Experiment no: 1.

Date: 04/10/2021.

Surabi Balakrishnan

S7-EE-B, Roll no: 39.

AUTOMATIC GENERATION CONTROL - SINGLE AREA S/M.

AIM

To determine the change in speed, frequency and steady state error corresponding to a load disturbance in a single area power system, with and without supplementary control using any software.

THEORY

Active power control is one of the important control actions to be performed during normal operation of the system to match the system generation with the continuously changing system load in order to maintain the consistency of system frequency to a fine tolerance level. This is one of the foremost requirements in providing quality power supply. A change in system load causes a change in the speed of all rotating masses (Turbine - generator rotor systems) of the system leading to change in system frequency. The speed change from synchronous speed initiates the governor control (primary control) action resulting in all the participating generator-turbine units taking up the change in load, stabilizing the system frequency. Restoration of frequency to nominal value requires secondary control action which adjusts the load reference set points of selected (regulating) generator - turbine units. The primary objectives of AGC are to regulate system frequency to the set nominal value & also to regulate the net interchange of each area to the scheduled value by adjusting the outputs of the regulating units. This function is referred to as load-frequency control.

A large power system can be divided into a number of sub-areas in which all the generators are tightly coupled such that they swing in unison with change in load or due to a speed-changer setting. Such an area, where all the generators are running coherantly is termed as a control area. In this area, frequency may be same in steady state & dynamic conditions. For developing a suitable control strategy, a control area can be reduced to a single generator, speed governor & load system.

GENERATOR MODEL

The swing equation with small deviation,

$$\frac{2H}{\omega_s} \cdot \frac{d^2 \Delta\delta}{dt^2} = \Delta P_m - \Delta P$$

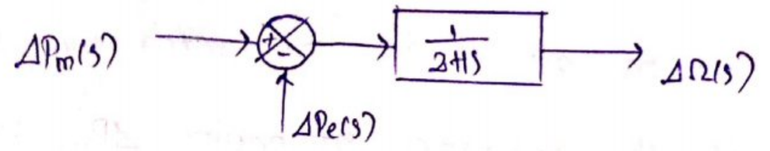
In terms of small deviation in speed

$$\frac{d}{dt}\left(\frac{\Delta\omega}{\omega_s}\right) = \frac{1}{2H}(\Delta P_m - \Delta P_e) \quad \text{with speed expressed in pu.}$$

$$\frac{d(\Delta\omega)}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e).$$

Taking Laplace transforms,

$$\Delta\Omega(s) = \frac{1}{2Hs}(\Delta P_m(s) - \Delta P_e(s))$$



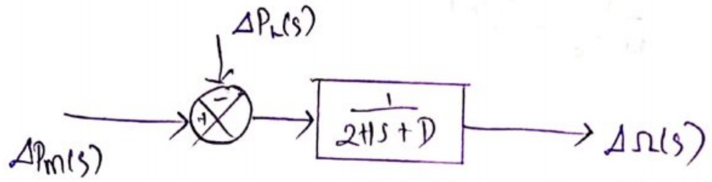
LOAD MODEL

The speed-load characteristics of a composite load is approximated as,

$$\Delta P_e = \Delta P_L + \Delta \omega D$$

where, ΔP_L is the non-frequency sensitive load change & $\Delta \omega D$ is the frequency sensitive load change.

D is expressed as percent change in load divided by percent change in frequency.



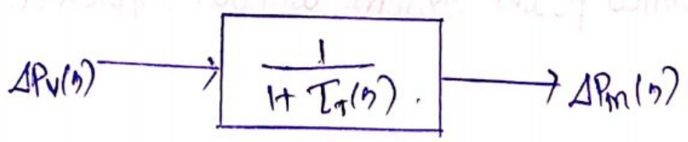
Generator-load block diagram.

PRIME MOVER MODEL

The simplest prime mover model for a non re-heat steam turbine can be approximated with a single time constant τ_T.

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T(s)}$$

where ΔP_m is the change in mechanical power output & ΔP_V is the change in steam valve position.



steam turbine model.

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Governor model

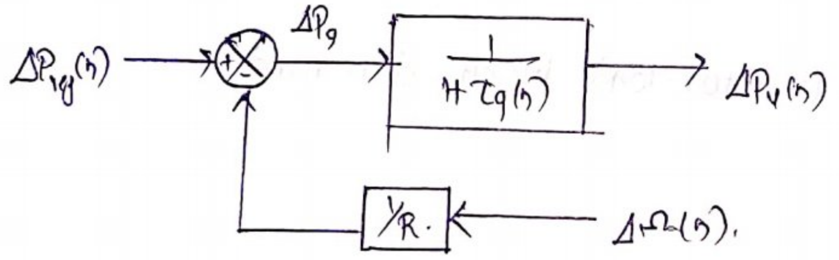
The speed governor mechanism act as a comparator whose output ΔP_g is the difference b/w the reference set power ΔP_{ref} and the power $\frac{1}{R}\Delta\omega$.

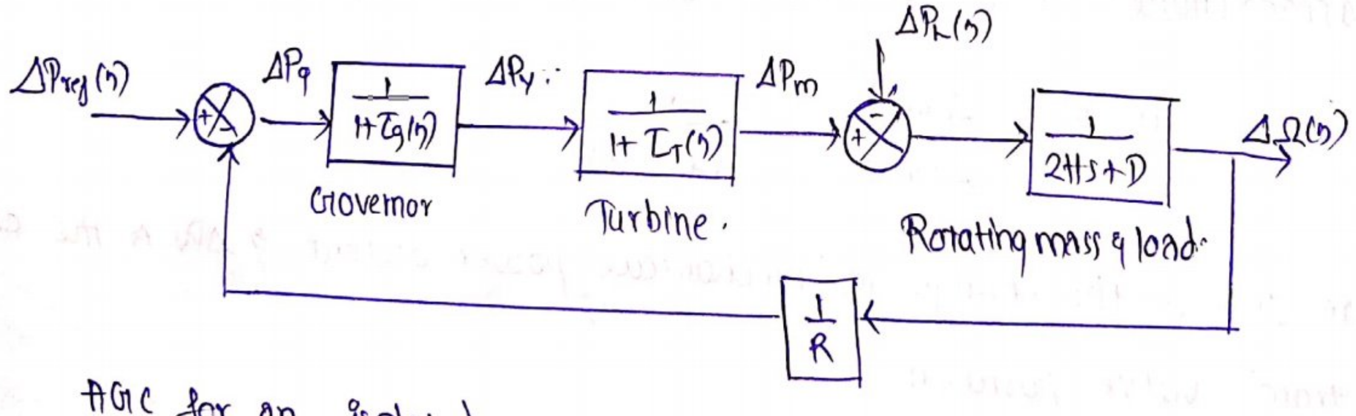
$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega$$

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\Omega(s)$$

The command ΔP_g is transferred through the hydraulic amplifier to the steam valve position command ΔP_V. Considering a simple time constant τ_g we have,

$$\Delta P_V(s) = \frac{1}{1+\tau_g} \cdot \Delta P_g(s)$$

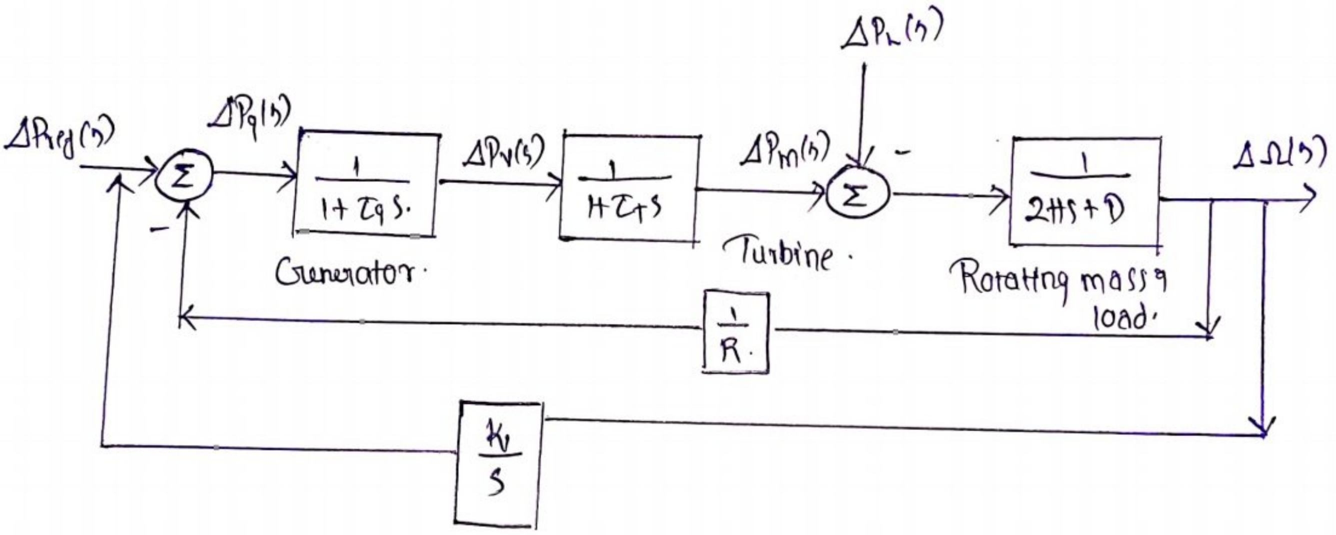




AGC for an isolated power system without supplementary control.

AGC in single area system

Depending on the governor speed regulation, a change in the system load will result in a steady state frequency deviation. To reduce frequency deviation, an integral controller is provided, which act on the load reference setting to change the speed set point. The integral controller gain K_I must be adjusted for a satisfactory transient response.



AGC for an isolated power system with supplementary control.

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DATE: 04.10.2021 SURABI BALAKRISHNAN

EXPERIMENT NO: 1 ROLL NO: 39

AUTOMATIC GENERATION CONTROL – SINGLE AREA SYSTEM

EXERCISE 1

DESIGN OF AN ISOLATED POWER SYSTEM WITH FOLLOWING PARAMETERS.

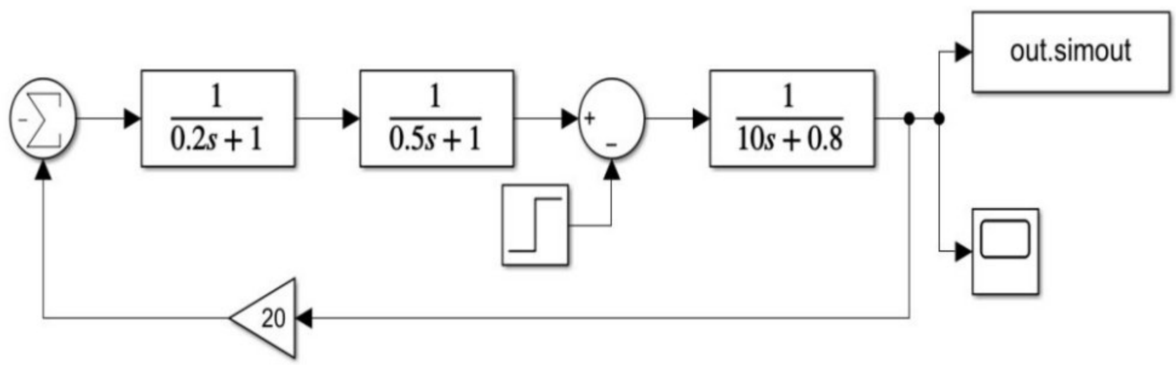
- Governor time constant = 0.2 sec
- Turbine time constant = 0.5 sec
- Generator inertia constant, H = 5 sec
- Governor speed regulation, R = 0.05 pu

The load varies by 0.8% for 1% change in frequency. (i.e., load damping constant D = 0.8. The turbine rated output is 250 MW at nominal frequency of 60 Hz. A sudden load change of 50 MW occurs. (i.e., ΔP_L = 50/250 = 0.2 pu)

ALGORITHM

- Draw each block in Simulink for the single area system.
- Enter the required values.
- Run the simulation.

SIMULINK BLOCK DIAGRAM FOR ISOLATED POWER SYSTEM WITHOUT SUPPLEMENTARY CONTROL



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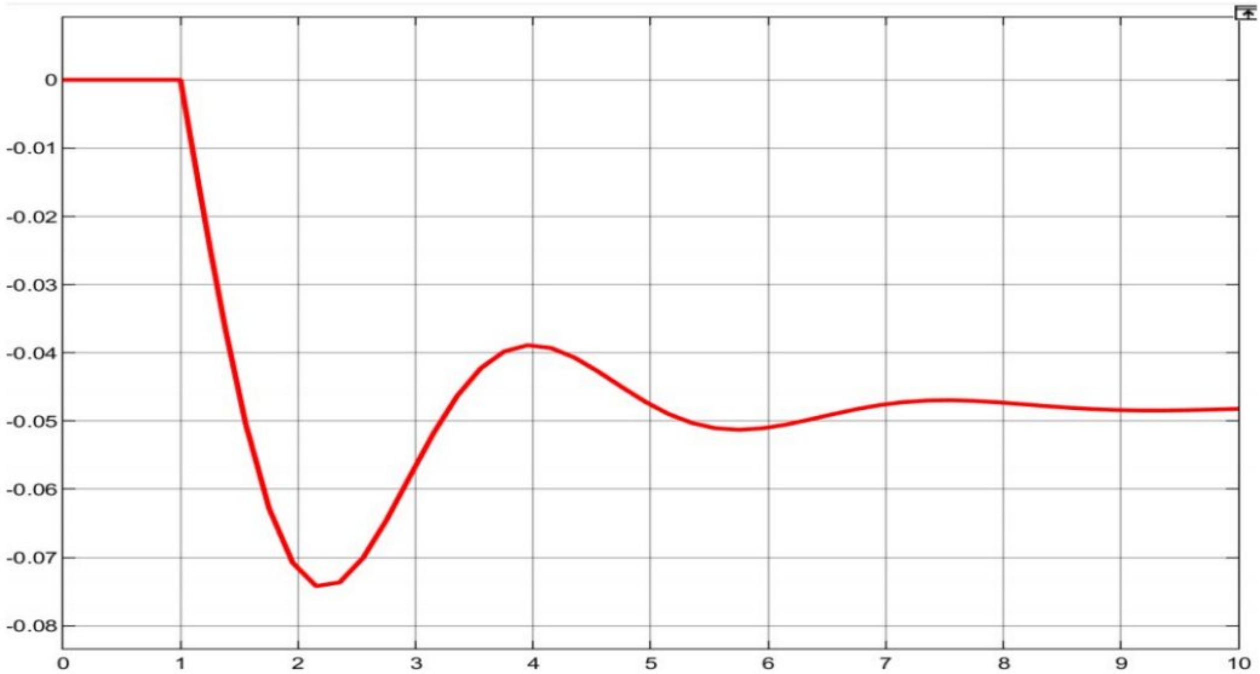
OUTPUT WAVEFORM



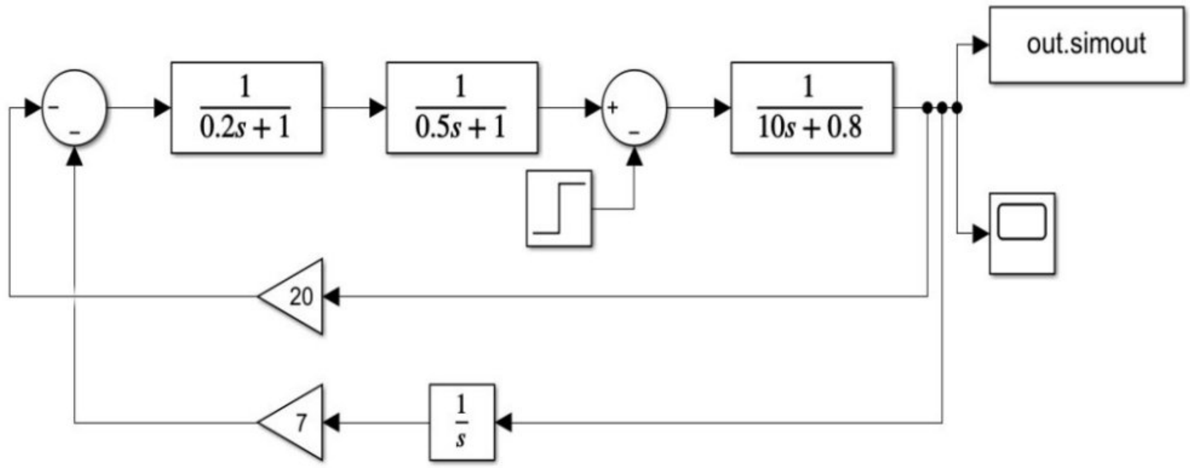
OBSERVATION

Steady state value = -0.048

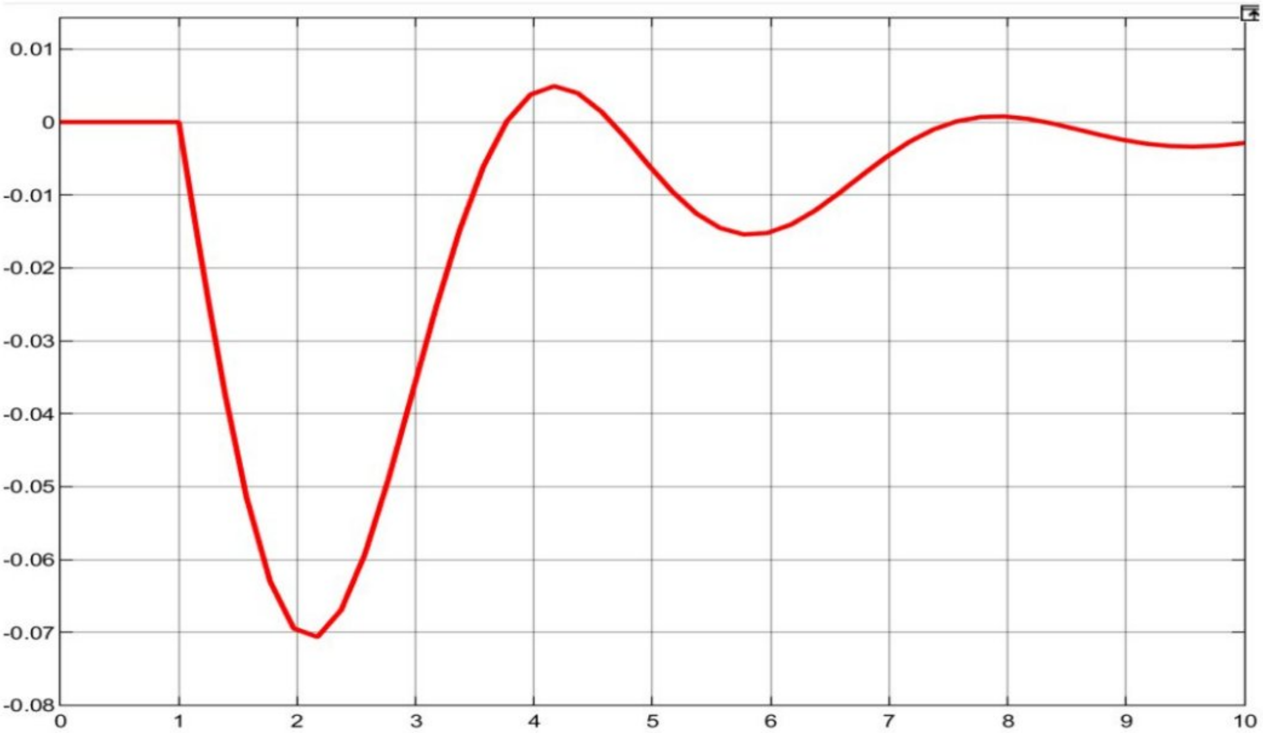
EXERCISE 2

DESIGN OF AN ISOLATED POWER SYSTEM WITH INTEGRAL CONTROL

SIMULINK BLOCK DIAGRAM FOR ISOLATED POWER SYSTEM WITH SUPPLEMENTARY CONTROL



OUTPUT WAVEFORM



OBSERVATION

Steady state value = 0

RESULT

Single area power system is simulated using MATLAB and the waveforms are plotted.

Date: 06/10/2021

Surobi Balakrishnan

Roll no : 39.

Experiment no: 2

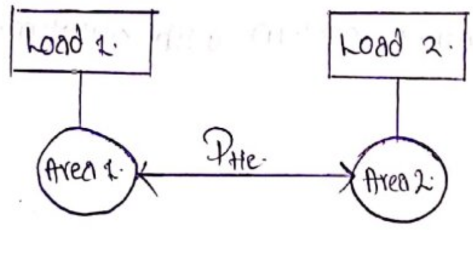
AUTOMATIC GENERATION CONTROL - 2 AREA SYSTEM

AIM:

To determine the change in speed, frequency and steady state error corresponding to a load disturbance in a 2 area power system, with & without supplementary control using any software.

PRINCIPLE:

A large power system can be divided into a number of load frequency control areas which are interconnected by tie lines. For simulation purpose, we consider a 2 area system. Each area contains an equivalent turbine, generator, load & governor system.



Consider the 2 area representation by an equivalent generating unit interconnected by a lossless tie-line with reactance X_{tie}. During normal operation, the real power transferred through tie line is given by,

$$P_{12} = \frac{|E_1||E_2| \sin\delta_{12}}{X_{12}}.$$

where $X_{12} = X_1 + X_{tie} + X_2$.

$\delta_{12} = \delta_1 - \delta_2$.

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For small deviation, $\Delta P_{12} = P_s \cdot \Delta \delta_{12}$.

The quantity P_s is the slope of the power angle curve at the initial operating angle $\delta_{120} = \delta_{10} - \delta_{20}$.

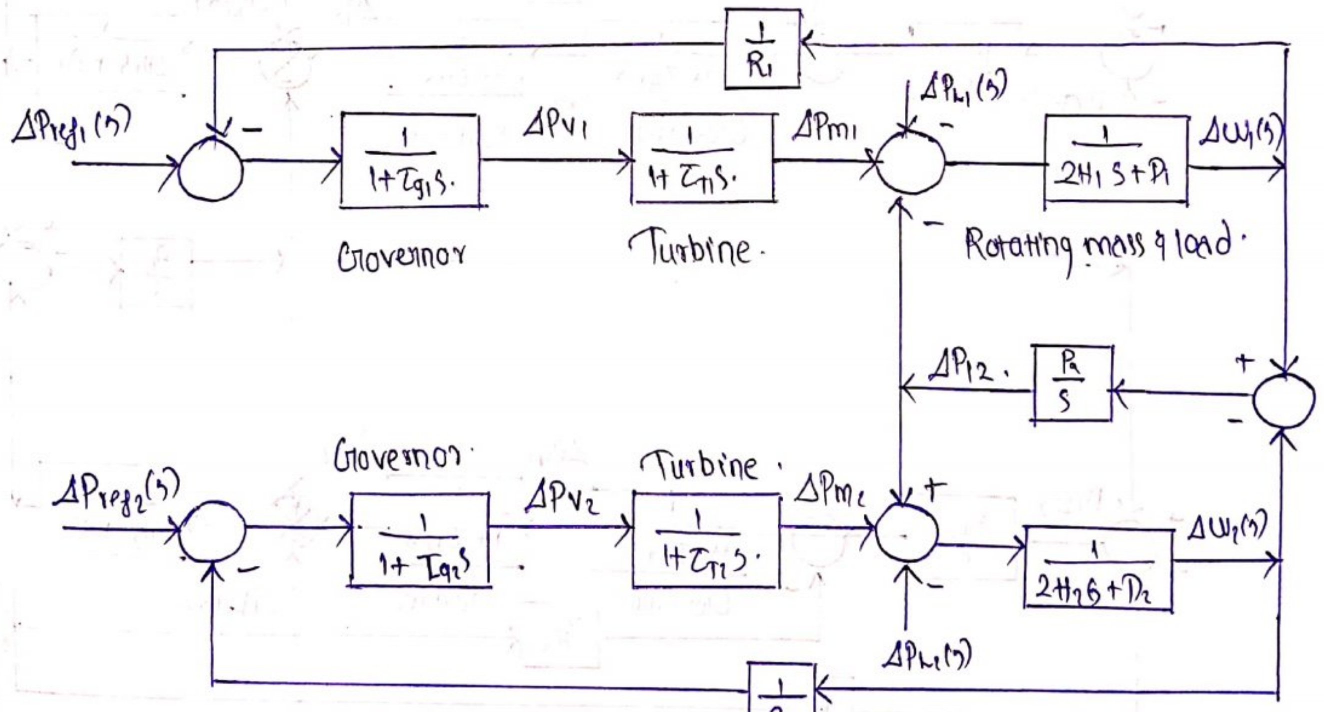
Thus $P_s = \frac{|E_1||E_2|}{X_{12}} \cos\delta_{120}$

The tie line power deviation is given by $\Delta P_{12} = P_s (\Delta\delta_1 - \Delta\delta_2)$.

Depending on the direction of the flow, the tie line power flow appears as a load increase in one area & a load decrease in the other area. If $\Delta\delta_1 > \Delta\delta_2$, the power flows from area 1 to 2.

Consider a load change ΔP_{L1} in area 1. In the steady state, both areas will have the same steady-state frequency deviation,

$\Delta\omega = \Delta\omega_1 = \Delta\omega_2$ and $\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1$, $\Delta P_{m2} - \Delta P_{12} = \Delta\omega D_1$



Two-area system with only primary LFC loop.

Tie-line bias control

In conventional LFC each area tend to reduce the area control error (ACE) to zero. (tie-line bias control)

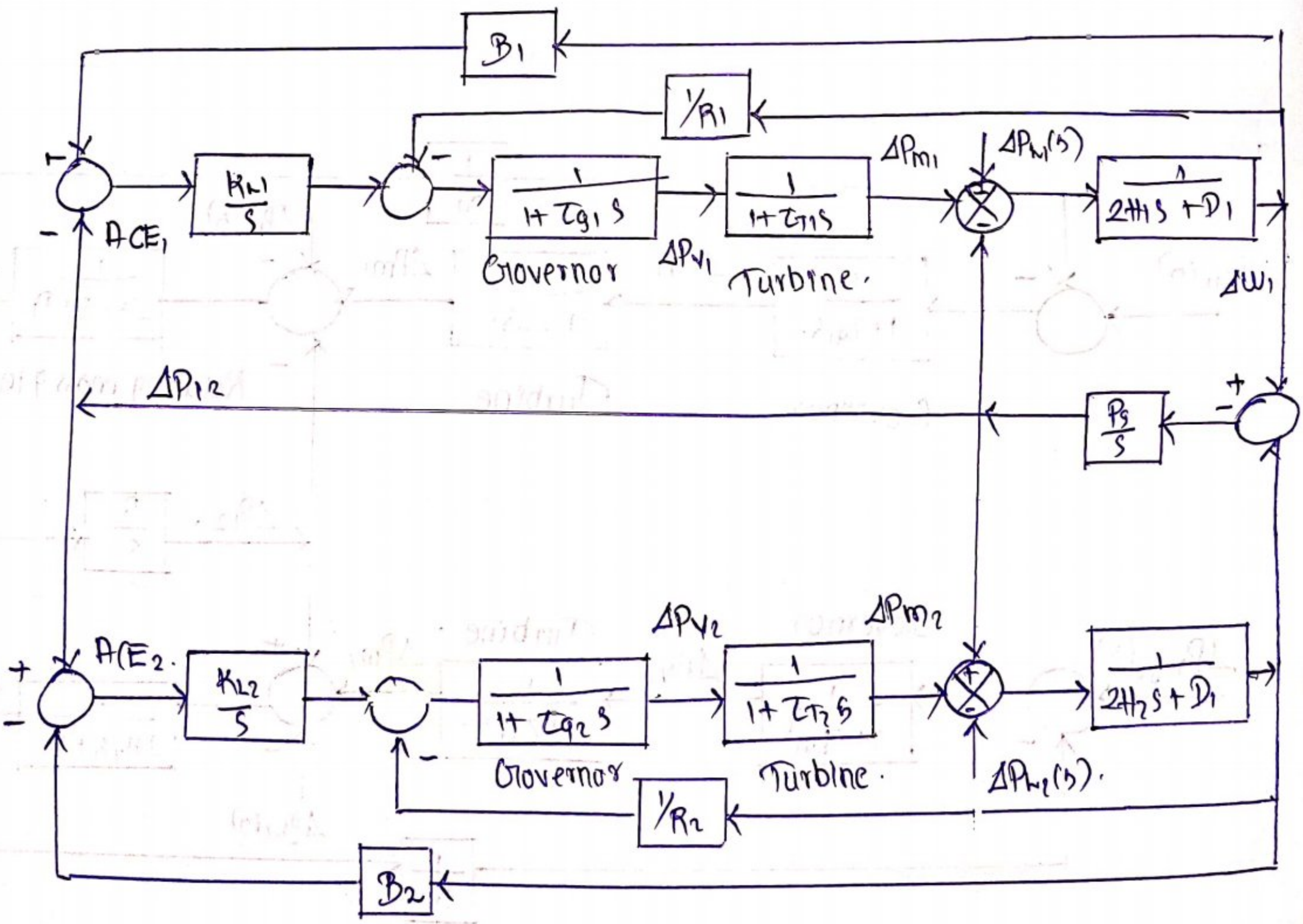
$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta \omega$$

The overall satisfactory performance is achieved when K_i (area bias) is selected equal to the frequency bias of that area.

$$ACE_1 = \Delta P_{12} + B_1 \Delta \omega_1 \quad \& \quad ACE_2 = \Delta P_{21} + B_2 \Delta \omega_2$$

$$B_1 = \frac{1}{R_1} + D_1$$

Two area system with tie-line bias control



EXPERIMENT NO: 2 NAME: SURABI BALAKRISHNAN

DATE: 09.10.2021 ROLL NO: 39

AUTOMATIC GENERATION CONTROL – TWO AREA SYSTEM

TWO-AREA SYSTEM WITH ONLY PRIMARY LFC LOOP

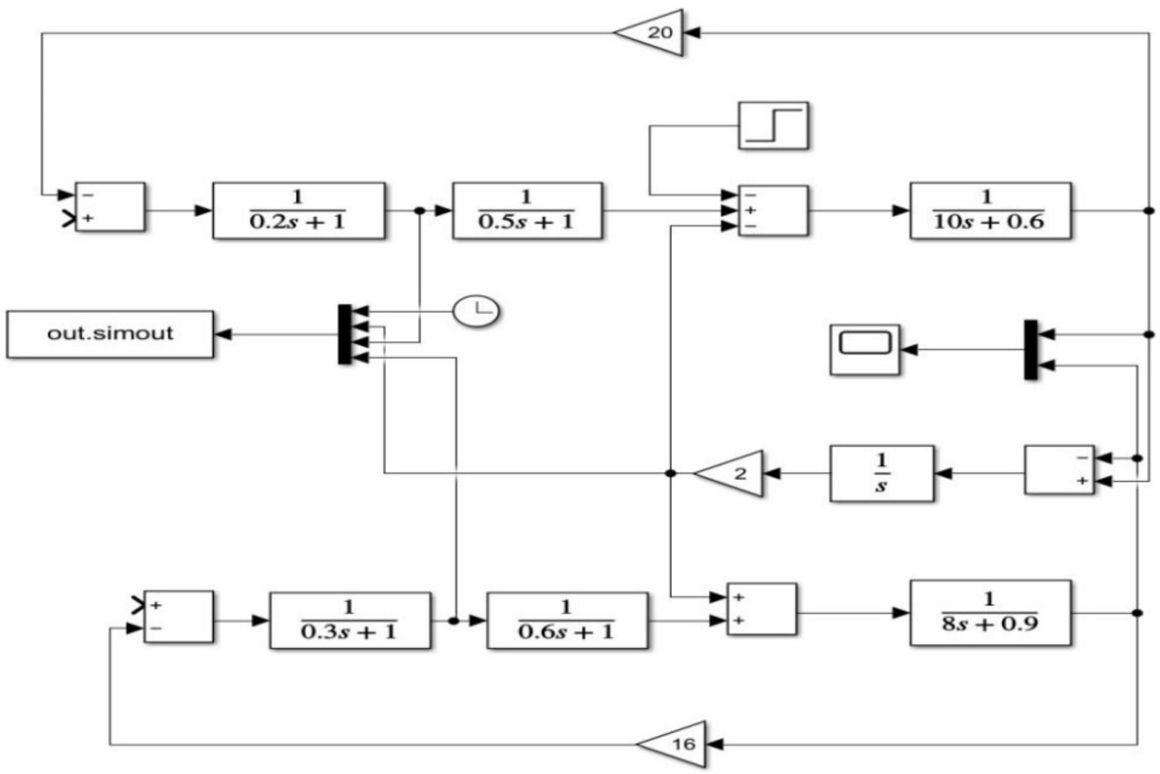
Exercise 1

A two-area system connected by a tie-line with following parameters on 1000 MVA base.

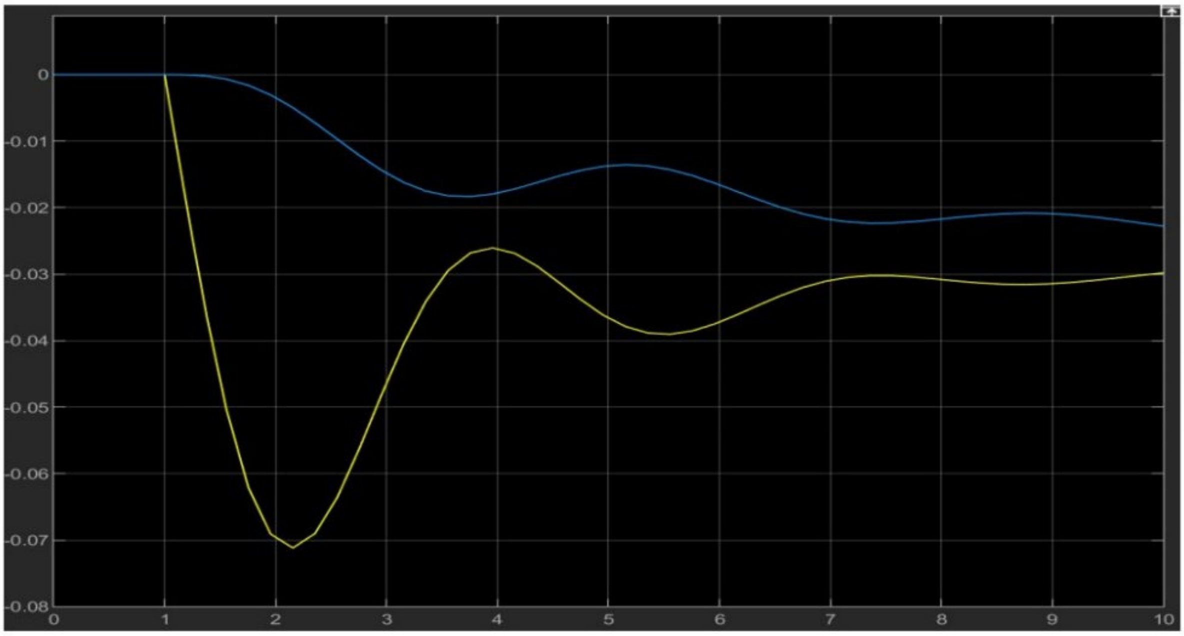
Area	1	2
Governor speed regulation	$R_1 = 0.05$ pu	$R_2 = 0.0625$pu
Load damping constant	D_1=0.8	D_2=0.9
Generator inertia constant	H_1=5 sec	H_2=4 sec
Governor time constant	τ_{g1}=0.2sec	τ_{g2}=0.3sec
Turbine time constant	τ_{T1}=0.5sec	τ_{T2}=0.6sec

The unit are operating in parallel at nominal frequency of 60 Hz. The synchronizing power coefficient is computed from the initial operating condition, given by Ps=2pu. A load change of 187.5 MW occurs in area 1. Obtain the frequency deviation response.

