_1C_1)V_S+(-B_1C_1+A_1D_1)I_S = (A_2C_1+C_2D_1)V_R + (B_2C_1 +D_2D_1)I_R$

$(A_1D_1- B_1C_1)I_S = (A_2C_1+C_2D_1)V_R +(B_2C_1+D_2D_1)I_R$……(8)

Since $A_1D_1 –B_1C_1 = 1$ ∴ from equation (7)

$\therefore \quad V_S = (A_1A_2+B_1C_2)V_R + (A_1B_1+B_1D2)I_R$……(9)

From equation (8)

$I_S = (A_2C_1+C_2D_1)\,V_R + (B_2C_1+D_2D_1)I_R$……..…..(10)

(1 Mark)

but $V_S = AV_R+BI_R$……(11)

$I_S = CV_R + DI_R$……..(12)

From equation (9), (10), (11) & (12)

$A = A_1A_2+B_1C_2$

$B = A_1B_2+B_1D_2$

$C = A_2C_1 + C_2D_1$

$D = B_2C_1+D_2D_1$

(1 Mark)

d) Describe series compensation. State the advantages of same.

Ans. ***(Series compensation 1, advantages 3M- one for each)***

Series compensation:

In series compensation, the Compensator is connected in series with the line in power system which feeds reactive power (capacitive or inductive) so that receiving end voltage is maintained or voltage drop in the line reduces.

. It works as a controllable voltage source. Series inductance exists in all AC transmission lines. long lines, when a large current flows, this causes a large voltage drop. To compensate, series capacitors are connected, decreasing the effect of the inductance. Also by connecting series capacitors in series with line, the inductive reactance of the line will be reduced due to which power factor of the system can be improved. But the effect on power factor is very little when compared to shunt capacitor

Advantages of reactive power compensation:

. In case of transmission line the major voltage drop and I^2R losses are caused by reactive power components. Most of the loads are of lagging type which absorbs VARs to supply the magnetizing current of transformers, induction motors. At any moment the maximum VARs which can be transferred over the lines are fixed by voltage profile…..

. Therefore during peak periods the VARs demanded by loads greatly exceeds the VARs which can be transmitted. Additional equipment is required for getting lagging VARs to meet the requirement of VARs. If this is not done system voltage at the busses becomes lower than nominal voltage

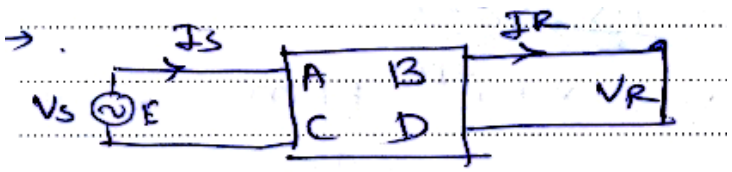
. During light periods the VARs produced by lines are much larger than the VARs required by consumer loads. Additional equipment is required for absorbing surplus lagging vars. If this is not done system voltage at the busses becomes higher than nominal voltage

. For maintaining the voltage level at busses constant and meet the requirement of VARs the additional equipment reactive power compensation is required. A shunt capacitance and shunt inductance is used generate or absorb the additional vars.…

Q.4) B) Attempt any one: 6

a) Prove that AD – BC = 1 for medium transmission line.

Ans. Consider a generalised circuit represented as below,



The genralised ckt. Equation can be written as

$Vs=AV_R+BI_R$ and $Is=CV_R+DI_R$

- Short ckt. Test on R.E. side ……

  When receiving end is short ckted $V_R= 0V$ $I_R = I_{SC}$

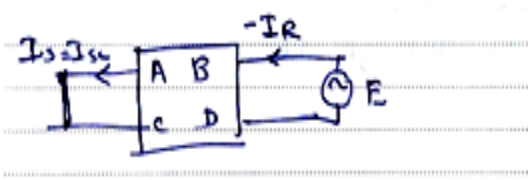
  subsituting in abvoe equation,

  $E=A(0) + B\ I_{SC}$ …… i.e. $B = E/I_{SC}$

  $I_R=I_{SC}=E/B$ (1)

