INTRODUCTION

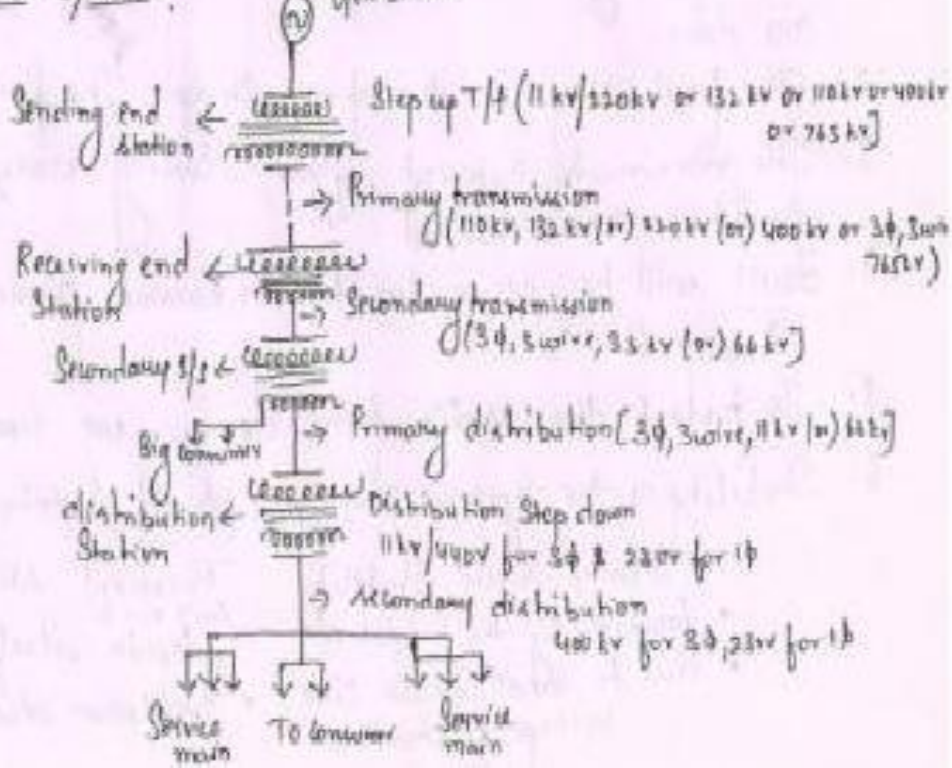
POWER SYSTEM ANALYSIS :-

1. Evaluation of power system is called power system analysis i.e studying the characteristics or behaviours.
2. Basically power system consists of generation system, transmission and distribution system.
3. The main characteristics of power system is it neither generate the energy nor store the energy.

Function of power system:-

1. To design a new system and also to design a future expansion of existing power system
2. To analysis the stability of system when it is subjected large and small distance
3. To design the circuit breaker for various power condition

Modern Power System:



Analysis for System planning and Operational Studies:-

Normal Condition:-

Uninterrupted power + reliable or constant power
Generation = Demand

SYSTEM PLANNING:-

1. To fullfil the demand, generation should be greater than the demand.
2. The transmission parameters due to be calculated
3. Voltage through transmission lines is proportional to the reactive power $V \propto Q$
4. This is studied via power flow through transmission lines.
5. Capacitor is used for boost up the voltage.

OPERATIONAL STUDIES:-

1. Once the system is in operation, the operational studies are done.
2. The first stage is the fault Study. The faults are studied.
3. The maximum current flow during various faults Condition are Studied.
4. Fault will be occur due to unbalance current is flow through it.
5. To protect the device from damage we use circuit breaker
6. Stability of the System can be classified into

Steady state Stability	Transient stability
* Gained by the system	* Can't able to Regain itself by system
* due to small fault like Voltage fluctuation	* breakdown due to large faults.

Basic Components of a power System:-

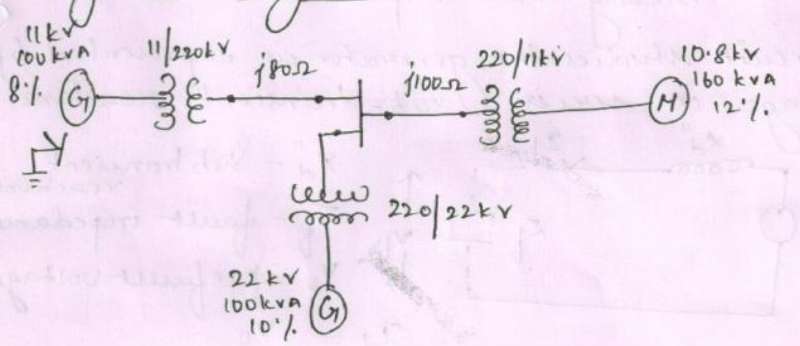
Generator – (G) , Two winding power T/f –

3-winding T/f – , Transmission –

C.B – , Loads

C.T – , P.T

Single line diagram:-

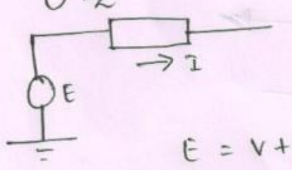


Modelling of power system Components:-

1. Generator modelling
2. Transformer modelling
3. Transmission line modelling
4. Load modelling.

1. Modelling of generators:-

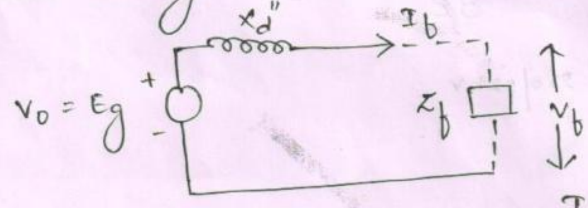
For power flow studies synchronous generated is represented by its generated voltage in series Thevenin's impedance



$$E = V + IZ$$

$Z \rightarrow$ steady state impedance

For short circuit studies the generator is represented by prefault voltage in series of Sub-transient reactance



x_d'' - Sub transient reactance

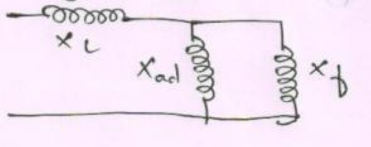
Z_f - fault impedance

V_0 - prefault voltage

$$I_f = \frac{V_0}{x_d'' + Z_f}$$

For the transient stability studies during transient period the damper winding has high resistance and this component of current leakage quickly.