SIMULINK DIAGRAM

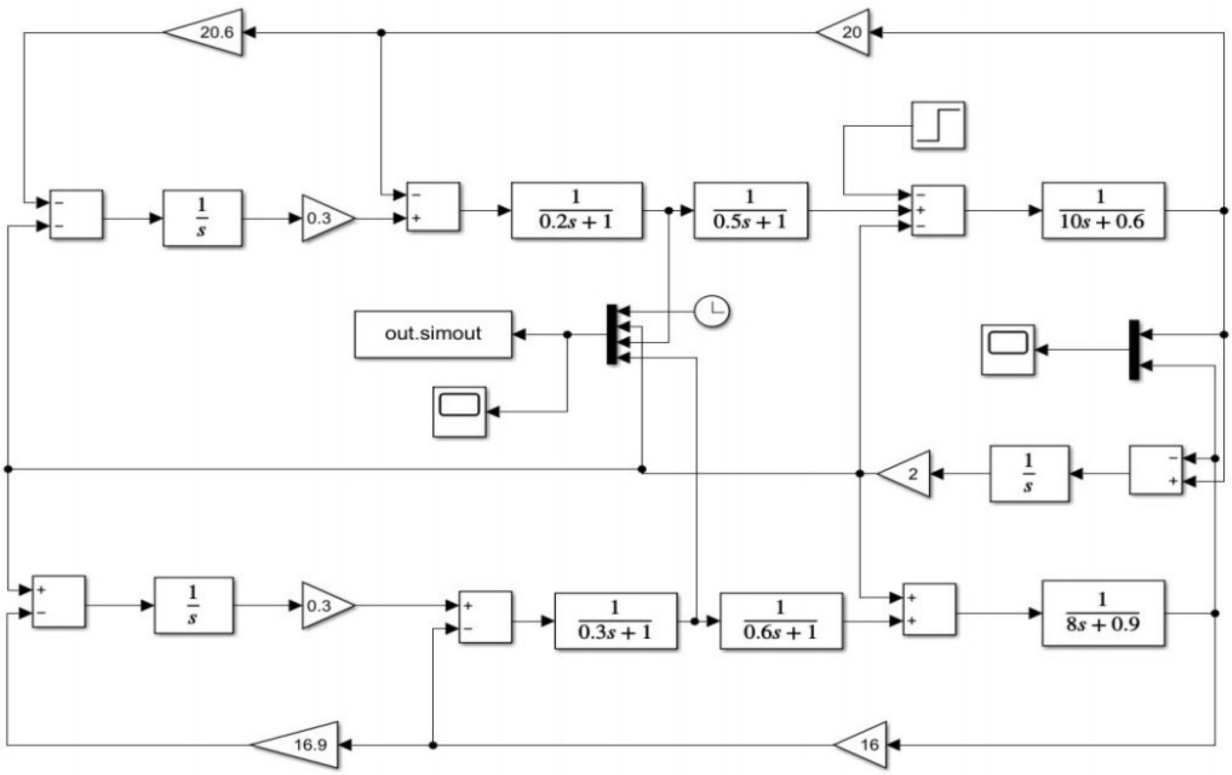


OUTPUT



TWO-AREA SYSTEM WITH TIE-LINE BIAS CONTROL

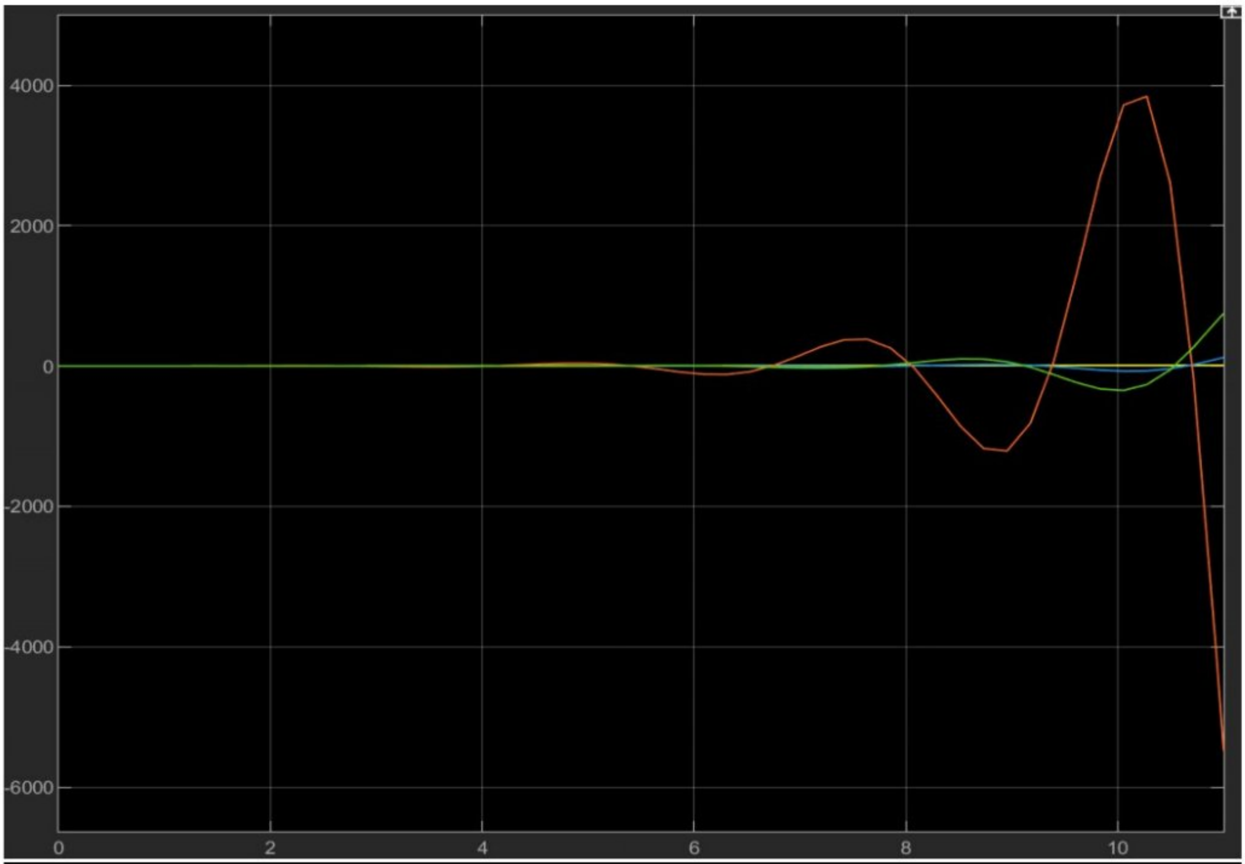
SIMULATION BLOCK DIAGRAM



Algorithm

- ✓ Draw each block in Simulink for the two area separately.
- ✓ Enter the required values.
- ✓ Run the simulation.

OUTPUT



RESULT

Two area power system is simulated using MATLAB and the waveforms are plotted.

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Experiment no: 03. Surabi Balakrishnan.

Date: 11/10/2021. S7-EE-B, Roll no: 39

FORMATION OF BUS ADMITTANCE MATRIX.

AIM:

To formulate a Y-Bus using 2 dimensional matrix by step by step method. Develop a computer program & implement on 4 bus system.

THEORY:

The Y-bus/Z-bus matrix constitutes the models of the passive portions of the power network. Y-bus matrix is often used in solving load flow problems. It has gained widespread applications owing to its simplicity of data preperation & the ease with which the bus admittance matrix can be formed & modified for network changes. Of course, sparsity is one of its greatest advantages as it heavily reduces computer memory & time requirements. In short circuit analysis, the generator & transformer impedances must also be taken into account. In contingency analysis, the shunt elements are neglected, while forming the Z-bus matrix, which is used to compute the outage distribution factors. This can be easily obtained by inverting the Y-bus matrix. The impedance matrix is a full matrix & is most useful for short circuit studies. Initially, the Y-bus matrix is formed by considering the line data only. After forming the Y bus matrix, the modified Y-bus matrix is formed by adding the generator & transformer admittances to the respective diagonal elements & is inverted to form the Z-bus matrix.

The performance equation for a n-bus system in terms of admittance matrix can be written

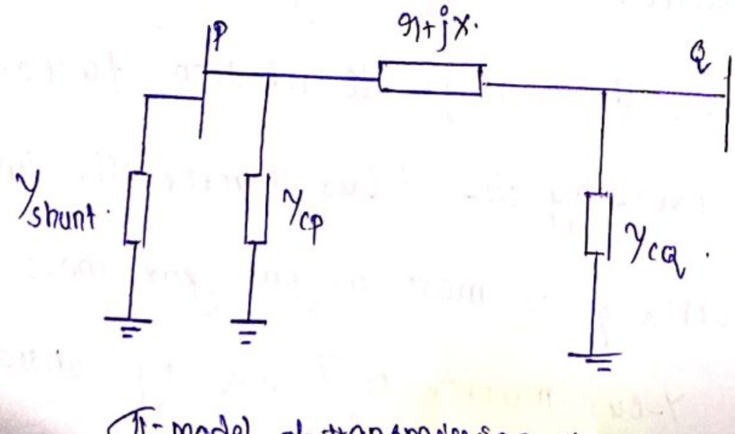
$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ Y_{n1} & Y_{n2} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix}$$

$$I = Y_{BUS} \cdot V.$$

The admittances $Y_{11}, Y_{22} \cdots Y_{nn}$ are called self admittances at node and all other admittances are called mutual admittances of all nodes

Inspection method.

The admittance matrix can be formed from the parameters of the system components. A diagonal element Y_{pp} is the sum of all admittances connected to the p^{th} bus. An off diagonal element Y_{pq} is the negative sum of all the admittances directly connected between p^{th} & q^{th} buses.



π-model of transmission line.

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We start with $[Y_{Bus}]$ array initially set to zero. The dimensions of $[Y_{Bus}]$ are $n \times n$ bus, where 'n' is the number of buses (or the total no. of nodes, including reference node). Consider an element having admittance Y_{pq} connected b/w buses p & q. Four entries in Y_{Bus} are affected. $Y_{pp}, Y_{qq}, Y_{pq}, Y_{qp}$. We modify these entries as below,

$$Y_{pp,new} = Y_{pp,old} + Y_{pq} + Y_{cp}.$$

$$Y_{qq,new} = Y_{qq,old} + Y_{qp} + Y_{cq}.$$

$$Y_{pq,new} = Y_{pq,old} - Y_{pq}$$

$$Y_{qp,new} = Y_{qp,old} - Y_{qp}.$$

We add the elements one by one & modify the entries of $[Y_{Bus}]$ as per equations (1,1). If an element is connected from i^{th} bus to reference, only entry Y_{pp} is affected.

EXPERIMENT NO:3 NAME: SURABI BALAKRISHNAN

DATE: 12/10/2021 ROLL NO: 39

FORMATION OF BUS ADMITTANCE MATRIX

PROBLEM:

Form the Y Bus for the system shown in figure by step-by-step method.

Line No. (k)	From Bus lp(k)	To Bus lq(k)	Line Impedance	Ycp	Ycq
1	1	2	0.01+j0.04	j0.08	j0.08
2	1	3	0+j0.1	0	0
3	2	3	0.04+j0.16	j0.09	j0.09
4	2	5	0.06+j0.18	j0.08	j0.08
5	2	5	0.06+j0.18	j0.08	j0.08
6	3	4	0+j0.1	0	0
7	4	5	0.1+j0.3	0	0

yshunt(i)	0	0	0	0	j0.03

ALGORITHM:

1. Read : n, nline

: lp(k), lq(k), r(k), x(k), ycp (k), ycq(k); for k=1 to nline

: yshunt(i); for i=1 to n

2. % Calculate primitive admittance for all lines

for k=1 to nline

zline(k)= r(k)+jx(k)

yline(k)=1/zline(k)

end

3. % Initialize Y-bus

Y(n,n)=0.0;

4. % Computation of Y-bus elements

for k=1 to nline

p=lp(k)

q=lq(k)

y(p,p)=y (p,p)+yline(k)+ycp(k)

y(q,q)=y(q,q)+yline(k)+ycq(k)

y(p,q)=y(p,q)-yline(k)

y(q,p)=y(q,p)-yline(k)

end

5. % Add shunt elements

for i=1 to n

y(i,i)=y(i,i)+yshunt(i)

end

6. Print y(i,j); for i=1 to n, j=1 to nline

PROGRAM:

```
clc;
clear;
opf=fopen('Y bus.op','w');
linedata = [ 1 2 0.1 0.04 0.08 0.08;
1 3 0 0.1 0 0;
2 3 0.04 0.16 0.09 0.09;
2 5 0.06 0.18 0.08 0.08;
2 5 0.06 0.18 0.08 0.08;
3 4 0 0.1 0 0;
4 5 0.1 0.3 0 0];
yshunt=[0 0 0 0 0.3];
n=5;
nline=7;
lp=linedata(:,1);
lq=linedata(:,2);
r=linedata(:,3);
x=linedata(:,4);
ycp=linedata(:,5);
ycq=j*linedata(:,6);
```


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```
y=zeros(n);
for k=1:nline
z(k)=complex(r(k),x(k));
yline(k)=1/z(k);
end
for k=1:nline
p=lp(k);
q=lq(k);
y(p,p)=y (p,p)+yline(k)+ycp(k);
y(q,q)=y(q,q)+yline(k)+ycq(k);
y(p,q)=y(p,q)-yline(k);
y(q,p)=y(q,p)-yline(k);
end
for i=1:n
y(i,i)=y(i,i)+yshunt(i);
end
%Print result
fprintf(opf,'Ybus\n');
for i=1: n
for j=1: n
fprintf(opf,'(%0.4g+%0.4gj)',real(y(i,j)),imag(y(i,j)));
end
fprintf(opf,'\n');
end
```

OUTPUT

1	2	3	4	5
8.7007 - 13.4483i	-8.6207 + 3.4483i	0.0000 + 10.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-8.6207 + 3.4483i	13.6746 - 19.2506i	-1.4706 + 5.8824i	0.0000 + 0.0000i	-3.3333 + 10.0000i
0.0000 + 10.0000i	-1.4706 + 5.8824i	1.4706 - 25.7924i	0.0000 + 10.0000i	0.0000 + 0.0000i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 10.0000i	1.0000 - 13.0000i	-1.0000 + 3.0000i
0.0000 + 0.0000i	-3.3333 + 10.0000i	0.0000 + 0.0000i	-1.0000 + 3.0000i	4.6333 - 12.8400i

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RESULT:

The Y- bus matrix was formed for the given system by step-by-step method and the results were verified by manual calculation.

Experiment no: 4. Surabi Balakrishnan

Date: 12/10/2021. Roll no: 39.

LOAD FLOW ANALYSIS USING GAUSS SEIDAL METHOD.

AIM.

To develop a computer program to solve the set of non linear load flow equations using Gauss-seidal load flow algorithm.

THEORY:

Load flow analysis is the most frequently performed system study by electric utilities. This analysis is performed on a symmetrical steady-state operating condition of a power system under 'normal' mode of operation & aims at obtaining bus voltages & line flows for a given load condition. This information is essential both for long term planning & next day operational planning. In long term planning, load flow analysis helps in investigating the effectiveness of alternative plans and choosing the best plan for system expansion to meet the projected operating state. In operational planning, it helps in choosing the best unit commitment plan & generation schedules to run the system efficiently for them next day's load condition without violating the bus voltage & line flow operating limits.

The Gauss-seidal method is an iterative algorithm for solving a set of non-linear algebraic equations. The relation

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ship between network bus voltages & currents may be represented by either loop equations or node equations. Node equations are normally preferred because the number of independent node equation is smaller than the number of independent loop equations.

The network equations in terms of bus admittance matrix can be written as, $I_{bus} = [Y_{BUS}] V_{bus}$.

At the p^{th} bus, current injection:

$$I_p = Y_{p1} V_1 + Y_{p2} V_2 + \dots\dots + Y_{pp} V_p + \dots\dots + Y_{pn} V_n$$

$$= \sum_{q=1}^{n} Y_{pq} V_q = Y_{pp} V_p + \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q.$$

$$V_p = \frac{1}{Y_{pp}} \left[I_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q \right] \quad p = 2, 3 \dots n.$$

At bus p, we can write, $P_p - jQ_p = V_p^* I_p$.

Hence, the current at any node p is related to P, Q & V as follows:

$$I_p = \frac{P_p - jQ_p}{V_p^*} \quad \text{(for any bus p except slack bus s)}$$

Substituting for I_p.

$$V_p = \frac{1}{Y_{pp}} \left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_q \right]; \quad p = 2, 3 \dots n.$$

I_p has been substituted by the real & reactive powers because normally in a power system, these quantities are specified.

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ALGORITHM

1. Start

2. Read the line data (Branch number, from bus, to bus, resistance, reactance, half line admittance, tap ratio).

3. Read the bus data (P_d, Q_d, P_g, Q_g, V, δ & type of the bus).

4. Form Y_{bus} by suitable method.

5. Assume flat voltage profile (1+j0) for all buses except slack bus. The voltage of the slack bus is the specified voltage.

6. Read V_{spec}, Q_{min} & Q_{max} for PV buses.

7. Assume suitable conversion criterion ε.

8. Set iteration count $itr = 0$.

9. Set bus count $p = 1$.

10. Check for slack bus. If yes, $V_1^1 = V_1^0$.

11. Check for generator bus. If yes, GOTO step 12. ELSE GOTO step 14.

12. Calculate, Q^{itr+1}. Temporarily set $V_p^{itr} = |V_{spec}|$.

$$Q_p^{itr+1} = -\text{im}\left[(V_p^{itr})\left[\sum_{q=1}^{p=1} Y_{pq} \cdot V_q^{itr+1} + \sum_{q=p}^{n} V_{pq} \cdot V_q^{itr}\right]\right]$$

If Q_p^{itr+1} is within limits, then consider this bus as a generator bus & set $Q_p = Q_p^{itr+1}$ for this iteration & GOTO step 13.

If calculated reactive power violates the limit, treat it as load bus.

If $Q_p^{itr+1} < Q_{min}$, then $Q_p = Q_{min}$.

If $Q_p^{itr+1} > Q_{max}$, then $Q_p = Q_{max}$.

Since treated as load bus, take V_p^{itr+1}, the actual value obtained in step 14.

13. For generator bus, magnitude of $V = |V_{spec}|$, phase angle only changes.

$$V_p^{itr+1} = |V_{spec}| \angle \delta_p^{itr+1}$$

Goto step 15.

14. For load bus,

$$V_p^{itr+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{V_p^{itr}} - \left[\sum_{Q=1}^{p-1} Y_{pQ} V_Q^{itr+1} + \sum_{Q=p+1}^{n} Y_{pQ} \cdot V_Q^{itr}\right]\right]$$

15. Calculate $\Delta V_1^{itr+1} = V_p^{itr+1} - V_p^{itr}$

16. Repeat the step 10 to step 15 until all bus voltages are calculated. ie, increment bus count by 1 GOTO step 10 until bus count is 'nbus'.

17. Find largest absolute value of change in voltage. ie, $|\Delta V_{max}|$ is the largest among $|\Delta V_1^{itr+1}|, |\Delta V_2^{itr+2}| \ldots |\Delta V_n^{itr+1}|$. If $|\Delta V_{max}| < \varepsilon$, GOTO step 18, else GOTO step 9 after incrementing iteration count.

18. Calculate line flows & slack bus power.

Slack bus power $= V_i^* \left[V_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} V_j\right]$.

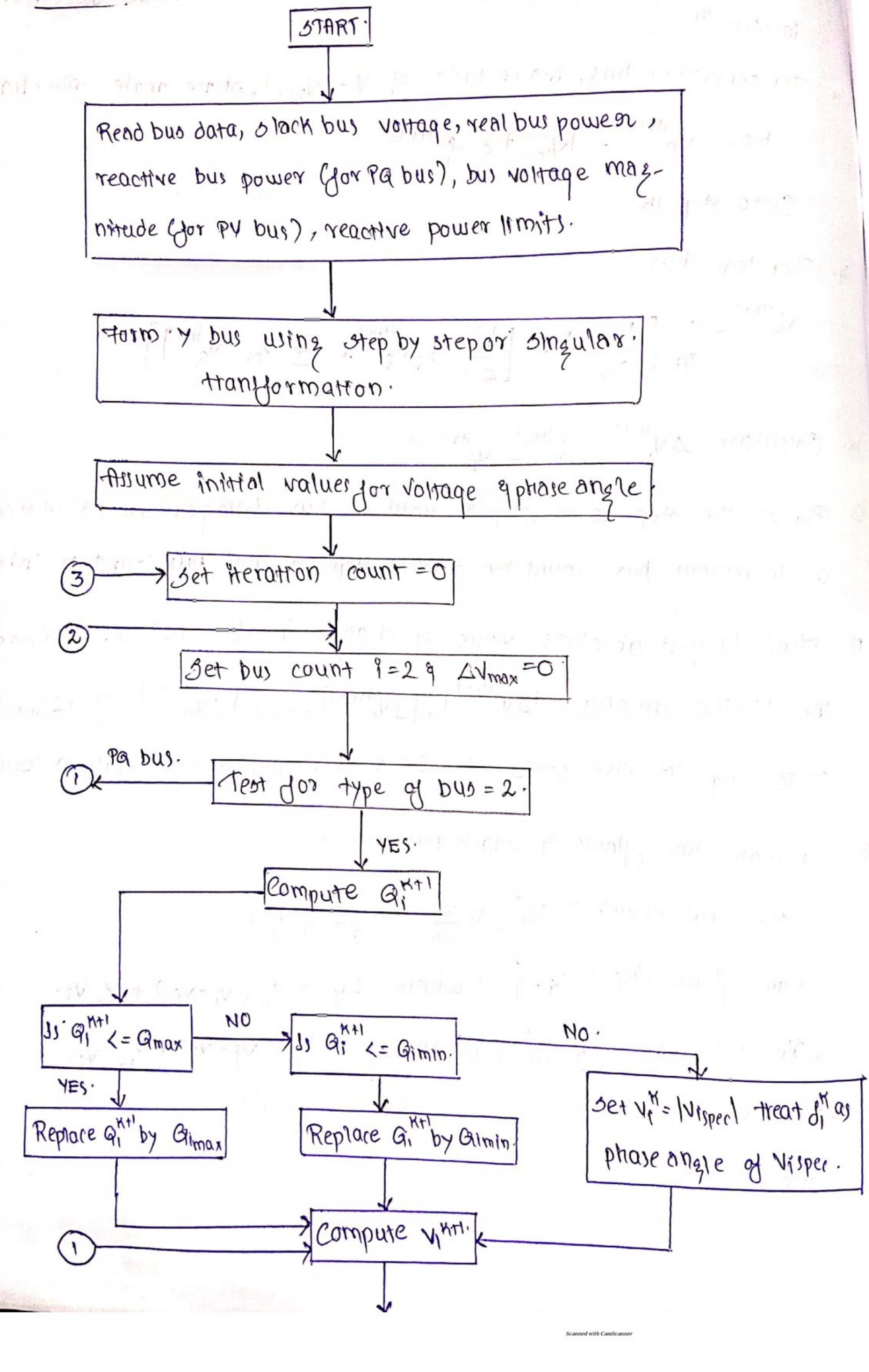
Line flows $S_{ij} = V_i I_{ij}^*$; where $I_{ij} = Y_{ij}(V_i - V_j) + Y_{i0} V_i$.

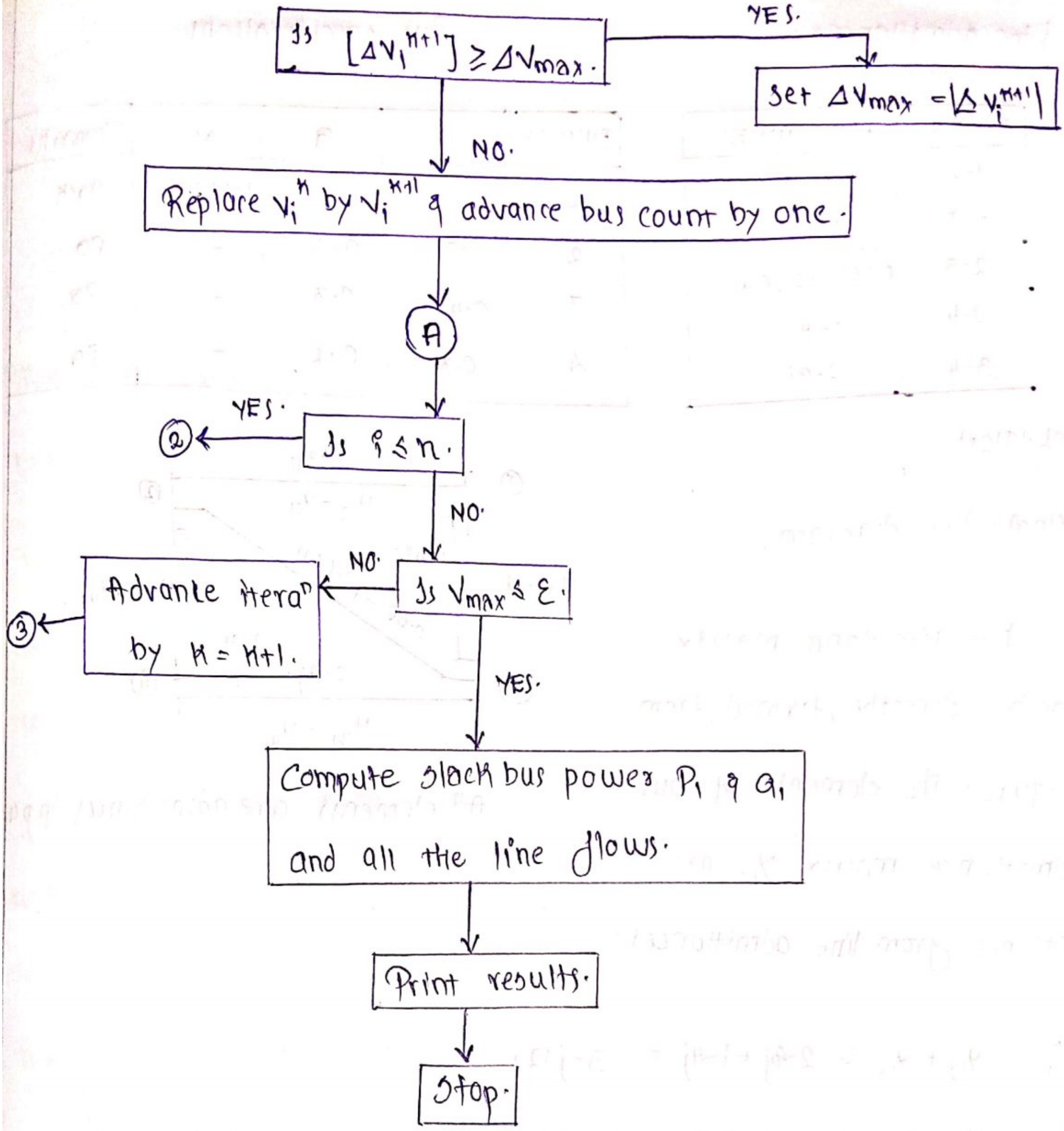
Similarly $S_{ji} = V_j \cdot I_{ji}^*$; where $I_{ji} = Y_{ji}(V_j - V_i) + Y_{j0} \cdot V_j$.

• Line loss $= S_{ij} + S_{ji}$.

19. Stop.

FLOW CHART


START
Read bus data, slack bus voltage, real bus power, reactive bus power (for PQ bus), bus voltage magnitude (for PV bus), reactive power limits.
Form Y bus using step by step or singular tranformation.
Assume initial values for voltage & phase angle
3
Set iteration count = 0
2
Set bus count i = 2 & ΔVmax = 0
PQ bus.
1
Test for type of bus = 2.
YES.
Compute Q_i^{K+1}
Is Q_i^{K+1} <= Qmax
NO
Is Q_i^{K+1} <= Qimin.
NO.
YES.
Replace Q_i^{K+1} by Qimax
Replace Q_i^{K+1} by Qimin.
Set V_i^K = |Vispec| treat δ_i^K as phase angle of Vispec.
1
Compute V_i^{K+1}.



Problem.

The system data for a load flow solution are given in table. Determine the voltages at the end of first iteration by Gauss-Seidal method. Take $\alpha = 1.6$.

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Line admittances:

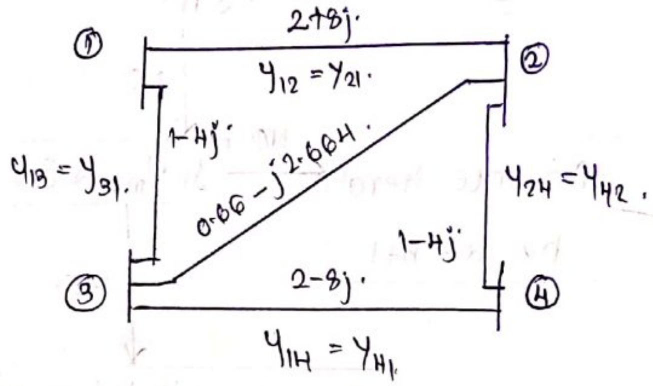
BUSCODE	ADMITTANCE
1-2	2-8j
1-3	1-4j
2-3	0.666-j2.664
2-4	1-4j
3-4	2-8j

Bus specifications

Buscode	P	Q	V	Remarks
1	-	-	$1.06\angle 0°$	Slack
2	0.5	0.2	-	PQ
3	0.4	0.3	-	PQ
4	0.3	0.1	-	PQ

SOLUTION

Single line diagram;



The bus admittance matrix can be directly formed from figure. The elements of bus admittance matrix Y_{jk} are obtained from line admittances.

All elements are admittances input.

$Y_{11} = y_{12} + y_{13} = 2-8j + 1-4j = 3-j12$

$Y_{22} = y_{12} + y_{23} + y_{24} = 2-8j + 0.66 - j2.664 + 1-4j = 3.66 - j14.664$

$Y_{33} = y_{13} + y_{23} + y_{34} = 1-4j + 0.66 - j2.664 + 2-8j = 3.66 - j14.664$

$Y_{44} = y_{34} + y_{24} = 1-4j + 2-8j = 3-j12$

$Y_{12} = Y_{21} = -y_{12} = -(1-4j) = -1+4j$

$Y_{14} = Y_{41} = 0$

$Y_{23} = Y_{32} = -y_{23} = -(0.66-j2.664) = -0.666 + j2.664$

$Y_{24} = Y_{42} = -y_{24} = -(1-4j) = -1+4j$

$Y_{34} = Y_{43} = -y_{34} = -(2-8j) = -2+8j$

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} = \begin{bmatrix} 3-j12 & -2+8j & -1+4j & 0 \\ -2+8j & 3.66-j14.664 & -0.66+j2.664 & -1+4j \\ -1+4j & -0.66+j2.664 & 3.66-j14.664 & -2+8j \\ 0 & -1+4j & -2+8j & 3-j12 \end{bmatrix}$$

The Initial values of bus voltages are considered as 1pu except slack bus. $\therefore V_2^0 = 1+j0$; $V_3^0 = 1+j0$; $V_4^0 = 1+j0$.

The bus-1 is a slack bus & so its voltage remain at the specified value for all iterations.

i.e, $V_1^0 = V_1^1 = \dots V_1^n = V_1 = 1.06+j0$ p.u.

Since the buses are PQ buses, the specified real & reactive powers are considered as load powers. Therefore a -ve is attached to specified power.

The $(K+1)^{th}$ iteration voltage of a PQ (load) bus-p is given by,

$$V_p^{K+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{(V_p^K)^*} - \sum_{q=1}^{p-1} Y_{pq} \cdot V_q^{K+1} - \sum_{q=p+1}^{n} Y_{pq} V_q^K\right]$$

For 1st iteration, K=0. The system has 4 buses & so p will be taken values from 1 to 4. Here all the buses are load buses except bus-1. The calculation of bus voltages for 1st iteration are shown below.

$V_1^1 = V_1^0 = 1.06 + j0$ pu ($\because$ Bus 1 is a slack bus).

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^{0*}} - Y_{21} \cdot V_1^1 - Y_{23} \cdot V_3^0 - Y_{24} \cdot V_4^0\right].$$

$$= \frac{1}{3.66-j14.664}\left[\frac{0.5-j0.2}{1-j0} - (-2+8j)(1.06) - (-0.66+2j2.664)(1+j0) - (-1+4j)(1+j0)\right]$$

$$= \frac{0.5-j0.2+2.12-j8.48+0.66-j2.664+1-4j)}{3.66-j14.664.}$$

$$= \frac{3.286-j14.944}{3.666-j14.664} = \frac{15.3010\angle-77.6^\circ}{15.1153\angle-75.96^\circ} = 1.0123\angle-1.64^\circ.$$

$$= 1.0119-j0.0290 \text{ pu.}$$

$$V'_{2\,su} = V_2^0 + \alpha(V_2'-V_1^0) = 1+1.16(1.0119-j0.0290-1)$$

$$= 1.0190+j0.0464.$$

Now $V_2' = V'_{2\,sa} = 1.0190-j0.0464\text{ pu} = 1.0201\angle-2.61^\circ$ pu.

$$V_2' = \frac{1}{Y_{32}}\left[\frac{P_3-jQ_3}{(V_3^0)^*} - Y_{32}V_1^0 - Y_{32}V_2' - Y_{34}V_4^0\right]$$

$$= \frac{1}{3.66-j14.664}\left[\frac{0.4-j0.3}{1-j0} - (-1+4j)(1.06) - (-0.66+2.664)(1.0190-j0.0464) - (-2+8j)(1+j0)\right]$$

$$= \frac{0.4\ j0.3+1.06-j4.24-(-0.55+j2.7455)+2-8j}{3.66-j14.664.}$$

$$= \frac{3.215-j14.6355}{3.66-j14.664} = \frac{15.0333\angle-77.65^\circ}{15.1153\angle-75.96^\circ}$$

$$= 0.9946\angle-1.69^\circ = 0.9942+j0.0299\text{ pu.}$$

$$V_{3acc}^1 = V_3^0 + \alpha(V_3^1 - V_3^0)$$

$$= 1+1.6(0.9942 - j0.0293 - 1) = 1+1.6(-0.0058 - j\cdot 0.0293)$$

$$= 0.9907 + j0.0469.$$

Now, $V_3^1 = V_{3acc}^1 = 0.9907 - j0.0469\ pu. = 0.9918 \angle -2.71^\circ pu.$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^0)^*} - Y_{41}V_1^1 - Y_{42}\cdot V_2^1 - Y_{43}\cdot V_3^1\right]$$

$$= \frac{1}{3-12j}\left[\frac{0.3-0.1j}{1-j0} - (0\times 1.06) - (-1+4j)(1.0190 - j0.0464) - (2+8j)(0.9907 - j0.0469)\right].$$

$$= \frac{0.3\cdot j0.1 - (-0.8334 + j4.1224) - (-1.6062 + j8.0194)}{3-j12}$$

$$= \frac{2.1396 - j12.0418}{3-j12.} = \frac{12.2304 \angle -79.92^\circ}{12.3693 \angle -75.96^\circ} = 0.9887 \angle +3.96^\circ$$

$$= 0.9864 + j0.0683\ pu.$$

$$V_{4acc}^1 = V_4^0 + \alpha(V_4^1 - V_4^0)$$

$$= 1+1.6(0.9864 - (j0.0683) - 1) = 0.9782 + j0.1093$$

$$V_4^1 = V_{4acc}^1 = 0.9782 - j0.1093\ pu = 0.9843 \angle +6.38^\circ\ pu.$$

results; The bus voltages at the end of first iteration are,

$$V_1^1 = 1.06 + j0 = 1.06 \angle 0^\circ\ pu.$$

$$V_2^1 = 1.019 + j0.0464 = 1.0201 \angle 2.61^\circ\ pu$$

$$V_3^1 = 0.9907 + j0.0469 = 0.9918 \angle 2.7^\circ pu.$$

$$V_4^1 = 0.982 + j0.1093 = 0.9843 \angle 6.38^\circ\ pu.$$

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EXPERIMENT NO: 04 NAME: SURABI BALAKRISHNAN

DATE: 12/10/2021 ROLL NO: 39

PROGRAM

```
clc
clear
%Bus data:
%function busdata = busdata6()
% |Bus | Type | Vsp | theta | P | Q |
busdata = [ 1 1 1.06 0 0 0;
2 3 1 0 0.5 0.2;
3 3 1 0 0.4 0.3;
4 3 1 0 0.3 0.1;
];
bus= busdata(:,1); % Bus number.
type = busdata(:,2); % Type of Bus 1-Slack, 2-PV, 3-PQ.
V = busdata(:,3); % Initial Bus Voltages.
th= busdata(:,4); % Initial Bus Voltage Angles
GenMW = busdata(:,5); % PGi, Real power injected into the buses.
GenMVAR= busdata (:,6); % QGi, Reactive power injected into the buses.
nbus = max(bus); % To get no. of buses.
P= GenMW ; % Pi PGi - PLi, Real Power at the buses
Q = GenMVAR ;
%Line data:
%function linedata = linedata6()
% | From | To | R | X |
% | Bus | Bus | | | | |
linedata = [1 2 2 -8;
    1 3 1 -4;
    2 3 0.666 -2.664;
    2 4 1 -4;
    3 4 2 -8;];
fb = linedata(:,1);
tb = linedata(:,2);
g = linedata(:,3);
b = linedata(:,4);
y = g+sqrt(-1)*b;
nbus = max(max(fb),max(tb)); % no of bus
nbranch = length(fb); % no of branch
ybus = zeros(nbus,nbus); % initialise Ybus
```


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```
%formation of offdiagonal element
for k=1: nbranch
ybus(fb(k),tb(k))= ybus(fb(k),tb(k))-y(k);
ybus(tb(k),fb(k))=ybus(fb(k),tb(k));
end
for m=1: nbus
for n=1: nbranch
if fb(n)== m
ybus(m,m)=ybus(m,m)+y(n);
elseif tb(n)== m
ybus(m,m)=ybus(m,m)+y(n);
end
end
end
disp ybus;
ybus
Vprev=V;
for i=2:nbus
    sumyv=0;
    for k = 1:nbus
        if i~=k
            sumyv=sumyv+(ybus(i,k)*V(k));
        end
    end
    v(i) = (1/ybus(i,i))*((P(i)-(sqrt(-1)*Q(i)))/conj(V(i)) - sumyv);
        V(i) = Vprev(i)+(1.6*(v(i)-Vprev(i)));
end
Vmag=abs(V)
Ang=180/pi*angle(V)
V
```


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OUTPUT

```
ybus =

   3.0000 -12.0000i  -2.0000 + 8.0000i  -1.0000 + 4.0000i   0.0000 + 0.0000i
  -2.0000 + 8.0000i   3.6660 -14.6640i  -0.6660 + 2.6640i  -1.0000 + 4.0000i
  -1.0000 + 4.0000i  -0.6660 + 2.6640i   3.6660 -14.6640i  -2.0000 + 8.0000i
   0.0000 + 0.0000i  -1.0000 + 4.0000i  -2.0000 + 8.0000i   3.0000 -12.0000i


Vmag =

    1.0600
    1.0867
    1.0932
    1.1711


Ang =

         0
    2.4372
    2.4540
    5.3446


V =

   1.0600 + 0.0000i
   1.0857 + 0.0462i
   1.0922 + 0.0468i
   1.1660 + 0.1091i
```

RESULT

The given set of load flow equations for the given power system network were solved using Gauss-Seidal method.

