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COLLEGE OF ENGINEERING & TECHNOLOGY

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EE 3611 – POWER SYSTEM SIMULATION LABORATORY

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COURSE : B.E
BRANCH : ELECTRICAL AND ELECTRONICS ENGINEERING
YEAR & SEM : III YEAR & VI SEM

Prepared by Dr. K. Sriram, AP/EEE

INDEX

FORMATION OF Y BUS MATRIX

EXERCISE 1

AIM

To compute bus admittance matrix for the given power system network using MATLAB software package.

THEORY

Bus admittance matrix is often used in power system studies. In most of the power system studies, it is necessary to form Y-Bus matrix of the system by considering certain power system parameters depending upon the type of analysis.

For example, in load flow analysis, it is necessary to form Y-Bus matrix taking in to account only line data and not taking into account the generator impedance, transformer impedances or load impedances. In short circuit analysis, the generator transient reactance's and transformer leakage impedances must be taken into account in addition to line data during the computation of Y-bus matrix.

In stability analysis, line data, the generator transient reactances, transformer leakage impedances and equivalent load impedances to ground must be taken into account in computing Y-bus matrix. Y-Bus may be computed by inspection method, only if there is negligible mutual coupling between the lines. Every transmission line will be represented by the nominal π equivalent. Shunt admittances are added to the diagonal elements of Y-bus corresponding to the buses at which these are connected. The off diagonal elements are unaffected by shunt admittances. The equivalent circuit of tap - changing transformer may be considered in forming Y-Bus matrix, if tap changing transformers are present in the system.

The dimension of the [Y-Bus] matrix is (n x n) where n is the total number of buses in the system other than reference bus which is the ground bus. In a power network, each bus is connected only to a few other buses. So, the [Y-Bus] of a large network is highly sparse. This property is not evident in small systems, but in systems with hundreds of buses, the sparsity is high. It may be as high as 99%. Hence, by applying sparsity technique, numerical computation time as well as computer storage requirement may be drastically reduced.

FORMATION OF Y-BUS MATRIX

$$\textbf{Generalized [Y-Bus]} = \begin{bmatrix} \mathbf{Y_{ii}} & \mathbf{Y_{ij}} \\ \mathbf{Y_{ji}} & \mathbf{Y_{jj}} \end{bmatrix}$$

Each diagonal term Y_{ii} (i = 1,2,.....n) is called the self admittance or driving point admittance of bus i and equals the sum of all admittances terminating on the particular bus.

Each off-diagonal term Y_{ij} (i, j = 1,2...n; j ≠ i) is the transfer admittance between buses i and j $Y_{ij} = - y_{ij}$, where y_{ij} is net admittance connected between buses i and j, n = total number of buses. Further, $Y_{ij} = Y_{ji}$ on account of symmetry of Y-bus matrix.

ALGORITHM FOR FORMATION OF Y - BUS MATRIX

Step (1) : Initialize [Y-Bus] matrix, that is replace all entries by zero

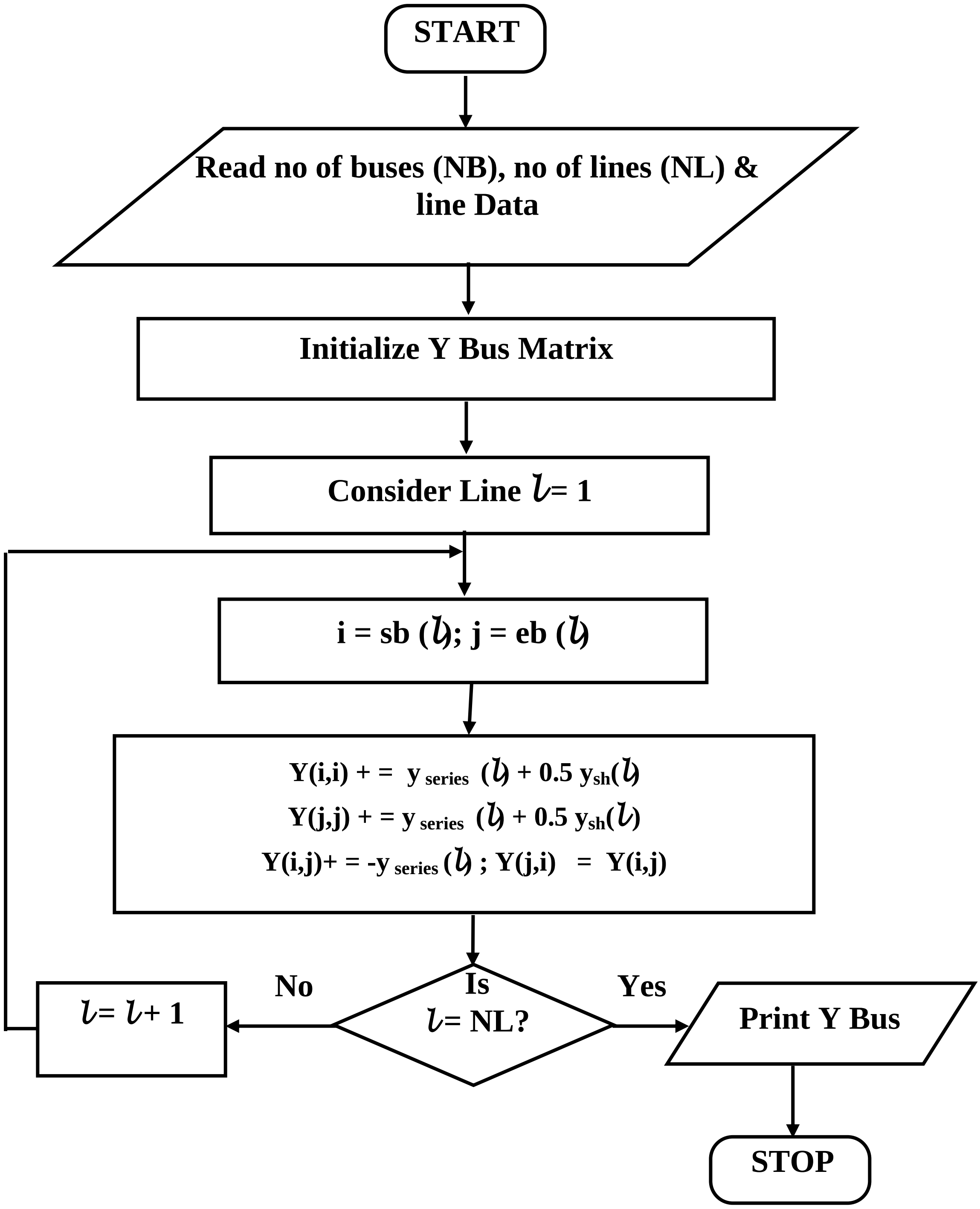
$Y_{ij} = Y_{ij} - y_{ij} = Y_{ji}$ = off diagonal element