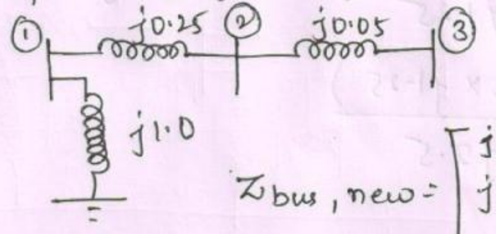
$\therefore$ Neglecting damper winding we have



Short Ckt transient reactance

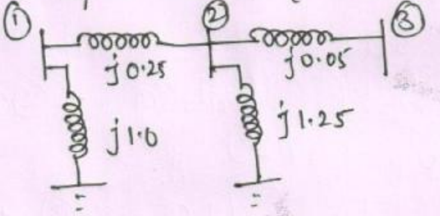
$$x_d' = x_l + \left[\frac{1}{x_{ad}} + \frac{1}{x_f}\right]^{-1}$$

Step ③ :- Addition of a branch of impedance $z = j0.05$ b/w bus ② (old bus) & bus ③ (new bus)



$$Z_{bus,new} = \begin{bmatrix} j1.0 & j1.0 & j1.0 \\ j1.0 & j1.25 & j1.25 \\ j1.0 & j1.25 & j1.25 + j0.05 \\ & & = j1.3 \end{bmatrix}$$

Step ④ :- Addition of a branch of impedance $z = j1.25$ b/w bus ① (old bus) & ref bus.



$$Z_{bus,new} = \begin{bmatrix} j1.0 & j1.0 & j1.0 & j1.0 \\ j1.0 & j1.25 & j1.25 & j1.25 \\ j1.0 & j1.25 & j1.3 & j1.25 \\ j1.0 & j1.25 & j1.25 & j1.25 + j1.25 \\ & & & j2.5 \end{bmatrix}$$

$$\boxed{Z_{jk,new} = Z_{jk\,old} - \frac{Z_{in} \times Z_{nk}}{Z_{nn}}}$$

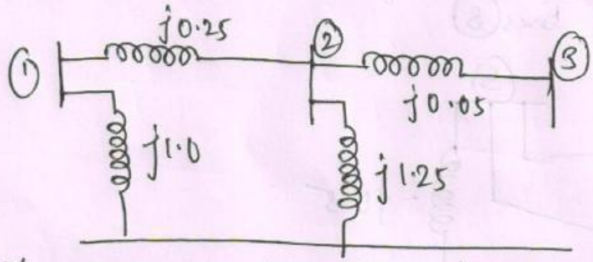
$$Z_{11} = j1.0 - \frac{j1.0 \times j1.0}{j2.5} , \quad \boxed{Z_{11} = j0.6}$$

$$Z_{12} = j1.0 - \frac{j1.0 \times j1.25}{j2.5} , \quad \boxed{Z_{12} = j0.5}$$

$$Z_{13} = j1.0 - \frac{j1.0 \times j1.25}{j2.5} , \quad \boxed{Z_{13} = j05}$$

Z-bus building algorithm

Formation Z-bus has Z bus building Algorithm:-



Formation of Z bus by using Z-bus building Algorithm involves 4 steps

Step ①:- Adding a branch of impendance Z b/w ref bus & the new bus.

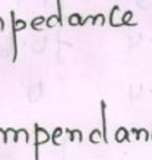
Step ②:- Adding a branch of impedance Z b/w old bus & the new bus.

Step ③:- Adding a branch of impendance Z b/w old bus & the ref bus.

Step ④:- Adding a branch of impedance Z b/w two existing buses

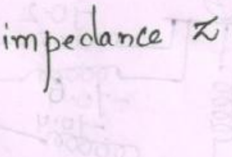
Step ①:- Addition of a branch of impedance $Z = j1.0$ b/w ref bus & bus ① (new bus)

$$Z_{bus,new} = \begin{bmatrix} j1.0 \end{bmatrix}$$

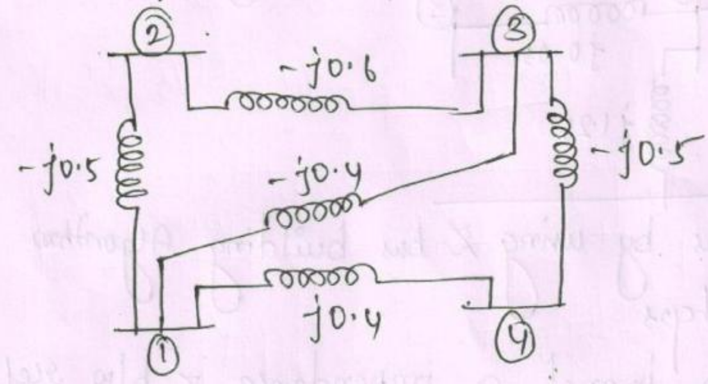


Step ②:- Addition of a branch of impedance $Z = j0.25$ b/w bus ① (old bus) & bus ② (new bus)

$$\therefore Z_{bus,new} = \begin{bmatrix} j1.0 & j1.0 \\ j1.0 & j1.0+j0.25 \\ & = j1.25 \end{bmatrix}$$

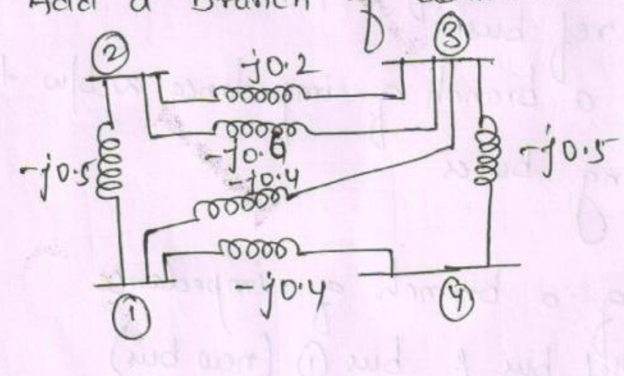


1. For the below network determine the new admittance matrix when a branch of admittance $j0.2$ is added b/w bus (2) & bus (3)



$$Y_{bus} = \begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ j0.4 & 0 & j0.5 & -j0.9 \end{bmatrix}$$

Add a branch of admittance in b/w bus (2) & (3)



$Y_{ii,new} = Y_{ii,old} + y$

$Y_{22,new} = Y_{22\,old} + y$

$Y_{22,new} = (-j1.1) + (j0.2)$

$\boxed{Y_{22} = -j0.9}$

$Y_{33,new} = Y_{33\,old} + y$

$Y_{33,new} = (-j0.15) + (j0.2)$

$\boxed{Y_{33} = -j1.3}$

$Y_{ij,new} = Y_{ij\,old} - y$

$= j0.6 - j0.2$

$Y_{23} = j0.4$

$Y_{32} = Y_{23} = j0.4$

$$Y_{bus} = \begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j0.9 & j0.4 & 0 \\ j0.4 & j0.4 & -j1.3 & j0.5 \\ j0.4 & 0 & j0.5 & -j0.9 \end{bmatrix}$$

Formula:-

To Calculate the admittance when an element of an admittance y is added or remove from the network

i) Addition of element b/w bus i & j

$$\boxed{\begin{aligned} Y_{ii,new} &= Y_{ii,old} + y \\ Y_{jj,new} &= Y_{jj,old} + y \\ Y_{ij,new} &= Y_{ij\,old} - y \end{aligned}}$$

ii) Removal of element b/w bus i & j

$$\boxed{\begin{aligned} Y_{ii,new} &= Y_{ii,old} - y \\ Y_{jj,new} &= Y_{jj,old} - y \\ Y_{ij,new} &= Y_{ij\,old} + y \end{aligned}}$$

iii) Addition of Shunt element at bus i

$$\boxed{Y_{ii,new} = Y_{ii,old} + y}$$

$$Y_{11,new} = -j1.3 - \frac{j0.4 \times j0.4}{-j0.9} = -j1.12, \boxed{Y_{11,new} = -j1.12}$$

$$Y_{12,new} = j0.5 - \frac{j0.4 \times 0}{-j0.9} = j0.5, \boxed{Y_{12,new} = j0.5}$$

$$Y_{13,new} = j0.4 - \frac{j0.4 \times j0.5}{-j0.9} = j0.6, \boxed{Y_{13,new} = j0.6}$$