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Experiment :05·
Date: 21/10/2021

Surabi Balakrishnan
S7 EE B , 39.

LOAD FLOW ANALYSIS USING NEWTON RAPHSON METHOD.

AIM;

To develop a computer program to solve the set of non linear load flow equations of IEEE- 14 bus system using Newton- Raphson load flow algorithm.

THEORY;

The Newton-Raphson method is a powerful method of solving non-linear algebraic equations. It work faster & is sure to converge in most cases as compared to the Gauss-Seidal method. It is indeed the practical method of load flow solution of large power networks. Its only drawback is the large requirement of computer memory. This method begins with initial guesses of all unknown variables (voltage magnitude & angles at load buses & voltage angles at generator buses). Next, a Taylor series is written, with the higher terms ignored, for each of the power balance equations included in the system of equations.

The non-linear equations governing the power system network are,

$$I_p = \sum_{p=q} Y_{pq} \cdot V_q \quad \text{for all } p.$$

where I_p is the current injected into bus p.

The complex power in p^{th} bus is given by, $S = V_p I_p^*$

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$$= V_p \left[\sum_{Q=1}^{n} Y_{pq} V_q\right]^* = V_p \left[\sum_{Q=1}^{n} Y_{pq}^* V_q^*\right] \quad ; \; p = 2 \ldots n.$$

Let $V_p = |V_p| e^{j\delta p}$

$V_q = |V_q| e^{j\delta q}$

$\delta_{pq} = \delta_p - \delta_q$ & $Y_{pq} = |Y_{pq}| e^{j\theta pq}$.

In polar coordinates, the power on p^{th} bus is given as,

$$S_p = P_p + jQ_p = \sum_{Q=1}^{n} |V_p||V_q| e^{j\delta pq} |Y_{pq}| e^{j\theta pq}.$$

Seperating the real & imaginary parts we get,

$$P_p = \sum_{Q=1}^{n} |V_p||V_q||Y_{pq}| \cos(\delta_p + \theta_{pq} - \delta_q)$$

$$Q_p = \sum_{Q=1}^{n} |V_p||V_q||Y_{pq}| \sin(\delta_p + \theta_{pq} - \delta_q)$$

The Newton Raphson method requires that a set of linear equations be formed expressing the relationship between the changes in real & reactive powers & the components of the bus voltages.

The result is a linear system of equation that can be expressed as,

$$\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$ where ΔP & ΔQ are called mismatch equations.

$$\Delta P_i = -P_i + \sum_{K=1}^{N} |V_i||V_K| (G_{iK} \cos\delta_{iK} + B_{iK} \sin\delta_{iK}).$$

$$\Delta Q_i = -Q_i + \sum_{K=1}^{N} |V_i||V_K| (G_{iK} \sin\delta_{iK} - B_{iK} \cos\delta_{iK}).$$

$$J = \begin{bmatrix} \dfrac{\partial \Delta P}{\partial \delta} & \dfrac{\partial \Delta P}{\partial |V|} \\[2ex] \dfrac{\partial \Delta Q}{\partial \delta} & \dfrac{\partial \Delta Q}{\partial |V|} \end{bmatrix}$$

And J is a matrix of partial derivatives known as Jacobian.

The linearised system of equations is solved to determine the next guess (m+1) of voltage magnitude & angles based on;

$$\delta^{m+1} = \delta^{m} + \Delta\delta$$

$$|V|^{m+1} = |V|^{m} + \Delta|V|$$

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equations is below a specified tolerance.

ALGORITHM

1. Read the line data & bus data. Assume flat voltage profile $1+j0$ for all buses except the slack bus.
2. Assume suitable value for convergence criterion
3. Set iteration count itr = 0 & assumed voltage profiles are defined as, $V_1^0, V_2^0 \ldots V_n^0$ except slack bus.
4. Set bus count $i = 1$.
5. Check for slack bus. if yes GOTO step 13 else goto step 6.
6. Calculate real & reactive power.

$$P_{cal\,i} = \text{Real}\left\{ V_i^{*} \sum_{k=1}^{n} Y_{ik} V_k \right\}.$$

$$Q_{cal\,i} = \text{img}\left\{ V_i^{*} \sum_{k=1}^{n} Y_{ik} V_k \right\}.$$

7. Calculate change in real power.

$$\Delta P_i = P_i^{spec} - P_{cal\,i}$$

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8. Check for generator bus. If yes,

If $Q_i^{iter+1} < Q_{min}$ then $Q_i = Q_{min}$.

If $Q_i^{iter+1} > Q_{max}$ then $Q_i = Q_{max}$

9. Change in reactive power $\Delta Q_i = Q_i^{spec} - Q_i$.

10. Check for convergence criterion.

$|\Delta P_i| \leq \varepsilon$ & $|\Delta Q_i| \leq \varepsilon$.

11. If ΔP_i & ΔQ_i are within the limit, then STOP else goto step 12.

Jacobian,
$$\begin{bmatrix} \frac{\partial \Delta P}{\partial \delta} & \frac{\partial \Delta P}{\partial V} \\ \frac{\partial \Delta Q}{\partial \delta} & \frac{\partial \Delta Q}{\partial V} \end{bmatrix}, \quad \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

13. Update voltage magnitude & phase angle.

$$V_i^{iter+1} = V_i^{iter} + \Delta V.$$

$$\delta_i^{iter+1} = \delta_i^{iter} + \Delta \delta$$

14. Increment by count by 1. GOTO step 6 & repeat all processes till convergence.

15. Stop.

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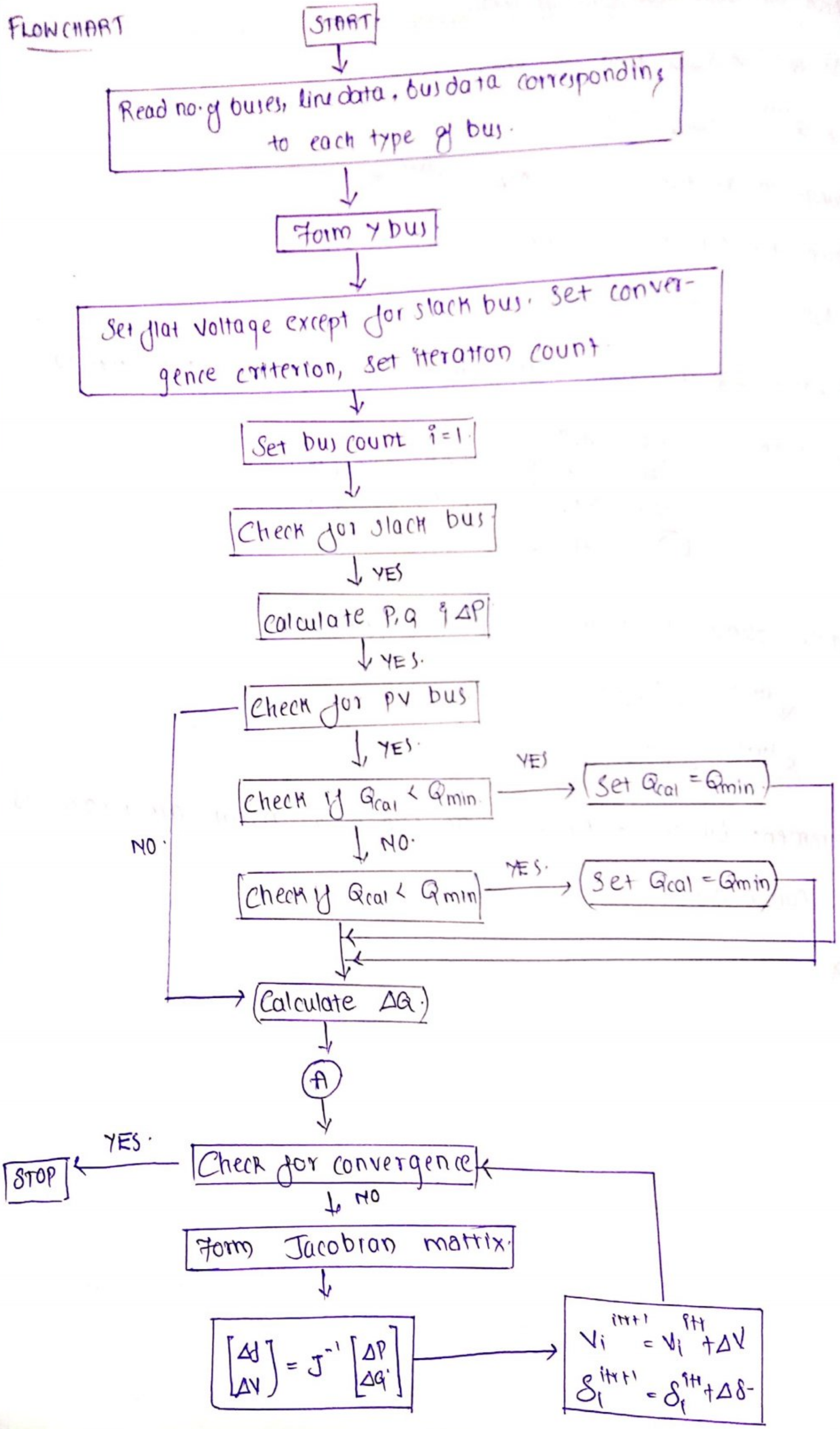
FLOWCHART



START
Read no. of buses, line data, bus data corresponding to each type of bus.
Form Y bus
Set flat voltage except for slack bus. Set convergence criterion, set iteration count
Set bus count i=1
Check for slack bus
YES
Calculate P, Q & ΔP
YES.
Check for PV bus
YES.
NO.
Check if Qcal < Qmin
YES
Set Qcal = Qmin
NO.
Check if Qcal < Qmin
YES.
Set Qcal = Qmin
Calculate ΔQ.
A
Check for convergence
YES.
STOP
NO
Form Jacobian matrix.
[Δδ ΔV] = J⁻¹ [ΔP ΔQ]
Vi^(iter+1) = Vi^iter + ΔV
δi^(iter+1) = δi^iter + Δδ

PROBLEM

Consider a 3-bus system. Each of the 3 lines has a series impedance of $0.02 + j0.08$ pu & a total shunt admittance of $j0.02$ pu. The specified quantities at the buses are tabulated below.

Bus	Real load demand, P_D.	Reactive load demand, Q_D.	Real power generation, P_G.	Reactive power generation Q_G	Voltage specification.
1	2.	1	Unspecified	Unspecified	$V_1 = 1.04 + j0$ (slack bus).
2	0	0	0.5	1.0	Unspecified (PQ bus)
3.	1.5.	0.6.	0.0	$Q_{G3} = ?$	$\lvert V_3 \rvert = 1.04$ (PV bus)

Controllable reactive power source is available at bus 3 with the constraint $0 \le Q_{G3} \le 1.5$ pu. Find the load flow solution using NR method. Use a tolerance of 0.01 for power mismatch.

Solution;

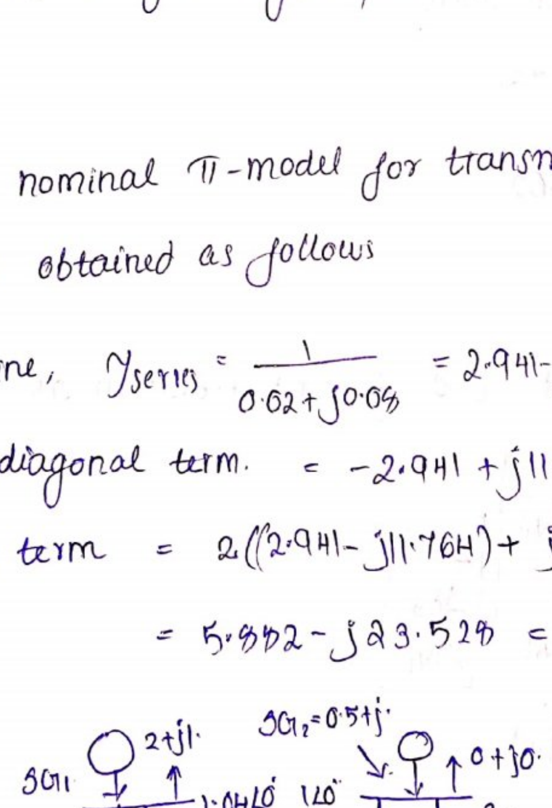
Using the nominal π-model for transmission lines, Y_{Bus} for the given system is obtained as follows

For each line, $Y_{series} = \dfrac{1}{0.02 + j0.08} = 2.941 - j11.764 = 12.13\angle -75.96^\circ$

Each off-diagonal term. $= -2.941 + j11.764$.

Each self term $= 2((2.941 - j11.764) + j0.01)$

$= 5.882 - j23.528 = 24.23\angle -75.95^\circ$.



$$Y_{BUS} = \begin{bmatrix} 24.23\angle -75.95^\circ & 12.13\angle 104.04^\circ & 12.13\angle 104.04^\circ \\ 12.13\angle 104.04^\circ & 24.23\angle -75.95^\circ & 12.13\angle 104.04^\circ \\ 12.13\angle 104.04^\circ & 12.13\angle 104.04^\circ & 24.23\angle -75.95^\circ \end{bmatrix}$$

To start iteration choose, $V_2^\circ = 1+j0$ & $\delta_3^\circ = 0$.

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21}+\delta_1-\delta_2) + |V_2|^2|Y_{22}|\cos\theta_{22} + |V_2||V_3||Y_{23}|\cos(\theta_{23}+\delta_3-\delta_2)$$

$$P_3 = |V_3||V_1||Y_{31}|\cos(\theta_{31}+\delta_1-\delta_3) + |V_3||V_2||Y_{32}|\cos(\theta_{32}+\delta_2-\delta_3) + |V_3|^2|Y_{33}|\cos\theta_{33}$$

$$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21}+\delta_1-\delta_2) - |V_2|^2|Y_{22}|\sin\theta_{22} - |V_2||V_3||Y_{23}|\sin(\theta_{23}+\delta_2-\delta_3)$$

Substituting given & assumed values of different quantities, we get values of powers as, $P_2^\circ = -0.23$ pu., $P_3^\circ = 0.12$ pu, $Q_2^\circ = -0.96$ pu.

Power residuals as per equation are,

$$\Delta P_2^\circ = P_2(\text{specified}) - P_2^\circ(\text{calculated})$$

$$= 0.5 - (-0.23) = 0.73$$

$$\Delta P_3^\circ = -1.5 - (0.12) = -1.62$$

$$\Delta Q_2^\circ = 1 - (-0.96) = 1.96$$

The changes in variables at the end of first iteration are obtained as,

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta Q_2 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_2|} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \Delta\delta_3 \\ \Delta|V_2| \end{bmatrix}$$

Jacobian elements can be evaluated by differentiating the expressions given above for P_2, P_3, Q_2 w.r.to δ_2, δ_3 & $|V_2|$ and substituting the given & assumed values at the start of iteration. The changes in variables are,

$$\begin{bmatrix} \Delta\delta_2^1 \\ \Delta\delta_3^1 \\ \Delta|V_2|^1 \end{bmatrix} = \begin{bmatrix} 24.47 & -12.23 & 5.64 \\ -12.23 & 24.95 & -3.05 \\ -6.11 & 3.05 & 22.54 \end{bmatrix}^{-1} \begin{bmatrix} 0.73 \\ -1.62 \\ 1.96 \end{bmatrix} = \begin{bmatrix} -0.023 \\ -0.0654 \\ 0.089 \end{bmatrix}$$

$$\begin{bmatrix} \delta_2^1 \\ \delta_3^1 \\ |V_2|^1 \end{bmatrix} = \begin{bmatrix} \delta_2^0 \\ \delta_3^0 \\ |V_2|^0 \end{bmatrix} + \begin{bmatrix} \Delta\delta_2^1 \\ \Delta\delta_3^1 \\ \Delta|V_2|^1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} -0.023 \\ -0.0654 \\ 0.089 \end{bmatrix} = \begin{bmatrix} -0.023 \\ -0.0654 \\ 1.089 \end{bmatrix}$$

We can now calculate, $Q_3^1 = 0.4677$.

$$Q_{G3}^1 = Q_3^1 + Q_{D3} = 0.4677 + 0.6 = 1.0677.$$

which is within limits.

If the same problem is solved using a digital computer, the solution converges in 3 iterations. The final results are;

$$V_2 = 1.081 \angle -0.024 \text{ rad}.$$

$$V_3 = 1.04 \angle -0.0655 \text{ rad}.$$

$$Q_{G3} = -0.15 + 0.6 = 0.45 \text{ (within limits)}.$$

$$S_1 = 1.031 + j(-0.791)$$

$$S_2 = 0.5 + j1.00$$

$$S_3 = -1.5 - j0.15$$

Transmission loss = 0.031 pu.

```
clc
clear
% Returns busdata.
% |no| type| V| del| Pg| QG| Pl| Ql |Qmax| Qmin|
busdata=[1 1 1.04 0 0 0 2 1 0 0;
2 3 1 0 0.5 1.0 0 0 0 0;
3 2 1.04 0 0 0 1.5 0.6 0 1.5;];
% |From| To |R |X|
linedata= [1 2 0.02 0.08;
1 3 0.02 0.08;
2 3 0.02 0.08;];
Shuntdata= sqrt(-1)*[0.02 0.02 0.02]' ;
fb = linedata(:,1);
tb = linedata(:,2);
R = linedata(:,3);
X = linedata(:,4);
z = R+sqrt(-1)*X;
y = 1./z;
nbus = max(max(fb),max(tb)); % no of bus
nbranch = length(fb); % no of branch
ybus = zeros(nbus,nbus); % initialise Ybus
%formation of offdiagonal element
for k=1: nbranch
ybus(fb(k),tb(k))= ybus(fb(k),tb(k))-y(k);
ybus(tb(k),fb(k))=ybus(fb(k),tb(k));
end
%formation of diagonal element
for m=1 : nbus
for n = 1:nbranch
if fb(n)== m
ybus(m,m)= ybus(m,m)+y(n);
elseif tb(n)== m
ybus(m,m)= ybus(m,m)+y(n);
end
end
end
%entry of shuntdata in IEEE 14 Bus system
for i = 1:nbus

ybus(i,i)= ybus(i,i)+ Shuntdata(i);
end
ybus
```

```
ybus = 3×3 complex

   5.8824 -23.5094i  -2.9412 +11.7647i  -2.9412 +11.7647i
  -2.9412 +11.7647i   5.8824 -23.5094i  -2.9412 +11.7647i
  -2.9412 +11.7647i  -2.9412 +11.7647i   5.8824 -23.5094i
```

```
%ymag=abs(ybus)
%yang=angle(ybus)*180/pi
bus = busdata(:,1);
type = busdata(:,2);
V = busdata(:,3);
del = busdata(:,4);
Pg = busdata(:,5);
```

```
Qg = busdata(:,6);
Pl = busdata(:,7);
Ql = busdata(:,8);
Qmin = busdata(:,9);
Qmax = busdata(:,10);
P = Pg - Pl;
Q = Qg - Ql;
Psp = P;
Qsp = Q;
G = real(ybus);
B = imag(ybus);
Pp(nbus,1)=0;Qq(nbus,1)=0;
for i=2:nbus
for j=1:nbus
Pp(i)=Pp(i)+V(i)*abs(ybus(i,j))*V(j)*cos(angle(ybus(i,j))-del(i)+del(j));
Qq(i)=Qq(i)-V(i)*abs(ybus(i,j))*V(j)*sin(angle(ybus(i,j))-del(i)+del(j));
end
end
for i=2:nbus
for j=2:nbus
if i~=j
j1(i,j)=V(i)*V(j)*(G(i,j)*sin(del(i)-del(j))-B(i,j)*cos(del(i)-del(j)));
j3(i,j)=-V(i)*V(j)*(G(i,j)*cos(del(i)-del(j))+B(i,j)*sin(del(i)-del(j)));
j2(i,j)=-j3(i,j);
j4(i,j)=j1(i,j);
else
j1(i,j)=-Qq(i)-B(i,j)*(V(i)^2);
j2(i,j)=Pp(i)+G(i,j)*(V(i)^2);
j3(i,j)=Pp(i)-G(i,j)*(V(i)^2);

j4(i,j)=Qq(i)-B(i,j)*(V(i)^2);
end
end
end
ja1(1:nbus-1,1:nbus-1)=j1(2:nbus,2:nbus);
ja2(1:nbus-1,1:nbus-1)=j2(2:nbus,2:nbus);
ja3(1:nbus-1,1:nbus-1)=j3(2:nbus,2:nbus);
ja4(1:nbus-1,1:nbus-1)=j4(2:nbus,2:nbus);
jacob=[ja1 ja2;ja3 ja4];
j=jacob(1:nbus,1:nbus)
```

```
j = 3×3

   24.4706  -12.2353    5.6471
  -12.2353   24.9600   -3.0588
   -6.1176    3.0588   22.5482
```

```
%Psp=transpose(Psp);
delp(1:nbus-1)=Psp(2:nbus)-Pp(2:nbus);
delq(1:nbus-2)=Qsp(2)-Qq(2);
Char=inv(j)*[delp delq]';
Chth(2:nbus,1)=Char(1:nbus-1);
V(2)=V(2)+Char(nbus);
del=del+Chth;
fprintf('Voltage Magnitude');
```

```
Voltage Magnitude
```

```
V
```

```
V = 3×1

    1.0400
    1.0895
    1.0400
```

```
fprintf('Volatge angle');
```

```
Volatge angle
```

```
del
```

```
del = 3×1

         0
   -0.0233
   -0.0655
```

```
for j=1:nbus
Pp(1)=Pp(1)+V(1)*abs(ybus(1,j))*V(j)*cos(angle(ybus(1,j))-del(1)+del(j));
Qq(1)=Qq(1)+V(1)*abs(ybus(1,j))*V(j)*sin(angle(ybus(1,j))-del(1)+del(j));
Qq(3)=Qq(3)-V(3)*abs(ybus(3,j))*V(j)*sin(angle(ybus(3,j))-del(3)+del(j));
end
Psp(1)=Pp(1);
Qsp(1)=-Qq(1);
Qsp(3)=-Qq(3);
S=Psp+(sqrt(-1)*(Qsp))
```

```
S = 3×1 complex

   1.0000 - 0.8826i
   0.5000 + 1.0000i
  -1.5000 - 0.2278i
```

```
Vs=V(fb);
Vr=V(tb);
dels=del(fb);
delr=del(tb);
G=real(ybus);
for i=1:nbranch
Pl(i)=G(i)*((Vs(i)^2)+(Vr(i)^2)-2*Vs(i)*Vr(i)*cos(dels(i)-delr(i)));

Ql(i)=G(i)*((Vs(i)^2)+(Vr(i)^2)-2*Vs(i)*Vr(i)*sin(dels(i)-delr(i)));
end
Pl
```

```
Pl = 3×1

    0.0181
   -0.0136
   -0.0131
```

```
Ql
```

```
Ql = 3×1

   13.0339
   -5.9461
   -6.3918
```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Experiment no. 6.

Date : 13/10/2021.

Surabi Balakrishnan.
S7 EE B, 39.

LOAD FLOW ANALYSIS USING FAST DECOUPLED METHOD.

AIM:

To develop a computer program to solve the set of nonlinear load flow equations using fast decoupled load flow algorithm.

THEORY

An important & useful property of power system is that the change in real power is primarily governed by the changes in the voltage angles, but not in voltage magnitude. On the other hand, the changes in reactive power are primarily governed by changes in voltage magnitudes, but not in voltage angles.

Under normal steady state conditions,

a) The voltage magnitude are all nearly equal to 1.

b) As the transmission lines are mostly reactive, the conductances are quite small as compared to the susceptance. ($G_{ij} << B_{ij}$)

c) The angular difference among the bus voltages are small.

d) The injected reactive power at any bus is always much less than the reactive power consumed by the elements connected to this bus when there elements are shorted to the ground.

($Q_{ij} << B_{ij} V_i^2$)

Hence the entries of the [H] & [L] submatrices of Jacobian matrix will become,

$$H_{ij} = L_{ij} = -|V_i||V_j|B_{ij} \quad ; i \neq j.$$

$$H_{ij} = L_{ij} = -B_{ij}|V_i|^2 \quad ; i = j.$$

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And submatrices $[N]$ & $[J] = 0$.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & 0 \\ 0 & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad \text{or.}$$

$$[\Delta P] = [|V_i|][|V_j|][B'_{ij}][\Delta \delta].$$

$$[\Delta Q] = [|V_i||V_j| B''_{ij}]\left[\frac{\Delta |V|}{|V|}\right]$$

B' & B" are the negative of imaginary part of the YBUS.

Further simplification done by,

i) Omitting from $[B']$ the representation of those network elements that predominantly affect reactive power flows, ie; shunt reactance & transformer off-nominal in-phase taps;

ii) Neglecting from $[B'']$ the angle shifting effects of phase shifters;

iii) Dividing each of the equations of P & Q by $|V_i|$ & setting $|V_j| = 1$ pu in the equations.

iv) Ignoring series resistance in calculating the elements of $[B']$ which then becomes the dc approximation power flow matrix.

$$[\Delta P / V_i] = [B'][\Delta \delta]$$
$$[\Delta Q / V_i] = [B'][\Delta |V|].$$

Both $[B']$ & $[B'']$ are real, sparse & have the structures of $[H]$ & $[L]$, respectively. Since they contain only admittances, they are constant and need to be inverted only once at the beginning thus algorithm becomes faster.

ALGORITHM

1) Read line data and bus data.

2) For buses 1 to n, calculate

$P_{sch} = P_{gen} - P_{load}$

$Q_{sch} = Q_{gen} - Q_{load}$

3) Form Ybus.

4) Form constant slope matrix B' & B''

5) Check for slack bus. If No, GOTO step 6.

6) Check for generator bus. If yes

If $Q_i^{iter+1} < Q_{min}$, then $Q_i = Q_{min}$.

If $Q_i^{iter+1} > Q_{max}$, then $Q_i = Q_{max}$.

7) Calculate ΔP & ΔQ.

$\Delta P_i = P_i^{spec} - P_i^{cal}$

$\Delta Q_i = Q_i^{spec} - Q_i^{cal}$

8) Check for convergence of ΔP & ΔQ. If not converged, GOTO step 9.

9) $\frac{\Delta P}{|V_i|} = B' \Delta \delta$, $\frac{\Delta Q}{|V_i|} = B'' \Delta V$.

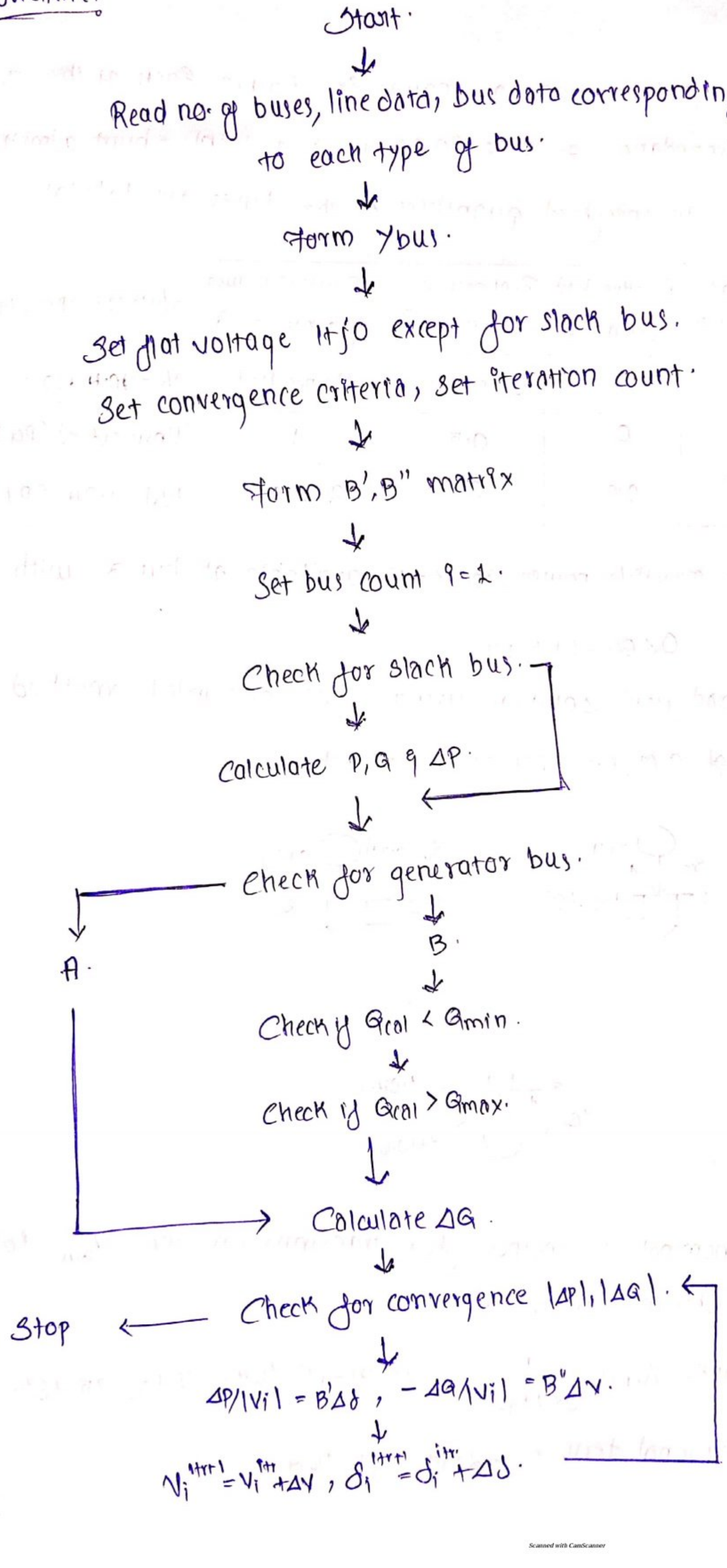
10) Update voltage magnitude & phase angles.

$V_i^{iter+1} = V_{i\,iter+1} + \Delta V$.

$\delta_i^{iter+1} = \delta^{iter+1} + \Delta \delta$.

11) Increment bus count by 1, GOTO step 6 & repeat all process till convergence.