2 mark

- Conducting S.C. test on S.E. side



$V_S = AV_R + BI_R$

$O = AE + B(--I_R)$

$I_R = \frac{AE}{B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$ (2 mark)

$I_S = - I_{SC} = CV_R + D(-I_R)$

$= - I_{SC} = (E\_D\left(\frac{AE}{B}\right)$ from equation (1)

From equation 1 $\rightarrow \frac{-E}{B} = CE - \frac{ADE}{B}$ .....(2 Mark)

$-\frac{1}{B} = CE - \frac{AD}{B}$

-1=BC-AD

AD-BC=1 proved.

b) A 275kV, 3 – phase line has the following line parameters: A = 0.93 $\lfloor 1.5^0$, B = 115 $\lfloor 77^0$.

If the receiving end voltage is 275 kV, determine the sending end voltage required if a load of 250 MW at 0.85 lagging p.f. is being delivered at the receiving end.

Ans.

$$given: V_R = 275KV, A = 0.93\angle 1.5, B = 115\angle 77$$
$$load = 250Mw, 0.85lag$$
$$load = \sqrt{3}V_R I_R \cos\emptyset_R = 250 \times 10^6 \ \sqrt{3}\ 275 \times 10^3 \times I_R \times 0.85$$
$$\therefore I_R = 617.48\ amp \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{2M})$$
$$\emptyset_R = \cos^{-1} 0.85 = 31.79 \ldots\ldots\ldots\ldots\ldots..(\mathbf{1M})$$

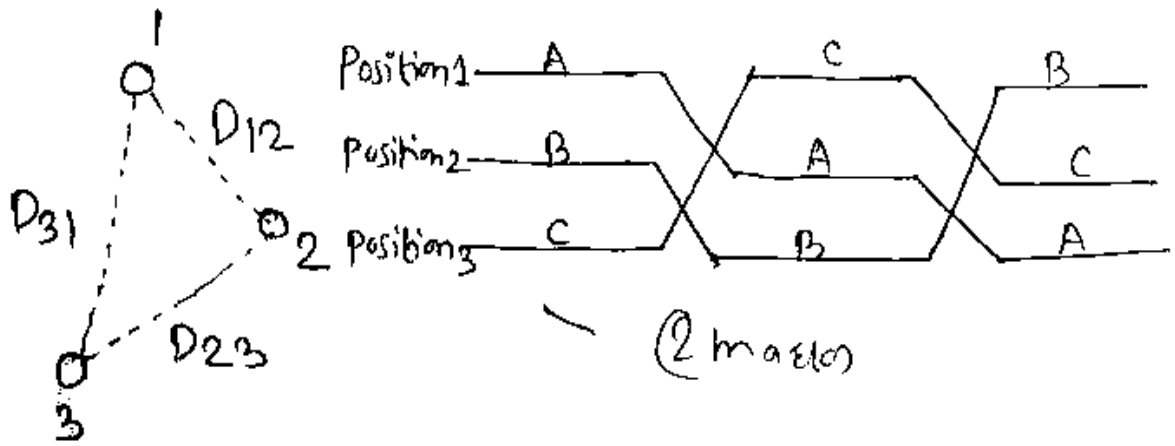
$$V_S = AV_R + BI_R$$
$$= 0.93\angle 1.5 \times 275/\sqrt{3} \times 10^3\angle 0 + 115\angle 77 \times 617.48\angle -31.79 \ldots.(\mathbf{2M})$$
$$= 147.65\angle 1.5 + 71010.2\angle 45.21$$
$$=$$
$$V_s = 204947.51\angle 15\ V \ldots\ldots\ldots\ldots\ldots(\mathbf{1M})$$

So Vs= $204947.51\ 10^{-3} X\ \sqrt{3}$ = 354.979 kV

Q.5) Attempt any two: 16

a) Describe the phenomenon of inductance of 3-phase line, single circuit, composed of solid conductor with asymmetrical spacing.

Ans. ***(Explanation 6 Marks)***



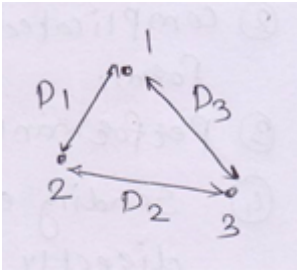
When 3d – line conductors are not equidistant from each other, the conductor spacing is said to be asymmetrical under such conditions, the flax linkages and inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the 3ϕ, ever if the currents in the conductors are balanced. Therefore the voltage drops are equal in all conductors. We generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over equal distance.