$$\boxed{Y_{21,new} = Y_{12,new} = j0.5}$$

$$Y_{22,new} = -j1.1 - \frac{0 \times 0}{-j0.9} = -j1.1, \boxed{Y_{22,new} = -j1.1}$$

$$Y_{23,new} = j0.6 - \frac{0 \times j0.5}{-j0.9} = j0.6, \boxed{Y_{23,new} = j0.6}$$

$$Y_{31,new} = Y_{13,new} = j0.6$$

$$Y_{32} = j0.6$$

$$Y_{33} = -j1.5 - \frac{j0.5 \times j0.5}{-j0.9} = j1.22$$

$$\boxed{Y_{33} = -j1.22}$$

$$Y_{bus} = \begin{bmatrix} -j1.12 & j0.5 & j0.6 \\ j0.5 & -j1.1 & j0.6 \\ j0.6 & j0.6 & -j1.22 \end{bmatrix}$$

$$Y_{41} = -y_{41} = 0$$

$$Y_{42} = -y_{42}$$

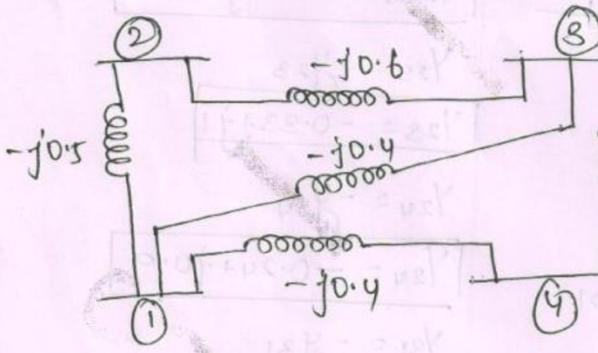
$$\boxed{Y_{42} = -0.24 + j0.94}$$

$$\boxed{Y_{43} = -0.29 + j1.18}$$

$$\boxed{Y_{44} = 0.49 - j2.24}$$

$$Y_{bus} = \begin{bmatrix} 0.88+j3.53 & -0.29+j1.17 & -0.59+j2.33 & 0 \\ -0.29+j1.17 & 0.86-j3.2 & -0.33+j & -0.24+j0.94 \\ -0.59+j2.35 & 0.33+j & 1.21-j4.65 & -0.29+j1.18 \\ 0 & -0.24+j0.94 & -0.29+j1.18 & 0.49-j2.14 \end{bmatrix}$$

3. Determine the bus admittance shown below. Determine the reduced admittance matrix by elimating node 4.



$$Y_{bus} = \begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ j0.4 & 0 & j0.5 & -j0.9 \end{bmatrix}$$

To find the element of reduced admittance matrix

$$\boxed{Y_{jk\,new} = Y_{jk\,old} - \frac{Y_{jn} \times Y_{nk}}{Y_{nn}}}$$

$n \rightarrow$ node to be eliminiate

$$\boxed{Y_{jk,new} = Y_{jk,old} - \frac{Y_{j4} \times Y_{4k}}{Y_{44}}}$$

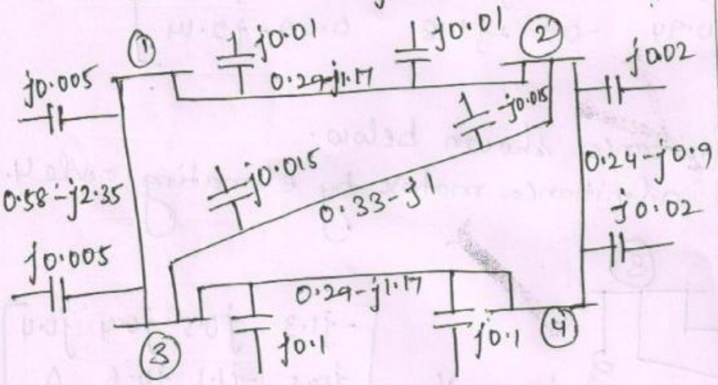
$n = 4$

$j = 1, 2, 3$

$k = 1, 2, 3$

2. The parameter of a four bus is shown below

line	line impedance	line charging admittance	line admittance
1-2	$0.2+j0.8$	$j0.02$	$0.29-j1.17$
2-3	$0.3+j0.9$	$j0.03$	$0.33-j1$
2-4	$0.25+j1.0$	$j0.04$	$0.24-j0.94$
3-4	$0.2+j0.8$	$j0.2$	$0.29-j1.17$
1-3	$0.1+j0.4$	$j0.01$	$0.58-j2.35$



$Y_{11} = y_{13}+y_{12}+y_{10}$

$= 0.58-j2.35+0.29-j1.17+j0.005+j0.01$

$\boxed{Y_{11} = 0.87-j3.5}$

$Y_{12} = -y_{12}$

$Y_{12} = -0.29+j1.17$

$Y_{13} = -y_{13}$

$\boxed{Y_{13} = -0.58+j2.35}$

$Y_{14} = -y_{14}$

$\boxed{Y_{14} = 0}$

$Y_{21} = -y_{21}$

$\boxed{Y_{21} = -0.29+j1.17}$

$Y_{22} = y_{21}+y_{23}+y_{24}+y_{20}$

$\boxed{Y_{22} = 0.86-j3.025}$

$Y_{23} = -y_{23}$

$\boxed{Y_{23} = -0.33+j1}$

$Y_{24} = -y_{24}$

$\boxed{Y_{24} = -0.24+j0.9}$

$Y_{31} = -y_{31}$

$\boxed{Y_{31} = -0.58+j2.35}$

$Y_{32} = -y_{32}$

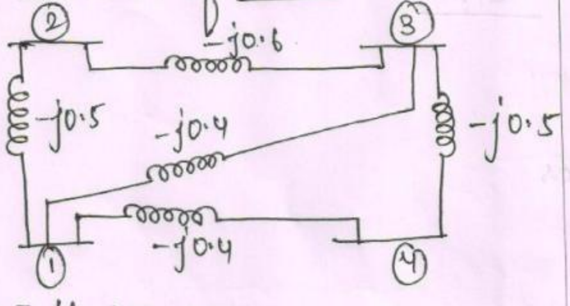
$\boxed{Y_{32} = 0.33+j1}$

$\boxed{Y_{33} = 1.21-j4.65}$

$Y_{34} = -y_{34}$

$\boxed{Y_{34} = -0.29+j1.18}$

Formation of Ybus :-



$Y_{11} = y_{12} + y_{13} + y_{14}$
$= -j0.5 + (-j0.4) + (-j0.4)$
$\boxed{Y_{11} = -j1.3}$

$Y_{12} = -(y_{12})$
$\boxed{Y_{12} = j0.5}$

$Y_{13} = -y_{13}$
$\boxed{Y_{13} = j0.4}$

$Y_{14} = -(y_{14})$
$\boxed{Y_{14} = -j0.4}$

$Y_{21} = -(y_{21}) =$
$\boxed{Y_{21} = j0.5}$

$Y_{22} = y_{21} + y_{23} + y_{24}$
$= -j0.5 + (-j0.6) + (0)$
$\boxed{Y_{22} = -j1.1}$

$Y_{23} = -y_{23}$
$\boxed{Y_{23} = j0.6}$

$Y_{24} = -y_{24}$
$\boxed{Y_{24} = 0}$

$Y_{31} = -y_{31}$
$\boxed{Y_{31} = j0.4}$

$Y_{32} = -y_{32}$
$\boxed{Y_{32} = j0.6}$

$Y_{33} = y_{31} + y_{32} + y_{34}$
$= -j0.4 + (-j0.6) + (-j0.5)$
$\boxed{Y_{33} = j1.5}$