FLOWCHART



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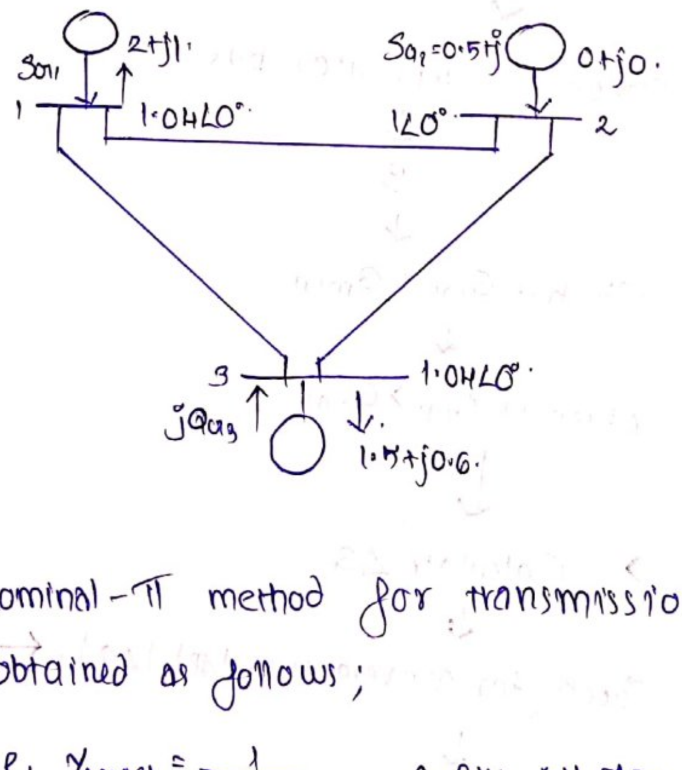
Problem;

Q: Consider the 3 bus system as shown in figure. Each of the 3 lines has a series impedance of $0.02+j0.08$ pu & a total shunt admittance of $j0.02$pu. The specified quantities at the buses are tabulated below.

Bus	Real load Demand, P_D	Reactive load demand, Q_D	Real power generation, P_G.	Reactive power generation, Q_G.	Voltage specification.
1	2	1	Unspecified.	Unspecified.	$V_1 = 1.04 + j0$ (Slack bus)
2	0	0	0.5	1.	Unspecified (PQ bus)
3.	1.5.	0.6.	0.	$Q_{G3} = ?$	$\lvert V_3 \rvert = 1.04$ (PV bus)

Controllable reactive power source is available at bus 3 with the constraint, $0 \leq Q_{G3} \leq 1.5$ pu.

Find the load flow solution using fast decoupled method. Use a tolerance of 0.01 for power mismatch.



Answer;

Using the nominal-π method for transmission lines, Y_{BUS} for given system is obtained as follows;

For each line, $Y_{series} = \frac{1}{0.02+j0.08} = 2.941 - j11.764 = 12.13\angle -75.96°$

Each off diagonal term $= -2.941 + j11.764$.

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Each self term $= 2((2.941) - j11.764) + j0.01)$

$= 5.882 - j23.528$

$= 24.23 \angle -75.95°$.

$$Y_{BUS} = \begin{bmatrix} 24.23\angle -75.95° & 12.13\angle 104.04° & 12.13\angle 104.04° \\ 12.13\angle 104.04° & 24.23\angle -75.95° & 12.13\angle 104.04° \\ 12.13\angle 104.04° & 12.13\angle 104.04° & 24.23\angle -75.95° \end{bmatrix}$$

To start iteration, choose $V_2^0 = 1+j0$ & $\delta_3^0 = 0$.

$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21}+\delta_1-\delta_2) + |V_2|^2|Y_{22}|\cos\theta_{22} + |V_2||V_3||Y_{23}|\cos(\theta_{23}+\delta_3-\delta_2)$

$P_3 = |V_3||V_1||Y_{31}|\cos(\theta_{31}+\delta_1-\delta_3) + |V_3||V_2||Y_{32}|\cos(\theta_{32}+\delta_2-\delta_3) + |V_3|^2|Y_{33}|\cos\theta_{33}$

$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21}+\delta_1-\delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22} - |V_2||V_3|$

Substituting given & assumed values of different quantities, we get the values as,

$P_2^0 = -0.23$ pu.

$P_3^0 = 0.12$ pu.

$Q_2^0 = -0.96$ pu.

Power residuals are; $\Delta P_2^0 = P_2$ (specified) $- P_2^0$ (calculated)

$= 0.5 - (-0.23) = 0.73$.

$\Delta P_3^0 = -1.5 - (0.12) = -1.62$.

$\Delta Q_2^0 = 1 - (-0.96) = 1.96$.

The matrix equations for the solution of load flow by FDLF method are,

$$\begin{bmatrix} \dfrac{\Delta P_2^0}{|V_2^0|} \\ \dfrac{\Delta P_3^0}{|V_3^0|} \end{bmatrix} = \begin{bmatrix} -B_{22} & -B_{23} \\ -B_{32} & -B_{33} \end{bmatrix} \begin{bmatrix} \Delta\delta_2^1 \\ \Delta\delta_3^1 \end{bmatrix}$$

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and

$$\left[\frac{\Delta Q_i^0}{|V_i^0|}\right] = \left[-B_{22}\right]\left[\Delta |V^1|\right]$$

$$\begin{bmatrix} \frac{0.739}{1} \\ \frac{-1.62}{1.04} \end{bmatrix} = \begin{bmatrix} 23.505 & -11.767 \\ -11.767 & 23.505 \end{bmatrix} \begin{bmatrix} \Delta\delta_2^0 \\ \Delta\delta_3^0 \end{bmatrix}.$$

$$\begin{bmatrix} 0.739 \\ -1.557 \end{bmatrix} = \begin{bmatrix} 23.507 & -11.767 \\ -11.767 & 23.505 \end{bmatrix} \begin{bmatrix} \Delta\delta_2' \\ \Delta\delta_3' \end{bmatrix}$$

$$\begin{bmatrix} \Delta\delta_2' \\ \Delta\delta_3' \end{bmatrix} = \begin{bmatrix} 23.505 & -11.765 \\ -11.767 & 23.505 \end{bmatrix}^{-1} \begin{bmatrix} 0.739 \\ -1.558 \end{bmatrix}$$

$$\begin{bmatrix} \Delta\delta_2' \\ \Delta\delta_3' \end{bmatrix} = \begin{bmatrix} -0.0023 \\ -0.0674 \end{bmatrix}$$

$$[2.125] = [23.507][\Delta |V_2'|]$$

$$\Delta |V_2'| = 0.09.$$

$$|V_2'| = 1.09\,pu. \quad ; \; (V_2^0 + \Delta V_2^0) ; \; V_2^0 = 1\,pu.$$

$$\delta_2' = \delta_2^0 + \Delta\delta_2^0 = 0 + -0.0023 = -0.0023 \text{ rad}.$$

$$\delta_3' = \delta_3^0 + \Delta\delta_3^0 = 0 + -0.0674 = -0.0674 \text{ rad}.$$

$$Q_3 = -|V_3||V_1||Y_{31}|\sin(\theta_{31}+\delta_1-\delta_3) + |V_3||V_2||Y_{32}|\sin(\theta_{32}+\delta_3-\delta_2) + |V_3|^2|Y_{33}|\sin\theta_{33}.$$

$$= \underline{-0.177}$$

Bus Voltages;

$$V_1 = 1.04\angle 0^\circ$$

$$V_2 = 1.0337\angle -0.0023.$$

$$V_3 = 1.04\angle -0.0674.$$

$$S_1 = 1 - 0.3199j.$$

$$S_2 = 0.5 + 1j.$$

$$S_3 = -1.5 - j0.177$$

```
clc
clear
%Bus data:
% no type Vol del Pg QG Pl Ql Qmax Qmin
busdata=[ 1 1 1.040 0 0 0 2 1 0 0;
2 3 1 0 0.5 1 0 0 0 0;
3 2 1.04 0 0 0 1.5 0.6 0 1.5];
%Line data:
%function linedata = linedata6()
% From To R X B/2 T
linedata= [ 1 2 0.02 0.08 0.02 1;
1 3 0.02 0.08 0.020 1;
2 3 0.02 0.08 0.020 1];
%Shunt data:
%function Shuntdata = Shuntdata6()
Shuntdata= sqrt(-1)*[0 0 0]' ;
%function ybus = ybusppg();
fb = linedata(:,1);
tb = linedata(:,2);
R = linedata(:,3);
X = linedata(:,4);
B = linedata(:,5);
T = linedata(:,6);
nbus = max(tb);
z = R+sqrt(-1)*X;
y = 1./z;
b= sqrt(-1)*B;
nbus = max(max(fb),max(tb)); % no of bus
nbranch = length(fb); % no of branch
ybus = zeros(nbus,nbus); % initialise Ybus
%formation of offdiagonal element
for k=1: nbranch
ybus(fb(k),tb(k))= ybus(fb(k),tb(k))-y(k)/T(k);
ybus(tb(k),fb(k))=ybus(fb(k),tb(k));
end
%formation of diagonal element
for m=1 : nbus
for n = 1:nbranch
if fb(n)== m
ybus(m,m)= ybus(m,m)+(y(n)/(T(k)^2))+b(n);
elseif tb(n)== m
ybus(m,m)= ybus(m,m)+y(n)+b(n);
end
end
end
%entry of shuntdata in IEEE 14 Bus system
for i = 1:nbus
ybus(i,i)= ybus(i,i)+ Shuntdata(i);
end
ybus
```

```
ybus = 3×3 complex

   5.8824 -23.4894i  -2.9412 +11.7647i  -2.9412 +11.7647i
  -2.9412 +11.7647i   5.8824 -23.4894i  -2.9412 +11.7647i
  -2.9412 +11.7647i  -2.9412 +11.7647i   5.8824 -23.4894i
```


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```
bus = busdata(:,1);
type = busdata(:,2);
V = busdata(:,3);
del = busdata(:,4);
Pg = busdata(:,5);
Qg = busdata(:,6);
Pl = busdata(:,7);
Ql = busdata(:,8);
Qmin = busdata(:,9);
Qmax = busdata(:,10);
nbus = max(bus);
fb=linedata(:,1);
tb=linedata(:,2);
Psp = Pg - Pl;
Qsp = Qg - Ql;
G = real(ybus);
B = imag(ybus);
pv = find(type == 2 | type == 1);
pq = find(type == 3);
npv = length(pv);
npq = length(pq);
B1=imag(ybus);
B1(1,:)=[];
B1(:,1)=[];
B2=imag(ybus);
B2(:,pv(1:npv))=[];
B2(pv(1:npv),:)=[];
Tol=1;
Iter=1;
while Tol>0.01
Iter
P=zeros(nbus,1);
Q=zeros(nbus,1);
for m=1:nbus
for n=1:nbus
P(m)=P(m)+V(m)*V(n)*(G(m,n)*cos(del(m)-del(n))+B(m,n)*sin(del(m)-del(n)));
Q(m)=Q(m)+V(m)*V(n)*(G(m,n)*sin(del(m)-del(n))-B(m,n)*cos(del(m)-del(n)));
end
end
delp=Psp-P;
delq=Qsp-Q;
dmp=delp;
dmq=delq;
dmp(1,:)=[];
dmq(pv(1:npv),:)=[];
dP=delp./V;
dQ=delq./V;
dP(1,:)=[];
dQ(pv(1:npv),:)=[];
x=-B1\dP;
x
delv=-B2\dQ;
delv
del(2:nbus)=del(2:nbus)+x;
k=1;
for i=1:nbus
if type(i)==3
```

```
V(i)=V(i)+delv(k);
k=k+1;
end
end
V
M=[dmp;dmq];
Iter=Iter+1;
Tol=max(abs(M));
end
```

```
Iter = 1
x = 2×1

   -0.0026
   -0.0677

delv = 0.0843
V = 3×1

    1.0400
    1.0843
    1.0400

Iter = 2
x = 2×1

   -0.0229
    0.0027

delv = 0.0037
V = 3×1

    1.0400
    1.0881
    1.0400

Iter = 3
x = 2×1

10^-3 ×
   -0.0810
   -0.4143

delv = -0.0059
V = 3×1

    1.0400
    1.0821
    1.0400

Iter = 4
x = 2×1

    0.0016
   -0.0001

delv = 2.3901e-04
V = 3×1

    1.0400
    1.0824
    1.0400

Iter = 5
x = 2×1

10^-3 ×
   -0.1155
    0.0346

delv = 3.8936e-04
V = 3×1

    1.0400
    1.0828
    1.0400
```


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```
disp('--------------------------------------- ');
```

```
---------------------------------------
```

```
disp(' Fast Coupled Loadflow Solution ');
```

```
Fast Coupled Loadflow Solution
```

```
disp('---------------------------------------');
```

```
---------------------------------------
```

```
disp(' |Bus | |Voltage| |Angle | |Real| | Reactive| ');
```

```
|Bus | |Voltage| |Angle | |Real| | Reactive|
```

```
disp(' | No.| |pu | |Radian| |Power| |Power | ');
```

```
| No.| |pu | |Radian| |Power| |Power |
```

```
disp('---------------------------------------');
```

```
---------------------------------------
```

```
for m=1:nbus
fprintf(' %3g ' ,m);
fprintf(' %8.3f ' ,V(m));
fprintf(' %8.3f ' ,del(m));
fprintf(' %8.3f ',P(m));
fprintf(' %8.3f ',Q(m));
fprintf('\n');
end
```

```
  1
   1.040
   0.000
   1.031
  -0.819
  2
   1.083
  -0.024
   0.503
   0.990
  3
   1.040
  -0.066
  -1.502
  -0.177
```

RESULT:

The given set of load flow equations for the given power system network were solved using Fast decoupled method.

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Experiment no: 7.

Date: 25/10/2021.

Surabi Balakrishnan.

Roll no: 39

DIELECTRIC STRENGTH OF TRANSFORMER OIL.

AIM

Determine dielectric strength of tranformer oil.

APPARATUS REQUIRED

1. Tranformer oil test kit.
2. Transformer oil.

THEORY

Transformer oil is mainly used to provide electrical insulation for transformer's core & windings. Also, it acts as a barrier between atmospheric oxygen paper insulation, hence minimize oxidation. Transformer oil have excellent electrical insulating properties & is stable at high temperatures. Transformer core will be heated up during loaded condition, this heat dissipate to the oil & hence act as a coolant.

There are 2 main types of transformer oil used in transformers;

1. Paraffin based transformer oil.
2. Naphtha based transformer oil.

Naphtha oil is more easily oxidised than paraffin oil. But the product of oxidation, i.e, sludge in the naphtha oil is more soluble than the sludge from the paraffin oil.

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Dielectric Strength of transformer Oil

The dielectric strength is an electrical property of transformer oil (breakdown voltage BDV), is measured using transformer oil test unit.

The oil is poured in a container known as test cell. The electrodes are polished spheres or semispheres of 12.7 to 13 mm diameter, preferably of brass. Electrodes are fixed with a gap of 2.5mm (in some kit it is 4mm) between them. A suitable gauge is used to adjust the gap. While preparing the oil sample, the test cell should be thoroughly cleaned & the moisture & suspended particles should be avoided. Figure 1 shows an experimental setup for finding out the dielectric strength of the given sample of oil.

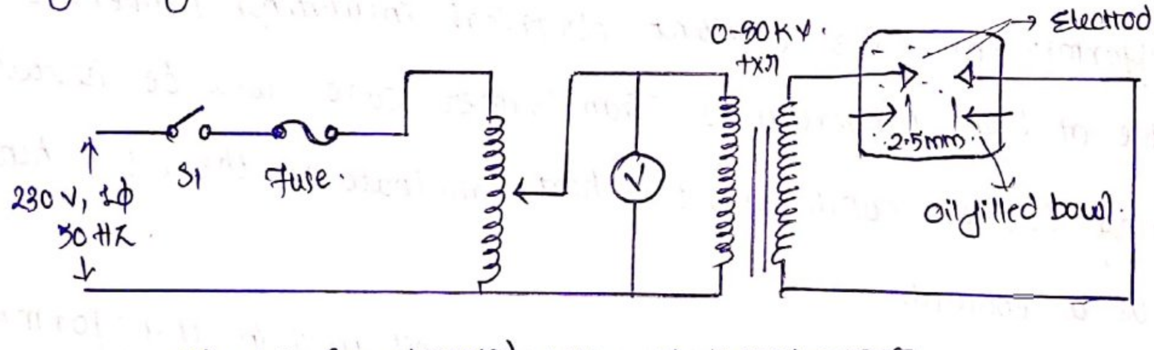

Fig 1; Experimental setup of transformer oil test unit.

The voltmeter is connected on to the primary side of the high voltage transformer but calibrated on the high voltage side. The gap between the spheres is adjusted to 2.5mm with the help of a guage & the spheres are immersed in oil. The voltage is increased gradually & continuosly till a flash over of the gap is seen or the MCB operates. Note down this voltage. Next, bring the voltage

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back to zero. this measurement is taken 3 to 6 times in the same sample of oil, and take the average value of these readings. Dry & clean oil gives BDV results, better than the oil with moisture content & other conducting impurities. Minimum break down voltage of transformer oil or dielectric strength of transformer oil at which this oil can safely be used in the transformer is considered as 30KV

PRECAUTIONS

1) Transformer oil should be free from moisture content.
2) Nobody should go near the HT bushing when test is being done.
3) The equipment must be grounded firmly.
4) The electrodes must be cleaned properly before & after the use.
5) Do not touch the equipment without grounding it with the grounding rod.
6) Before starting the experiment, make sure the electrodes are properly aligned and zero reading is adjusted.

PROCEDURE

1) Study the enclose instructions of transformer oil testing.
2) Pour the testing oil to the container till the electrodes are immersed.
3) Place the container between the transformer terminals & close the safety door. (transparent door.)
4) Switch on the test kit.
5) Keep the toggle switch in raise position.

6) Press the On-push button (Red). Autotransformer nob start rotation in constant speed.

7.) Observe the spark formed between the electrode. The breaker trips when spark occurs.

8) Note down the reading shown on the voltmeter.

9) Keep the toggle switch in lower position.

10) Press the On-push button (Red). Autotransformer knob will start rotating in the opposite direction. Once the voltmeter displays zero, reading, press HT OFF button. (Green).

11) Repeat step 5 to 10 five times & get a total of 6 observations.

12) Switch off the test kit.

OBSERVATION:

Sl.no	Breakdown voltage (KV)	Average value (KV)
1	33.9	25.53
2	23.6.	
3	24.8	
4	24.1	
5	23.8	
6	23.0.	

RESULT:

The breakdown voltage of given transformer oil sample = 25.53 KV

INFERENCE:

The breakdown voltage of the tested oil is below 30 KV, indicates that the oil contains moisture & impurities. Hence it needs to be purified before the transformer put in service.

Experiment no: 8

Date: 01/11/2021.

Surabi Balakrishnan.

Roll no: 39.

Y-BUS FORMATION USING MIPOWER SOFTWARE

AIM- To formulate a Y-bus using Mipower software.

THEORY-

Assume that the bus impedance matrix Z_{BUS} is known for a partial network of m buses & a reference node 0. The performance equation of this network,

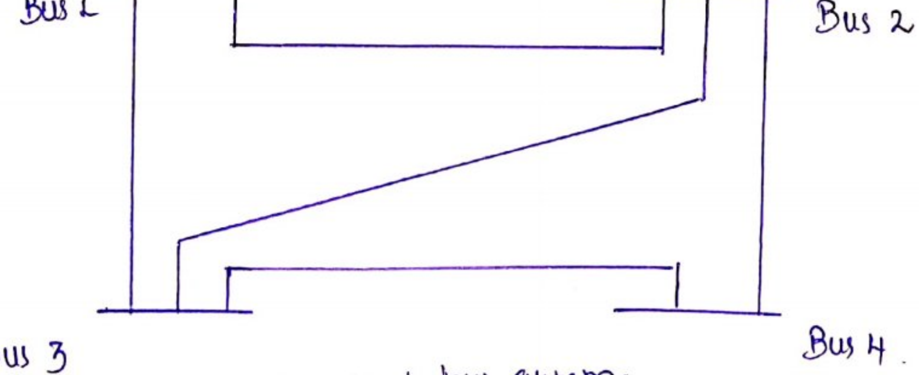
$E_{BUS} = Z_{BUS} \times I_{BUS}$.

where E_{BUS} = m×1 vector of bus voltages measured with respect to the reference node.

I_{BUS} = m×1. vector of impressed bus currents.

EXERCISE-

Figure shows the one line diagram of a simple 4-bus system. Table gives the line impedances identified by the buses on which they terminate. The shunt admittance at all the buses is assumed negligible. Form Y_{BUS}.



Sample 4 bus system.

System parameters

Line, Bus to Bus	R pu.	X pu.
1-2.	0.05.	0.15.
1-3	0.1	0.3
2-3	0.15.	0.45.
2-4	0.1.	0.3
3-4.	0.05	0.15

Procedure to solve the exercise in MiPower;

1) To solve Y-bus using MiPower package, invoke "MiPower Extras" in the MiPower main screen & select "Y-Bus Z-bus formation".

2) Enter the bus & line details.

3) Save the file & click Execute to run the program.

4) Program executes, Open output file to view the report.

Start Date and Time : Tuesday, November 02, 2021 02:15:55 AM

Product Version : 9.2 File Version : 2.0

YBUS ZBUS FORMATION

INPUT DATA

Number of Buses : 4
Number of Transformers : 0
Number of Transmission Lines : 5
Number of Shunt Impedance Elements : 0
Number of Shunt Admittance Elements : 0

Study Option : Y Bus Generation

Transmission Line Data

Status	FromBus	ToBus	Resistance(p.u.)	Reactance(p.u.)	B / 2(p.u.)
In Service	1	2	0.05000	0.15000	1.00000
In Service	1	3	0.10000	0.30000	1.00000
In Service	2	3	0.15000	0.45000	1.00000
In Service	2	4	0.10000	0.30000	1.00000
In Service	3	4	0.05000	0.15000	1.00000

OUTPUT DATA

Y Bus Matrix

+3.00000-7.00000j	-2.00000+6.00000j	-1.00000+3.00000j	+0.00000+0.00000j
-2.00000+6.00000j	+3.66667-8.00000j	-0.66667+2.00000j	-1.00000+3.00000j
-1.00000+3.00000j	-0.66667+2.00000j	+3.66667-8.00000j	-2.00000+6.00000j
+0.00000+0.00000j	-1.00000+3.00000j	-2.00000+6.00000j	+3.00000-7.00000j

End Date and Time : Tuesday, November 02, 2021 02:15:55 AM

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Experiment no.9

Date : 01/11/2021.

Surabi Balakrishnan.

Roll no : 39.

LOAD FLOW ANALYSIS - GAUSS SEIDAL METHOD

OBJECTIVE

To conduct the load flow analysis of power system networks using Gauss seidal method in MiPower software.

To verify the result with manual calculation for atleast 1 iteration.

THEORY

Load flow analysis is one of the most common computational procedures used in power system analysis. The load flow problem can be defined as: Given the load power consumption at all buses of a known electric power system configuration & the power generation at each generator, find the power flow in each line & transformer of the interconnecting network & the voltage magnitude & phase angle at each bus.

EXERCISE

Figure shows the one-line diagram of a sample 4 bus system. Table 1 gives the line impedances identified by the buses on which these terminate. The shunt admittance at all buses is assumed negligible. The generators are connected at all the 4 buses, while loads are at buses 2 & 3. Values of real & reactive power are listed in table 2. All buses other than the slack are PQ type. Assuming a flat voltage start, find the voltages & bus angles at the 3 buses at the end of the first GS iteration.

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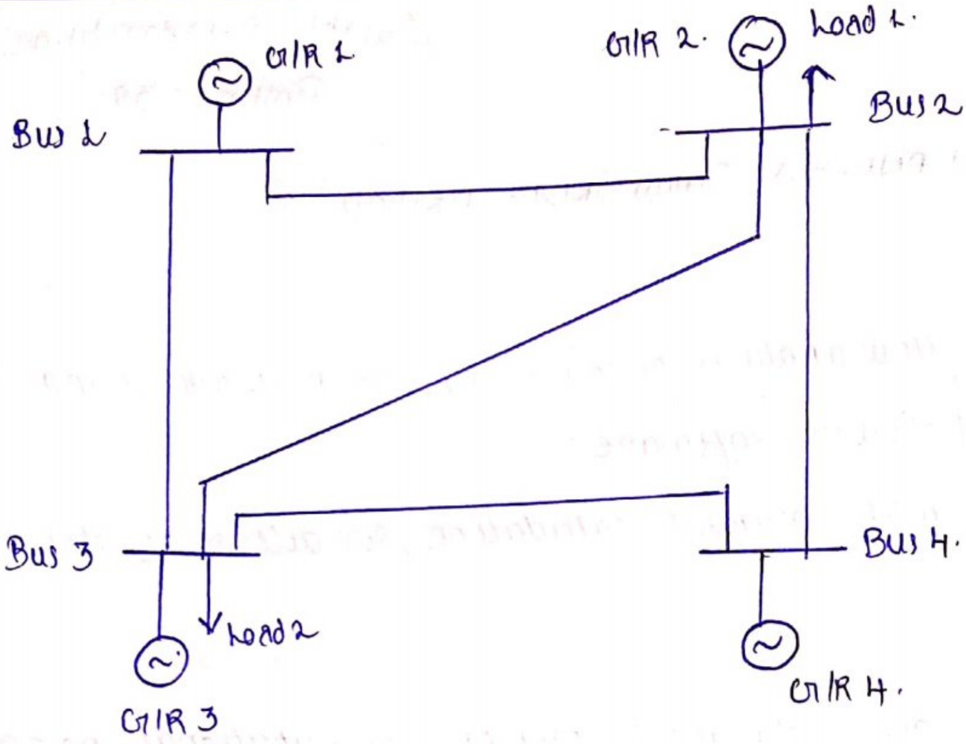

Sample system for analysis.

Table 1; Line details.

Line bus to bus	R pu.	X pu.
1-2.	0.05	0.15.
1-3.	0.10	0.30
2-3	0.15.	0.45.
2-4	0.10.	0.30.
3-4.	0.05.	0.15.

Table 2; Generation & load details.

Bus	Pi, pu.	Qi, pu.	Vi, pu.	Remarks.
1.	-	-	1.04∠0°.	Slack bus
2	0.5	-0.2.	-	PQ bus.
3	-1	0.5.	-	PQ bus
4.	0.3	-0.1	-	PQ bus.

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PROCEDURE

- Procedure to solve the exercise in MiPower.

Open power system network editor.

select menu option Database → Configure.

Click Browse button & browse the desired directory & specify the name of the database to be associated with single line diagram.

Click open button after entering the desired database name.

Configure Database dialog will appear with path chosen.

Click OK button on the configure database dialog & make necessary modifications.

- Voltage configuration for the bus.

To configure the base voltages for the single line diagram.

Select menu option Configure → Base Voltage.

- Procedure to draw the single line diagram.

① How to draw bus?

Click on Bus icon provided on power system tool bar.

Draw a bus & a dialog box appears prompting to give the Bus ID & Bus name. Click OK.

Database manager with corresponding Bus data form will appear.

After entering the data, click save. Follow same procedure for other buses.

Bus number	Bus name.	Nominal voltage (KV)
1	Slack	11
2	PQ1	11
3	PQ2	11
4.	PQ3	11

② How to draw transmission line?

Click on transmission line icon provided on power system toolbar.

To draw the line, click in b/w 2 buses & to connect to the from bus. double click LMB (Left mouse button) on the from bus & join it to another bus by double clicking the mouse button on the To Bus.

Element ID dialog will appear.

Enter the element ID number & click OK. Database manager will open.

Enter the details of that line.

Click on transmission line library >> button.

Line & cable library form will appear. Enter transmission line library data in the form. After entering data, Save & close.

Transmission line element data;

From bus No.	To Bus No.	De-rated MVA.	Structure Ref no.
1	2	100	30
1	3	100	31
2	3	100	32
2	4	100	31
3.	4.	100.	30.

Transmission line library data.

Structure ref no	Impedance R+j X.	Line charging B/2.	Thermal rating (MVA)
30	0.05 + j0.15.	0	100
31	0.10 + j0.30	0	100
32	0.15 + j0.45.	0	100.

③ How to draw generators ?

Click on generator icon provided on power system tool bar.

Connect it to bus 1 by clicking the LMB on bus 1.

The element ID dialog will appear. Enter ID number & click OK.

Database with corresponding generator data form will appear.

Make all the resistances, reactances, time constants, moment of inertia & damping factor zero.

After entering data, save & close. Similarly connect other generators

Generator data;

Generator no:	1	2	3	4
Bus no:	1	2	3	4.
Manufacturer ref no:	30	30	30	30.
No. of units parallel.	1	1	1	1.
Specified voltage.	1.04	1.0	1.0	1.0.
Derated MVA.	1000	1000	1000	1000
Scheduled power.	800	100	50	30.
Real power minimum.	0	0	0	0.
Real power maximum.	800	800	900	800.
Reactive power minimum	0	10	100	-10
Reactive power maximum.	600	10	100.	-10

Generator library;

Manufacturer ref. no.	30
MVA rating.	1000.
MW rating.	800
KV rating.	11.

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(4) How to draw load?

Click on Load icon provided on power system tool bar.

Connect load 1 at Pq1 by clicking the LMB on bus 2.

Element ID dialog will appear. Give ID no. as 1 & say OK.

Load data form will appear. Enter load details & click save button

Load no.	Bus no.	Real power demand, MW	Reactive power demand
1	2	50	30 MVAR
2	3	150	50 MVAR.

Procedure to perform load flow analysis;

1) Prepare single line diagram & database for the given exercise with generator, transmission line & load data as explained above.

2) Verify the data entered in MiPower before executing load flow analysis.

3) Select menu option, Solve → load flow analysis → Study info.

4) Select Gauss Seidal method, enter acceleration factor of 1.000001. Tolerance 0.0001, select slack bus, enter 0 for Q check limit. Click OK.

5) Execute load flow analysis. Click on Report → Standard.

6) In the report, scroll down to bus voltage at each iteration section. Tabulate bus voltages at the end of first iteration.

7) Tabulate the load flow results.

8) The bus voltages, power generations, line flows, losses etc at the end of iterations are available in the report.

9) To plot the result on single line diagram, click on plot load flow analysis. Set voltage, power flow units etc. Click OK. The no. of iterations undergone for load flow convergence, load flow results will be displayed.

Hand calculation

verification of the bus voltages at the end of first iteration can be done using equation.

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} = \begin{bmatrix} 3-9j & -2+j6 & -1+3j & 0 \\ -2+6j & 3.66-j11 & -0.66+2j & -1+3j \\ -1+3j & -0.66+2j & 3.66-j11 & -2+6j \\ 0 & -1+3j & -2+6j & 3-9j \end{bmatrix}$$

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{(V_2^0)^*} - Y_{21}V_1 - Y_{23}V_3^0 - Y_{24}\cdot V_4^0\right]$$

$$= \frac{1}{3.66-11j}\left[\frac{0.5+j0.2}{1-j0} - (-2+6j)1.04 - (-0.66+j2)1 - (-1+3j)1\right]$$

$$= 1.019 + j0.046 \text{ pu}.$$

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^0)^*} - Y_{31}V_1 - Y_{32}V_2^1 - Y_{34}V_4^0\right]$$

$$= \frac{1}{3.66-11j}\left[\frac{-1-j0.5}{1-j0} - (1.04(-1+3j)) - (-0.666+2j)(1.019+j0.046) - (-2+6j)\right]$$

$$= 1.028 - j0.087 \text{ pu}.$$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^0)^*} - Y_{41}V_1 - Y_{42}V_2^1 - Y_{43}V_3^1\right]$$

$$= \frac{1}{3-9j}\left[\frac{0.3+0.1j}{1-0j} - (-1+3j)(1.019+j0.046) - (-2+6j)(1.028-j0.087)\right]$$

$$= 1.025 - j0.0093 \text{ pu}.$$

RESULT

Load flow analysis has been conducted on the given system using GS method. The system is found to operate observing real & reactive power balance constraints. The inequality constraint violation observed is noted. The system is found to be in the 'normal' state of operation

```
|:::::       LOAD FLOW BY GAUSS-SIEDEL METHOD    :::::|
|-----CASE NO :  1     CONTINGENCY  : 0  SCHEDULE NO : 0-----|
|-----CONTINGENCY NAME : Base Case       RATING CONSIDERED : NOMINAL -----|
|~~~~~ INPUT DATA ~~~~~|
|***** SYSTEM SPECIFICATION *****|
Largest Bus Number Used              :    4
Actual Number of Buses               :    4
Number of Two Winding Transformers   :    0    Number of Three Winding Transformers :    0
Number of Transmission Lines         :    5    Number of Series Reactors            :    0
Number of Series Capacitors          :    0    Number of Circuit Breakers           :    0
Number of Shunt Reactors             :    0    Number of Shunt Capacitors           :    0
Number of Shunt Impedances           :    0    Number of Generators                 :    4
Number of Loads                      :    2    Number of Load Characteristics       :    0
Number of Frequency Relays           :    0    Number of Gen.Capability Curves      :    0
Number of Filters                    :    0    Number of Tie Line Schedules         :    0
Number of Convertors                 :    0    Number of DC Links                   :    0
Number of Shunt Connected FACTS      :    0    Number of Power Injections           :    0
Number of TCSC Connected             :    0    Number of SPS Connected              :    0
Number of UPFC Connected             :    0    Number of Wind Generators            :    0
Number of wtg Curves                 :    0    Number of wtg Detailed Curves        :    0
Number of solar plants               :    0    Number of Synchronous motors         :    0
-------------------------------------------------------------------------------
Load Flow With Gauss Seidel Method              :   5
Number of Zones                                 :   1
Print Option                                    :   4 - Detailed Print
Plot Option                                     :   1 - Plotting with p.u. Voltage
No Frequency Dependent Load Flow, Control Option:   0
Base MVA                                        : 100.0
Nominal System Frequency (Hz)                   :  50.0
Frequency Deviation (Hz)                        :   0.0
Flows in MW and MVAr, Option                    :   0
Slack Bus                                       :   1
Transformer Tap Control Option                  :   0
Q Checking Limit  (Enabled)                     :   0
Real Power Tolerance (p.u.)                     :   0.00010
Reactive Power Tolerance (p.u.)                 :   0.00010
Maximum Number of Iterations                    :  15
Bus Voltage below which Load Model is Changed   :   0.75000
Circuit Breaker Resistance (p.u.)               :   0.00000
Circuit Breaker Reactance (p.u.)                :   0.00010
Transformer R/X Ratio                           :   0.05000
------------------------------------------------------------------------------
|***** PRESENT WORTH ANALYSIS DATA *****|
Annual Percentage Interest Charges              :  15.000
Annual Percent Operation & Maintenance Charges  :   4.000
Life of Equipment (Years)                       :  20.000
Energy Unit Charge (kWh)                        :   2.500 Rs
Loss Load Factor                                :   0.300
Cost Per MVAr (Lakhs)                           :   5.000 Rs
-------------------------------------------------------------------------------
|***** ZONE WISE SCALING FACTORS *****|
ZONE   P LOAD   Q LOAD   P GEN   Q GEN SH REACT  SH CAP  C LOAD
---- -------- -------- -------- -------- -------- -------- --------
  0    1.000    1.000    1.000    1.000    1.000    1.000    1.000
  1    1.000    1.000    1.000    1.000    1.000    1.000    1.000
-------------------------------------------------------------------------------
|~~~~~ SYSTEM DATA ~~~~~|
|***** BUS DATA *****|
 BUS NO. AREA ZONE   BUS kV VMIN(p.u.) VMAX(p.u.)     NAME
-------- ---- ---- -------- ---------- ---------- --------
       1    1    1  11.000      0.950      1.050     Bus1
       2    1    1  11.000      0.950      1.050     Bus2
       3    1    1  11.000      0.950      1.050     Bus3
       4    1    1  11.000      0.950      1.050     Bus4

|***** TRANSMISSION LINE DATA *****|
```