Step (2) : Compute

$$Y_{ii} = [\sum_{\substack{j=1 \\ J \neq i}}^{n} y_{ij}] + y_{io} = \text{diagonal element}$$

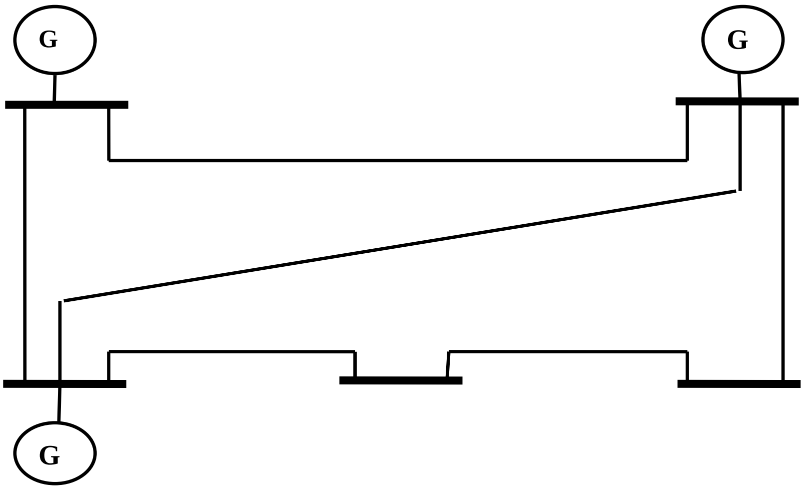
Where y_{io} is the net bus to ground admittance connected at bus i.

FLOWCHART FOR FORMATION OF Y - BUS MATRIX



The [Y-Bus] matrix is formed by inspection method for a three-bus sample power system. The one line diagram and line data are given below.

SINGLE - LINE DIAGRAM



Line Specification

Line no.	Start bus	End bus	Series Impedance (P.U.)	Half-line charging admittance (P.U)	Rating (MW)
1	1	2	0.001 + j0.01	0.001	60
2	2	3	0.002+ j0.02	0.0005	40
3	3	4	0.004 + j0.03	0.0015	60
4	4	5	0.003 + j0.01	0.0001	60
5	5	1	0.004 + j0.03	0.0005	40
6	2	5	0.001 + j0.04	0.002	60

ybus.m (Program for the Y-BUS formation)

```
linedata =  [1      1      2      0.001        0.01         0.001
             2      2      3      0.002         0.02        0.0005
             3      3      4      0.004        0.03         0.0015
             4      4      5      0.003        0.01         0.0001
             5      5      1      0.004        0.03         0.0005
             6      2      5      0.001        0.04         0.002];
fb = linedata(:,1);
tb = linedata(:,2);
r = linedata(:,3);
x = linedata(:,4);
b = linedata(:,5);
z = r + i*x;
y = 1./z;
b = i*b;
nbus = max(max(fb),max(tb));
nbranch = length(fb);
Y = zeros(nbus,nbus);
for k=1:nbranch
    Y(fb(k),tb(k)) = Y(fb(k),tb(k))-y(k);
    Y(tb(k),fb(k)) = Y(fb(k),tb(k));
 end
  for m =1:nbus
    for n =1:nbranch
       if fb(n) == m
          Y(m,m) = Y(m,m) + y(n)+ b(n);
       elseif tb(n) == m
          Y(m,m) = Y(m,m) + y(n) + b(n);
       end
    end
 end

Y
```

RESULT

Thus for a given system bus admittance matrix was formulated using Mi – Power software package and the results were presented.