$\boxed{Y_{34} = j0.5}$

$\boxed{Y_{41} = j0.4}$

$\boxed{Y_{42} = 0}$

$\boxed{Y_{43} = j0.5}$

$\boxed{Y_{44} = -j0.9}$

$$Y_{Bus} = \begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ j0.4 & 0 & -j0.5 & -j0.9 \end{bmatrix}$$

Formation of Y_{bus} Matrix:-

$Z = R + jx$

Y — admittances

$Y = 1/Z$

$Y = 1/R+jx$

$\frac{1}{R} = G, \frac{1}{x} = B$

$$\boxed{Y = G + jB}$$

$\frac{1}{x} = B$ – Susceptance

$\frac{1}{R} = G$ – Conductance

x — Reactance

Bus:-

1. Meeting point of 2 or more branches
2. Conductor made up of Cu or Al
3. Voltage is constant
4. frequency is constant

Let load is series Connected

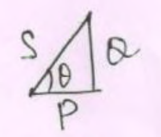
$$Z_{pu.} = R_{pu} + jX_{pu}$$

$$R_{pu} = V^2_{pu} \cdot S_b \cdot \frac{P}{P^2+Q^2}$$

$$X_{pu} = V^2_{p.u.} \cdot S_b \cdot \frac{Q}{P^2+Q^2_2}$$

$$V_{pu} = \frac{V}{V_b} = \frac{11}{11} = 1\,pu$$

$$S_b = 20\,MVA$$



$$\cos\theta = P/S \Rightarrow P = S\cos\theta = 5 \times 0.8 = 4$$

$$\sin = Q/S \Rightarrow Q = S\sin\theta = 5 \times 0.6 = 3$$

$$R_{pu} = 1^2 \cdot 20 \times \frac{4}{4^2+3^2} = 3.2\,pu$$

$$X_{pu} = 1^2 \cdot 20 \cdot \frac{3}{4^2+3^2} = 2.4\,pu$$

$$\boxed{Z_{pu} = (3.2 + j2.4)}$$

Transformer, T_1:-

$$kV_b \text{ new} = kV_b \text{ old} \times \frac{LV}{HV}$$

$$= 132 \times \frac{12.5}{132}$$

$$kV_b \text{ new} = 12.5\,kV$$

$$Z_{pu,T_1} = 0.1 \times \left(\frac{20}{25}\right) \times \left(\frac{12.5}{12.5}\right)^2$$

$$\boxed{Z_{pu,T_1} = j0.08\,pu}$$

Generator, G

$$Z_{pu,G} = 0.15 \times \left(\frac{20}{20}\right) \times \left(\frac{11}{12.5}\right)^2$$

$$\boxed{Z_{pu,G} = j0.116\,pu}$$

Transformer, T_2

kV_b old 132 11 kV_b new

$$kV_b \text{ new} = 132 \times \frac{11}{132}$$

$$\boxed{kV_b \text{ new} = 11\,kV}$$

$$Z_{pu,T_2} = 0.1 \times \left(\frac{20}{20}\right) \times \left(\frac{11}{11}\right)^2$$

$$\boxed{Z_{pu,T_2} = j0.1\,pu}$$

Load:-

$$Z_{pu,M} = 0.15 \times \left(\frac{20}{15}\right) \times \left(\frac{11}{11}\right)^2$$

$$\boxed{Z_{pu,M} = j0.2\,pu}$$

4. The rating of Single line diagram of the given below:-

Synchronous Generator:-
20MVA, 11kV, $x'' = 0.15$ pu

Synchronous motor
15MVA, 11kV, $x'' = 0.15$ pu

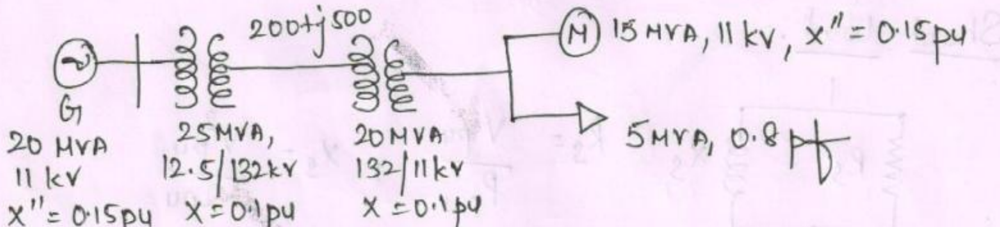
Transformer, T_1
25MVA, 12.5 (Δ) / 132 kV (Y), $x = 0.1$ pu

Transformer, T_2
20MVA, 132 (Y) / 11 kV (Δ), $x = 0.1$ pu

line impedance : $200 + j500\,\Omega$

Static load :- 5MVA, 0.8pf lagging

Choose 132kV, 20MVA as base values on Transmission line



Sol:-

Transmission line, T_L

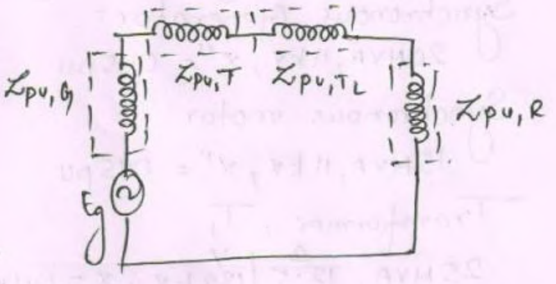
$$Z_{pu,T_L} = \frac{Z}{Z_b}$$

$$Z_b = \frac{(kVA)^2}{MVA} = \frac{(132)^2}{20} = 871.2\,\Omega$$

$$Z_{pu,T_L} = \frac{Z}{Z_b} = \frac{200 + j500}{871.2} = 0.229 + j0.573$$

$$\boxed{Z_{pu,T_L} = 0.229 + j0.573}$$

Resistive Load:-



$$Z_{pu,\,R} = \frac{Z}{Z_b}$$

$$= \frac{500}{Z_b}$$

$$Z_b = \frac{(210)^2}{100} = 441\,\Omega$$

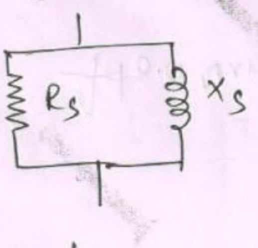
$$Z_b = 441\,\Omega$$

$$Z_{pu,\,R} = \frac{j\,500}{441}$$

$$\boxed{Z_{pu,\,R} = j\,1.133\ pu}$$

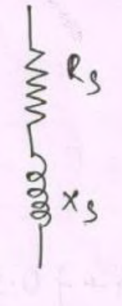
Load Representation:-

Shunt Load:-



$$R_s = \frac{V^2_{pu}}{P_{pu}}, \quad X_s = \frac{V^2_{pu}}{Q_{pu}}$$

Series load



$$R_s = V^2_{pu} \cdot S_b \cdot \frac{P}{P^2+Q^2}$$

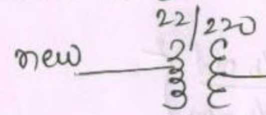
$$X_s = V_{pu}^2 \cdot S_b \frac{Q}{P^2+Q^2}$$