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STA	CKT	FROM NODE	FROM NAME*	TO NODE	TO NAME*	LINE PARAMETER R(p.u.)	X(p.u.)	B/2(p.u.)	RATING MVA	KMS
3	1	2	Bus2	3	Bus3	0.12397	0.37190	0.00000	3	1.00
3	1	1	Bus1	3	Bus3	0.08264	0.12397	0.00000	90	1.00
3	1	1	Bus1	2	Bus2	0.04132	0.12397	0.00000	100	1.00
3	1	2	Bus2	4	Bus4	0.08264	0.24793	0.00000	100	1.00
3	1	3	Bus3	4	Bus4	0.04132	0.12397	0.00000	100	1.00

Total Line Charging Susceptance (p.u.) : 0.00000
Total Line Charging MVAr at 1 p.u. Voltage : 0.000
Number of Lines Opened on Both the Ends : 0
Total Line Charging susceptance of Existing Lines (p.u.) : 0.00000
Total Line Charging MVAr at 1 p.u. Voltage of Existing Lines : 0.000

Total Capacitive Susceptance : 0.00000 p.u. - 0.000 MVAr
Total Inductive Susceptance : 0.00000 p.u. - 0.000 MVAr

|***** GENERATOR DATA *****|

Sl.No*	FROM NODE	FROM NAME*	REAL POWER(MW)	Q-MIN MVAr	Q-MAX MVAr	V-SPEC p.u.	CAP. CURV	MVA RATING	STAT
1	1	Bus1	800.0000	0.0000	600.0000	1.0400	0	1000.00	3
2	2	Bus2	800.0000	10.0000	600.0000	1.0000	0	1000.00	3
3	4	Bus4	30.0000	-10.0000	-10.0000	1.0000	0	1000.00	3
4	3	Bus3	50.0000	100.0000	100.0000	1.0000	0	1000.00	3

|***** LOAD DATA *****|

Sl.No. *	FROM NODE	FROM NAME*	REAL MW	REACTIVE MVAr	COMP MVAr	COMPENSATING MIN	MVAR MAX	VALUE STEP	CHAR NO. STAT	F/V NO.
1	2	Bus2	50.000	30.000	0.000	0.000	0.000	0.000	0	0
									3	0
2	3	Bus3	150.000	50.000	0.000	0.000	0.000	0.000	0	0
									3	0

|***** OUTPUT DATA *****|
Total Specified MW Generation : 1680.00000
Total Minimum MVAr Limit of Generator : 100.00000
Total Maximum MVAr Limit of Generator : 1290.00000
Total Specified MW Load : 200.00000 Changed to 200.00000
Total Specified MVAr Load : 80.00000 Changed to 80.00000
Total Specified MVAr Compensation : 0.00000 Changed to 0.00000

Total (Including Out of Service Units)
Total Specified MW Generation : 1680.00000
Total Minimum MVAr Limit of Generator : 100.00000
Total Maximum MVAr Limit of Generator : 1290.00000
Total Specified MW Load : 200.00000 Changed to 200.00000
Total Specified MVAr Load : 80.00000 Changed to 80.00000
Total Specified MVAr Compensation : 0.00000 Changed to 0.00000

|----- GENERATOR DATA FOR FREQUENCY DEPENDENT LOAD FLOW -----|

SLNO*	FROM NODE	FROM NAME*	P-RATE MW	P-MIN MW	P-MAX MW	%DROOP C0	PARTICI FACTOR C1	BIAS SETTING C2
1	1	Bus1	800.000	0.0000	800.0000	4.0000	0.0000	0.0000
						0.0000	0.0000	0.0000
2	2	Bus2	800.000	0.0000	800.0000	4.0000	0.0000	0.0000
						0.0000	0.0000	0.0000
3	4	Bus4	800.000	0.0000	800.0000	4.0000	0.0000	0.0000
						0.0000	0.0000	0.0000

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```
    4        3     Bus3  800.000    0.0000  800.0000    4.0000     0.0000     0.0000
                                                         0.0000     0.0000     0.0000
Acceleration Factor :  1.00

|~~~~~ OUTPUT RESULTS ~~~~~|
Y BUS in POLAR FORM
-------------------
                    1                  2                  3                  4
              --------------     --------------     --------------     --------------
        1    14.238(-64.44)      7.653(108.43)      6.712(123.69)      0.000(0.00)
        2     7.653(108.43)     14.030(-71.57)      2.551(108.43)      3.826(108.43)
        3     6.712(123.69)      2.551(108.43)     16.772(-65.52)      7.653(108.43)
        4     0.000(0.00)      3.826(108.43)      7.653(108.43)    11.479(-71.57)
--------------------------------------------------------------------------------
|----- BUS VOLTAGES AT EACH ITERATION -----|
1  Bus1  1.040000+j0.000000  0.000000+j0.000000
2  Bus2  1.177340+j0.511646  0.177340+j0.511646
3  Bus3  1.053243+j0.010491  0.053243+j0.010491
4  Bus4  1.094609+j0.205091  0.094609+j0.205091

 Iteration count =    1  Error =   0.283710 Bus =     2
1  Bus1  1.040000+j0.000000  0.000000+j0.000000
2  Bus2  1.009556+j0.471670  -0.167784+j-0.039976
3  Bus3  1.080513+j0.099040  0.027271+j0.088549
4  Bus4  1.052306+j0.247564  -0.042303+j0.042473

|***** BUS VOLTAGES AND POWERS *****|
    NODE      FROM   V-MAG  ANGLE         MW      MVAr        MW      MVAr      MVAr
     NO.      NAME    p.u. DEGREE        GEN       GEN      LOAD      LOAD      COMP
-------- -------- ------ ------  -------- --------  -------- -------- --------
       1      Bus1  1.0400   0.00  -525.068  412.363     0.000     0.000     0.000
       2      Bus2  1.0399  36.74   800.000   10.000    50.000    30.000     0.000
       3      Bus3  1.0276  11.64    50.000  100.000   150.000    50.000     0.000
       4      Bus4  1.0094  21.56    30.000  -10.000     0.000     0.000     0.000
--------------------------------------------------------------------------------
NUMBER OF BUSES EXCEEDING MINIMUM VOLTAGE LIMIT (@ mark) :     0
NUMBER OF BUSES EXCEEDING MAXIMUM VOLTAGE LIMIT (# mark) :     0
NUMBER OF GENERATORS EXCEEDING MINIMUM Q LIMIT (< mark)  :     0
NUMBER OF GENERATORS EXCEEDING MAXIMUM Q LIMIT (> mark)  :     0

|***** LINE FLOWS AND LINE LOSSES *****|
SLNO CS      FROM     FROM       TO       TO        FORWARD             LOSS           %
             NODE     NAME     NODE     NAME        MW     MVAr        MW     MVAr LOADING
---- -- -------- -------- -------- -------- -------- -------- -------- -------- -------
   1  1         2     Bus2        3     Bus3  118.899   -9.051  16.3007  48.9020  3288.9!
   2  1         1     Bus1        3     Bus3 -107.396   99.720  16.4113  24.6170   156.0!
   3  1         1     Bus1        2     Bus2 -417.672  312.643 103.9917 311.9753   501.7!
   4  1         2     Bus2        4     Bus4  108.067   -8.446   8.9801  26.9403   104.2@
   5  1         3     Bus3        4     Bus4 -121.477   68.118   7.5904  22.7713   135.5!
--------------------------------------------------------------------------------
! NUMBER OF LINES LOADED BEYOND  125%            :    4
@ NUMBER OF LINES LOADED BETWEEN 100% AND 125% :    1
# NUMBER OF LINES LOADED BETWEEN  75% AND 100% :    0
$ NUMBER OF LINES LOADED BETWEEN  50% AND  75% :    0
^ NUMBER OF LINES LOADED BETWEEN  25% AND  50% :    0
& NUMBER OF LINES LOADED BETWEEN   1% AND  25% :    0
* NUMBER OF LINES LOADED BETWEEN   0% AND   1% :    0

BUSES BETWEEN WHICH ANGLE DIFFERENCE IS > 30 degrees ARE:
--------------------------------------------------------------------------------
        1       -       2
--------------------------------------------------------------------------------
ISLAND FREQUENCY SLACK-BUS   CONVERGED(1)
------ --------- ----------- ------------
     1  50.00000           1       0
```


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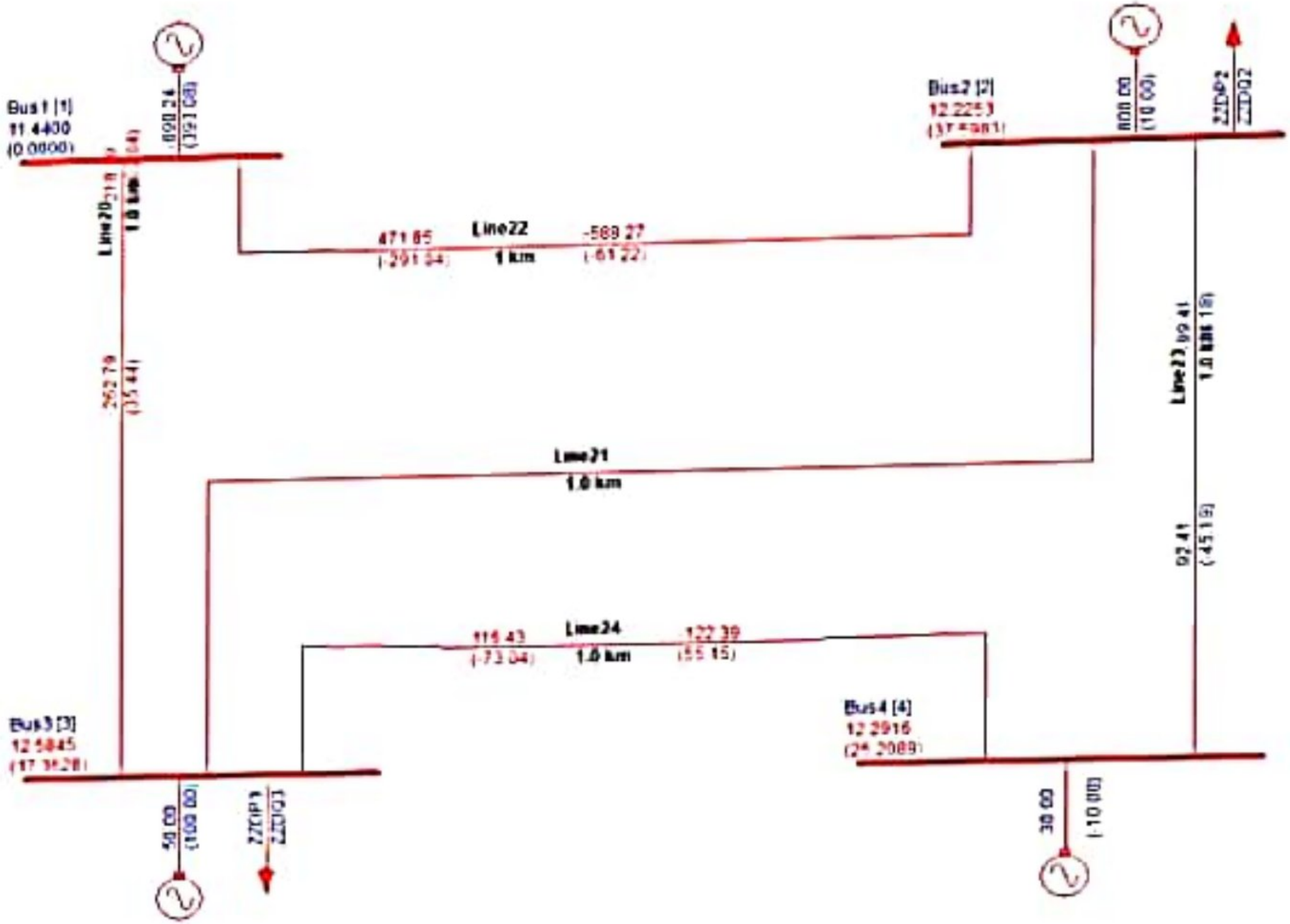
```
|***** SUMMARY OF RESULTS *****|

TOTAL REAL POWER GENERATION (CONVENTIONAL)   :    880.000 MW
TOTAL REAL POWER INJECTION (-ve LOAD)        :      0.000 MW
TOTAL REACT. POWER GENERATION (CONVENTIONAL) :    512.363 MVAr
GENERATION p.f.                              :      0.864
TOTAL REAL POWER GENERATION (WIND)           :      0.000 MW
TOTAL REACT. POWER GENERATION (WIND)         :      0.000 MVAr
TOTAL REAL POWER GENERATION (SOLAR)          :      0.000 MW
TOTAL REACT. POWER GENERATION (SOLAR)        :      0.000 MVAr
TOTAL SHUNT REACTOR INJECTION                :     -0.000 MW
TOTAL SHUNT REACTOR INJECTION                :     -0.000 MVAr
TOTAL SHUNT CAPACIT.INJECTION                :     -0.000 MW
TOTAL SHUNT CAPACIT.INJECTION                :     -0.000 MVAr
TOTAL TCSC REACTIVE DRAWL                    :      0.000 MVAr
TOTAL SPS REACTIVE DRAWL                     :      0.000 MVAr
TOTAL UPFC INJECTION                         :     -0.000 MVAr
TOTAL SHUNT FACTS INJECTION                  :      0.000 MVAr
TOTAL SHUNT FACTS DRAWAL                     :      0.000 MVAr
TOTAL REAL POWER LOAD                        :    200.000 MW
TOTAL REAL POWER DRAWAL (-ve gen.)           :    525.068 MW
TOTAL REACTIVE POWER LOAD                    :     80.000 MVAr
LOAD p.f.                                    :      0.928
TOTAL COMPENSATION AT LOADS                  :      0.000 MVAr
TOTAL HVDC REACTIVE POWER                    :      0.000 MVAr
TOTAL REAL POWER LOSS (AC+DC)                :    153.274177 MW (153.274177+  0.000000)
PERCENTAGE REAL  LOSS (AC+DC)                :     17.418
TOTAL REACTIVE POWER  LOSS                   :    435.205886 MVAr
-------------------------------------------------------------------------------
|----- ZONE WISE DISTRIBUTION -----|
Description        Zone # 1
---------------- ----------
MW generation      354.9321
MVAr generation    512.3634
MW wind gen.         0.0000
MVAr wind gen.       0.0000
MW solar gen.        0.0000
MVAr solar gen.      0.0000
MW load            200.0000
MVAr load           80.0000
MVAr compensation    0.0000
MW loss            153.2742
MVAr loss          435.2059
MVAr - inductive     0.0000
MVAr - capacitive    0.0000

|----- AREA WISE DISTRIBUTION -----|
Description        Area # 1
---------------- ----------
MW generation      354.9321
MVAr generation    512.3634
MW wind gen.         0.0000
MVAr wind gen.       0.0000
MW solar gen.        0.0000
MVAr solar gen.      0.0000
MW load            200.0000
MVAr load           80.0000
MVAr compensation    0.0000
MW loss            153.2742
MVAr loss          435.2059
MVAr - inductive     0.0000
MVAr - capacitive    0.0000
```


Bus1 [1]
11.4400
(0.0000)
-690.24
Line20
262.79
(35.44)
Line22
471.85
(-291.04)
1 km
-588.27
(-61.22)
Bus2 [2]
12.2253
600.00
(10.00)
22DP2
Line23
1.0 km
92.41
(-45.19)
Line21
1.0 km
Line24
115.43
(-73.04)
1.0 km
-122.39
(55.15)
Bus3 [3]
12.5845
(17.3628)
50.00
(100.00)
22DP1
Bus4 [4]
12.2916
30.00
(-10.00)

Experiment no: 10.

Date: 09/11/2021.

Surabi Balakrishnan.

Roll no: 39.

SHORT CIRCUIT ANALYSIS - SYMMETRICAL FAULTS

AIM:

To conduct the fault analysis of power system networks to solve a symmetrical fault.

OBJECTIVE:

To understand the effect of three phase to ground fault on a bus with simulation of a sample power system network.

THEORY:

A fault in a circuit is any failure, which interferes with the normal flow of current. The fault occurs in power system due to insulation failure of equipment, flashover of lines initiated by a lighting stroke, due to permanent damage to conductors & towers or due to accidental faulty operations.

3ϕ to ground fault.

The 3ϕ fault current can be computed through the application of Thevnin's theorem. In this method, the synchronous machines are represented by their reactances in series with voltages behind transient reactances.

The 3ϕ fault is a balanced fault & hence only positive sequence exists & that there is no coupling between sequence networks. The fault current can be calculated as,

$$I^f = \frac{V^o}{Z^{th} + Z_f}$$

where; V^o is the prefault voltage.

Z^{th} is the Thevenin's equivalent impedance.

Z_f is the fault impedance.

Post fault voltage is given by, $V^f = V^o - Z_{th} \cdot I^f$.

where, V^f is post fault v/g & I^f is fault current.

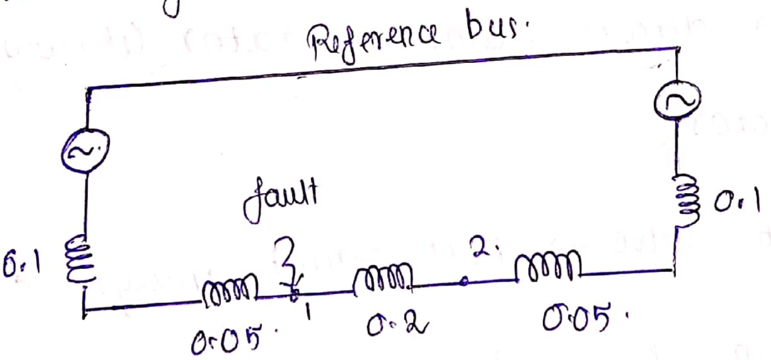
EXERCISE

For the system shown in figure, determine the fault level when a 3ϕ to ground fault occurs on bus 1.

Rating of each machine 1200 KVA, 600V with $X_1 = X_2 = 10\%$, $X_0 = X_n = 5\%$.

Each 3ϕ transformer is rated 1200 KVA, 600V delta / 3300V Y/n with leakage reactance of 5%. The reactance of the transmission line is $X_1 = X_2 = 20\%$ & $X_0 = 40\%$ on a base of 1200KVA, 3300V.

The sequence diagram is as shown.



Positive sequence network.

The equivalent impedance for the given fault point is calculated with reference to the figure of positive sequence network.

$X_{th} = (0.1 + 0.05) \parallel (0.2 + 0.05 + 0.1) = 0.105$ pu.

The fault current in pu, $I^f = V^0/X_{th} = 1/0.105 = 9.52$ pu.

Base current $= \dfrac{\text{Base KVA}}{\sqrt{3} \times \text{Base KV}} = \dfrac{1.2 \times 10^3}{\sqrt{3} \times 3.3} = 209.95$ A.

Fault current $= 9.52 \times 209.95 = 1998.7$ A.

Fault level in MVA $= \sqrt{3} \times 3.3 \times 10^3 \times 1998.7 = 11.42$ MVA.

PROCEDURE TO SOLVE EXERCISE IN MIPOWER

- Prepare single line diagram & database for given exercise with generator, transmission line & transformer. Select base MVA as 1.2 MVA with pu status checked in electrical & current information dialog.
- While connecting transformer, double click on HV bus (from bus) and then LV bus (To bus). Enter transformer element data and library details.
- Enter generator data & library details. Select generator winding connection as star grounded.
- Enter 2nd generator details. Same generator library can be used for the 2nd generator.
- Select menu option. Solve → Short circuit analysis → Study info.
- Select 3ϕ to ground fault. Select fault on bus, click on the zone & select corresponding bus. (Bus L). Click OK.
- Select output plot option as Phase A fault MVA level, output print option as Data & results; flow option as fault contribution from all buses & post fault voltages computed in pu. Click OK.

Execute short circuit analysis.

Click on report → Standard.

Tabulate fault current in KA & fault MVA ratings in table.

To plot study results on single line diagram, select menu option plot → Short circuit study.

Short circuit study results will be plotted on the network.

Short circuit study results.

Bus no.	Fault MVA.	Fault current (KA)
Bus 1.	14.975 MVA	2.6. KA.

```
|:::::           SHORT CIRCUIT STUDIES :::::|
|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                      :        5
Number of Two Winding Transformers                   :        2
Number of Transmission Lines                         :        1
Number of Generators                                 :        2

|*****CONTROL PROPERTY*****|
Number of Zones                                      :        1
Number of Areas                                      :        1
Number of Owners                                     :        1
Print Option                                         :        3(Both Data and Result Printing)
Plot Option                                          :        7(Plot File - Phase A,  MVA)
Base MVA                                             : 100.000MVA
Nominal System Frequency                             :  50.000Hz
Pre-Fault Voltage Option                             :        0(Voltage of 1.00000 p.u. is Assumed )
Tap Option                                           :        0(Use Nominal Tap)
Flow Option                                          :        3(Fault Contribution Computed from all Buses)
Post Fault Voltage Option                            :        1(Computed at all Buses in p.u.)
Breaker Option                                       :        1
Motor Option                                         :        0
Output Converter Option                              :        2

|-----FAULT DETAILS-----|
Number of Faulted Buses                 :1

CASE       | FAULT BUS   | FAULT TYPE| PHASE FAULT IMPEDANCE |GROUND FAULT IMPEDANCE
NUMBER     |             |           |RESISTANCE |REACTANCE  |RESISTANCE | REACTANCE
         1 BUS.1        LLLG           0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                     :0.01000p.u.
Angle Tolerance                         :1.000deg
Maximum Number of Iterations            :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                   :0.05000
Transformer Zero Sequence Impedance     :0.01745

TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels   :3

Transmission Line|Zero Sequence Impedance           |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor
%-----------------------------------------------------------%
       400.00000          2.50000          2.50000          0.80000
         3.30000          2.50000          2.50000          0.02500
         0.60000          2.50000          2.50000          0.60000

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance            :0.17500
Negative Sequence Reactance             :0.17500
Zero Sequence Resistance                :0.03750
Zero Sequence Reactance                 :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance             :0.81000
Zero Sequence Impedance                 :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance  :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance   :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID      |AREA  |ZONE  |OWNER |    RATED    | BUS NAME | V MAG    | V ANG  |  PGEN     |  QGEN     |  PLOAD    |  QLOAD    |  QCOMP
              |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|           | (p.u.)   | (deg)  |  (MW)     |  (MVAr)   |  (MW)     |  (MVAr)   |  (MVAr)
BUS.1               1      1      1        3.300 Bus1         1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.2               1      1      1        3.300 Bus2         1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.3               1      1      1        0.600 Bus3         1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.4               1      1      1        0.600 Bus4         1.00000    0.000       0.000       0.000       0.000       0.000       0.000

|-----TWO WINDING TRANSFORMER DATA-----|
UID   |FROM BUS|TO BUS|STATUS| NO OF  |  R1  |  X1  |  R0  |  X0   | FROM SIDE GROUNDING| TO SIDE GROUNDING|NOMTAP|PHASE SHIFT|    CB RATING(MVA)  |WIND CONN
      |        |      |      |CIRCUITS| (p.u)| (p.u)| (pu) | (p.u) |  R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.)|      |   (deg)   |  FROM     | TO     |FROM|TO

TF2.1 BUS.1     BUS.3    3       1     0.00042 4.16667 0.00042 4.16667 0.00000    0.00000    0.00000  0.00000 1.000      330.000     100.000   350.000 G   D
TF2.2 BUS.2     BUS.4    3       1     0.00042 4.16667 0.00042 4.16667 0.00000    0.00000    0.00000  0.00000 1.000      330.000     100.000   350.000 S   D

|-----TRANSMISSION LINE DATA-----|
     UID     | FROM BUS    | TO BUS       |STATUS| NO OF   |   R1    |  X1      | +VEB/2  | R0       |   X0     |ZERO B/2 | CB RATING(MVA)
             |             |              |      |CIRCUITS| (p.u.)  | (p.u.)   | (p.u.)  | (p.u.)   |  p.u.    | (p.u.)  | FROM      | TO
LIN.2          BUS.1         BUS.2              3        1   0.00000    1.83655   0.00000   0.00000    3.67310   0.00000     100.000      100.000

|-----GENERATOR DATA-----|
     UID     | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
             |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |   (MVA)   |
GEN.1          BUS.3             3    1   0.00000    8.33333    0.00000    8.33333    0.00000    4.16667      350.000 G
GEN.2          BUS.4             3    1   0.00000    8.33333    0.00000    8.33333    0.00000    4.16667      350.000 G

|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
LLLG FAULT ON    BUS.1 : NAME     Bus1
--------- --------    --------- --------     ---------------- ------------
        CURRENT (AMP/DEGREE)                               MVA
 SEQUENCE (1,2,0)      PHASE (A,B,C)        SEQUENCE (1,2,0) PHASE (A,B,C)
    A        deg         A          deg              MVA             MVA
--------- --------    --------- --------     ---------------- ------------
 2619.977  -89.998    2619.977  -89.998             14.975          14.975
    0.000    0.000    2619.977  150.002              0.000          14.975
    0.000    0.000    2619.977   30.002              0.000          14.975

R / X OF THE SHORT CIRCUIT PATH          : 0.000
Time Constant                            : 101.54224s
PEAK ASYMMETRICAL SHORT-CIRCUIT CURRENT : 7410.16313A
PASCC = k * sqrt(2) * If , k = 1.99993

|-----POST FAULT BUS VOLTAGES-----|
UID                BUS               SEQUENCE (1,2,0)         PHASE (A,B,C)        LINE-LINE MAG
                   NAME
                                     p.u.          deg        p.u.         deg          p.u.
------------    ------------      --------- --------      --------- --------      -------------
BUS.1              Bus1               0.00000    0.003       0.00000    0.003       0.00000
                                      0.00000    0.000       0.00000 -119.997       0.00000
                                      0.00000    0.000       0.00000  120.003       0.00000

BUS.2              Bus2               0.12810    0.002       0.12810    0.002       0.12810
                                      0.00000    0.000       0.12810 -119.998       0.12810
                                      0.00000    0.000       0.12810  120.002       0.12810
```

BUS.3	Bus3	0.33333	29.996	0.33333	29.996	0.33333
		0.00000	0.000	0.33333	-90.004	0.33333
		0.00000	0.000	0.33333	149.996	0.33333
BUS.4	Bus4	0.41874	29.998	0.41874	29.998	0.41874
		0.00000	0.000	0.41874	-90.002	0.41874
		0.00000	0.000	0.41874	149.998	0.41874

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.1	Bus1	BUS.3	Bus3	1399.637	90.002	1399.637	90.002	8.000
					0.000	0.000	1399.637	-29.998	8.000
					0.000	0.000	1399.637	-149.998	8.000
TF2.2	BUS.2	Bus2	BUS.4	Bus4	1220.340	90.002	1220.340	90.002	6.975
					0.000	0.000	1220.340	-29.998	6.975
					0.000	0.000	1220.340	-149.998	6.975
TF2.1	BUS.3	Bus3	BUS.1	Bus1	7698.004	-59.998	7698.004	-59.998	8.000
					0.000	0.000	7698.004	-179.998	8.000
					0.000	0.000	7698.004	60.002	8.000
TF2.2	BUS.4	Bus4	BUS.2	Bus2	6711.870	-59.998	6711.870	-59.998	6.975
					0.000	0.000	6711.870	-179.998	6.975
					0.000	0.000	6711.870	60.002	6.975

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.2	BUS.1	Bus1	BUS.2	Bus2	1220.340	90.002	1220.340	90.002	6.975
					0.000	0.000	1220.340	-29.998	6.975
					0.000	0.000	1220.340	-149.998	6.975
LIN.2	BUS.2	Bus2	BUS.1	Bus1	1220.340	-89.998	1220.340	-89.998	6.975
					0.000	0.000	1220.340	150.002	6.975
					0.000	0.000	1220.340	30.002	6.975

|*****FAULT CONTRIBUTIONS FROM GENERATOR*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
GEN.1	BUS.3	Bus3	7698.004	120.002	7698.004	120.002	8.000		
			0.000	0.000	7698.004	0.002	8.000		
			0.000	0.000	7698.004	-119.998	8.000		
GEN.2	BUS.4	Bus4	6711.870	120.002	6711.870	120.002	6.975		
			0.000	0.000	6711.870	0.002	6.975		
			0.000	0.000	6711.870	-119.998	6.975		

Case Number	Type of Fault	Bus ID	Bus Name	Element ID	Breaker Location	Breaker Rating (MVA)	Breaker Flow (MVA)	Sufficiency
1	LLLG	BUS.1	Bus1					
				TF2.1	From	100.000	6.975	Sufficient -----
				LIN.2	From	100.000	8.000	Sufficient -----

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	LLLG MVA	Current(kA)
BUS.1	Bus1	3.300	14.975	2.620

Experiment no: 11.

Date : 09/11/2021.

Surabi Balakrishnan.

Roll no: 39.

Short circuit analysis - Unsymmetrical faults.

AIM:

To conduct the fault analysis of power system networks to solve unsymmetrical faults.

OBJECTIVE:

To conduct the fault analysis of power system networks with simulation to solve following 3 unsymmetrical fault.

- Line to ground fault.
- Line to line fault.
- Double line to ground fault.

THEORY:

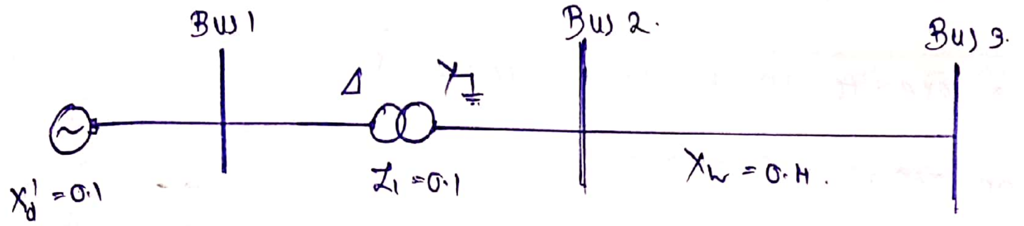
Since the symmetrical 3ϕ faults being balanced, analysis is conveniently preceded on 1ϕ basis. A 3ϕ fault being most severe must be used to calculate the rupturing capacity of circuit breakers, even though this type of fault has a low frequency of occurence, when compared to the unsymmetrical faults. There are, however, situations when an LG fault can cause greater fault current than a 3ϕ fault. Apart from this, unsymmetrical fault analysis is important for relay setting, 1ϕ switching and system stability studies.

EXERCISE:

For the system shown in figure, find the fault currents, fault MVA for the following type of faults at A. Bus 3, B. on line b/w buses 2 & 3.

- Single line to ground fault.
- Line to line fault.
- Double line to ground fault.

System details are given in tables & figures. Impedences are on 1000 MVA base. For the transmission line, assume $X_1 = X_2$, $X_0 = 2.5 X_1$.



- Sample 3 bus system.

Table; Generator data.

Bus no.	Bus name	V-specified in pu.	Generation. MW	MVAR.
1	Bus 1.	1.00 + j0.0	30	60
2	Bus 2.	0	0	0
3.	Bus 3.	0	0	0.

Table; Line parameters

Sl. no.	Bus no.	Impedance (pu).	Line charging admittance (pu)
1	2-3.	0.0 + j0.4.	0.

Procedure to solve the exercise in Mipower;

1) Procedure to solve single line to ground fault;

- Prepare a single line diagram & database for the given exercise with generator, transmission line & transformer.
- Select menu option solve → short circuit analysis → Study info.
- Select single line to ground fault & select fault on bus 3.
- Select short circuit output options. i.e., output plot option as phase current A. click OK.

- Execute short circuit analysis.
- Click on report → standard.
- Tabulate fault current in KA & fault MVA rattings in table.
- Select menu option solve → short circuit analysis → study info.
- Select single line to ground fault & fault on line 2-3 at a distance of 50% & execute short circuit analysis.
- Click on report → standard.
- Tabulate fault current in KA & fault MVA ratings in Table.

Table : Short circuit study results (SLGF on bus).

Bus no.	Fault MVA.	Fault current in KA.
Bus 3.	499.098 MVA.	1.307 KA.

Table ; Short circuit study results (SLGF on line).

Bus no.	Fault MVA.	Fault current (KA)
Fault on line 2-3	500 MVA	1.312 KA.

2) Procedure to solve line to line fault ;

- Select menu option Solve → Short circuit analysis → study info.
- Select line to line fault & Select fault on bus 3.
- Select short circuit output options. Click OK.
- Execute short circuit analysis. click on report → standard.
- Tabulate fault current in KA & fault MVA ratings in Table.
- Select menu option; solve → short circuit analysis → study info.
- Select line to line fault & select fault on line 2-3 at a distance of 50%.
- Execute short circuit analysis. Click on report → standard. Tabulate results.

Table; Short circuit study results (line to line fault on bus)

Bus no	Fault MVA	Fault current (KA)
Bus 3 - phase B.		
Bus 3 - phase C.		

Table; Short circuit study results (line to line fault on line).

Fault on line 2-3	Fault MVA	Fault current (KA)
Phase B		
Phase C.		

3) Procedure to solve double line to ground fault.

- Select menu option solve → short circuit analysis → study info.
- Select double line to ground fault & select fault on bus 3.
- Select short circuit output options. Execute short circuit analysis.
- Click on report → standard
- Tabulate fault current in KA & fault MVA ratings in table.
- Select menu option solve → short circuit analysis → study info.
- Select double line to ground fault & select fault on line 2-3 at a distance of 50%.
- Execute short circuit analysis. Click on report → standard.
- Tabulate fault current in KA & fault MVA ratings in table.
- Tabulate summary of results in table.

Table; Short circuit study results (double line to ground fault on bus)

Fault on bus 3.	Fault MVA.	Fault current in KA
Phase B		
Phase C.		

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Table - Short circuit study results (double line to ground fault on line)

Fault on line 2-3.	Fault MVA.	Fault current (KA)
Phase B.		
Phase C.		

Short circuit study results

Fault Details.		Fault MVA	Fault current (KA)
3ϕ fault on bus 3.			
3ϕ fault on line 2-3.			
Line to line fault on bus 3	Phase B		
	Phase C.		
Line to line fault on line 2-3	Phase B		
	Phase C.		
Double line to ground fault on bus 3.	Phase B		
	Phase C.		
Double line to ground fault on line 2-3.	Phase B		
	Phase C.		