Transposition makes it possible for each phase conductor to have the same average inductance. Modern transmission lines are not transposed of regular intervals although an interchange in the positions of the conductors is mode at the switching stations to balance the inductance. For all practical purposes the asymmetry between the phases of an untransposed line may be neglected and the inductance of an untransposed line may be taken equal to that of a transposed line.

b) Calculate the inductance and capacitance per km of a line consisting of solid conductors of 30mm diameter placed at the corners of a triangle with sides 3, 4 and 5 meters. The conductors are adequately transposed.

Ans.

L/Km = ?, C≠km = ?



d=30mm, r=15mm =15 X 10^{-3}m

D_1=3m, D_2 = 4m, D_3=5m

(i) L/m=2 X 10^{-7} ln $\frac{D_m}{D_s}$

D_s = 0.7788r

= 0.7788 X 15 X 10^{-3}

=0.01168m…….(1mark)

D_m = $(D_1D_2D_3)^{1/3}$

= $(3X\ 4\ X\ 5)^{1/3}$

=23.237m……(1mark)

L/m = 2 X 10^{-7} ln $\frac{23.237}{0.01168}$

= 2 X 10^{-7}ln 1989.47

=1.519 X 10^{-6} H/m……(1mark)

=1.519 X 10-6 X 1000

L =1.519 X 10^{-3} H/Km=1.519 mH……(1mark)

ii) C/m = $\frac{2\pi\varepsilon_0}{\ln\frac{D_m}{D_s}}$ ……(1mark)

Ds = r =15 X 10^{-3m}

D_m = $(D_1D_2D_3)^{1/3}$ = 23.237m…….(1mark)

C/km = $\frac{2\ X\ \pi\ X\ 8.854\ X\ 10^{-12}}{\ln\frac{23.237}{15\ X\ 10^{-3}}}$

= $\frac{5.560\ X\ 10^{-11}}{7.345}$

C/m = 7.57 X 10-^{12}……..(1mark)

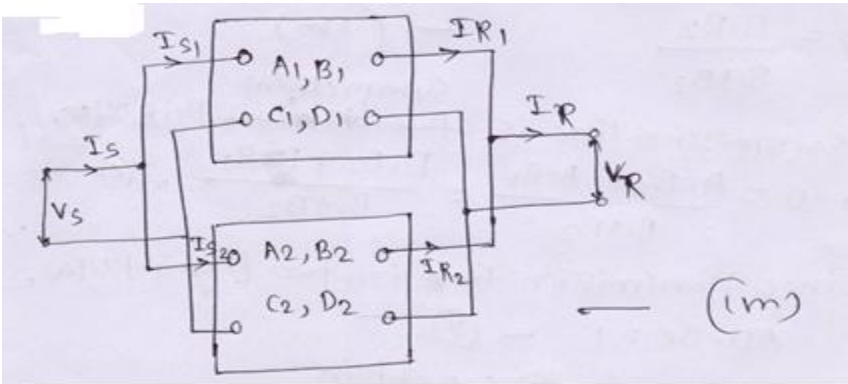
C/km = 7.57 X 10^{-12} X 1000

= 7.57 X 10^{-9}F/km

C/km = 7.57nF……(1 mark)

c) i) Derive the genaralised circuit constants of two network connected in parallel.

Ans.



The above fig shows the two N/w connected in parallel. The derivation is based on the fact that transmission line is a reciprocal N/w and when two reciprocal N/w's are connected in parallel, the resulting N/w is also reciprocal.