FORMATION OF Z BUS MATRIX

EXERCISE 2

AIM

To obtain the bus impedance matrix Z – bus of the given power system network using MATLAB software package.

THEORY

Z - bus matrix is an important matrix used in different kinds of power system studies such as short circuit study, load flow study, etc.

In short circuit analysis, the generator and transformer impedances must 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.

Z-bus can be easily obtained by inverting the Y-bus formed by inspection method or by analytical method. Taking inverse of the Y-bus for large systems is time consuming; Moreover, modification in the system requires the whole process to be repeated to reflect the changes in the system. In such cases, the Z–bus is computed by Z–bus building algorithm.

ALGORITHM FOR FORMATION OF Z-BUS MATRIX

Step 1 : Read the values such as number of lines, number of buses and line data, Generator data and Transformer data.

Step 2 : Initialize Y_{bus} matrix. Y-$_{bus}$ [i] [j] = complex (0.0,0.0) for all values of i and j

Step 3 : Compute Y- bus Matrix by considering only line data.

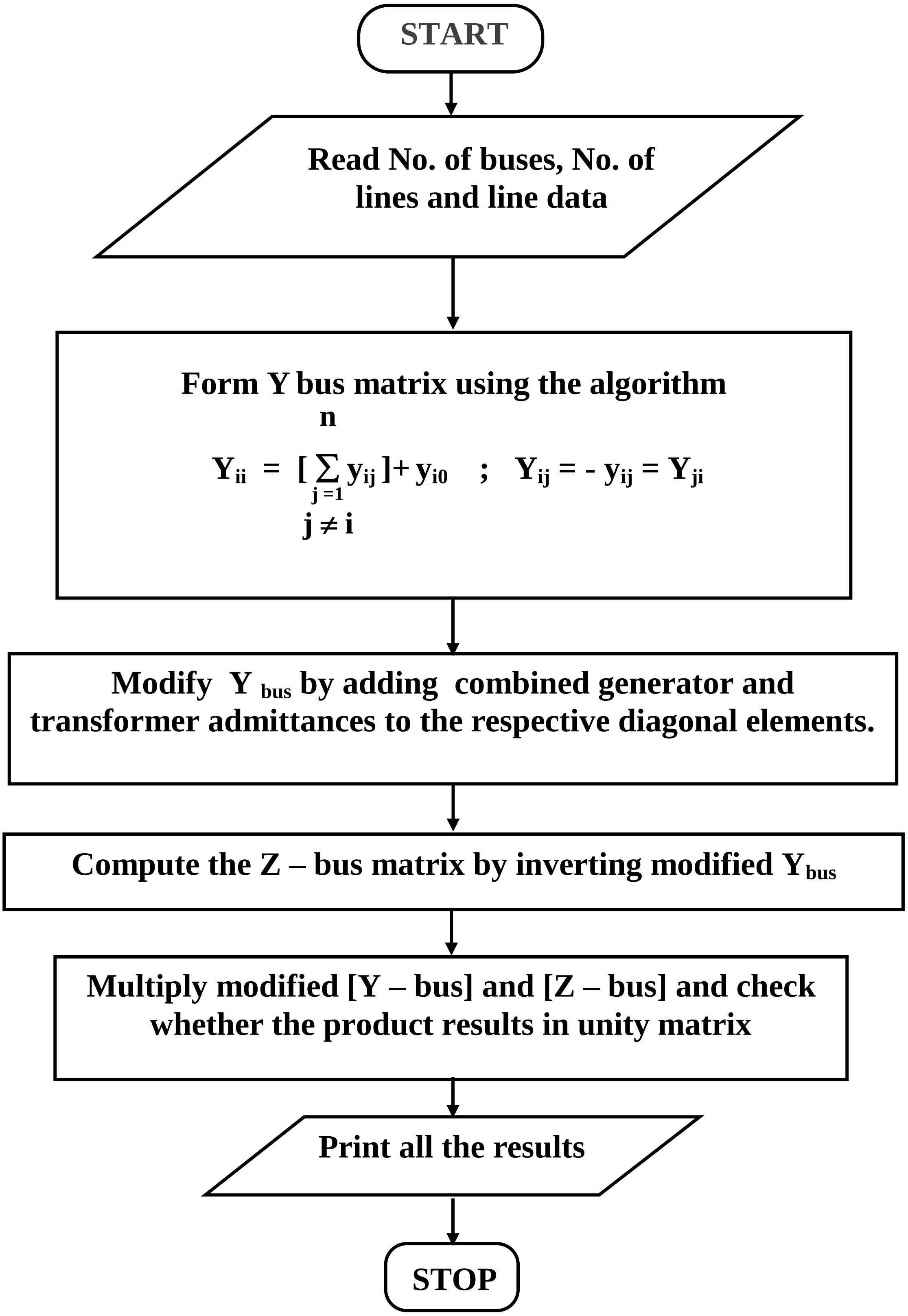
Step 4 : Modify the Y_{bus} matrix by adding the combined transformer and the generator admittances to the respective diagonal elements of Y– bus matrix.