```
|:::::           SHORT CIRCUIT STUDIES :::::|
|----- CASE NO  : 1        SCHEDULE NO : 0-----|

|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                      :       3
Number of Two Winding Transformers                   :       1
Number of Transmission Lines                         :       1
Number of Generators                                 :       1

|*****CONTROL PROPERTY*****|
Number of Zones                                      :       1
Number of Areas                                      :       1
Number of Owners                                     :       1
Print Option                                         :       3(Both Data and Result Printing)
Plot Option                                          :       7(Plot File - Phase A,  MVA)
Base MVA                                             : 100.000MVA
Nominal System Frequency                             :  50.000Hz
Pre-Fault Voltage Option                             :       0(Voltage of 1.00000 p.u. is Assumed )
Tap Option                                           :       0(Use Nominal Tap)
Flow Option                                          :       3(Fault Contribution Computed from all Buses)
Post Fault Voltage Option                            :       1(Computed at all Buses in p.u.)
Breaker Option                                       :       1
Motor Option                                         :       0
Output Converter Option                              :       2

|-----FAULT DETAILS-----|
Number of Faulted Buses                  :1

CASE       | FAULT BUS  | FAULT TYPE| PHASE FAULT IMPEDANCE |GROUND FAULT IMPEDANCE
NUMBER     |            |           |RESISTANCE |REACTANCE  |RESISTANCE | REACTANCE
         1 BUS.3       LLLG           0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                      :0.01000p.u.
Angle Tolerance                          :1.000deg
Maximum Number of Iterations             :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                    :0.05000
Transformer Zero Sequence Impedance      :0.01745

TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels    :2

Transmission Line|Zero Sequence Impedance           |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor
        220.00000           2.50000          2.50000          0.80000
         11.00000           2.50000          2.50000          0.02500

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance             :0.17500
Negative Sequence Reactance              :0.17500
Zero Sequence Resistance                 :0.03750
Zero Sequence Reactance                  :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance              :0.81000
Zero Sequence Impedance                  :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance   :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance    :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID      |AREA  |ZONE  |OWNER |    RATED    | BUS NAME | V MAG     | V ANG   |   PGEN      |    QGEN     |   PLOAD     |   QLOAD     |   QCOMP
              |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|            | (p.u.)    | (deg)   |   (MW)      |   (MVAr)    |   (MW)      |   (MVAr)    |   (MVAr)
BUS.1              1      1      1      11.000 Bus1          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.2              1      1      1     220.000 Bus2          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.3              1      1      1     220.000 Bus3          1.00000    0.000        0.000        0.000        0.000        0.000        0.000

|-----TWO WINDING TRANSFORMER DATA-----|

     UID      |  FROM BUS  |    TO BUS    |STATUS| NO OF  |  R1      |  X1      |  R0      |  X0      |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|     CB RATING(MVA)     |WIND CONN
              |            |              |      |CIRCUITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |      |
(deg)  |  FROM      | TO        |FROM|TO
TF2.1         BUS.2        BUS.1            3        1   0.00499   0.09988   0.00499   0.09988   0.00000   0.00000   0.00000   0.00000  0.975
30.000   10000.000     350.000 G     D

|-----TRANSMISSION LINE DATA-----|

     UID      | FROM BUS    | TO BUS       |STATUS| NO OF  |   R1     |  X1      | +VEB/2   | R0       |   X0     |ZERO B/2 | CB RATING(MVA)
              |             |              |      |CIRCUITS|  (p.u.)  | (p.u.)   | (p.u.)   | (p.u.)   |  p.u.    |  (p.u.) |  FROM      | TO

LIN.1         BUS.2        BUS.3            3        1   0.00000   0.00083   0.00000   0.00000   0.00207   0.00000   10000.000   10000.000

|-----GENERATOR DATA-----|

     UID      | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
              |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |  (MVA)    |
GEN.1         BUS.1            3     1   0.00000   0.10000   0.00000   0.10000   0.00000   0.10000      350.000 G

|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
LLLG FAULT ON    BUS.3 : NAME      Bus3
```

CURRENT (AMP/DEGREE) SEQUENCE (1,2,0) A	deg	PHASE (A,B,C) A	deg	MVA SEQUENCE (1,2,0) MVA	PHASE (A,B,C) MVA
1307.168	-88.575	1307.168	-88.575	498.098	498.098
0.000	0.000	1307.168	151.425	0.000	498.098
0.000	0.000	1307.168	31.425	0.000	498.098

R / X OF THE SHORT CIRCUIT PATH : 0.025
Time Constant : 0.12793s
PEAK ASYMMETRICAL SHORT-CIRCUIT CURRENT : 3597.78446A
PASCC = k * sqrt(2) * If , k = 1.94621

|-----POST FAULT BUS VOLTAGES-----|

UID	BUS NAME	SEQUENCE (1,2,0) p.u.	deg	PHASE (A,B,C) p.u.	deg	LINE-LINE MAG p.u.
BUS.1	Bus1	0.50221	-31.414	0.50221	-31.414	0.50221
		0.00000	0.000	0.50221	-151.414	0.50221
		0.00000	0.000	0.50221	88.586	0.50221
BUS.2	Bus2	0.00412	1.425	0.00412	1.425	0.00412
		0.00000	0.000	0.00412	-118.575	0.00412
		0.00000	0.000	0.00412	121.425	0.00412
BUS.3	Bus3	0.00000	0.000	0.00000	0.000	0.00000
		0.00000	0.000	0.00000	-120.000	0.00000
		0.00000	0.000	0.00000	120.000	0.00000

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.1	Bus1	BUS.2	Bus2	26143.354	-118.575	26143.354	-118.575	498.098
					0.000	0.000	26143.354	121.425	498.098
					0.000	0.000	26143.354	1.425	498.098
TF2.1	BUS.2	Bus2	BUS.1	Bus1	1307.168	91.425	1307.168	91.425	498.098
					0.000	0.000	1307.168	-28.575	498.098
					0.000	0.000	1307.168	-148.575	498.098

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.1	BUS.2	Bus2	BUS.3	Bus3	1307.168	-88.575	1307.168	-88.575	498.098
					0.000	0.000	1307.168	151.425	498.098
					0.000	0.000	1307.168	31.425	498.098
LIN.1	BUS.3	Bus3	BUS.2	Bus2	1307.168	91.425	1307.168	91.425	498.098
					0.000	0.000	1307.168	-28.575	498.098
					0.000	0.000	1307.168	-148.575	498.098

|*****FAULT CONTRIBUTIONS FROM GENERATOR*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
GEN.1	BUS.1	Bus1	26143.354	61.425	26143.354	61.425	498.098		
			0.000	0.000	26143.354	-58.575	498.098		
			0.000	0.000	26143.354	-178.575	498.098		

|*****BREAKER SUFFICIENCY*****|

Case Number	Type of Fault	Bus ID	Bus Name	Element ID	Breaker Location	Breaker Rating (MVA)	Breaker Flow (MVA)	Sufficiency	Flow Exceeds by (%)
1	LLLG	BUS.3	Bus3						
				LIN.1	To	10000.000	0.000	Sufficient	-----

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	LLLG MVA	Current(kA)
BUS.3	Bus3	220.000	498.098	1.307

```
|:::::           SHORT CIRCUIT STUDIES :::::|
|----- CASE NO  : 1        SCHEDULE NO : 0-----|
|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                      :       3
Number of Two Winding Transformers                   :       1
Number of Transmission Lines                         :       1
Number of Generators                                 :       1

|-----FAULT DETAILS-----|
Number of Faults on Transmission Lines   :1

CASE       |  FAULT    |FAULT TYPE |   FAULT   |PHASE FAULT IMPEDANCE|GND FAULT IMPEDANCE
NUMBER     |   LINE    |           |  POINT (%)|RESISTANCE | REACTANCE |RESISTANCE | REACTANCE
        1 LIN.1       SLG             50.000     0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                     :0.01000p.u.
Angle Tolerance                         :1.000deg
Maximum Number of Iterations            :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                   :0.05000
Transformer Zero Sequence Impedance     :0.01745

TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels   :2
%------------------------------------------------------------%
Transmission Line|Zero Sequence Impedance           |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor
%------------------------------------------------------------%
       220.00000          2.50000         2.50000          0.80000
        11.00000          2.50000         2.50000          0.02500
%------------------------------------------------------------%
GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance            :0.17500
Negative Sequence Reactance             :0.17500
Zero Sequence Resistance                :0.03750
Zero Sequence Reactance                 :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance             :0.81000
Zero Sequence Impedance                 :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance  :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance   :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

    UID     |AREA  |ZONE  |OWNER |   RATED    | BUS NAME | V MAG    | V ANG  |   PGEN     |   QGEN    |  PLOAD    |  QLOAD    |  QCOMP
            |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|          | (p.u.)   | (deg)  |   (MW)     |  (MVAr)   |   (MW)    |  (MVAr)   |  (MVAr)
BUS.1              1      1      1      11.000 Bus1          1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.2              1      1      1     220.000 Bus2          1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.3              1      1      1     220.000 Bus3          1.00000    0.000       0.000       0.000       0.000       0.000       0.000

|-----TWO WINDING TRANSFORMER DATA-----|

    UID     |  FROM BUS   |   TO BUS    |STATUS| NO OF   |  R1      |  X1      |  R0      |  X0      |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|     CB RATING(MVA)     |WIND CONN
            |             |             |      |CIRCUITS| (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |      |
(deg)  |  FROM        | TO          |FROM|TO
TF2.1         BUS.2         BUS.1             3         1   0.00499    0.09988    0.00499    0.09988    0.00000    0.00000    0.00000    0.00000  0.975
30.000   10000.000      350.000 G    D

|-----TRANSMISSION LINE DATA-----|

    UID     | FROM BUS    | TO BUS      |STATUS| NO OF   |   R1    |  X1     | +VEB/2  | R0      |   X0    |ZERO B/2 | CB RATING(MVA)
            |             |             |      |CIRCUITS|  (p.u.) | (p.u.)  | (p.u.)  | (p.u.)  |  p.u.   |  (p.u.) |  FROM       | TO

LIN.1         BUS.2         BUS.3             3         1   0.00000    0.00083    0.00000    0.00000    0.00207    0.00000    10000.000   10000.000

|-----GENERATOR DATA-----|

    UID     | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
            |            |      |UNITS| (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  |   (MVA)   |
GEN.1         BUS.1              3     1   0.00000   0.10000   0.00000   0.10000   0.00000   0.10000      350.000 G


|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
SLG FAULT ON    LIN.1 AT 50.00%        CURRENT (AMP/DEGREE)
 SEQUENCE (1,2,0)       PHASE (A,B,C)        SEQUENCE (1,2,0) PHASE (A,B,C)
    A         deg         A         deg              MVA              MVA
--------- --------     --------- --------     ---------------- -------------
 1312.160  -90.000      3936.479  -90.000            500.000      1500.000
 1312.160  -90.000         0.000    0.000            500.000         0.000
 1312.160  -90.000         0.000    0.000            500.000         0.000

|-----POST FAULT BUS VOLTAGES-----|
UID              BUS            SEQUENCE (1,2,0)        PHASE (A,B,C)       LINE-LINE MAG
                 NAME
                                p.u.        deg        p.u.        deg          p.u.
------------    ------------    --------- --------     --------- --------     -------------
BUS.1            Bus1             0.50000  -30.000      0.50000  -90.000        0.00000
                                  0.50000 -150.000      0.50000  -90.000        0.86603
                                  0.00000  180.000      1.00000   90.000        0.86603
```

BUS.2	Bus2	0.02498 88.569		1.50000 177.138		1.02139
		0.99969	178.569	0.86603	-90.000	1.00000
		0.50000	177.138	0.86603	90.000	0.97814
BUS.3	Bus3	0.02501	93.306	1.50929	177.155	1.02443
		1.00175	178.572	0.86603	-90.205	1.00000
		0.50516	177.167	0.86603	90.205	0.98130
DUMBUS.4	FAULTBUS	0.02501	93.306	1.50929	177.155	1.02443
		1.00175	178.572	0.86603	-90.205	1.00000
		0.50516	177.167	0.86603	90.205	0.98130

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.2	Bus2	BUS.1	Bus1	1312.160	90.000	3936.479	90.000	1500.000
					1312.160	90.000	0.000	88.885	0.000
					1312.160	90.000	0.000	88.885	0.000

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.1	BUS.2	Bus2	BUS.3	Bus3	1312.160	-90.000	3936.479	-90.000	1500.000
					1312.160	-90.000	0.000	-91.026	0.000
					1312.160	-90.000	0.000	-91.026	0.000
LIN.1	BUS.3	Bus3	BUS.2	Bus2	0.000	-91.611	0.000	-91.692	0.000
					0.000	-91.611	0.000	88.613	0.000
					0.000	-92.505	0.000	88.613	0.000

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	SLG MVA	Current(kA)
BUS.1	Bus1	11.000	1500.000	78.730

```
|:::::            SHORT CIRCUIT STUDIES :::::|
|----- CASE NO  : 1         SCHEDULE NO : 0-----|

|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                    :       3
Number of Two Winding Transformers                 :       1
Number of Transmission Lines                       :       1
Number of Generators                               :       1

|*****CONTROL PROPERTY*****|
Number of Zones                                    :       1
Number of Areas                                    :       1
Number of Owners                                   :       1
Print Option                                       :       3(Both Data and Result Printing)
Plot Option                                        :       7(Plot File - Phase A,  MVA)
Base MVA                                           :       100.000MVA
Nominal System Frequency                           :       50.000Hz
Pre-Fault Voltage Option                           :       0(Voltage of 1.00000 p.u. is Assumed )
Tap Option                                         :       0(Use Nominal Tap)
Flow Option                                        :       3(Fault Contribution Computed from all Buses)
Post Fault Voltage Option                          :       1(Computed at all Buses in p.u.)
Breaker Option                                     :       1
Motor Option                                       :       0
Output Converter Option                            :       2

|-----FAULT DETAILS-----|
Number of Faulted Buses                :1

CASE       | FAULT BUS  | FAULT TYPE| PHASE FAULT IMPEDANCE |GROUND FAULT IMPEDANCE
NUMBER     |            |           |RESISTANCE |REACTANCE  |RESISTANCE | REACTANCE
         1 BUS.3       LL             0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                    :0.01000p.u.
Angle Tolerance                        :1.000deg
Maximum Number of Iterations           :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                  :0.05000
Transformer Zero Sequence Impedance    :0.01745

TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels   :2

Transmission Line|Zero Sequence Impedance            |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor
        220.00000          2.50000          2.50000          0.80000
         11.00000          2.50000          2.50000          0.02500

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance           :0.17500
Negative Sequence Reactance            :0.17500
Zero Sequence Resistance               :0.03750
Zero Sequence Reactance                :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance            :0.81000
Zero Sequence Impedance                :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance  :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance   :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID     |AREA  |ZONE  |OWNER |   RATED    | BUS NAME | V MAG    | V ANG   |   PGEN     |    QGEN    |   PLOAD    |   QLOAD    |   QCOMP
             |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|           | (p.u.)   | (deg)   |   (MW)     |   (MVAr)   |    (MW)    |   (MVAr)   |   (MVAr)
BUS.1              1      1      1      11.000 Bus1          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.2              1      1      1     220.000 Bus2          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.3              1      1      1     220.000 Bus3          1.00000    0.000        0.000        0.000        0.000        0.000        0.000

|-----TWO WINDING TRANSFORMER DATA-----|

     UID     |  FROM BUS  |    TO BUS   |STATUS| NO OF  |  R1      |  X1      |  R0      |  X0      |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|     CB RATING(MVA)     |WIND CONN
             |            |             |      |CIRCUITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |      |
(deg)  |  FROM      | TO         |FROM|TO
TF2.1        BUS.2        BUS.1             3        1   0.00499    0.09988    0.00499    0.09988    0.00000    0.00000    0.00000    0.00000  0.975
30.000   10000.000     350.000 G    D

|-----TRANSMISSION LINE DATA-----|

     UID     | FROM BUS    | TO BUS      |STATUS| NO OF  |   R1     |  X1      | +VEB/2   | R0       |   X0     |ZERO B/2 | CB RATING(MVA)
             |             |             |      |CIRCUITS|  (p.u.)  | (p.u.)   | (p.u.)   | (p.u.)   |  p.u.    |  (p.u.) |  FROM      | TO

LIN.1        BUS.2         BUS.3             3        1   0.00000    0.00083    0.00000    0.00000    0.00207    0.00000   10000.000   10000.000

|-----GENERATOR DATA-----|

     UID     | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
             |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |   (MVA)   |
GEN.1        BUS.1              3     1  0.00000    0.10000    0.00000    0.10000    0.00000    0.10000      350.000 G

|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
LL FAULT ON    BUS.3 : NAME     Bus3
```

CURRENT (AMP/DEGREE) SEQUENCE (1,2,0) A	deg	PHASE (A,B,C) A	deg	MVA SEQUENCE (1,2,0) MVA	PHASE (A,B,C) MVA
653.584	-88.575	0.000	0.000	249.049	0.000
653.584	91.425	1132.040	-178.575	249.049	431.365
0.000	0.000	1132.040	1.425	0.000	431.365

|-----POST FAULT BUS VOLTAGES-----|

UID	BUS NAME	SEQUENCE (1,2,0) p.u.	deg	PHASE (A,B,C) p.u.	deg	LINE-LINE MAG p.u.
BUS.1	Bus1	0.75105	-30.473	0.89573	-16.275	1.00000
		0.24905	31.425	0.90763	-163.944	0.67074
		0.00000	0.000	0.50221	88.586	0.65455
BUS.2	Bus2	0.50206	0.006	1.00000	0.000	0.86598
		0.49794	-0.006	0.49992	-179.592	0.00412
		0.00000	0.000	0.50010	179.592	0.86608
BUS.3	Bus3	0.50000	0.000	1.00000	0.000	0.86603
		0.50000	0.000	0.50000	-180.000	0.00000
		0.00000	0.000	0.50000	180.000	0.86603

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.1	Bus1	BUS.2	Bus2	13071.677	-118.575	13071.677	-178.575	249.049
					13071.677	121.425	13071.677	-178.575	249.049
					0.000	0.000	26143.354	1.425	498.098
TF2.1	BUS.2	Bus2	BUS.1	Bus1	653.584	91.425	0.000	92.684	0.000
					653.584	-88.575	1132.040	1.425	431.365
					0.000	0.000	1132.040	-178.575	431.365

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.1	BUS.2	Bus2	BUS.3	Bus3	653.584	-88.575	0.000	90.000	0.000
					653.584	91.425	1132.040	-178.575	431.365
					0.000	0.000	1132.040	1.425	431.365
LIN.1	BUS.3	Bus3	BUS.2	Bus2	653.584	91.425	0.000	-90.000	0.000
					653.584	-88.575	1132.040	1.425	431.365
					0.000	0.000	1132.040	-178.575	431.365

|*****FAULT CONTRIBUTIONS FROM GENERATOR*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
GEN.1	BUS.1	Bus1	13071.677	61.425	13071.677	1.425	249.049		
			13071.677	-58.575	13071.677	1.425	249.049		
			0.000	0.000	26143.354	-178.575	498.098		

|*****BREAKER SUFFICIENCY*****|

Case Number	Type of Fault	Bus ID	Bus Name	Element ID	Breaker Location	Breaker Rating (MVA)	Breaker Flow (MVA)	Sufficiency	Flow Exceeds by (%)
1	LL	BUS.3	Bus3						
				LIN.1	To	10000.000	0.000	Sufficient	-----

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	LL MVA	Current(kA)
BUS.3	Bus3	220.000	431.365	1.132

```
|:::::  SHORT CIRCUIT STUDIES :::::|
|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                   :       3
Number of Two Winding Transformers                :       1
Number of Transmission Lines                      :       1
Number of Generators                              :       1

|-----FAULT DETAILS-----|
Number of Faults on Transmission Lines   :1

CASE       |  FAULT    |FAULT TYPE |   FAULT   |PHASE FAULT IMPEDANCE|GND FAULT IMPEDANCE
NUMBER     |   LINE    |           |  POINT (%)|RESISTANCE | REACTANCE |RESISTANCE | REACTANCE
         1 LIN.1        LL            50.000     0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                      :0.01000p.u.
Angle Tolerance                          :1.000deg
Maximum Number of Iterations             :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                    :0.05000
Transformer Zero Sequence Impedance      :0.01745
TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels    :2

Transmission Line|Zero Sequence Impedance            |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor

      220.00000           2.50000     2.50000           0.80000
       11.00000           2.50000     2.50000           0.02500

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance             :0.17500
Negative Sequence Reactance              :0.17500
Zero Sequence Resistance                 :0.03750
Zero Sequence Reactance                  :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance              :0.81000
Zero Sequence Impedance                  :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance   :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance    :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID     |AREA  |ZONE  |OWNER |   RATED    | BUS NAME | V MAG    | V ANG  |   PGEN     |    QGEN    |   PLOAD    |   QLOAD    |   QCOMP
             |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|           | (p.u.)   | (deg)  |   (MW)     |   (MVAr)   |   (MW)     |   (MVAr)   |   (MVAr)
BUS.1             1      1      1     11.000 Bus1          1.00000    0.000       0.000        0.000        0.000        0.000        0.000
BUS.2             1      1      1    220.000 Bus2          1.00000    0.000       0.000        0.000        0.000        0.000        0.000
BUS.3             1      1      1    220.000 Bus3          1.00000    0.000       0.000        0.000        0.000        0.000        0.000

|-----TWO WINDING TRANSFORMER DATA-----|

     UID     |  FROM BUS  |    TO BUS    |STATUS| NO OF  |  R1      |  X1      |  R0      |  X0      |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|      CB RATING(MVA)     |WIND CONN
             |            |              |      |CIRCUITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |       |
(deg)  |   FROM      | TO          |FROM|TO
TF2.1        BUS.2        BUS.1              3        1   0.00499    0.09988    0.00499    0.09988    0.00000    0.00000    0.00000    0.00000  0.975
30.000   10000.000     350.000 G     D

|-----TRANSMISSION LINE DATA-----|

     UID     | FROM BUS    | TO BUS      |STATUS| NO OF  |   R1     |  X1      | +VEB/2  | R0       |   X0     |ZERO B/2 | CB RATING(MVA)
             |             |             |      |CIRCUITS|  (p.u.)  | (p.u.)   | (p.u.)  | (p.u.)   |  p.u.    |  (p.u.) |  FROM       | TO

LIN.1        BUS.2         BUS.3             3        1   0.00000    0.00083    0.00000    0.00000    0.00207    0.00000   10000.000   10000.000

|-----GENERATOR DATA-----|

     UID     | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
             |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |   (MVA)   |
GEN.1        BUS.1             3     1   0.00000    0.10000    0.00000    0.10000    0.00000    0.10000      350.000 G

|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
LL FAULT ON    LIN.1 AT 50.00%        CURRENT (AMP/DEGREE)                             MVA
 SEQUENCE (1,2,0)      PHASE (A,B,C)        SEQUENCE (1,2,0) PHASE (A,B,C)
   A         deg          A         deg              MVA              MVA
--------- --------    --------- --------      ---------------- ------------
 1312.160  -90.000      0.000    0.000            500.000         0.000
 1312.160   90.000   2272.727  180.000            500.000       866.025
    0.000    0.000   2272.727   -0.000              0.000       866.025

|-----POST FAULT BUS VOLTAGES-----|
UID              BUS            SEQUENCE (1,2,0)        PHASE (A,B,C)       LINE-LINE MAG
                 NAME
                                p.u.       deg       p.u.        deg          p.u.
------------     ------------   --------- --------   --------- --------    -------------
BUS.1            Bus1            0.50000  -30.000    0.86603    0.000        1.00000
                                 0.50000   30.000    0.86603  180.000        0.50000
                                 0.00000    0.000    0.00000 -116.565        0.50000

BUS.2            Bus2            0.02498   88.569    1.00000    0.000        0.97814
                                 0.99969   -1.431    0.97814  117.837        1.00000
```

		0.00000	0.000	1.02139	-122.132	1.02139
BUS.3	Bus3	0.02501	93.306	1.00000	0.000	0.97919
		1.00175	-1.428	0.98130	117.740	1.00413
		0.00000	0.000	1.02443	-122.025	1.02241
DUMBUS.4	FAULTBUS	0.02501	93.306	1.00000	0.000	0.97919
		1.00175	-1.428	0.98130	117.740	1.00413
		0.00000	0.000	1.02443	-122.025	1.02241

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.2	Bus2	BUS.1	Bus1	1312.160	90.000	0.000	0.000	0.000
					1312.160	-90.000	2272.727	-0.000	866.025
					0.000	0.000	2272.727	180.000	866.025

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.1	BUS.2	Bus2	BUS.3	Bus3	1312.160	-90.000	0.000	0.000	0.000
					1312.160	90.000	2272.727	180.000	866.025
					0.000	0.000	2272.727	-0.000	866.025
LIN.1	BUS.3	Bus3	BUS.2	Bus2	0.000	-91.611	0.000	0.000	0.000
					0.000	88.389	0.000	178.389	0.000
					0.000	0.000	0.000	-1.611	0.000

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	LL MVA	Current(kA)
BUS.1	Bus1	11.000	866.025	45.455

```
|:::::           SHORT CIRCUIT STUDIES :::::|

|~~~~~INPUT DATA~~~~~|
|*****ELEMENT COUNT*****|
Number of Buses                                  :       3
Number of Two Winding Transformers               :       1
Number of Transmission Lines                     :       1
Number of Generators                             :       1

|*****CONTROL PROPERTY*****|
Number of Zones                                  :       1
Number of Areas                                  :       1
Number of Owners                                 :       1
Print Option                                     :       3(Both Data and Result Printing)
Plot Option                                      :       7(Plot File - Phase A,  MVA)
Base MVA                                         :       100.000MVA
Nominal System Frequency                         :       50.000Hz
Pre-Fault Voltage Option                         :       0(Voltage of 1.00000 p.u. is Assumed )
Tap Option                                       :       0(Use Nominal Tap)
Flow Option                                      :       3(Fault Contribution Computed from all Buses)
Post Fault Voltage Option                        :       1(Computed at all Buses in p.u.)
Breaker Option                                   :       1
Motor Option                                     :       0
Output Converter Option                          :       2

|-----FAULT DETAILS-----|
Number of Faulted Buses                 :1

CASE       | FAULT BUS   | FAULT TYPE| PHASE FAULT IMPEDANCE |GROUND FAULT IMPEDANCE
NUMBER     |             |           |RESISTANCE |REACTANCE  |RESISTANCE | REACTANCE
         1 BUS.3       LLG           0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                     :0.01000p.u.
Angle Tolerance                         :1.000deg
Maximum Number of Iterations            :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                   :0.05000
Transformer Zero Sequence Impedance     :0.01745
TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels   :2

Transmission Line|Zero Sequence Impedance            |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor

    220.00000          2.50000          2.50000          0.80000
     11.00000          2.50000          2.50000          0.02500

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance            :0.17500
Negative Sequence Reactance             :0.17500
Zero Sequence Resistance                :0.03750
Zero Sequence Reactance                 :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance             :0.81000
Zero Sequence Impedance                 :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance  :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance   :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID      |AREA  |ZONE  |OWNER |   RATED    | BUS NAME | V MAG    | V ANG  |   PGEN     |   QGEN    |   PLOAD    |  QLOAD    |  QCOMP
              |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|          | (p.u.)   | (deg)  |   (MW)     |  (MVAr)   |   (MW)     | (MVAr)    | (MVAr)
BUS.1              1      1      1      11.000 Bus1        1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.2              1      1      1     220.000 Bus2        1.00000    0.000       0.000       0.000       0.000       0.000       0.000
BUS.3              1      1      1     220.000 Bus3        1.00000    0.000       0.000       0.000       0.000       0.000       0.000

|-----TWO WINDING TRANSFORMER DATA-----|

     UID      |  FROM BUS  |   TO BUS   |STATUS| NO OF  | R1       | X1       | R0       | X0       |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|     CB RATING(MVA)     |WIND CONN
              |            |            |      |CIRCUITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |      |
(deg)  |  FROM      | TO        |FROM|TO
TF2.1        BUS.2        BUS.1           3        1   0.00499   0.09988   0.00499   0.09988   0.00000   0.00000   0.00000   0.00000  0.975
30.000   10000.000     350.000 G    D
|-----TRANSMISSION LINE DATA-----|

     UID      | FROM BUS    | TO BUS      |STATUS| NO OF  |   R1     |  X1      | +VEB/2  | R0       |   X0     |ZERO B/2 | CB RATING(MVA)
              |             |             |      |CIRCUITS|  (p.u.)  | (p.u.)   | (p.u.)  | (p.u.)   |  p.u.    |  (p.u.) |  FROM     | TO

LIN.1        BUS.2        BUS.3           3        1   0.00000   0.00083   0.00000   0.00000   0.00207   0.00000   10000.000   10000.000
|-----GENERATOR DATA-----|

     UID      | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
              |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |   (MVA)   |
GEN.1        BUS.1            3     1   0.00000   0.10000   0.00000   0.10000   0.00000   0.10000     350.000 G

|~~~~~OUTPUT RESULTS~~~~~|
|*****Case Number : 1*****|
LLG FAULT ON    BUS.3 : NAME     Bus3
--------- --------    --------- --------    ---------------- ------------
       CURRENT (AMP/DEGREE)                               MVA
 SEQUENCE (1,2,0)      PHASE (A,B,C)        SEQUENCE (1,2,0) PHASE (A,B,C)
```

```
   A        deg         A        deg          MVA            MVA
--------- --------   --------- --------   ---------------- -------------
  977.669  -88.344      0.000  180.000          372.542         0.000
  329.530   90.741   1501.200  141.062          125.568       572.034
  648.202   92.121   1483.298   42.379          246.998       565.212
|-----POST FAULT BUS VOLTAGES-----|
UID            BUS            SEQUENCE (1,2,0)       PHASE (A,B,C)      LINE-LINE MAG
               NAME
                              p.u.       deg       p.u.       deg         p.u.
------------   ------------   --------- --------   --------- --------   -------------
BUS.1          Bus1             0.62771  -30.983     0.69603  -21.841     0.75323
                                0.12557   30.741     0.70191 -159.735     0.57888
                                0.00000    0.000     0.50221   88.586     0.57174

BUS.2          Bus2             0.25517   -0.656     0.75323   -0.695     0.43834
                                0.25106   -0.690     0.00712 -147.851     0.00412
                                0.24700   -0.742     0.00705  151.740     0.43849

BUS.3          Bus3             0.25209   -0.684     0.75628   -0.684     0.43664
                                0.25209   -0.684     0.00000 -117.732     0.00000
                                0.25209   -0.684     0.00000  122.207     0.43664

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|
UID             FROM        FROM          TO         TO                   CURRENT                                     FAULT MVA
                 BUS        BUSNAME       BUS        BUSNAME          SEQUENCE(1,2,0)         PHASE(A,B,C)            PHASE(A,B,C)
                                                                      A        deg          A        deg                 MVA
------------   ------------ ------------   ------------ ------------   --------- --------   --------- --------    -------------
TF2.1          BUS.1        Bus1           BUS.2        Bus2          19553.373 -118.344    17127.651 -137.621       326.326
                                                                       6590.608  120.741    17334.365  141.062       330.264
                                                                          0.000    0.000    26143.354    1.425       498.098
TF2.1          BUS.2        Bus2           BUS.1        Bus1            977.669   91.656        0.000  -88.965         0.000
                                                                        329.530  -89.259     1501.200  -38.938       572.034
                                                                        648.202  -87.879     1483.298 -137.621       565.212
|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|
UID             FROM        FROM          TO         TO                   CURRENT                                     FAULT MVA
                 BUS        BUSNAME       BUS        BUSNAME          SEQUENCE(1,2,0)         PHASE(A,B,C)            PHASE(A,B,C)
                                                                      A        deg          A        deg                 MVA
------------   ------------ ------------   ------------ ------------   --------- --------   --------- --------    -------------
LIN.1          BUS.2        Bus2           BUS.3        Bus3            977.669  -88.344        0.000   91.028         0.000
                                                                        329.530   90.741     1501.200  141.062       572.034
                                                                        648.202   92.121     1483.298   42.379       565.212
LIN.1          BUS.3        Bus3           BUS.2        Bus2            977.669   91.656        0.000  -88.972         0.000
                                                                        329.530  -89.259     1501.200  -38.938       572.034
                                                                        648.202  -87.879     1483.298 -137.621       565.212
|*****FAULT CONTRIBUTIONS FROM GENERATOR*****|
UID             FROM        FROM          TO         TO                   CURRENT                                     FAULT MVA
                 BUS        BUSNAME       BUS        BUSNAME          SEQUENCE(1,2,0)         PHASE(A,B,C)            PHASE(A,B,C)
                                                                      A        deg          A        deg                 MVA
------------   ------------ ------------   ------------ ------------   --------- --------   --------- --------    -------------
GEN.1          BUS.1        Bus1           19553.373   61.656    17127.651   42.379       326.326
                                            6590.608  -59.259    17334.365  -38.938       330.264
                                               0.000    0.000    26143.354 -178.575       498.098
|*****BREAKER SUFFICIENCY*****|
Case Number  Type of Fault  Bus ID        Bus Name      Element ID   Breaker Location  Breaker Rating  Breaker Flow  Sufficiency   Flow Exceeds by
                                                                                           (MVA)          (MVA)                          (%)
------------ ------------- ------------ ------------- ------------- ----------------- -------------- ------------- ------------- -------------
----------------
         1 LLG          BUS.3         Bus3
                                                    LIN.1         To                 10000.000        0.000  Sufficient  -----
|*****BUS FAULT SUMMARY*****|
 Bus Number   Bus Name       Rated               LLG
                           Voltage(kV)    MVA     | Current(kA)
------------ ------------ ------------  ------------ ------------
BUS.3        Bus3            220.000      572.034        1.501
```

```
|:::::  SHORT CIRCUIT STUDIES :::::|
|~~~~~INPUT DATA~~~~~|

|*****ELEMENT COUNT*****|
Number of Buses                                    :       3
Number of Two Winding Transformers                 :       1
Number of Three Winding Transformers               :       0
Number of Transmission Lines                       :       1
Number of Generators                               :       1

|-----FAULT DETAILS-----|
Number of Faults on Transmission Lines   :1

CASE       |  FAULT   |FAULT TYPE |   FAULT   |PHASE FAULT IMPEDANCE|GND FAULT IMPEDANCE
NUMBER     |   LINE   |           |  POINT (%)|RESISTANCE | REACTANCE |RESISTANCE | REACTANCE
          1 LIN.1      LLG            50.000     0.00000     0.00000     0.00000     0.00000

|-----ITERATIVE SHORT CIRCUIT DATA -----|
Magnitude Tolerance                      :0.01000p.u.
Angle Tolerance                          :1.000deg
Maximum Number of Iterations             :15

|-----MULTIPLICATION FACTORS-----|
TRANSFORMER MULTIPLICATION FACTORS
Transformer R/X Ratio                    :0.05000
Transformer Zero Sequence Impedance      :0.01745
TRANSMISSION LINE MULTIPLICATION FACTORS
Number of Transmission Voltage Levels   :2

Transmission Line|Zero Sequence Impedance            |Zero Sequence Admittance
Voltage          |Resistance Factor|Reactance Factor|Admittance Factor
        220.00000           2.50000          2.50000           0.80000
         11.00000           2.50000          2.50000           0.02500

GENERATOR  MULTIPLICATION FACTORS
Negative Sequence Resistance             :0.17500
Negative Sequence Reactance              :0.17500
Zero Sequence Resistance                 :0.03750
Zero Sequence Reactance                  :0.03750
LOAD MULTIPLICATION FACTORS
Negative Sequence Impedance              :0.81000
Zero Sequence Impedance                  :1.60000
SERIES REACTOR MULTIPLICATION FACTORS
Series Reactor Zero Sequence Impedance  :1.00000
SHUNT REACTOR MULTIPLICATION FACTORS
Shunt Reactor Zero Sequence Impedance   :0.62500

|*****ELEMENT DATA*****|
|-----BUS DATA-----|

     UID      |AREA  |ZONE  |OWNER |   RATED    | BUS NAME | V MAG    | V ANG   |  PGEN       |   QGEN      |  PLOAD      |  QLOAD      |  QCOMP
              |NUMBER|NUMBER|NUMBER|VOLTAGE(kV)|          | (p.u.)   | (deg)   |  (MW)       |  (MVAr)     |  (MW)       |  (MVAr)     |  (MVAr)
BUS.1              1      1      1     11.000 Bus1          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.2              1      1      1    220.000 Bus2          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
BUS.3              1      1      1    220.000 Bus3          1.00000    0.000        0.000        0.000        0.000        0.000        0.000
|-----TWO WINDING TRANSFORMER DATA-----|