Transformer T_3 :-

$$Z_{pu,T_3} = 0.1 \times \left(\frac{50}{35}\right) \times \left(\frac{220}{220}\right)^2$$

$$\boxed{Z_{pu,T_3} = j0.142\,pu}$$

Generator, G_3 :-

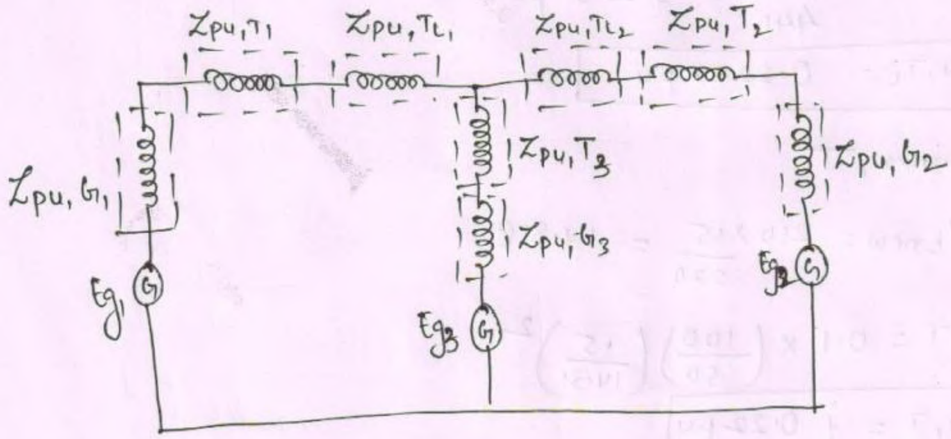


$$KV_b \text{ new} = 220 \times \frac{22}{220}$$

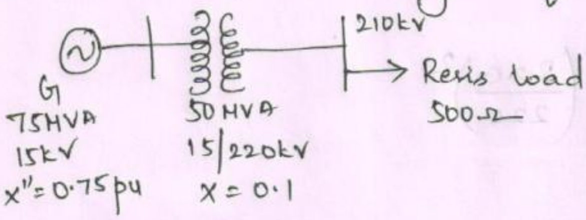
$$\boxed{KV_b \text{ new} = 22\,kV}$$

$$Z_{pu,G_3} = 0.2 \times \left(\frac{50}{30}\right) \times \left(\frac{20}{22}\right)^2$$

$$\boxed{Z_{pu,G_3} = j\,0.275\,pu}$$



3. Draw the impedance diagram of the given ckt



Assume 100MVA & 210kV in transmission line

Sol

$$Z_{pu,new} = Z_{pu,old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{kV_{b\,old}}{kV_{b\,new}}\right)^2$$

Transmission Line, T_L

$$Z_{pu,T_L} = \frac{Z}{Z_b}$$

$$Z_b = \frac{(kVA)^2}{MVA} = \frac{(210)^2}{100} = 441\,\Omega$$

$$Z_{pu,T_L} = \frac{100}{441} = 0.2267\,pu$$

$$\boxed{Z_{pu,T_L} = 0.2267\,pu}$$

Transformer, T

$$kV_{b\,new} = \frac{210 \times 15}{220} = 14.318$$

$$Z_{pu,T} = 0.1 \times \left(\frac{100}{50}\right)\left(\frac{15}{14.31}\right)^2$$

$$\boxed{Z_{pu,T} = j\,0.22\,pu}$$

Generator, G

$$Z_{pu,G} = 0.75 \times \left(\frac{100}{75}\right)\left(\frac{15}{14.318}\right)^2$$

$$\boxed{Z_{pu,G} = j1.1pu.}$$

Transmission line, $T_L = j\,100\,\Omega$

$$Z_{pu},T_L = \frac{Z}{Z_b} = \frac{j100}{Z_b}$$

$$Z_b = \frac{(kV_b)^2}{MVA} = \frac{(220)^2}{50} = 968\,\Omega$$

$$Z_{pu},T_L = j\frac{100}{968}$$

$$\boxed{Z_{pu},T_L = j\,0.103\,pu}$$

$\boxed{\begin{array}{l} Y \text{ connection}, V_P = V_L/\sqrt{3} \\ \quad V_L = \sqrt{3}V_P \\ \Delta \text{ connection}, V_P = V_L \end{array}}$

Transformer T_2:-

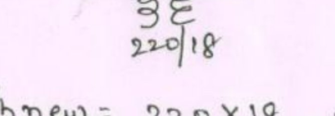
30 MVA, $\sqrt{3}\times127/18$ kV, $x = 0.1$ pu

30 MVA, 220/18 kV, $x = 0.1$ pu

$$Z_{pu},T_2 = 0.1\times\left(\frac{50}{30}\right)\times\left(\frac{220}{220}\right)^2$$

$$\boxed{Z_{pu},T_2 = j\,0.167\,pu}$$

Generator, G_2:-



$$kV_b\,new = 220\times\frac{18}{220} = 18\,kV$$

$$Z_{pu},G_2 = 0.2\times\left(\frac{50}{30}\right)\times\left(\frac{18}{18}\right)^2$$

$$\boxed{Z_{pu},G_2 = j\,0.333\,pu}$$

Draw the impedance diagram with all the reactance marked in per unit choose a base of 50 MVA, 13.8 kV

Sol:-

$$Z_{pu,new} = Z_{pu\ old} \times \frac{MVA_b\ new}{MVA_b\ old} \times \left[\frac{kV_b\ old}{kV_b\ new}\right]^2$$

$MVA_b = 50\ MVA$

$kV_b = 13.8\ kV$

Generator 1:-

$$Z_{pu, G_1, new} = \cancel{\frac{200}{500}} \times 0.2 \times \frac{50}{20} \times \left[\frac{13.8}{13.8}\right]^2$$

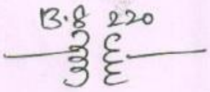
$$\boxed{Z_{pu, G} = j\,0.5\ pu}$$

Transformer 1:-

$$Z_{pu, T_1, new} = 0.2 \times \frac{50}{25} \times \left[\frac{13.8}{13.8}\right]^2$$

$$\boxed{Z_{pu, T_1} = j\,0.4\ pu}$$

Transmission line, T_L — $j\,80\,\Omega$



$$kV_{b\,new} = 13.8 \times \left[\frac{220}{13.8}\right]$$

$$\boxed{kV_{b\,new} = 220\,kV}$$

$$Z_{pu, T_L} = \frac{Z}{Z_b} = \frac{j80}{Z_b}$$

$$Z_b = \frac{(kV_b)^2}{MVA} = \frac{(220)^2}{50}$$

$Z_b = 968\,\Omega$; $Z_{pu, T_L} = \frac{j80}{968} = j\,0.082$, $\boxed{Z_{pu,T_L} = j\,0.08}$