Writing the equation for the terminal conditions,

$V_S=A_1V_R+B_1I_{R1}$.....(1)

$V_S=A_2V_R+B2I_{R2}$.....(2)

Since the overall expression require us

$V_S=AV_R+BI_R$……(3)

Where $I_R=IR_1+IR_2$

Therefore, multiplying equations (1) & (2) by B_2 and B_1 respectively adding, we get

$(B_1+B_2)V_S = (A_1B_2+A_2B_1)V_R + B_1B_2(I_{R1}+I_{R2})$

$V_S = \frac{A_1B_2 + A_2B_1}{B_1 + B_2} V_R + \frac{B_1 B_2}{B_1 + B_2} I_R$……(4)……(1M)

Comparing the coefficients of equations 3) & 4), we get

$A = \frac{A_1B_2 + A_2 B_1}{B_1 + B_2}$…….(5)

& $B = \frac{B_1 B_2}{B_1 + B_2}$……...(1 M)

Since transmission line is symmetrical pair N/w

∴ $A = D = \frac{A_1B_2 + A_2B_1}{B_1 + B_2} = \frac{D_1B_2 + D_2 B_1}{B_1 + B_2}$……..(6)

Also since transmission line is a two terminal N/W,

AD-BC=1……..(7)

Using equation (5), (6) & (7) we obtain

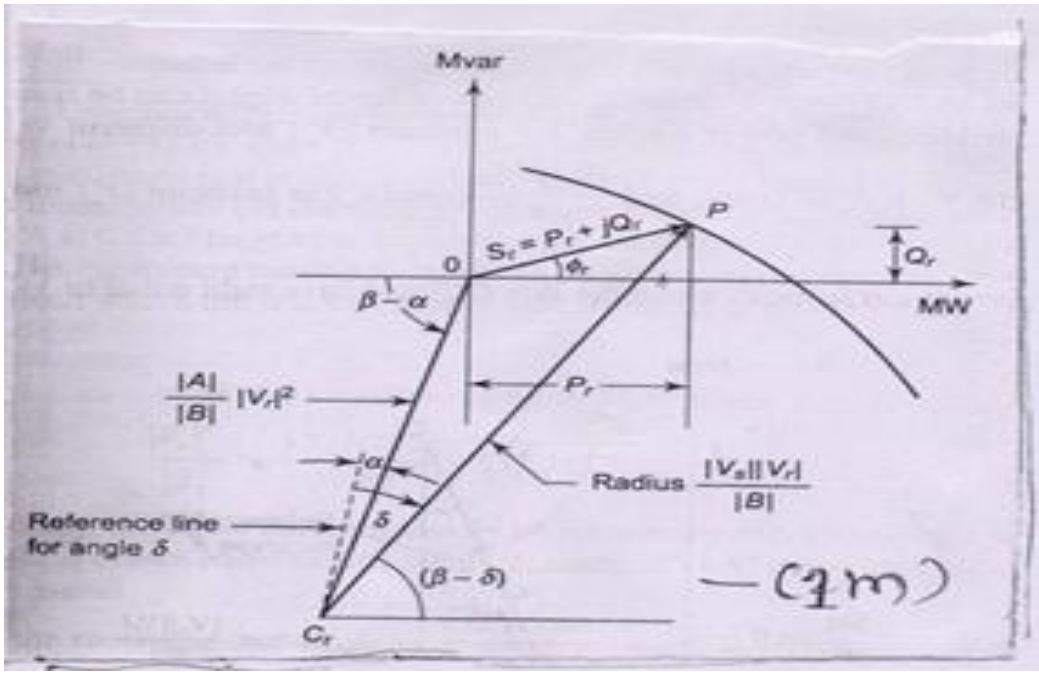
$C = C_1 + C_2 + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}$……1M)

ii) Describe the stepwise procedure for drawing receiving end circle diagram.

Ans. ***(Diagram 2M, procedure 2M)***

$S_R = P_R = Jqr$

$S_R = \frac{-1A||V_{R12}}{(B)} < (\beta-\alpha) + \frac{IVR||VSI}{(B)} < (\beta-\delta)$



1) First draw the Mw asis as X axis and MVAR axis Y axis
2) To draw circle we should know the centre of the circle. By using equation $\frac{|AllVR|^2}{|B|}$ draw a line in 3rd quadrant with an angle of $(\beta - \propto)$ taking D-ve MW axis as a base and 0 as centre.
3) Draw line OC_r by converting the power into cm scale
4) The radius of receiving end circle is calculated by using equation $\frac{|V_R V_S|}{(B)}$ as radius & 0 as centre draw a receiving end circle. which will be come in 1st quardent.
5) By drawing circle we can calculate my parameters such as S_R, Q_R, P_R, $P_{Rma}x$ etc.