Step 5 : Compute the Z– bus matrix by inverting the modified Y_{bus} matrix.

Step 6 : Check the inversion by multiplying modified Y_{bus} and Z-bus matrices to see whether the resulting matrix is unity matrix or not. If it is unity matrix, the result is correct.

Step 7 : Print Z-bus matrix.

FLOWCHART FOR FORMATION OF Z-BUS MATRIX



THEORY

Z – bus matrix is an important matrix used in different kinds of power system studies such as short circuit study, load flow study, etc.

In short circuit analysis, the generator and transformer impedances must 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.

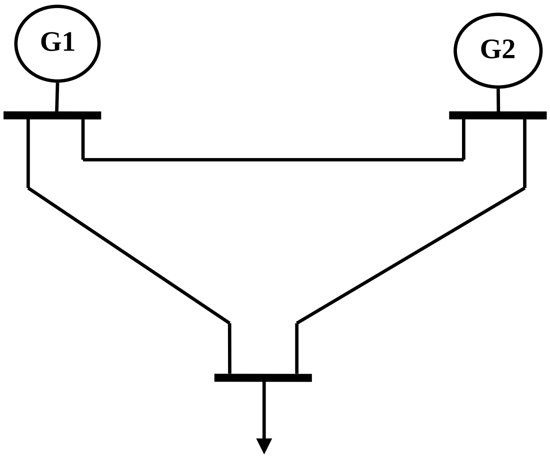
This can be easily obtained by inverting the Y_{bus} formed by inspection method or by analytical method.

Taking inverse of the Y_{bus} for large systems is time consuming, more over, modification in the system requires the whole process to be repeated to reflect the changes in the system. In such cases, the Z – bus is computed by Z- bus building algorithm.

SIMULATION

In this exercise, Z-bus for the system is developed by first forming the Y_{bus} and then inverting it to get the Z-bus matrix. The generator and transformer impedances are taken into account while forming the Y-bus matrix. Note that all loads should be neglected

Y-bus is a sparse matrix, Z-bus is a full matrix, i.e. zero elements of Y_{bus} become non–zero values in the corresponding Z-bus elements. The bus impedance matrix is most useful for short circuit studies.



Line Specification

Line no.	Start bus	End bus	Series impedance (P.U.)	Half-line charging admittance (P.U.)	Rating MW
1	1	2	0.001 + j 0.015	0.001	60
2	2	3	0.002 + j 0.021	0.005	40
3	3	1	0.004 + j 0.046	0.0015	65

Shunt element Details

Bus	MVAR
3	50

zbus.m (Program for Z-bus formation)

```
linedata =  [1       1       2       0.001          0.015          0.001
               2       2       3       0.002          0.021          0.0005
               3       3       1       0.004          0.046          0.0015 ];
fb = linedata(:,1);
tb = linedata(:,2);
r = linedata(:,3);
x = linedata(:,4);
b = linedata(:,5);
z = r + i*x;
y = 1./z;
b = i*b;

nbus = max(max(fb),max(tb));
nbranch = length(fb);
Y = zeros(nbus,nbus);

for k=1:nbranch
    Y(fb(k),tb(k)) = Y(fb(k),tb(k))-y(k);
    Y(tb(k),fb(k)) = Y(fb(k),tb(k));
 end



 for m =1:nbus
    for n =1:nbranch
       if fb(n) == m
          Y(m,m) = Y(m,m) + y(n)+ b(n);
       elseif tb(n) == m
          Y(m,m) = Y(m,m) + y(n) + b(n);
       end
    end
 end
 Y
zbus = inv(Y)
```

RESULT

Thus for a given system bus impedance matrix was formulated using Mi – Power package.

LOAD FLOW ANALYSIS BY GAUSS – SEIDAL METHOD

EXERCISE 3

AIM

To conduct load flow analysis of a power system by Gauss – Seidal method using Mi - Power software package.

THEORY

Load flow study

This study helps in designing the power system network such that there are no overloads or over voltages or under voltages or excessive loss of power.

For each load condition, this analysis may be conducted so that the system performance will be good under all possible load conditions. The load flow analysis program computes the voltage magnitude, phase angles and transmission line power flow for a network under steady state operating condition.

The main objective of the study is to obtain the magnitude and phase angle of the voltage at each bus & Real and Reactive power in each line.

The load flow solution also gives the initial condition of the system when the transient behaviour of the system is to be studied. This study is essential to decide the best operation of the operating system and for planning the future expansion of the system. It is also essential for designing a new power system. This study is used for both Off-line and On-line analysis.

Off-line Analysis : Giving the data to computer as obtained from the data book.