Motor :- M :-

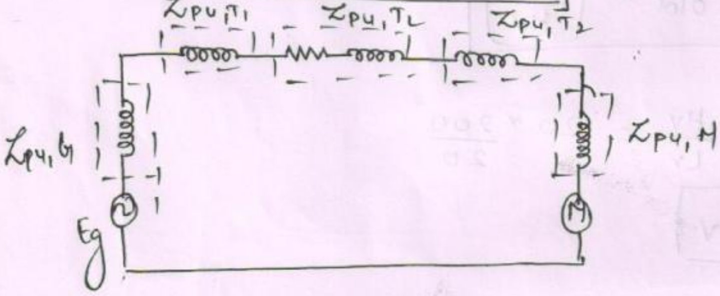
$$kV_{b\,new} = kV_{b\,old} \times \frac{LV}{HV}$$

$$= 200 \times 20/200$$

$$\boxed{kV_{b\,new} = 20\,kV}$$

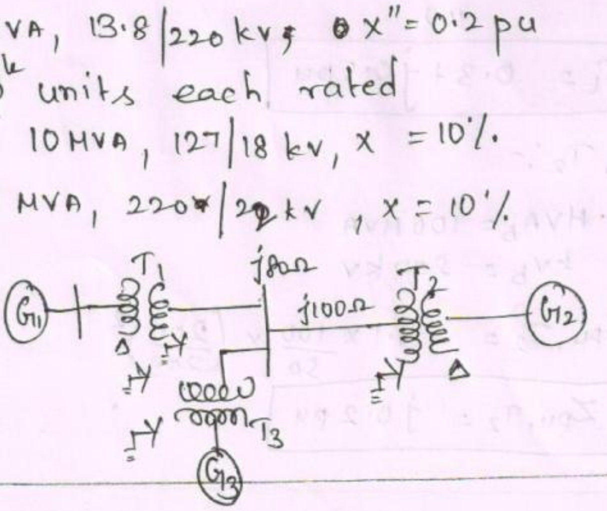
$$Z_{pu,M} = 0.08 \times \left(\frac{100}{43.2}\right) \times \left(\frac{18}{20}\right)^2$$

$$\boxed{Z_{pu,M} = j\,0.15\ pu}$$



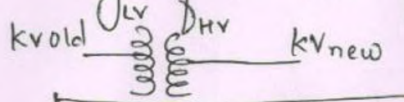
(2). The one line diagram of a unloaded power system which is shown in the fig below. Reactance on two section of Tr. line are shown in the diagram. The generators and T/f are rated below:-

G_1 : 20 MVA, 13.8 kV, $x'' = 0.2\,pu$
G_2 : 30 MVA, 18 kV, $x'' = 0.2\,pu$
G_3 : 30 MVA, 20 kV, $x'' = 0.2\,pu$
T_1 : 25 MVA, 13.8/220 kV, $x'' = 0.2\,pu$
T_2 : 3, single ϕ units each rated
10 MVA, 127/18 kV, $x = 10\%$.
T_3 : 35 MVA, 220/22 kV, $x = 10\%$.

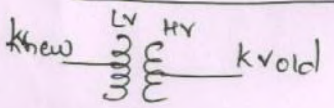


Transmission line:-

Change of kv base of transformer



$$\boxed{kV_{b\,new} = kV_{b\,old} \times \left[\frac{HV}{LV}\right]}$$



$$\boxed{kV_{b\,new} = kV_{b\,old} \times \left[\frac{LV}{HV}\right]}$$

$$kV_{b\,new} = kV_{b\,old} \times \frac{HV}{LV} = 20 \times \frac{200}{20}$$

$$\boxed{kV_{b\,new} = 200\,kV}$$

$$Z_{pu} = \frac{Z}{Z_b} = \frac{120 + j200}{Z_b}$$

$$Z_b = \frac{kV_b^2}{MVA_b} = \frac{(200)^2}{100}$$

$$\boxed{Z_b = 400}$$

$$= \frac{120 + j200}{400}$$

$$\boxed{Z_{pu,T_L} = 0.3 + j0.5\,pu}$$

Transformer, T_2:-

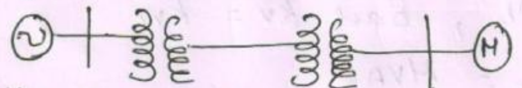
$$MVA_b = 100\,MVA$$

$$kV_b = 200\,kV$$

$$Z_{pu,T_2} = 0.1 \times \frac{100}{50} \times \left(\frac{200}{200}\right)^2$$

$$\boxed{Z_{pu,T_2} = j0.2\,pu}$$

1. 3ϕ power and line - line voltage rating of a electrical power system is shown below



$G_1 = 60\,MVA, 20\,kV, x'' = 9\% = 0.09$

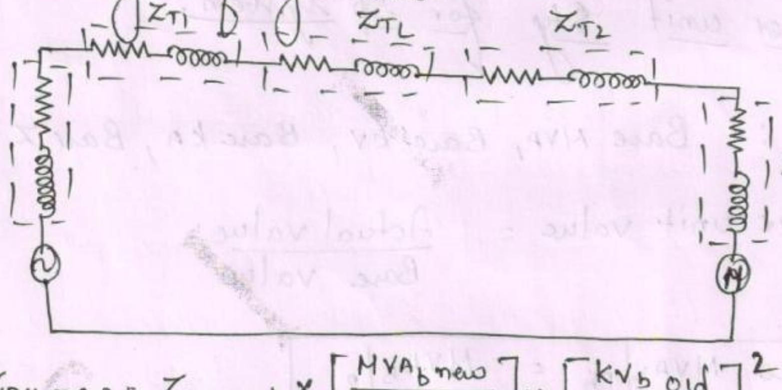
$T_1 = 50\,MVA, 20/200\,kV, x = 10\% = 0.1$

$T_2 = 50\,MVA, 200/20\,kV, x = 10\% = 0.1$

$M = 43.2\,MVA, 18\,kV, x'' = 8\% = 0.08$

$\text{line} = 200\,kV, \quad Z = 120 + j\,200\,\Omega$

Draw the impedance diagram showing all impedance in per unit on a 100 MVA base, choose 20 kV has a base voltage of generator.



$$Z_{pu,new} = Z_{pu,old} \times \left[\frac{MVA_{b\,new}}{MVA_{b\,old}}\right] \times \left[\frac{kV_{b\,old}}{kV_{b\,new}}\right]^2$$

old - given value
new - assume value

Let $MVA_b = 100\,MVA, \; kV_b = 20\,kV$

Generator :-

$$Z_{pu,G,new} = 0.09 \times \left[\frac{100}{60}\right] \times \left[\frac{20}{20}\right]^2$$

$$\boxed{Z_{pu,G,new} = j\,0.15\,pu}$$

Transformer :-

$$Z_{pu,T,new} = 0.1 \times \left[\frac{100}{50}\right] \times \left[\frac{20}{20}\right]^2$$

$$\boxed{Z_{pu,T,new} = j\,0.2\,pu}$$

Here,

Base value of power & voltage are assumed

Base MVA = MVA_b , Base kV = kV_b

Base current, $KA_b = \frac{MVA_b}{kV_b}$

Base impedance, $Z_b = \frac{kV_b}{KA_b}$

$$\text{Base impedance} = \frac{kV_b}{\frac{MVA_b}{kV_b}} = \frac{kV_b \times kV_b}{MVA_b}$$

From the above base value, the per unit value of power, voltage, current & impedance can be found.