Q.6) Attempt any four: **16**

a) Describe the role of power system engineer.

Ans. ***(1M for each point)***

Note: Any four points relevant to answer.

Role of power system engineer:

- On planning side, he or she has to make decisions on how much electricity to generate where, when and by using what fuel.
- It has to be involved in construction tasks of great magnitude both in generation and transmission.
- He has to solve problems of planning and coordinated operation of a vast and complex power N/w, so as to achieve a high degree of economy and reliability.
- In a country like India, he has to additionally face the perennial problem of power shortages and to evolve strategies for energy conservation and load management.
- Plan for expansion of network.
- Power transection with neighboring grid system
- Generation , Transmission & Distribution of power with min. cost

b) A 3-phase, 50Hz, transmission line consists of three equal conductors of radi ir, placed in a horizontal plane, with a spacing of 6 m between the middle and each outer conductor, as shown in Fig.1. Determine the inductive reactance per phase per km of the transposed line if the radius of each conductor is 12.5mm.

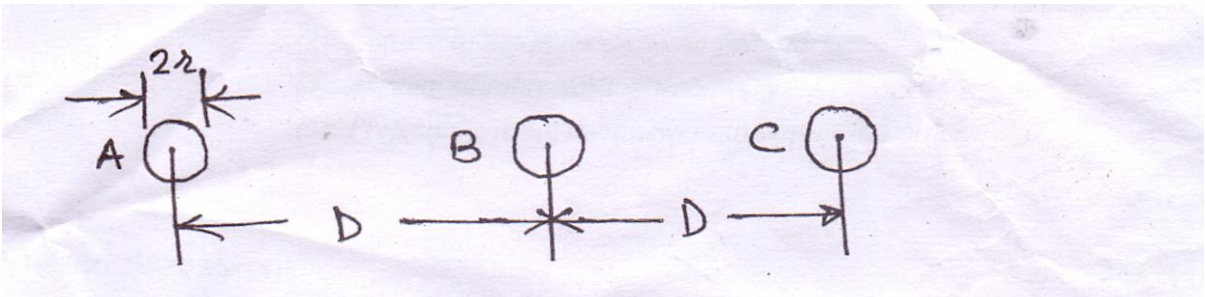


Fig. 1

Ans.

Given,

$D_{AB} = D_{BC} = 6m$, $D_{AC} = 12$ m

$r = 12.5$ mm $= 12.5 \times 10^{-3}$ m

$X_L = ?$

$L/ph/m = 2 \times 10^{-7} \ln \frac{D_m}{D_s}$

$D_s = r^1 = 0.7788r$

$= 0.7788 \times 12.5 \times 10^{-3}$

$= 0.009735m$……..(1M)

$D_m = (D_{AB}.\ D_{BC}.\ D_{CA})^{1/3}$

$= (6 \times 6 \times 12)^{1/3}$

$= 7.559m$……...(1M)

$\therefore L = 2 \times 10^{-7} \ln \left(\frac{7.559}{0.009735}\right)$

$L = 1.3309 \times 10^{-6}$ H/m

$L = 1.3309 \times 10^{-6} \times 1000$ H/km

$= 1.3309 \times 10^{-3}$ H/km

L = 1.3309 mH/km……..……..(1M)

$\therefore X_L = 2\pi FL$

$= 2 \times \pi \times 50 \times 1.3309 \times 10^{-3}$

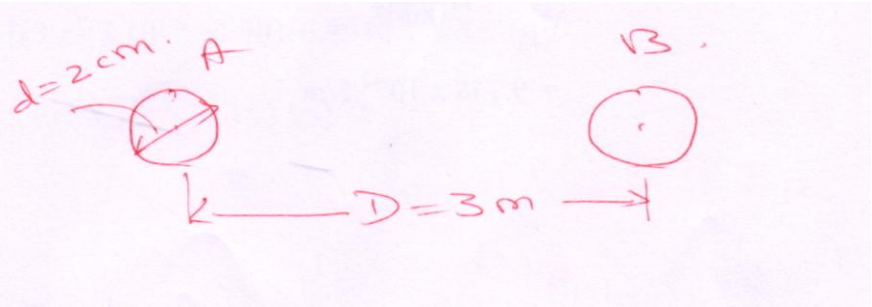
$X_L = 0.4179\ \Omega/km$……(1M)

c) A two-conductor, single-phase line operates at 50 Hz. The diameter of each conductor is 2 cm and are spaced 3 m apart. Calculate:
a) The capacitance of each conductor to neutral per km
b) Line-to-line capacitance

Ans.