   UID |  FROM BUS  |   TO BUS   |STATUS| NO OF  |  R1     |  X1     |  R0     |  X0     |FROM SIDE GROUNDING| TO SIDE GROUNDING |NOMTAP|PHASE
SHIFT|     CB RATING(MVA)     |WIND CONN
       |            |            |      |CIRCUITS| (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  | R(p.u.) | X(p.u.) | R(p.u.) | X(p.u.) |      |    (deg)
|  FROM      | TO          |FROM|TO
TF2.1    BUS.2        BUS.1             3       1  0.00499   0.09988   0.00499   0.09988   0.00000   0.00000   0.00000   0.00000  0.975
30.000   10000.000     350.000 G    D

|-----TRANSMISSION LINE DATA-----|

     UID      | FROM BUS    | TO BUS      |STATUS| NO OF  |   R1    |  X1     | +VEB/2  | R0      |   X0     |ZERO B/2 | CB RATING(MVA)
              |             |             |      |CIRCUITS| (p.u.)  | (p.u.)  | (p.u.)  | (p.u.)  |  p.u.    | (p.u.)  |  FROM      | TO

LIN.1         BUS.2         BUS.3              3       1   0.00000   0.00083   0.00000   0.00000   0.00207   0.00000   10000.000   10000.000

|-----GENERATOR DATA-----|

     UID      | BUS NUMBER |STATUS|NO OF|   R1     |   X1     |   R2     |   X2     |   R0     |   X0     | CB RATING | WIND CONN
              |            |      |UNITS| (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   | (p.u.)   |   (MVA)   |
GEN.1         BUS.1              3     1   0.00000   0.10000   0.00000   0.10000   0.00000   0.10000     350.000 G

|~~~~~OUTPUT RESULTS~~~~~|

|*****Case Number : 1*****|
LLG FAULT ON    LIN.1 AT 50.00%         CURRENT (AMP/DEGREE)
 SEQUENCE (1,2,0)       PHASE (A,B,C)        SEQUENCE (1,2,0) PHASE (A,B,C)
   A        deg          A        deg             MVA              MVA
--------- --------     --------- --------     ---------------- -------------
 2624.319  -90.000       0.000    0.000             1000.000          0.000
    0.000    0.000    4545.455  120.000                0.000       1732.051
 2624.319   90.000    4545.455   60.000             1000.000       1732.051

|-----POST FAULT BUS VOLTAGES-----|
UID              BUS             SEQUENCE (1,2,0)         PHASE (A,B,C)        LINE-LINE MAG
                 NAME
                                 p.u.          deg        p.u.          deg          p.u.
------------    ------------     --------- --------      --------- --------     -------------
BUS.1            Bus1             0.00000  -30.000       0.00000  -30.000        0.00000
                                  0.00000    0.000       0.00000 -150.000        0.00000
                                  0.00000    0.000       0.00000   90.000        0.00000

BUS.2            Bus2             1.00000  177.138       0.00000   -3.978        1.00000
```

		0.00000	-0.000	1.73205	27.138	1.00000
		1.00000	-2.862	1.73205	-32.862	1.00000
BUS.3	Bus3	1.00413	177.149	0.00620	-0.000	1.00413
		0.00000	-0.000	1.74472	27.056	1.00413
		1.01032	-2.833	1.74441	-32.740	1.00413
DUMBUS.4	FAULTBUS	1.00413	177.149	0.00620	-0.000	1.00413
		0.00000	-0.000	1.74472	27.056	1.00413
		1.01032	-2.833	1.74441	-32.740	1.00413

|*****FAULT CONTRIBUTIONS FROM TWO WINDING TRANSFORMER*****|

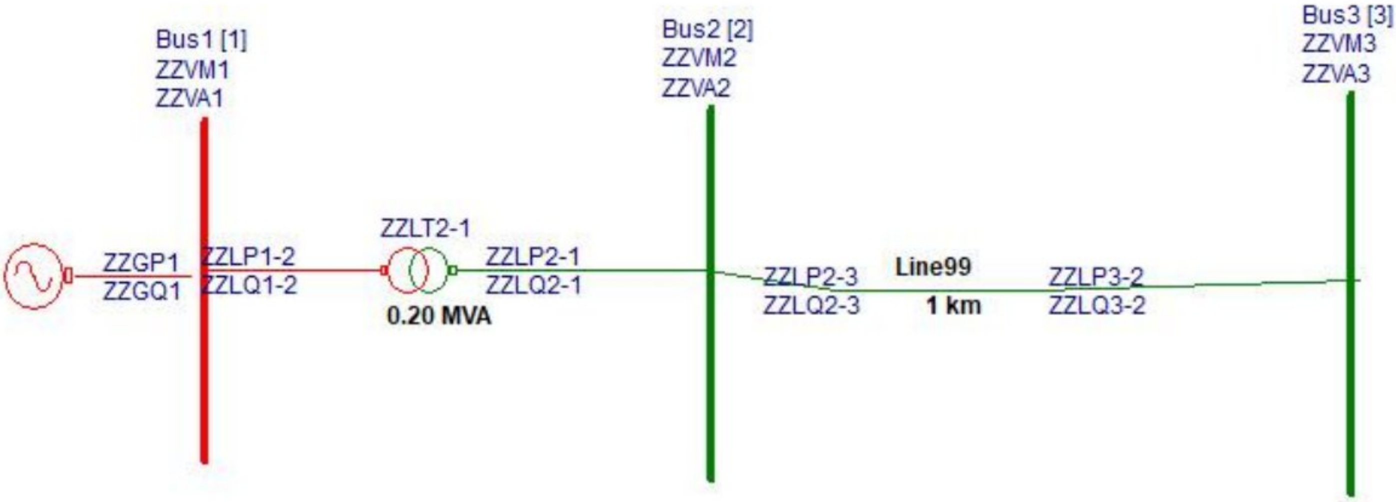
UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
TF2.1	BUS.2	Bus2	BUS.1	Bus1	2624.319	90.000	0.000	-91.115	0.000
					0.000	0.000	4545.455	-60.000	1732.051
					2624.319	-90.000	4545.455	-120.000	1732.051

|*****FAULT CONTRIBUTIONS FROM TRANSMISSION LINE*****|

UID	FROM BUS	FROM BUSNAME	TO BUS	TO BUSNAME	CURRENT SEQUENCE(1,2,0) A	deg	PHASE(A,B,C) A	deg	FAULT MVA PHASE(A,B,C) MVA
LIN.1	BUS.2	Bus2	BUS.3	Bus3	2624.319	-90.000	0.000	88.943	0.000
					0.000	0.000	4545.455	120.000	1732.051
					2624.319	90.000	4545.455	60.000	1732.051
LIN.1	BUS.3	Bus3	BUS.2	Bus2	0.000	-91.432	0.000	-91.164	0.000
					0.000	0.000	0.000	139.494	0.000
					0.000	87.495	0.000	37.399	0.000

|*****BUS FAULT SUMMARY*****|

Bus Number	Bus Name	Rated Voltage(kV)	LLG MVA	Current(kA)
BUS.1	Bus1	11.000	1732.051	90.909


Bus1 [1]
ZZVM1
ZZVA1
Bus2 [2]
ZZVM2
ZZVA2
Bus3 [3]
ZZVM3
ZZVA3
ZZLT2-1
ZZGP1
ZZGQ1
ZZLP1-2
ZZLQ1-2
ZZLP2-1
ZZLQ2-1
0.20 MVA
ZZLP2-3
ZZLQ2-3
Line99
1 km
ZZLP3-2
ZZLQ3-2

Experiment no: 12
Date: 22/11/2021.

Surabi Balakrishnan
Roll no: 39.

Stability Analysis

AIM:

To simulate transient stability for a sample power system network

OBJECTIVE:

To find the critical clearing angle by applying equal area criteria for a power system network using Mipower.

THEORY:

Power system stability is the ability of the various synchronous machines of the system to remain in synchronism or in step with each other. Transients in electrical system can be classified into electromagnetic & electromechanical.

Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance like transmission line faults, sudden load change, loss of generation, line switching etc.

EXERCISE:

Sample 3 bus system is shown in figure. System consist of a synchronous machine connected to an infinite bus. Generator parameters & transmission line parameters are given in tables. Impedance of lines & generators are in pu on 25 MVA base & system frequency is 60 Hz. 3ϕ to ground fault is occured on bus 2 at 1 sec & fault is cleared at 1.2 secs by opening the lines 1-2 & 2-3. Plot the swing curve & comment on results.

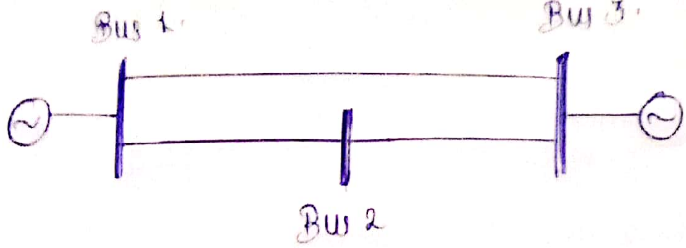


Table : Generator details.

	G1	G2
MVA rating	25	100
MW rating.	20	90
Specified voltage in pu.	1.03	1.0
Inertia H.	2.76	500.
Transient reactance x'_d in pu.	0.3	0.0001.
Real power minimum.	0	0
Real power maximum.	20	90.
Reactive power minimum	0	- 50.
Reactive power maximum.	16.	60
Model type.	classical/infinite	classical/infinite.

Transmission line details.

Impedance of lines in pu on 25 MVA base.		
Bus no.	Impedance R+jX.	Line charging B/2.
1-2.	0 + j0.1.	0
2-3	0 + j0.1	0
1-3.	0 + j0.2	0

› Procedure to solve exercise in Mipower.

- Create database & single line diagram for given data in Mipower.
- Select menu option. Solve → load flow analysis → study info.
- Select load flow type as fast decoupled with slack bus concept LFA & with P & Q tolerances of 0.001. Select bus 3 as slack bus.
- Execute load flow analysis.

- Execute load flow analysis & click on report → standard.
- Select solve → transient stability → study info.
- Stability dialog appears. Select constant voltage behind X_d', simulation time to be given as 5s in step of 0.001s.
- Select disturbance as 3ϕ to ground fault & click on info button.
- Enter the details & click OK.
- Select disturbance as change in line parameters. Enter the details & click OK. Open the line b/w buses 2 & 3 at 1.2 seconds.
- Execute transient stability.
- Click on report & check the complete execution of study.
- Click on graph button & plot the results (Time Vs terminal voltage, Time Vs swing curve, & time Vs frequency)
- In the time Vs frequency plot, find out time for 1 cycle after clearing the fault. Natural frequency of oscillation $f = 1/T$.

Tabulate the results.

- Repeat the above steps for fault clearing time of 1.3 sec & tabulate the results in table & comment on results.
- Increase the fault clearing time in steps & check the swing curve angle. Note down the time at which the swing angle curve crosses 180°. This is the critical clearing time.

Case details.	Fault clearing time.	Time taken for 1 comple cycle in S.	Frequency of oscillation in Hz.
Classical model frequency plot	Fault cleared at 1.2 sec.	1.56	0.64.
Classical model frequency plot.	Fault cleared at 1.3 sec.		

|~~~~~ INPUT DATA ~~~~~|
|***** SYSTEM SPECIFICATION *****|

Largest Bus Number Used : 3
Actual Number of Buses : 3
Number of Transmission Lines : 3
Number of Generators : 2

Load Flow - Fast De-Coupled Technique : 0
Number of Zones : 1
Print Option : 3 - Both Data and Results Print
Plot Option : 1 - Plotting with p.u. Voltage
No Frequency Dependent Load Flow, Control Option: 0
Base MVA : 25.0
Nominal System Frequency (Hz) : 60.0
Frequency Deviation (Hz) : 0.0
Flows in MW and MVAr, Option : 0
Slack Bus : 3
Transformer Tap Control Option : 0
Q Checking Limit (Enabled) : 4
Real Power Tolerance (p.u.) : 0.00100
Reactive Power Tolerance (p.u.) : 0.00100
Maximum Number of Iterations : 15
Bus Voltage below which Load Model is Changed : 0.75000
Circuit Breaker Resistance (p.u.) : 0.00000
Circuit Breaker Reactance (p.u.) : 0.00010
Transformer R/X Ratio : 0.05000

|***** PRESENT WORTH ANALYSIS DATA *****|
Annual Percentage Interest Charges : 15.000
Annual Percent Operation & Maintenance Charges : 4.000
Life of Equipment (Years) : 20.000
Energy Unit Charge (kWh) : 2.500 Rs
Loss Load Factor : 0.300
Cost Per MVAr (Lakhs) : 5.000 Rs

|***** ZONE WISE SCALING FACTORS *****|

ZONE	P LOAD	Q LOAD	P GEN	Q GEN	SH REACT	SH CAP	C LOAD
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000

|~~~~~ SYSTEM DATA ~~~~~|
|***** BUS DATA *****|

BUS NO.	AREA	ZONE	BUS kV	VMIN(p.u.)	VMAX(p.u.)	NAME
1	1	1	11.000	0.950	1.050	Bus1
2	1	1	11.000	0.950	1.050	Bus2
3	1	1	11.000	0.950	1.050	Bus3

|***** TRANSMISSION LINE DATA *****|

STA	CKT	FROM NODE	FROM NAME*	TO NODE	TO NAME*	LINE PARAMETER R(p.u.)	X(p.u.)	B/2(p.u.)	RATING MVA	KMS
3	1	1	Bus1	2	Bus2	0.00000	0.10000	0.00000	3	1.00
3	1	2	Bus2	3	Bus3	0.00000	0.10000	0.00000	3	1.00
3	1	1	Bus1	3	Bus3	0.00000	0.20000	0.00000	3	1.00

Total Line Charging Susceptance (p.u.) : 0.00000
Total Line Charging MVAr at 1 p.u. Voltage : 0.000
Number of Lines Opened on Both the Ends : 0
Total Line Charging susceptance of Existing Lines (p.u.) : 0.00000
Total Line Charging MVAr at 1 p.u. Voltage of Existing Lines : 0.000

Total Capacitive Susceptance : 0.00000 p.u. - 0.000 MVAr
Total Inductive Susceptance : 0.00000 p.u. - 0.000 MVAr

|***** GENERATOR DATA *****|

Sl.No*	FROM NODE	FROM NAME*	REAL POWER(MW)	Q-MIN MVAr	Q-MAX MVAr	V-SPEC p.u.	CAP. CURV	MVA RATING	STAT
1	1	Bus1	20.0000	0.0000	15.0000	1.0300	0	25.00	3
2	3	Bus3	80.0000	-50.0000	60.0000	1.0000	0	100.00	3

|***** OUTPUT DATA *****|

Total Specified MW Generation : 100.00000
Total Minimum MVAr Limit of Generator : -50.00000
Total Maximum MVAr Limit of Generator : 75.00000
Total Specified MW Load : 0.00000 Changed to 0.00000
Total Specified MVAr Load : 0.00000 Changed to 0.00000
Total Specified MVAr Compensation : 0.00000 Changed to 0.00000

Total (Including Out of Service Units)
Total Specified MW Generation : 100.00000
Total Minimum MVAr Limit of Generator : -50.00000
Total Maximum MVAr Limit of Generator : 75.00000
Total Specified MW Load : 0.00000 Changed to 0.00000
Total Specified MVAr Load : 0.00000 Changed to 0.00000
Total Specified MVAr Compensation : 0.00000 Changed to 0.00000

|----- GENERATOR DATA FOR FREQUENCY DEPENDENT LOAD FLOW -----|

SLNO*	FROM NODE	FROM NAME*	P-RATE MW	P-MIN MW	P-MAX MW	%DROOP C0	PARTICI FACTOR C1	BIAS SETTING C2
1	1	Bus1	20.000	0.0000	20.0000	4.0000	0.0000	0.0000
						0.0000	0.0000	0.0000
2	3	Bus3	80.000	0.0000	80.0000	4.0000	0.0000	0.0000
						0.0000	0.0000	0.0000

|~~~~~ OUTPUT RESULTS ~~~~~|
|----- CONVERGENCE INDEX -----|

ITERATION COUNT	MAX P BUS NUMBER	MAX P PER UNIT	MAX Q BUS NUMBER	MAX Q PER UNIT
1	1	0.800	2	0.285
2	2	0.012	2	0.000
3	2	0.000	2	0.000
4	2	0.000	2	0.000
5	2	0.000	2	0.000

Number of P Iterations : 2 and Number of Q Iterations : 4
|***** BUS VOLTAGES AND POWERS *****|

NODE NO.	FROM NAME	V-MAG p.u.	ANGLE DEGREE	MW GEN	MVAr GEN	MW LOAD	MVAr LOAD	MVAr COMP
1	Bus1	1.0300	4.45	20.000	8.503	0.000	0.000	0.000
2	Bus2	1.0142	2.26	0.000	0.000	0.000	0.000	0.000
3	Bus3	1.0000	0.00	-20.002	-6.722	0.000	0.000	0.000

NUMBER OF BUSES EXCEEDING MINIMUM VOLTAGE LIMIT (@ mark) : 0
NUMBER OF BUSES EXCEEDING MAXIMUM VOLTAGE LIMIT (# mark) : 0
NUMBER OF GENERATORS EXCEEDING MINIMUM Q LIMIT (< mark) : 0
NUMBER OF GENERATORS EXCEEDING MAXIMUM Q LIMIT (> mark) : 0

|***** LINE FLOWS AND LINE LOSSES *****|

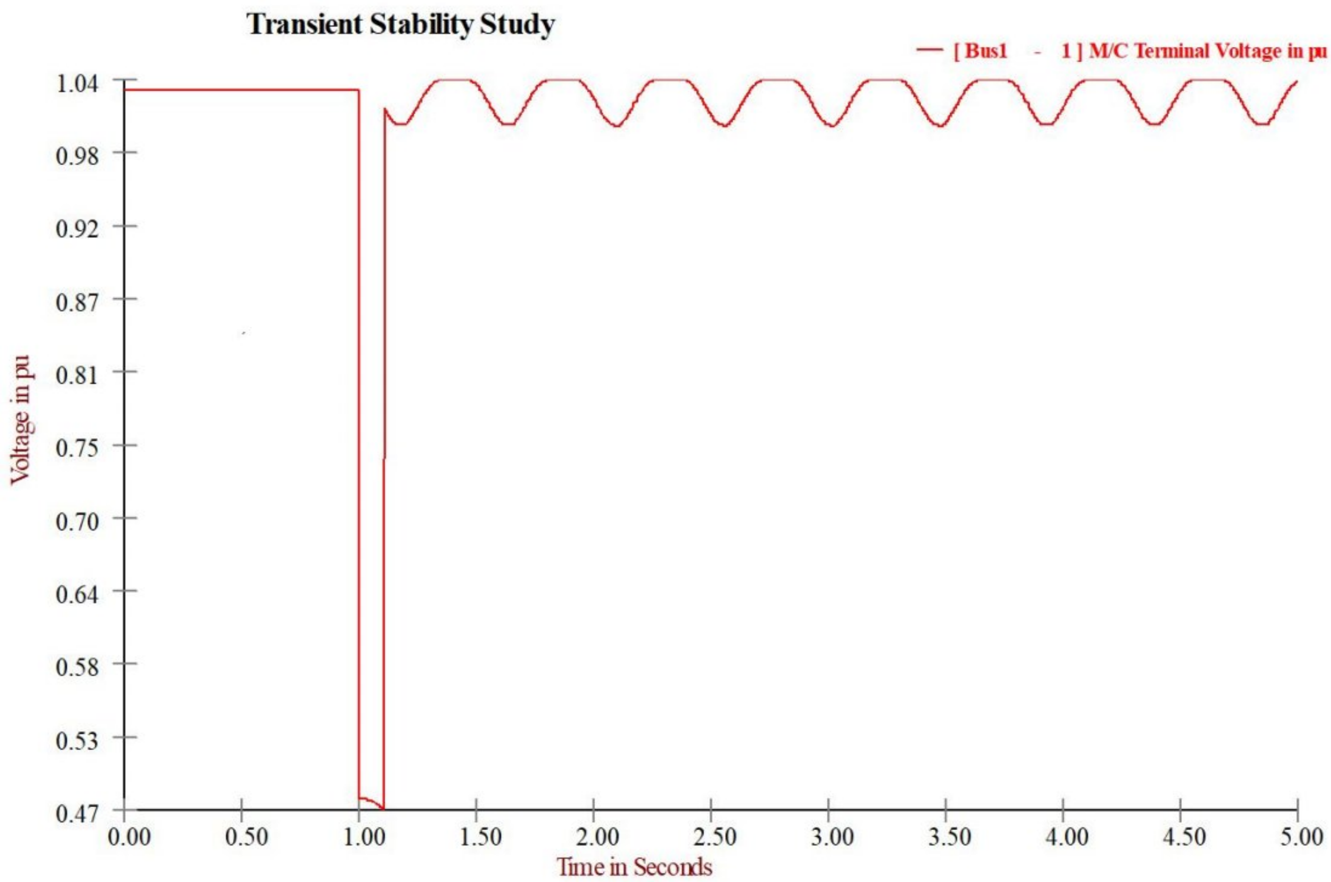
SLNO	CS	FROM NODE	FROM NAME	TO NODE	TO NAME	FORWARD MW	FORWARD MVAr	LOSS MW	LOSS MVAr	% LOADING
1	1	1	Bus1	2	Bus2	9.998	4.251	0.0000	0.4450	302.5!
2	1	2	Bus2	3	Bus3	10.002	3.806	0.0000	0.4453	302.6!
3	1	1	Bus1	3	Bus3	10.000	4.251	0.0000	0.8904	302.6!

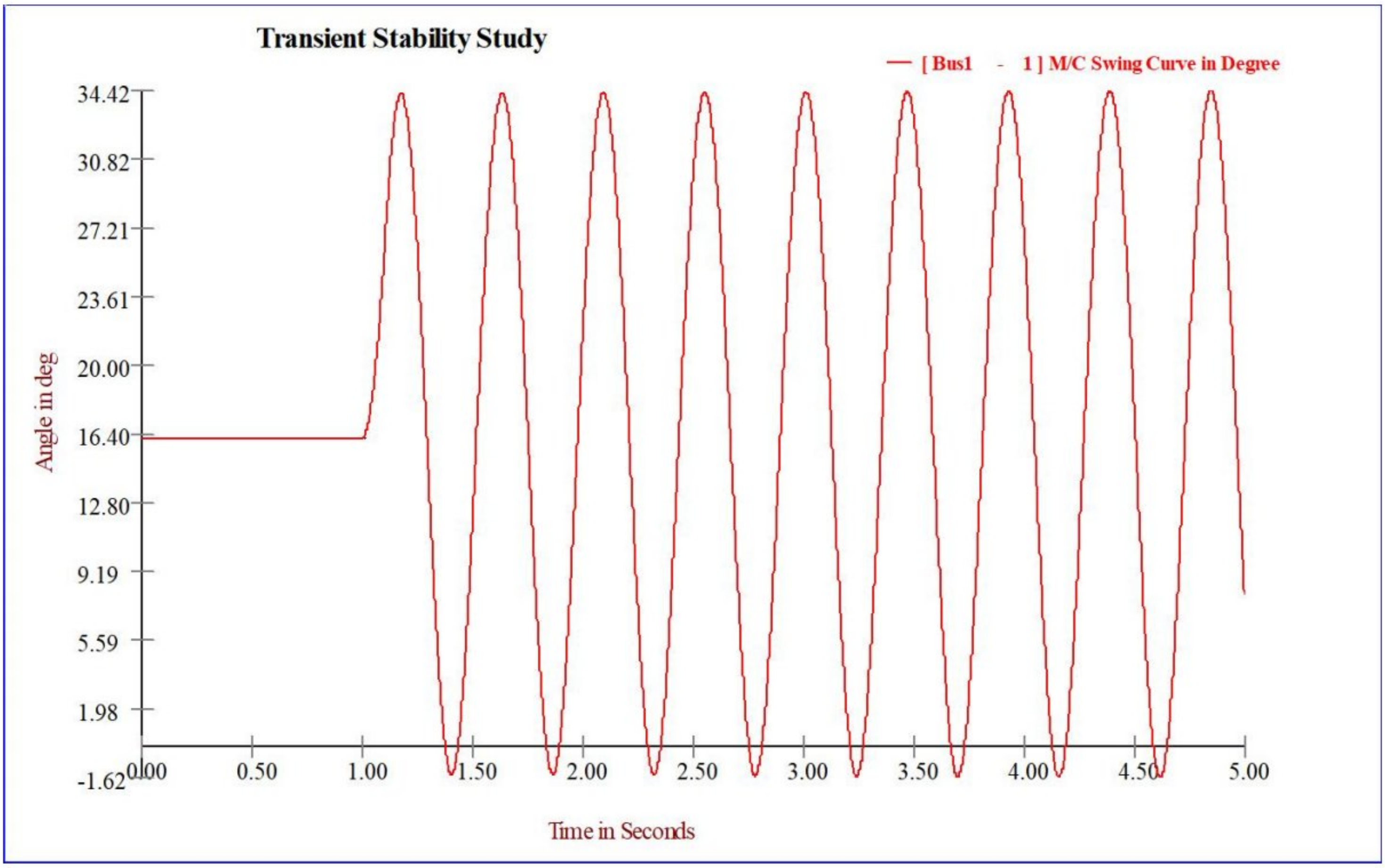
! NUMBER OF LINES LOADED BEYOND 125% : 3
@ NUMBER OF LINES LOADED BETWEEN 100% AND 125% : 0
# NUMBER OF LINES LOADED BETWEEN 75% AND 100% : 0
$ NUMBER OF LINES LOADED BETWEEN 50% AND 75% : 0
^ NUMBER OF LINES LOADED BETWEEN 25% AND 50% : 0
& NUMBER OF LINES LOADED BETWEEN 1% AND 25% : 0
* NUMBER OF LINES LOADED BETWEEN 0% AND 1% : 0
BUSES BETWEEN WHICH ANGLE DIFFERENCE IS > 30 degrees ARE: ZERO

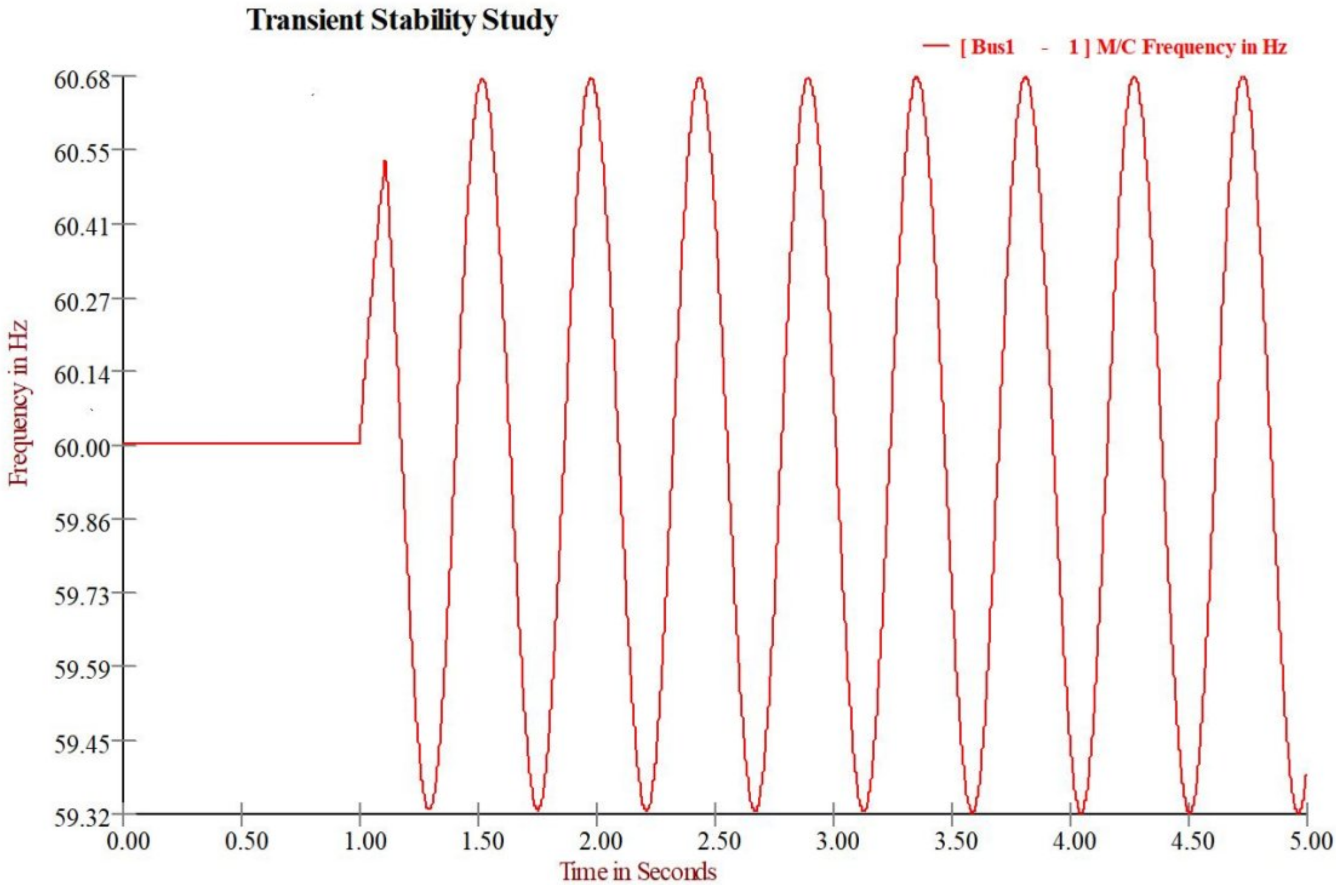
ISLAND	FREQUENCY	SLACK-BUS	CONVERGED(1)
1	60.00000	3	1

|***** SUMMARY OF RESULTS *****|

```
TOTAL REAL POWER GENERATION (CONVENTIONAL)   :      20.000 MW
TOTAL REAL POWER INJECTION (-ve LOAD)        :       0.000 MW
TOTAL REACT. POWER GENERATION (CONVENTIONAL) :       1.781 MVAr
GENERATION p.f.                              :       0.996