Calculating per unit Qty for 3ϕ system :-

To calculate : Base MVA, Base kV, Base kA, Base Z

WKT :- $\text{Per unit value} = \frac{\text{Actual value}}{\text{Base value}}$

Here :-

$$\boxed{\text{Base } MVA_b|_{ph} = MVA_b/3}$$

$$\boxed{\text{Base Volt } (kV_b)|_{ph} = kV_b/\sqrt{3}}$$

$$\boxed{\text{Base current } (kA_b)|_{ph} = \frac{MVA_b/3}{kV_b/\sqrt{3}}}$$

$$\boxed{\text{Base impedance}|_{ph} = Z_b = \frac{(kV_b/\sqrt{3})^2}{MVA/3} = kV_b^2/MVA}$$

$$\boxed{Z_{ph\,new} = Z_{ph\,old} \times \left(\frac{MVA_b\,new}{MVA_b\,old}\right) \times \left(\frac{kV_b\,old}{kV_b\,new}\right)^2}$$ Old - given value

Per Unit Representation:-

$$\text{Per unit} = \frac{\text{Actual value}}{\text{Base value}}$$

Advantage:-

1) The per unit impedances refer to both primary & secondary phase of transformer are the same.
2) The per unit impedances refer to both primary and secondary.
3) Choice of Confusion b/w line Qty & phase Qty greatly reduce.
4) The manufacture data is used to given in data
5) The computation effect is greatly reduce in per unit.

Calculation of per unit Qty for 1φ system:-

Parameters:-

i) Power, $P = MVA_b$
ii) Voltage, $V = KV_b$
iii) Current, $I = KA_b$
iv) impedance, $Z = Z_b$

} base

To calculate:-

Base MVA, Base kV, Base kA, Base Z

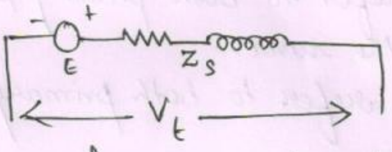
WKt:-

$$\text{Per unit value} = \frac{\text{Actual value}}{\text{Base value}}$$

Synchronous Motor Load:-

In motoring operation of Synchronous machine that current I_a is reverse so that voltage equation is

$$E = V_t - I_a Z_s$$

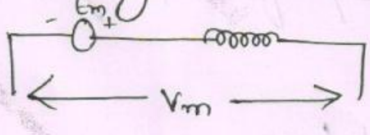


Here synchronous motor load is represent is same way as synchronous generator

Induction Motor Load:-

For transient an steady state condition induction motors are neglected the stator current becomes zero.

Induction motor load is considered in fault current Calculation during Sub transient condition.

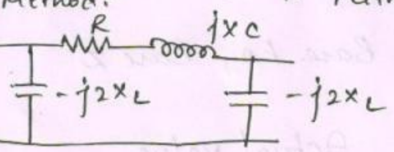


$X_d'' =$ Sub transient reactance of I.M

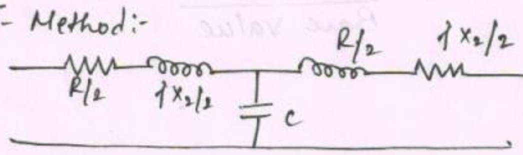
3) Transmission Line Representation:-

* It represented by its resistance, inductance and capacitance
* There are two type of Transmission line they are
  * T Method
  * π Method

π- Method:-



T- Method:-



3) Modelling of Loads:-

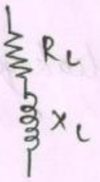
* Loads are composite in nature consisting of industrial & domestic load.
* Industrial load consists at large 3ϕ motor.
* Domestic load consists of lighting, heating & 1ϕ devices.

Representation of load:-

(Passive load no rotating)

a) Constant impedance representation:-

* used in stability
* load impedance is calculated as follows:-



$Z_L = V/I$

WKT, $S = P + jQ = VI^*$

$S^* = P - jQ = V^* I$

$I = \dfrac{P - jQ}{V^*}$

$\therefore Z_L = V \Big/ \dfrac{(P - jQ)}{V^*}, \quad Z_L = V^2 / P - jQ$

b) Constant power representation:-

* used in transient stability.
* Here passive loads are represented by constant active & reactive components.

c) Constant Current representation:-

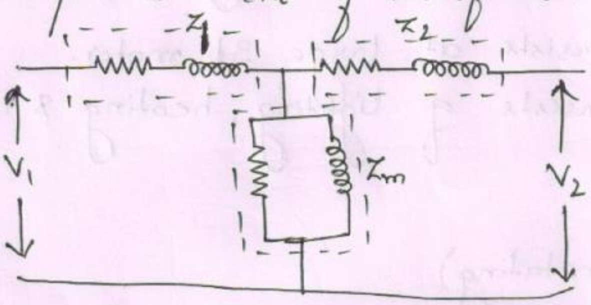
* Transient stability analysis use constant current Representation

load current, $I_L = \dfrac{P - jQ}{V^*}$, $I_L = I \angle \delta - \theta$

where $\theta = \tan^{-1} Q/P$ - power factor angle

2) Modelling of Transformer:-

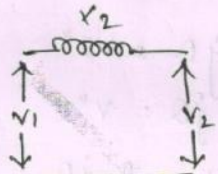
Equivalent Ckt of transformer:-



a) Power flow Studies:-

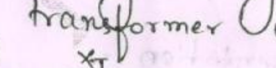
Here the Shunt impedance its magnetising in nature it affect its negelected in power flow.

Here transformer are model by series leakage reactance as shown.



b) Short Circuit Studies:-

Here also magnetising impedance are neglected Model of transformer is the reactance only



X_T - leakage reactance

c) Stability Studies:-

Here transformer are modelled by series reactance which is leakage reactance.

$Z_{11} = 0.753j - \dfrac{0.158j \times 0.158j}{0.673j}$, Z_{11} new $= 0.715j$

$Z_{12} = 0.654j - \dfrac{0.158j \times 0.19j}{0.673j} = Z_{12,new} = 0.609j$

$Z_{13} = 0.496j - \dfrac{(0.158j \times 0.158j)}{0.673j} = Z_{13,new} = 0.533j$

$Z_{14} = 0.496j - \dfrac{0.158j \times (-0.358j)}{0.673j}$, $Z_{14,new} = 0.580j$

$Z_{21,new} = 0.609j$

$Z_{22,new} = 0.785j - \dfrac{(0.19j \times 0.19j)}{0.673j}$, $Z_{22,new} = 0.731j$

$Z_{23,new} = 0.595j - \dfrac{(0.49j \times (-0.158j))}{0.673j}$, $Z_{23,new} = 0.639j$

$Z_{24,new} = 0.595j - \dfrac{(0.19j) \times (-0.356j)}{0.673j}$, $Z_{24,new} = 0.696j$

$Z_{31,new} = 0.533j$, Z_{32} new $= 0.639j$,

$Z_{33,new} = 0.753j - \dfrac{(0.158j \times 0.158j)}{0.673j}$, $Z_{34,new} = 0.668j$

$Z_{41,new} = 0.580j$, $Z_{42,new} = 0.696j$, $Z_{43,new} = 0.668j$

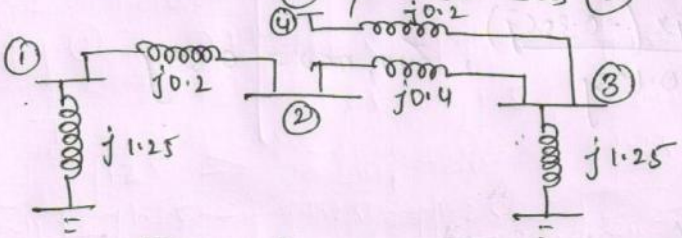
$Z_{44,new} = 0.953j - \dfrac{(-0.356j) \times (-0.358j)}{0.673j}$, $Z_{44,new} = 0.7625j$

$$Z_{bus,new} = \begin{bmatrix} 0.715j & 0.609j & 0.533j & 0.580j \\ 0.609j & 0.731j & 0.639j & 0.696j \\ 0.533j & 0.639j & 0.715j & 0.668j \\ 0.580j & 0.696j & 0.668j & 0.762j \end{bmatrix}$$

$$Z_{bus} = \begin{bmatrix} 0.754j & 0.654j & 0.496j \\ 0.654j & 0.785j & 0.595j \\ 0.496j & 0.595j & 0.753j \end{bmatrix}$$