F = 50Hz, d = 2cm, ∴ r = 1cm = 1 X 10^{-2}m

D = 3m



C_n/F_{cm} =?, C_{12}=?

1) $C_{L-L/m} = C_{12/m} = \frac{\pi\varepsilon_0}{\ln\frac{D}{r}}$ …….(1 Mark)

$$= \frac{\pi \text{ x } 8.854 \text{ X } 10^{-12}}{\ln\frac{3}{1 \text{ X } 10^{-12}}}$$

$$= \frac{2.780 \text{ X } 10^{-11}}{5.703}$$

C_{12} = 4.873 X 10^{-12} F/M

= 4.873 X 10^{-12} x 10001

C_{12} = 4.873 10^{-9}

C_{12} = 4.873 nF/km (capacitance of line to line)…….(2 mark)

2) C_n = 2 X C_{12}

= 2 X 4.873 X 10^{-9}

C_n = 9.746 X 10^{-9}

C_n = 9.746 X n F/km (Capacitance to neutral)……(1 mark)

OR

1) Capacitance to neutral

$C_{n/m} = \frac{2\pi\varepsilon_0}{\ln\frac{D}{r}}$ ……..(1 mark)

$= \frac{2 \text{ X } \pi \text{ X } 8.854 \text{ X } 10^{-12}}{\ln\frac{3}{1 \text{ X} 10^{-2}}}$

$= 9.748 \text{ x } 10^{-12}$ F/m

$C_{n/km} = 9.748 \text{ X } 10^{-12} \text{ x } 1000$

$= 9.748 \text{ X } 10^{-9}$

$C_n = 9.748$ n F/km……(2 Mark)

2) Capacitance to L – L

$C_{12} = \frac{C_n}{2} = \frac{9.748}{2}$

$C_{12} = 4.874$ nF/km……(1 Mark)

d) **A single circuit 50 Hz, 3-phase transmission line has the following parameters per km: R = 0.2 ohm, L = 1.3 mH and C = 0.01μF. The voltage at the receiving end is 132 kV. If the line is open at the receiving end, find the rms value of the incident voltage to neutral at the receiving end as reference.**

Ans. (4 M)

Data is insufficient:

[Assumptions – Long transmission line / Medium transmission line, Load on the system, Length of the line, Assuming voltage at V_S]

For medium transmission line,
From R, L, C, Calculate

$Z = R + j X_L$

$= R + 2\pi fL$

$= 0.2 + j\, 0.4082\ \Omega$ /km

$Y = j X_C = j2\pi Ifc$

$= 3.14 \text{ X } 10^{-6} \angle 90^0\ \Omega$/ km

For medium to line-

$$A = 1 + \frac{Y_z}{\propto}$$

∴ For GC Equations

$V_S = AV_R + BI_R$

For no loud condition
$V_S = AV_{RNL} + B\ I_{RNL}$

Where $I_{RNL} = 0$

$$\therefore\ V_{RNL} = \frac{V_S}{A}$$

Note: If student attempted this question 4 Marks can be allotted).

e) Explain the advantages of generalised circuit representation.

Ans. ***(Any four, 1M each)***

Advantages of generalized :

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

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.
   = $3\ V_S I_S \cos \phi_S$ for 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 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

$$A = \frac{A_1 B_2 + A_2 B_1}{B_1 + B_2}$$

$$B = \frac{B_1 B_2}{B_1 + B_2}$$

$$D = \frac{D_1 B_2 + D_2 B_1}{B_1 + B_2}$$

$$C = C_1 + C_2 - \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}$$