On-line Analysis : Giving data to computer as obtained from the system (current data)

This analysis can be done in any one of the following ways

1. Gauss - Seidal method
2. Newton – Raphson method
3. Fast decoupled method

PROBLEM FORMULATION (GAUSS-SEIDAL METHOD)

The performance equation of a power system may be written as

$$[I_{BUS}] = [Y_{BUS}] [V_{BUS}] \quad (1)$$

Selecting one of the buses as the reference bus, we get (n-1) simultaneous equations. The bus loading equations can be written as

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad (i = 1,2,3 \ldots\ldots n) \quad (2)$$

$$P_i = \mathrm{Re}\left(\sum_{k=1}^{n} V_i^* Y_{ik} V_k \right) \quad (3)$$

$$Q_i = -\mathrm{Im}\left(\sum_{k=1}^{n} V_i^* Y_{ik} V_k \right) \quad (4)$$

ADVANTAGE OF GAUSS – SEIDAL METHOD

1. Simplicity of the technique
2. Small system memory requirement
3. Less computational time per iteration

DISADVANTAGES OF GAUSS – SEIDAL METHOD

1. Slow rate of convergence, so large number of iterations
2. Number of iterations increases with increase in number of buses
3. Convergence Depends on choice of slack bus
4. Useful only for system having small number of buses

ALGORITHM:

Step 1 : Form Y-bus matrix

Step 2 : Assume $V_k = V_{k\,(spec\,)}\angle 0^0$ at all generator buses.

Step 3 : Assume $V_k = 1\angle 0^0 = 1+j0$ at all load buses.

Step 4 : Set iteration count = 1 (iter = 1)

Step 5 : Let bus number i =1.

Step 6 : If 'i' refers to generator bus go to step no.7, otherwise go to step 8.

Step 7a: If 'i' refers to the slack bus go to step 9. Otherwise go to step 7(b).

Step 7b: Compute Q_i using

$$Q_i^{cal} = -\mathrm{Im}\left[\sum_{j=1}^{N} V_i * Y_{ij} V_j\right]$$

$$Q_{Gi} = Q_i^{cal} + Q_{Li}$$

Check for Q limit violation

If $Q_{i\,(min)} < Q_{Gi} < Q_{i\,(max)}$, then $Q_{i\,(spec)} = Q_i^{cal}$

If $Q_{Gi} < Q_{i\,(min)}$, then $Q_{i\,(spec)} = Q_{i\,(min)} - Q_{Li}$

If $Q_{Gi} > Q_{i\,(max)}$, then $Q_{i\,(spec)} = Q_{i\,(max)} - Q_{Li}$

If Q_{limit} is violated, then treat this bus as P-Q bus till convergence is obtained.

Step 8 : Compute V_i using the equation,

$$V_i^{new} = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^{old*}} - \sum_{i=1}^{j-1} Y_{ij}\, V_j^{new} - \sum_{i=j+1}^{n} Y_{ij}\, V_i^{old}\right]$$

Step 9 : If i is less than the number of buses, increment i by 1 and go to step 6.

Step 10: Compare two successive iteration values for V_i

If $V_i^{new} - V_i^{old}$ < tolerance, go to step 12.

Step 11: Update the new voltage as

$V^{new} = V^{old} + \alpha\,(V^{new} - V^{old})$

$V^{old} = V^{new}$

iter = iter +1; go to step 5

Step 12: Compute relevant quantities.

Slack bus power, $S_i = P_i - jQ_i = V * I = \sum_{j=1}^{N} Y_{ij}\, V_j$

Line flow, $S_{ij} = P_{ij} + jQ_{ij}$

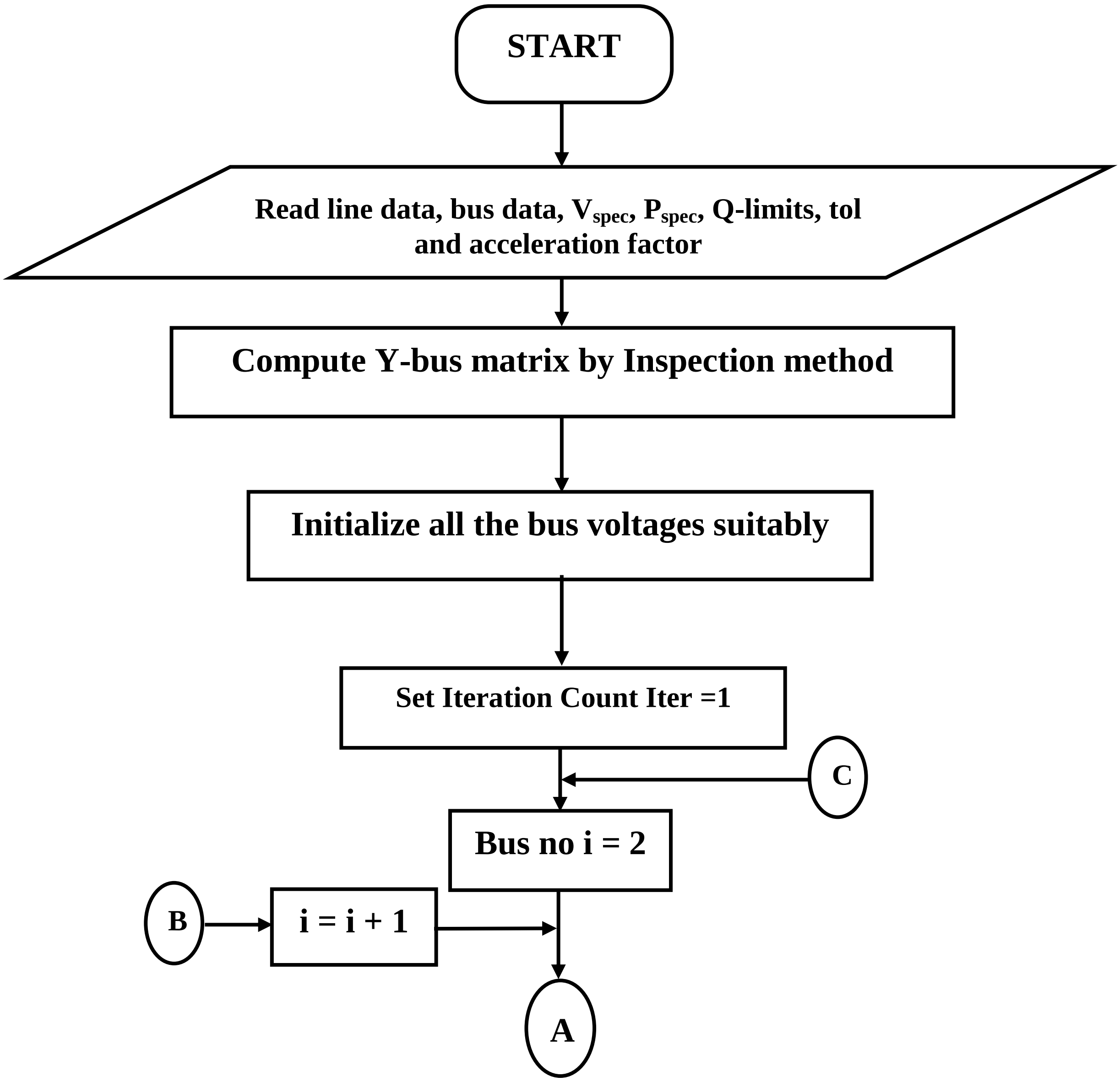
$= V_i\left[V_i^* - V_j^*\right] Y_{ij\,series}^* + |V_i|^2\, Y_{ii}^*$