TOTAL REAL POWER GENERATION (WIND)           :       0.000 MW
TOTAL REACT. POWER GENERATION (WIND)         :       0.000 MVAr
TOTAL REAL POWER GENERATION (SOLAR)          :       0.000 MW
TOTAL REACT. POWER GENERATION (SOLAR)        :       0.000 MVAr
TOTAL SHUNT REACTOR INJECTION                :      -0.000 MW
TOTAL SHUNT REACTOR INJECTION                :      -0.000 MVAr
TOTAL SHUNT CAPACIT.INJECTION                :      -0.000 MW
TOTAL SHUNT CAPACIT.INJECTION                :      -0.000 MVAr
TOTAL TCSC REACTIVE DRAWL                    :       0.000 MVAr
TOTAL SPS REACTIVE DRAWL                     :       0.000 MVAr
TOTAL UPFC INJECTION                         :      -0.000 MVAr
TOTAL SHUNT FACTS INJECTION                  :       0.000 MVAr
TOTAL SHUNT FACTS DRAWAL                     :       0.000 MVAr
TOTAL REAL POWER LOAD                        :       0.000 MW
TOTAL REAL POWER DRAWAL (-ve gen.)           :      20.002 MW
TOTAL REACTIVE POWER LOAD                    :       0.000 MVAr
LOAD p.f.                                    :       0.000
TOTAL COMPENSATION AT LOADS                  :       0.000 MVAr
TOTAL HVDC REACTIVE POWER                    :       0.000 MVAr
TOTAL REAL POWER LOSS (AC+DC)                :       0.000000 MW (  0.000000+  0.000000)
PERCENTAGE REAL  LOSS (AC+DC)                :       0.000
TOTAL REACTIVE POWER  LOSS                   :       1.780756 MVAr
|----- ZONE WISE DISTRIBUTION -----|
Description        Zone # 1
---------------- ----------
MW generation       -0.0020
MVAr generation      1.7808
MW wind gen.        0.0000
MVAr wind gen.      0.0000
MW solar gen.        0.0000
MVAr solar gen.      0.0000
MW load              0.0000
MVAr load            0.0000
MVAr compensation    0.0000
MW loss              0.0000
MVAr loss            1.7808
MVAr - inductive     0.0000
MVAr - capacitive    0.0000

|----- AREA WISE DISTRIBUTION -----|
Description        Area # 1
---------------- ----------
MW generation       -0.0020
MVAr generation      1.7808
MW wind gen.        0.0000
MVAr wind gen.      0.0000
MW solar gen.        0.0000
MVAr solar gen.      0.0000
MW load              0.0000
MVAr load            0.0000
MVAr compensation    0.0000
MW loss              0.0000
MVAr loss            1.7808
MVAr - inductive     0.0000
MVAr - capacitive    0.0000
```


Transient Stability Study
— [Bus1 - 1] M/C Terminal Voltage in pu
1.04
0.98
0.92
0.87
0.81
0.75
0.70
0.64
0.58
0.53
0.47
Voltage in pu
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Time in Seconds


Transient Stability Study
— [Bus1 - 1] M/C Swing Curve in Degree
34.42
30.82
27.21
23.61
20.00
16.40
12.80
9.19
5.59
1.98
-1.62
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Angle in deg
Time in Seconds



Transient Stability Study
[Bus1 - 1] M/C Frequency in Hz
Frequency in Hz
60.68
60.55
60.41
60.27
60.14
60.00
59.86
59.73
59.59
59.45
59.32
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Time in Seconds

Experiment no : 13

Surabi Balakrishnan.
Roll no : 39.

Date : 29/11/2021.

SOLAR POWER CALCULATIONS

AIM

To calculate the rating of solar panel required for a given area on rooftop for a given load.

OBJECTIVE

To calculate rating of solar panel & compare the calculations with modelling in MiPower.

THEORY

Solar power is the conversion of sunlight into electricity either directly using solar photovoltaic systems or indirectly using solar thermal systems (concentrated solar power).

Solar power technologies classification;

- Solar photovoltaic.
- Solar thermal.

Exercise

A 4 bus slm is shown in figure. The load & generation data and system parameters are given in table. Calculate the rating of solar panel required for a given area on rooftop or for a given load using load flow solution.

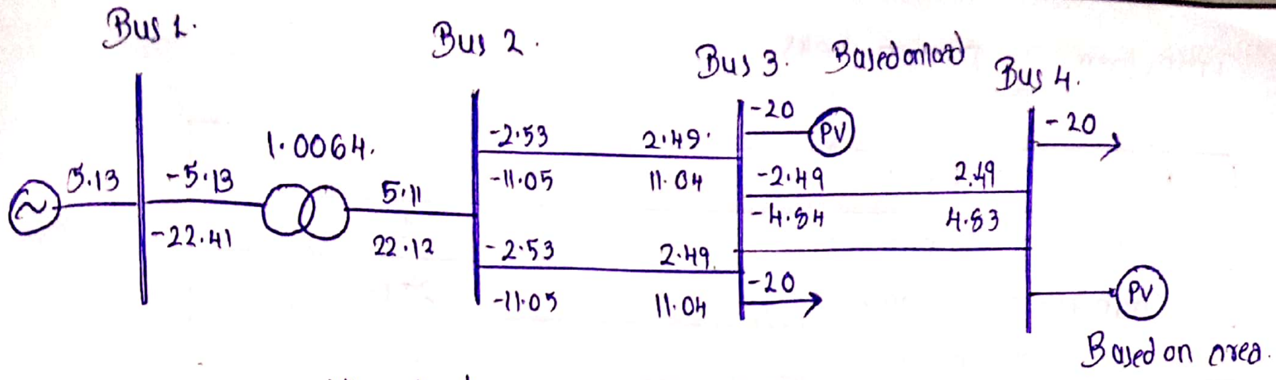


fig: 4 bus system.

Generator & load data.

Bus no.	Bus name.	Bus v/g in KV.	V-specified in PU.	Generation		Load.	
				MW	MVAR	MW	MVAR.
1	Bus 1.	11.	1.00+j0.0	21	15.75.	0	0
2	Bus 2	0.415	0	-	-	0	0
3	Bus 3	0.415	0	-	-	0.02	0.009.
4.	Bus 4.	0.415	0	-	-	0.02	0.009.

Transmission line parameters.

Sl no.	Bus no.	Length	Impedance (pu)	Library ref. no.
1.	2-3	0.05 Km	1.04 + j0.382.	2-Weasel
2	3-4.	0.05 Km.	1.04+j0.382	2-weasel.

Solar PV parameters.

Sl no	Library no	Bus no.	Solar irradiance (W/m^2)	Cell temperature (°C)	PV array data.	
					Modules	String.
1.	Type 17.	3 (based on load)	1000	25	20	4
2	Type 17	4 (based on area)	1000	25	20	3

Procedure to solve the exercise in MiPower.

1) Create database & single line diagram in MiPower from the given data.

2) Connect solar PV plant to bus 3 & bus 4 as shown in figure.

Transformer data & library details are provided in figure.

Transformer parameters:

Transformer details.	
Transformer number.	1.
Transformer name.	2T1.
From Bus number	1.
To bus number.	2
Control bus number.	1
No. of units in parallel.	1
Manufacturer ref. number.	1.
De-rated MVA.	0.2
From breaker rating.	350
to braker rating.	50
Nominal tap position.	5.

3) Enter the details as shown in table.

4) Enter PV Array data values using 2 different methods.

i) Based on given area.

ii) Based on given load.

5) Execute load flow analysis & compare the results with maximum solar power generation with the respective plants.

|~~~~~ INPUT DATA ~~~~~|

|***** SYSTEM SPECIFICATION *****|

Largest Bus Number Used	:	4
Actual Number of Buses	:	4
Number of Two Winding Transformers	:	1
Number of Transmission Lines	:	4
Number of Generators	:	1
Number of Loads	:	2

Load Flow With Newton Raphson Method	:	6
Number of Zones	:	1
Print Option	:	3 - Both Data and Results Print
Plot Option	:	1 - Plotting with p.u. Voltage
No Frequency Dependent Load Flow, Control Option	:	0
Base MVA	:	100.0
Nominal System Frequency (Hz)	:	50.0
Frequency Deviation (Hz)	:	0.0
Flows in MW and MVAr, Option	:	0
Slack Bus	:	1
Transformer Tap Control Option	:	0
Q Checking Limit (Enabled)	:	4
Real Power Tolerance (p.u.)	:	0.00100
Reactive Power Tolerance (p.u.)	:	0.00100
Maximum Number of Iterations	:	15
Bus Voltage below which Load Model is Changed	:	0.75000
Circuit Breaker Resistance (p.u.)	:	0.00000
Circuit Breaker Reactance (p.u.)	:	0.00010
Transformer R/X Ratio	:	0.05000

|***** PRESENT WORTH ANALYSIS DATA *****|

Annual Percentage Interest Charges	:	15.000
Annual Percent Operation & Maintenance Charges	:	4.000
Life of Equipment (Years)	:	20.000
Energy Unit Charge (kWh)	:	2.500 Rs
Loss Load Factor	:	0.300
Cost Per MVAr (Lakhs)	:	5.000 Rs

|***** ZONE WISE SCALING FACTORS *****|

ZONE	P LOAD	Q LOAD	P GEN	Q GEN	SH REACT	SH CAP	C LOAD
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000

|~~~~~ SYSTEM DATA ~~~~~|

|***** BUS DATA *****|

BUS NO.	AREA	ZONE	BUS kV	VMIN(p.u.)	VMAX(p.u.)	NAME
1	1	1	11.000	0.950	1.050	Bus1
2	1	1	0.415	0.950	1.050	Bus2
3	1	1	0.415	0.950	1.050	Bus3
4	1	1	0.415	0.950	1.050	Bus4

|***** TRANSFORMER DATA *****|

STATUS	CKT	FROM NODE	FROM NAME*	TO NODE	TO NAME*	IMPEDANCE R(p.u.)	X(p.u.)	NOMINAL TAP	RATING MVA
	CTR					MINTAP	MAXTAP	TAPSTEP	SHIFT-DE
3	1	1	Bus1	2	Bus2	2.71817	54.36350	1.00635	0.20
	0					0.91051	1.00635	0.02500	0.000

|***** TRANSMISSION LINE DATA *****|

STA	CKT	FROM NODE	FROM NAME*	TO NODE	TO NAME*	LINE PARAMETER R(p.u.)	X(p.u.)	B/2(p.u.)	RATING MVA	KMS
3	1	2	Bus2	3	Bus3	30.19310	11.09010	0.00000	2	0.05
3	1	2	Bus2	3	Bus3	30.19310	11.09010	0.00000	2	0.05
3	1	3	Bus3	4	Bus4	30.19310	11.09010	0.00000	2	0.05
3	1	3	Bus3	4	Bus4	30.19310	11.09010	0.00000	2	0.05

```
Total Line Charging Susceptance  (p.u.)                        :    0.00000
Total Line Charging MVAr at 1 p.u. Voltage                     :    0.000
Number of Lines Opened on Both the Ends                        :    0
Total Line Charging susceptance of Existing Lines (p.u.)       :    0.00000
Total Line Charging MVAr at 1 p.u. Voltage of Existing Lines :    0.000
------------------------------------------------------------------------------
Total Capacitive Susceptance          :   0.00000 p.u. -    0.000 MVAr
Total Inductive Susceptance           :   0.00000 p.u. -    0.000 MVAr

|***** GENERATOR DATA *****|

Sl.No*     FROM     FROM      REAL     Q-MIN     Q-MAX    V-SPEC CAP.     MVA STAT
           NODE     NAME*POWER(MW)      MVAr      MVAr      p.u. CURV  RATING
------ -------- -------- --------- --------- --------- --------- ---- ------- ----
     1        1     Bus1  25.0000   15.7500   15.7500    1.0000    0   26.25    3

|***** LOAD DATA *****|

Sl.No.     FROM     FROM     REAL REACTIVE     COMP COMPENSATING MVAR VALUE CHAR  F/V
*          NODE     NAME*      MW     MVAr     MVAr     MIN     MAX    STEP  NO.  NO.
                                                                            STAT
------ -------- -------- -------- -------- -------- ------- ------- ------- ---- ----
     1        3     Bus3    0.020    0.009    0.000   0.000   0.000   0.000    0    0
                                                                               3    0
     2        4     Bus4    0.020    0.009    0.000   0.000   0.000   0.000    0    0
                                                                               3    0
|***** OUTPUT DATA *****|

Total Specified MW Generation          :  25.00000
Total Minimum MVAr Limit of Generator  :  15.75000
Total Maximum MVAr Limit of Generator  :  15.75000
Total Specified MW Load                :   0.04000 Changed to    0.04000
Total Specified MVAr Load              :   0.01800 Changed to    0.01800
Total Specified MVAr Compensation      :   0.00000 Changed to    0.00000
------------------------------------------------------------------------------
Total (Including Out of Service Units)
Total Specified MW Generation          :  25.00000
Total Minimum MVAr Limit of Generator  :  15.75000
Total Maximum MVAr Limit of Generator  :  15.75000
Total Specified MW Load                :   0.04000 Changed to    0.04000
Total Specified MVAr Load              :   0.01800 Changed to    0.01800
Total Specified MVAr Compensation      :   0.00000 Changed to    0.00000

|----- GENERATOR DATA FOR FREQUENCY DEPENDENT LOAD FLOW -----|
SLNO*      FROM     FROM   P-RATE     P-MIN     P-MAX    %DROOP   PARTICI      BIAS
           NODE     NAME*      MW        MW        MW               FACTOR   SETTING
                                                              C0        C1        C2
------ -------- -------- -------- --------- --------- --------- --------- ---------
     1        1     Bus1   21.000    0.0000   25.0000    4.0000    0.0000    0.0000
                                                         0.0000    0.0000    0.0000
Slack Bus Angle (degree) :   0.00
------------------------------------------------------------------------------
|~~~~~ OUTPUT RESULTS ~~~~~|
|***** BUS VOLTAGES AND POWERS *****|

    NODE     FROM  V-MAG  ANGLE        MW     MVAr        MW     MVAr      MVAr
     NO.     NAME   p.u. DEGREE       GEN      GEN      LOAD     LOAD      COMP
-------- -------- ------ ------ -------- -------- -------- -------- --------
       1     Bus1 1.0000   0.00     0.039    0.018     0.000    0.000     0.000  <
       2     Bus2 0.9829  -1.23     0.000    0.000     0.000    0.000     0.000
       3     Bus3 0.9759  -1.20     0.000    0.000     0.020    0.009     0.000
       4     Bus4 0.9724  -1.18     0.000    0.000     0.020    0.009     0.000
------------------------------------------------------------------------------
NUMBER OF BUSES EXCEEDING MINIMUM VOLTAGE LIMIT (@ mark) :    0
NUMBER OF BUSES EXCEEDING MAXIMUM VOLTAGE LIMIT (# mark) :    0
NUMBER OF GENERATORS EXCEEDING MINIMUM Q LIMIT (< mark)  :    1
NUMBER OF GENERATORS EXCEEDING MAXIMUM Q LIMIT (> mark)  :    0

|***** TRANSFORMER FLOWS AND TRANSFORMER LOSSES *****|

Sl.NoCS     FROM     FROM       TO       TO        FORWARD           LOSS           %
            NODE     NAME     NODE     NAME       MW     MVAr        MW     MVAr LOADING
---- -- -------- -------- -------- -------- -------- -------- -------- -------- -------
   1  1        1     Bus1        2     Bus2    0.039    0.018   0.0001   0.0010    21.7&
```

! NUMBER OF TRANSFORMERS LOADED BEYOND 125% : 0
@ NUMBER OF TRANSFORMERS LOADED BETWEEN 100% AND 125% : 0
# NUMBER OF TRANSFORMERS LOADED BETWEEN 75% AND 100% : 0
$ NUMBER OF TRANSFORMERS LOADED BETWEEN 50% AND 75% : 0
^ NUMBER OF TRANSFORMERS LOADED BETWEEN 25% AND 50% : 0
& NUMBER OF TRANSFORMERS LOADED BETWEEN 1% AND 25% : 1
* NUMBER OF TRANSFORMERS LOADED BETWEEN 0% AND 1% : 0

|***** LINE FLOWS AND LINE LOSSES *****|

SLNO	CS	FROM NODE	FROM NAME	TO NODE	TO NAME	FORWARD MW	FORWARD MVAr	LOSS MW	LOSS MVAr	% LOADING
2	1	2	Bus2	3	Bus3	0.020	0.009	0.0001	0.0001	0.9*
3	1	2	Bus2	3	Bus3	0.020	0.009	0.0001	0.0001	0.9*
4	1	3	Bus3	4	Bus4	0.010	0.004	0.0000	0.0000	0.5*
5	1	3	Bus3	4	Bus4	0.010	0.004	0.0000	0.0000	0.5*

! NUMBER OF LINES LOADED BEYOND 125% : 0
@ NUMBER OF LINES LOADED BETWEEN 100% AND 125% : 0
# NUMBER OF LINES LOADED BETWEEN 75% AND 100% : 0
$ NUMBER OF LINES LOADED BETWEEN 50% AND 75% : 0
^ NUMBER OF LINES LOADED BETWEEN 25% AND 50% : 0
& NUMBER OF LINES LOADED BETWEEN 1% AND 25% : 0
* NUMBER OF LINES LOADED BETWEEN 0% AND 1% : 4

|***** SUMMARY OF RESULTS *****|

TOTAL REAL POWER GENERATION (CONVENTIONAL) : 0.039 MW
TOTAL REAL POWER INJECTION (-ve LOAD) : 0.000 MW
TOTAL REACT. POWER GENERATION (CONVENTIONAL) : 0.018 MVAr
GENERATION p.f. : 0.908
TOTAL REAL POWER GENERATION (WIND) : 0.000 MW
TOTAL REACT. POWER GENERATION (WIND) : 0.000 MVAr
TOTAL REAL POWER GENERATION (SOLAR) : 0.000 MW
TOTAL REACT. POWER GENERATION (SOLAR) : 0.000 MVAr
TOTAL SHUNT REACTOR INJECTION : -0.000 MW
TOTAL SHUNT REACTOR INJECTION : -0.000 MVAr
TOTAL SHUNT CAPACIT.INJECTION : -0.000 MW
TOTAL SHUNT CAPACIT.INJECTION : -0.000 MVAr
TOTAL TCSC REACTIVE DRAWL : 0.000 MVAr
TOTAL SPS REACTIVE DRAWL : 0.000 MVAr
TOTAL UPFC INJECTION : -0.000 MVAr
TOTAL SHUNT FACTS INJECTION : 0.000 MVAr
TOTAL SHUNT FACTS DRAWAL : 0.000 MVAr
TOTAL REAL POWER LOAD : 0.040 MW
TOTAL REAL POWER DRAWAL (-ve gen.) : 0.000 MW
TOTAL REACTIVE POWER LOAD : 0.018 MVAr
LOAD p.f. : 0.912
TOTAL COMPENSATION AT LOADS : 0.000 MVAr
TOTAL HVDC REACTIVE POWER : 0.000 MVAr

TOTAL REAL POWER LOSS (AC+DC) : 0.000415 MW (0.000415+ 0.000000)
PERCENTAGE REAL LOSS (AC+DC) : 1.054
TOTAL REACTIVE POWER LOSS : 0.001166 MVAr
|----- ZONE WISE DISTRIBUTION -----|

Description	Zone # 1
MW generation	0.0393
MVAr generation	0.0181
MW wind gen.	0.0000
MVAr wind gen.	0.0000
MW solar gen.	0.0000
MVAr solar gen.	0.0000
MW load	0.0400
MVAr load	0.0180
MVAr compensation	0.0000
MW loss	0.0004
MVAr loss	0.0012
MVAr - inductive	0.0000
MVAr - capacitive	0.0000

|----- AREA WISE DISTRIBUTION -----|

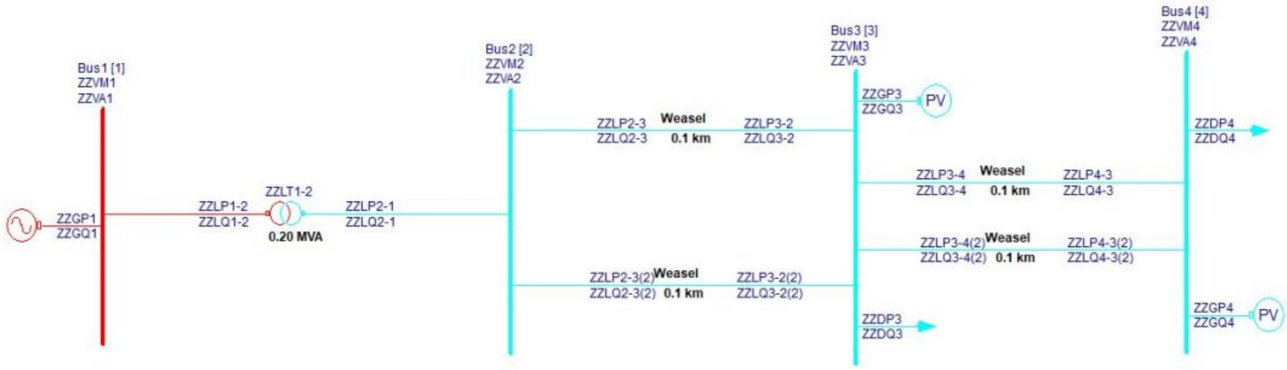
```
Description        Area # 1
---------------- ----------
MW generation        0.0393
MVAr generation      0.0181
MW wind gen.        0.0000
MVAr wind gen.      0.0000
MW solar gen.        0.0000
MVAr solar gen.      0.0000
MW load              0.0400
MVAr load            0.0180
MVAr compensation    0.0000
MW loss              0.0004
MVAr loss            0.0012
MVAr - inductive     0.0000
MVAr - capacitive    0.0000
```

```
--------------------------------------------------------------------------------
|~~~~~ INPUT DATA ~~~~~|
|***** SYSTEM SPECIFICATION *****|
Largest Bus Number Used             :    4
Actual Number of Buses              :    4
Number of Two Winding Transformers  :    1
Number of Transmission Lines        :    4
Number of Generators                :    1
Number of Loads                     :    2
Number of solar plants              :    2
--------------------------------------------------------------------------------
Load Flow With Newton Raphson Method           :    6
Number of Zones                                :    1
Print Option                                   :    3 - Both Data and Results Print
Plot Option                                    :    1 - Plotting with p.u. Voltage
No Frequency Dependent Load Flow, Control Option:   0
Base MVA                                       :  100.0
Nominal System Frequency (Hz)                  :   50.0
Frequency Deviation (Hz)                       :    0.0
Flows in MW and MVAr, Option                   :    0
Slack Bus                                      :    1
Transformer Tap Control Option                 :    0
Q Checking Limit  (Enabled)                    :    4
Real Power Tolerance (p.u.)                    :    0.00100
Reactive Power Tolerance (p.u.)                :    0.00100
Maximum Number of Iterations                   :   15
Bus Voltage below which Load Model is Changed  :    0.75000
Circuit Breaker Resistance (p.u.)              :    0.00000
Circuit Breaker Reactance (p.u.)               :    0.00010
Transformer R/X Ratio                          :    0.05000

|***** PRESENT WORTH ANALYSIS DATA *****|
Annual Percentage Interest Charges             :   15.000
Annual Percent Operation & Maintenance Charges :    4.000
Life of Equipment (Years)                      :   20.000
Energy Unit Charge (kWh)                       :    2.500 Rs
Loss Load Factor                               :    0.300
Cost Per MVAr (Lakhs)                          :    5.000 Rs
--------------------------------------------------------------------------------

|***** ZONE WISE SCALING FACTORS *****|

ZONE   P LOAD   Q LOAD    P GEN    Q GEN SH REACT   SH CAP   C LOAD
---- -------- -------- -------- -------- -------- -------- --------
   0    1.000    1.000    1.000    1.000    1.000    1.000    1.000
   1    1.000    1.000    1.000    1.000    1.000    1.000    1.000
--------------------------------------------------------------------------------

|~~~~~ SYSTEM DATA ~~~~~|
|***** BUS DATA *****|
 BUS NO. AREA ZONE   BUS kV VMIN(p.u.) VMAX(p.u.)     NAME
-------- ---- ---- -------- ---------- ---------- --------
       1    1    1   11.000      0.950      1.050     Bus1
       2    1    1    0.415      0.950      1.050     Bus2
       3    1    1    0.415      0.950      1.050     Bus3
       4    1    1    0.415      0.950      1.050     Bus4
--------------------------------------------------------------------------------

|***** TRANSFORMER DATA *****|
STATUS CKT     FROM     FROM       TO       TO      IMPEDANCE         NOMINAL   RATING
               NODE    NAME*     NODE    NAME*   R(p.u.)  X(p.u.)       TAP      MVA
       CTR                                        MINTAP    MAXTAP   TAPSTEP SHIFT-DE
------ --- -------- -------- -------- -------- --------- --------- --------- --------
     3   1        1     Bus1        2     Bus2   2.71817  54.36350   1.00635     0.20
         0                                       0.91051   1.00635   0.02500    0.000

|***** TRANSMISSION LINE DATA *****|

STA CKT     FROM     FROM       TO       TO          LINE PARAMETER        RATING    KMS
            NODE    NAME*     NODE    NAME*  R(p.u.)   X(p.u.) B/2(p.u.)     MVA
--- --- -------- -------- -------- -------- --------- --------- --------- ------ ------
  3   1        2     Bus2        3     Bus3  30.19310  11.09010   0.00000      2   0.05
  3   1        2     Bus2        3     Bus3  30.19310  11.09010   0.00000      2   0.05
  3   1        3     Bus3        4     Bus4  30.19310  11.09010   0.00000      2   0.05
```

```
  3   1       3    Bus3       4    Bus4  30.19310  11.09010   0.00000      2   0.05
Total Line Charging Susceptance  (p.u.)                    :    0.00000
Total Line Charging MVAr at 1 p.u. Voltage                 :    0.000
Number of Lines Opened on Both the Ends                    :    0
Total Line Charging susceptance of Existing Lines (p.u.)   :    0.00000
Total Line Charging MVAr at 1 p.u. Voltage of Existing Lines :    0.000
-------------------------------------------------------------------------------
Total Capacitive Susceptance          :   0.00000 p.u. -    0.000 MVAr
Total Inductive Susceptance           :   0.00000 p.u. -    0.000 MVAr

-------------------------------------------------------------------------------

|***** GENERATOR DATA *****|
Sl.No*     FROM     FROM      REAL     Q-MIN     Q-MAX    V-SPEC CAP.     MVA STAT
           NODE     NAME*POWER(MW)      MVAr      MVAr      p.u. CURV  RATING
------ -------- -------- --------- --------- --------- --------- ---- ------- ----
     1        1     Bus1  25.0000  15.7500  15.7500    1.0000    0   26.25    3
-------------------------------------------------------------------------------

|----- SOLAR PV DETAILED MODEL DATA -----|
Sl.No*     FROM     FROM IRR_DATA IRR_TILTED  GHI DHI/  DHI  DNI  AMB. MOUNTING  TILT AZMITH STATUS
           NODE     NAME*     TYPE      PLANE        DNI           TEMP.     TYPE ANGLE  ANGLE
------ -------- -------- -------- ---------- ---- ---- ---- ---- ----- -------- ----- ------ ------
     1        3     Bus3        0   1000.000    0    0    0    0 15.00        0 0.000  0.000      3
     2        4     Bus4        0   1000.000    0    0    0    0 15.00        0 0.000  0.000      3
-------------------------------------------------------------------------------
|----- SOLAR TIME AND LOCATION DATA -----|
Sl.No*     FROM     FROM  DAY MONTH HOUR  MIN LATITUDE  LONGITUDE STANDARD_MERIDIAN
           NODE     NAME*                    DEG. MIN. DEG. MIN.     DEG.     MIN.
------ -------- -------- ---- ----- ---- ---- ---- ---- ---- ---- -------- --------
     1        3     Bus3    0     0    0    0    0    0    0    0        0        0
     2        4     Bus4    0     0    0    0    0    0    0    0        0        0
-------------------------------------------------------------------------------
|----- SOLAR LIBRARY DATA -----|
Sl.No*     FROM     FROM DATA   SER.   SHU. REV.SAT.     IL  DIODE No.SER. T_COEFF_I EB_GAP   PMax EFF.  VMpp
IMpp T_COEFF T_CoEFF_P T_COEFF_V
           NODE     NAME* TYPE   RES.   RES.  CURRENT        FACTOR   CELLS
      TYPE
------ -------- -------- ---- ------ ------ -------- ------ ------ ------- --------- ------ ------ ---- -----
----- ------- --------- ---------
     1        3     Bus3    1  0.000  0.000    0.000  0.000  0.000       0     0.000  0.000 250.00 15.00 30.20
8.30       0    -0.438     -0.331
     2        4     Bus4    1  0.000  0.000    0.000  0.000  0.000       0     0.000  0.000 250.00 15.00 30.20
8.30       0    -0.438     -0.331
-------------------------------------------------------------------------------
|----- CELL TEMPERATURE AND PV ARRAY DATA -----|
Sl.No*     FROM     FROM CELL_TEMP  TEMP.   NOCT  NOCT  ALPHA No.Of MODULES No.Of STRINGS
           NODE     NAME*      TYPE         TEMP. COND.           in STRING      in ARRAY
------ -------- -------- --------- ------ ------ ----- ------ ------------- -------------
     1        3     Bus3         0  25.00  45.00     0   0.00            20             4
     2        4     Bus4         0  25.00  45.00     0   0.00            20             3
-------------------------------------------------------------------------------
|----- INVERTER AND MODE OF OPERATION DATA -----|

Sl.No*     FROM     FROM DC POWER AC POWER      AC  EFF.     No.of   MODE Of  P.F. V_SPEC    Q-MIN    Q-MAX
           NODE     NAME*   RATING   RATING VOLTAGE       INVERTERS OPERATION         p.u.     MVAr     MVAr
------ -------- -------- -------- -------- ------- ----- --------- --------- ----- ------ -------- --------
     1        3     Bus3    0.006     0.005   0.415 98.50          3         0 1.000 0  0.000    0.000    0.000
     2        4     Bus4    0.006     0.005   0.415 98.50          3         0 1.000 0  0.000    0.000    0.000

|***** LOAD DATA *****|

Sl.No.     FROM     FROM     REAL REACTIVE     COMP COMPENSATING MVAR VALUE CHAR  F/V
*          NODE     NAME*      MW     MVAr     MVAr      MIN     MAX    STEP  NO.  NO.
                                                                            STAT
------ -------- -------- -------- -------- -------- ------- ------- ------- ---- ----
     1        3     Bus3    0.020    0.009    0.000    0.000   0.000   0.000    0    0
                                                                             3    0
     2        4     Bus4    0.020    0.009    0.000    0.000   0.000   0.000    0    0
                                                                             3    0
|***** OUTPUT DATA *****|
Total Specified MW Generation          :   25.00000
Total Minimum MVAr Limit of Generator  :   15.75000
Total Maximum MVAr Limit of Generator  :   15.75000
```

```
Total Specified MW Load                :   0.04000 Changed to    0.04000
Total Specified MVAr Load              :   0.01800 Changed to    0.01800
Total Specified MVAr Compensation      :   0.00000 Changed to    0.00000
-------------------------------------------------------------------------------
Total (Including Out of Service Units)
Total Specified MW Generation          :  25.00000
Total Minimum MVAr Limit of Generator  :  15.75000
Total Maximum MVAr Limit of Generator  :  15.75000
Total Specified MW Load                :   0.04000 Changed to    0.04000
Total Specified MVAr Load              :   0.01800 Changed to    0.01800
Total Specified MVAr Compensation      :   0.00000 Changed to    0.00000
-------------------------------------------------------------------------------
|----- GENERATOR DATA FOR FREQUENCY DEPENDENT LOAD FLOW -----|
SLNO*      FROM     FROM   P-RATE     P-MIN     P-MAX    %DROOP   PARTICI     BIAS
           NODE     NAME*      MW        MW        MW              FACTOR  SETTING
                                                              C0        C1       C2
------ -------- -------- -------- --------- --------- --------- --------- ---------
    1        1     Bus1   21.000    0.0000   25.0000    4.0000    0.0000    0.0000
                                                        0.0000    0.0000    0.0000
-------------------------------------------------------------------------------
|~~~~~ OUTPUT RESULTS ~~~~~|

|***** BUS VOLTAGES AND POWERS *****|
    NODE      FROM   V-MAG  ANGLE        MW     MVAr        MW     MVAr     MVAr
     NO.      NAME    p.u. DEGREE       GEN      GEN      LOAD     LOAD     COMP
-------- --------  ------ ------  -------- --------  -------- -------- --------
       1      Bus1 1.0000   0.00     0.010    0.018     0.000    0.000    0.000  <
       2      Bus2 0.9837  -0.29     0.000    0.000     0.000    0.000    0.000
       3      Bus3 0.9812  -0.16     0.015    0.000     0.020    0.009    0.000
       4      Bus4 0.9800  -0.10     0.015    0.000     0.020    0.009    0.000
-------------------------------------------------------------------------------
NUMBER OF BUSES EXCEEDING MINIMUM VOLTAGE LIMIT (@ mark) :    0
NUMBER OF BUSES EXCEEDING MAXIMUM VOLTAGE LIMIT (# mark) :    0
NUMBER OF GENERATORS EXCEEDING MINIMUM Q LIMIT (< mark)  :    1
NUMBER OF GENERATORS EXCEEDING MAXIMUM Q LIMIT (> mark)  :    0

|***** TRANSFORMER FLOWS AND TRANSFORMER LOSSES *****|
Sl.NoCS     FROM     FROM       TO       TO       FORWARD            LOSS          %
            NODE     NAME     NODE     NAME       MW     MVAr       MW     MVAr LOADING
---- -- -------- -------- -------- -------- -------- -------- -------- -------- -------
   1  1        1     Bus1        2     Bus2    0.010    0.018   0.0000   0.0002    10.1&
-------------------------------------------------------------------------------
! NUMBER OF TRANSFORMERS LOADED BEYOND  125%          :    0
@ NUMBER OF TRANSFORMERS LOADED BETWEEN 100% AND 125% :    0
# NUMBER OF TRANSFORMERS LOADED BETWEEN  75% AND 100% :    0
$ NUMBER OF TRANSFORMERS LOADED BETWEEN  50% AND  75% :    0
^ NUMBER OF TRANSFORMERS LOADED BETWEEN  25% AND  50% :    0
& NUMBER OF TRANSFORMERS LOADED BETWEEN   1% AND  25% :    1
* NUMBER OF TRANSFORMERS LOADED BETWEEN   0% AND   1% :    0

|***** LINE FLOWS AND LINE LOSSES *****|
SLNO CS     FROM     FROM       TO       TO       FORWARD            LOSS          %
            NODE     NAME     NODE     NAME       MW     MVAr       MW     MVAr LOADING
---- -- -------- -------- -------- -------- -------- -------- -------- -------- -------
   2  1        2     Bus2        3     Bus3    0.005    0.009   0.0000   0.0000     0.4*
   3  1        2     Bus2        3     Bus3    0.005    0.009   0.0000   0.0000     0.4*
   4  1        3     Bus3        4     Bus4    0.002    0.004   0.0000   0.0000     0.2*
   5  1        3     Bus3        4     Bus4    0.002    0.004   0.0000   0.0000     0.2*
-------------------------------------------------------------------------------
! NUMBER OF LINES LOADED BEYOND  125%          :    0
@ NUMBER OF LINES LOADED BETWEEN 100% AND 125% :    0
# NUMBER OF LINES LOADED BETWEEN  75% AND 100% :    0
$ NUMBER OF LINES LOADED BETWEEN  50% AND  75% :    0
^ NUMBER OF LINES LOADED BETWEEN  25% AND  50% :    0
& NUMBER OF LINES LOADED BETWEEN   1% AND  25% :    0
* NUMBER OF LINES LOADED BETWEEN   0% AND   1% :    4

|***** SUMMARY OF RESULTS *****|

TOTAL REAL POWER GENERATION (CONVENTIONAL)   :      0.010 MW
TOTAL REAL POWER INJECTION (-ve LOAD)        :      0.000 MW
TOTAL REACT. POWER GENERATION (CONVENTIONAL) :      0.018 MVAr
GENERATION p.f.                              :      0.485
TOTAL REAL POWER GENERATION (WIND)           :      0.000 MW
```

```
TOTAL REACT. POWER GENERATION (WIND)          :      0.000 MVAr
TOTAL REAL POWER GENERATION (SOLAR)           :      0.030 MW
TOTAL REACT. POWER GENERATION (SOLAR)         :      0.000 MVAr
TOTAL SHUNT REACTOR INJECTION                 :     -0.000 MW
TOTAL SHUNT REACTOR INJECTION                 :     -0.000 MVAr
TOTAL SHUNT CAPACIT.INJECTION                 :     -0.000 MW
TOTAL SHUNT CAPACIT.INJECTION                 :     -0.000 MVAr
TOTAL TCSC REACTIVE DRAWL                     :      0.000 MVAr
TOTAL SPS REACTIVE DRAWL                      :      0.000 MVAr
TOTAL UPFC INJECTION                          :     -0.000 MVAr
TOTAL SHUNT FACTS INJECTION                   :      0.000 MVAr
TOTAL SHUNT FACTS DRAWAL                      :      0.000 MVAr
TOTAL REAL POWER LOAD                         :      0.040 MW
TOTAL REAL POWER DRAWAL (-ve gen.)            :      0.000 MW
TOTAL REACTIVE POWER LOAD                     :      0.018 MVAr
LOAD p.f.                                     :      0.912
TOTAL COMPENSATION AT LOADS                   :      0.000 MVAr
TOTAL HVDC REACTIVE POWER                     :      0.000 MVAr
TOTAL REAL POWER LOSS (AC+DC)                 :      0.000090 MW (  0.000090+  0.000000)
PERCENTAGE REAL  LOSS (AC+DC)                 :      0.226
TOTAL REACTIVE POWER  LOSS                    :      0.000255 MVAr

-------------------------------------------------------------------------------
|----- ZONE WISE DISTRIBUTION -----|
Description        Zone # 1
--------------- ----------
MW generation        0.0098
MVAr generation      0.0177
MW wind gen.        0.0000
MVAr wind gen.      0.0000
MW solar gen.        0.0300
MVAr solar gen.      0.0000
MW load              0.0400
MVAr load            0.0180
MVAr compensation    0.0000
MW loss              0.0001
MVAr loss            0.0003
MVAr - inductive     0.0000
MVAr - capacitive    0.0000
|----- AREA WISE DISTRIBUTION -----|
Description        Area # 1
--------------- ----------
MW generation        0.0098
MVAr generation      0.0177
MW wind gen.        0.0000
MVAr wind gen.      0.0000
MW solar gen.        0.0300
MVAr solar gen.      0.0000
MW load              0.0400
MVAr load            0.0180
MVAr compensation    0.0000
MW loss              0.0001
MVAr loss            0.0003
MVAr - inductive     0.0000
MVAr - capacitive    0.0000
```


Bus1 [1]
ZZVM1
ZZVA1
ZZGP1
ZZGQ1
ZZLP1-2
ZZLQ1-2
ZZLT1-2
0.20 MVA
ZZLP2-1
ZZLQ2-1
Bus2 [2]
ZZVM2
ZZVA2
ZZLP2-3
ZZLQ2-3
Weasel
0.1 km
ZZLP3-2
ZZLQ3-2
ZZLP2-3(2)
ZZLQ2-3(2)
Weasel
0.1 km
ZZLP3-2(2)
ZZLQ3-2(2)
Bus3 [3]
ZZVM3
ZZVA3
ZZGP3
ZZGQ3
PV
ZZLP3-4
ZZLQ3-4
Weasel
0.1 km
ZZLP4-3
ZZLQ4-3
ZZLP3-4(2)
ZZLQ3-4(2)
Weasel
0.1 km
ZZLP4-3(2)
ZZLQ4-3(2)
ZZDP3
ZZDQ3
Bus4 [4]
ZZVM4
ZZVA4
ZZDP4
ZZDQ4
ZZGP4
ZZGQ4
PV