Step (5)

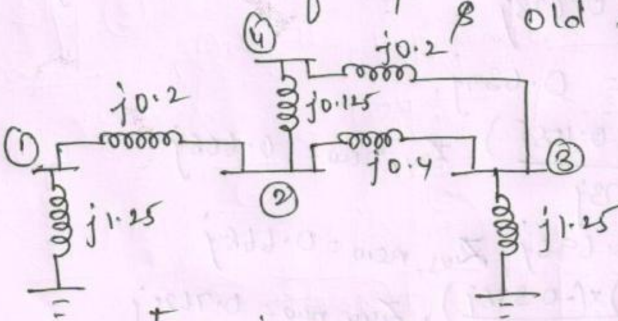
Addition of branch of impedance, $j=0.2$ in b/w old bus (3) & new bus (2)



$$Z_{bus} = \begin{bmatrix} 0.754j & 0.654j & 0.496j & 0.496j \\ 0.654j & 0.785j & 0.595j & 0.595j \\ 0.496j & 0.595j & 0.753j & 0.753j \\ 0.496j & 0.595j & 0.753j & 0.953j \end{bmatrix}$$

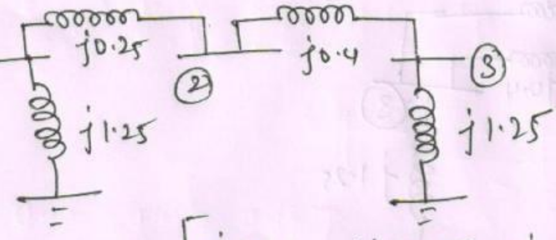
Step 6:-

Addition of impedance, $j0.125$ in b/w the old bus(4) & old bus (2).



$$Z_{bus} = \begin{bmatrix} 0.754j & 0.654j & 0.496j & 0.496j & 0.158j \\ 0.654j & 0.785j & 0.595j & 0.595j & 0.19j \\ 0.496j & 0.595j & 0.753j & 0.753j & -0.156j \\ 0.496j & 0.595j & 0.753j & 0.953j & -0.358j \\ 0.158j & 0.19j & -0.158j & -0.358j & 0.673j \end{bmatrix}$$

Step ④ :- Add the impedance $z = j1.25$ b/w bus ③ & ref bus



$$Z_{bus,new} = \begin{bmatrix} j1.25 & j1.25 & j1.25 & j1.25 \\ j1.25 & j1.5 & j1.5 & j1.5 \\ j1.25 & j1.5 & j1.9 & j1.9 \\ j1.25 & j1.5 & j1.9 & j3.15 \end{bmatrix}$$

$$Z_{11} = j1.25 - \frac{j1.25 \times j1.25}{j3.15}, \boxed{Z_{11} = 0.754j}$$

$$Z_{12} = j1.25 - \frac{j1.25 \times j1.5}{j3.15}, \boxed{Z_{12} = 0.654j}$$

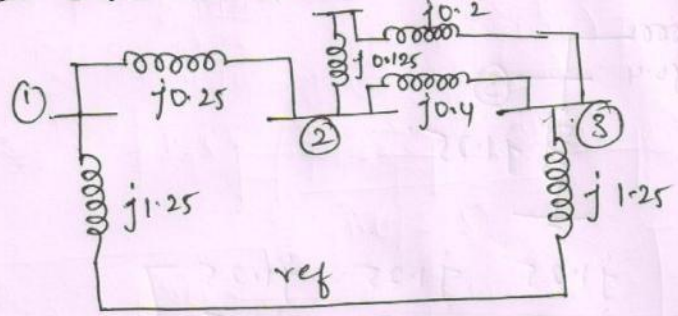
$$Z_{13} = j1.25 - \frac{j1.25 \times j1.9}{j3.15}, \boxed{Z_{13} = 0.496j}$$

$$Z_{22} = 1.5j - \frac{1.5j \times 1.5j}{3.15j}, \boxed{Z_{22} = 0.785j}$$

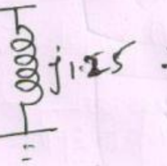
$$Z_{23} = 1.5j - \frac{1.5j \times 1.9j}{3.15j}, \boxed{Z_{23} = 0.595j}$$

$$Z_{33} = 1.9j - \frac{1.9j \times 1.9j}{3.15j}, \boxed{Z_{33} = 0.753j}$$

Prob From the Z bus - matrix the Ckt shown below

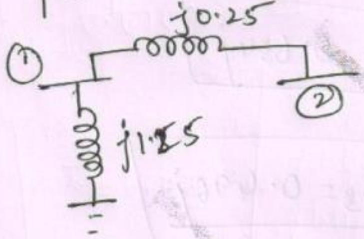


Step ① :- Add the impedance, $z = j1.25$ b/w ref bus & bus ①



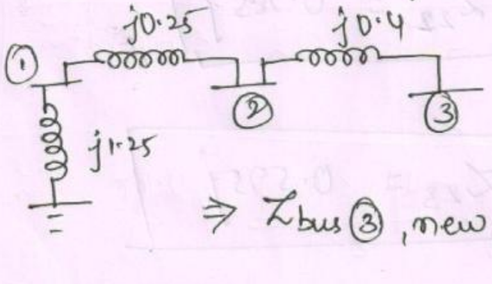
$$\Rightarrow Z_{bus,\,new} = \begin{bmatrix} j1.25 \end{bmatrix}$$

Step ② :- Add the impedance $z = j0.25$ b/w bus ① & bus ②



$$\Rightarrow Z_{bus,\,new} = \begin{bmatrix} j1.25 & j1.25 \\ j1.25 & j1.5 \end{bmatrix}$$

Step ③ :- Add the impedance, $z = j0.4$, b/w bus ② & bus ③



$$\Rightarrow Z_{bus\,③,\,new} = \begin{bmatrix} j1.25 & j1.25 & j1.25 \\ j1.25 & j1.5 & j1.5 \\ j1.25 & j1.5 & j1.9 \end{bmatrix}$$

$$Z_{21} = Z_{12} = j0.5$$

$$Z_{22} = j1.25 - \left(\frac{j1.25 \times j1.25}{j1.25}\right), \quad Z_{22} = j0.625$$

$$Z_{23} = j1.25 - \left(\frac{j1.25 \times j1.25}{j2.5}\right)$$

$$\boxed{Z_{23} = j0.625}$$

$$\boxed{Z_{31} = Z_{13} = j0.5}$$

$$\boxed{Z_{32} = Z_{23} = j0.625}$$

$$Z_{33} = j1.3 - \left(\frac{j1.25 \times j1.25}{j2.5}\right)$$

$$Z_{33} = j0.675$$

$$Z_{bus} = \begin{bmatrix} 0.6j & j0.5 & 0.5j \\ 0.5j & j0.625 & j0.625 \\ j0.5 & j0.625 & j0.675 \end{bmatrix}$$