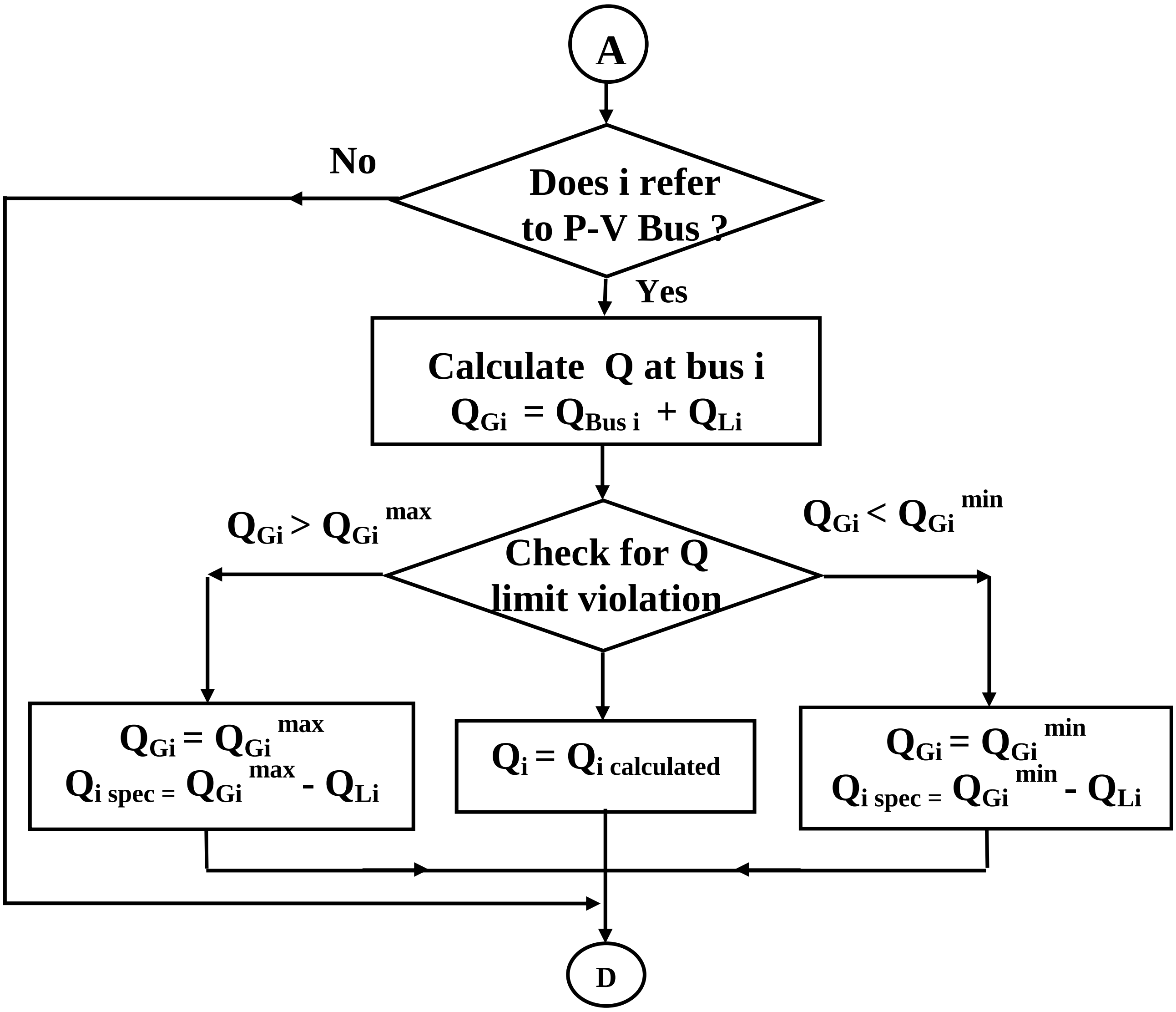
$P_{Loss} = P_{ij} + P_{ji}$

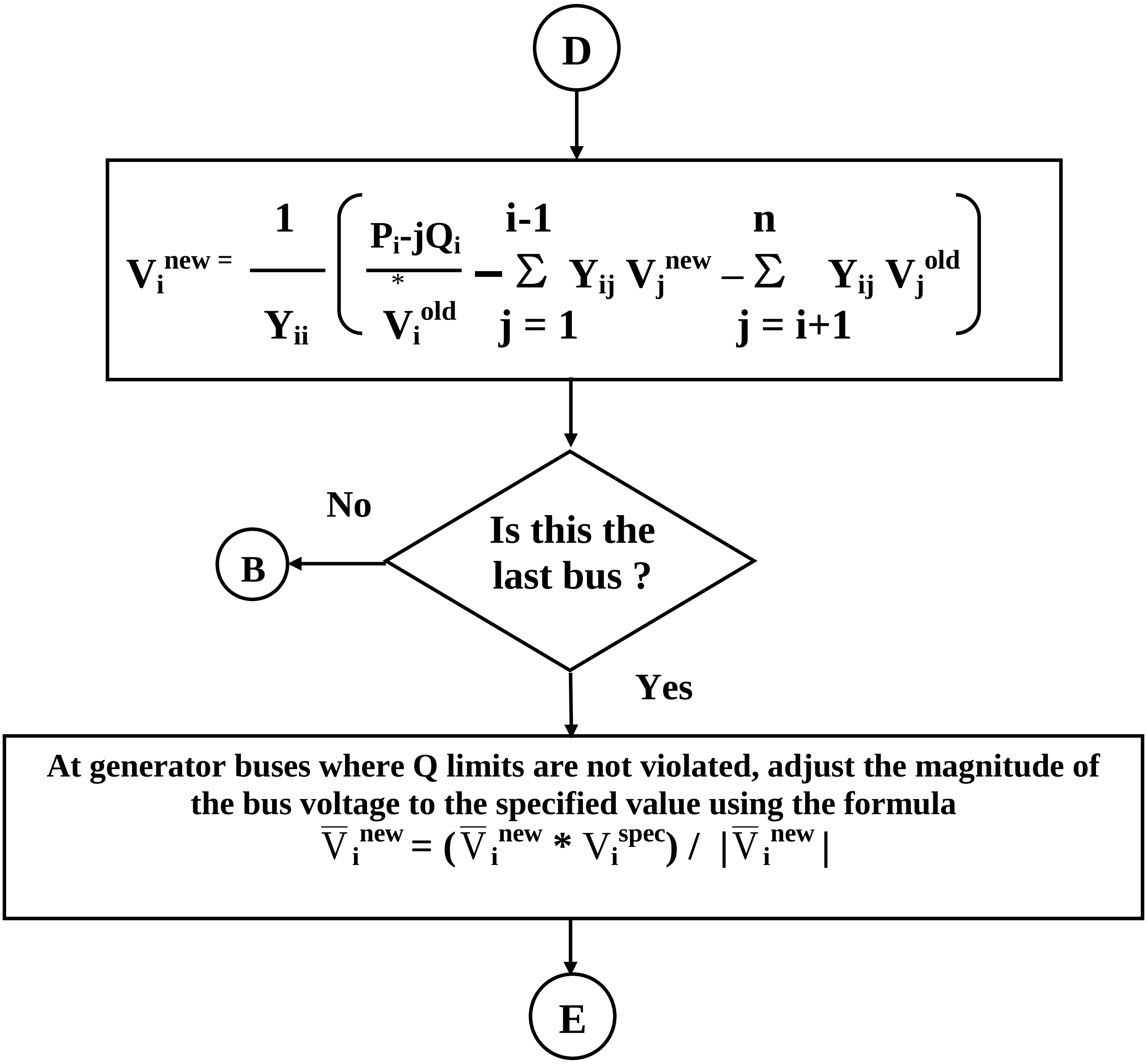
$Q_{Loss} = Q_{ij} + Q_{ji}$

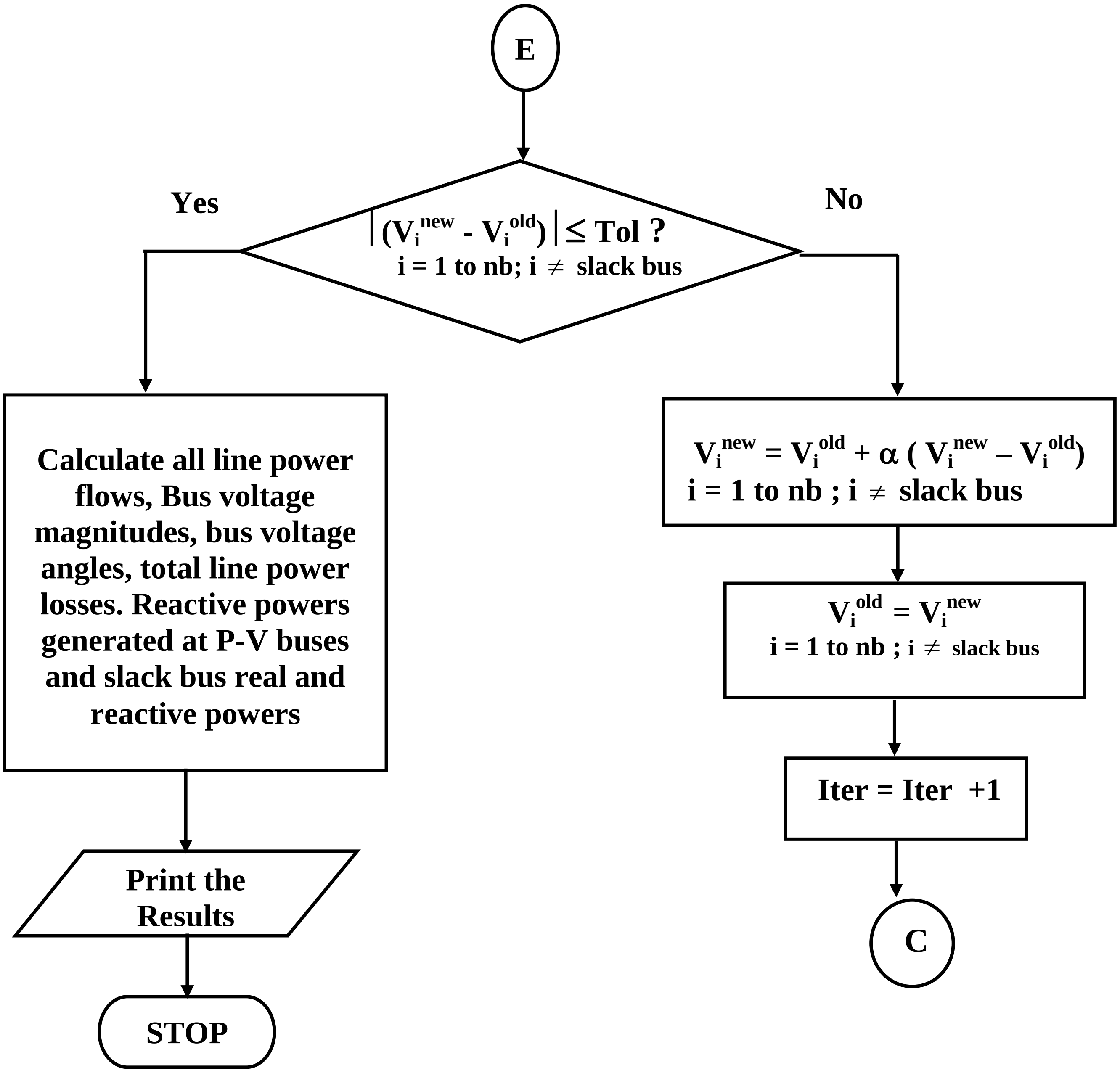
Step 13: Stop the execution.

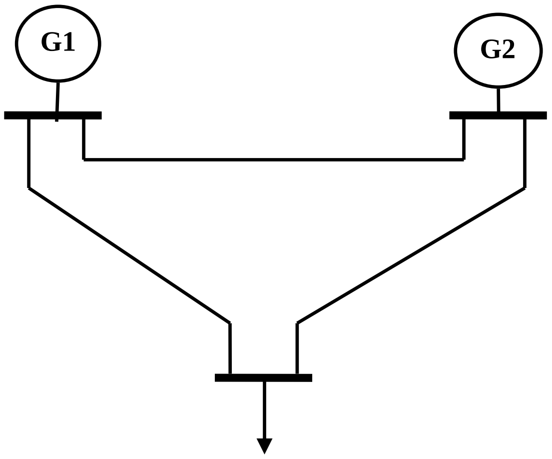
FLOW CHART FOR THE GAUSS-SEIDAL LOAD FLOW ANALYSIS




A
Does i refer to P-V Bus ?
No
Yes
Calculate Q at bus i
$Q_{Gi} = Q_{Bus\ i} + Q_{Li}$
Check for Q limit violation
$Q_{Gi} > Q_{Gi}^{max}$
$Q_{Gi} < Q_{Gi}^{min}$
$Q_{Gi} = Q_{Gi}^{max}$
$Q_{i\ spec} = Q_{Gi}^{max} - Q_{Li}$
$Q_i = Q_{i\ calculated}$
$Q_{Gi} = Q_{Gi}^{min}$
$Q_{i\ spec} = Q_{Gi}^{min} - Q_{Li}$
D


D
$V_i^{new} = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{V_i^{*old}} - \sum_{j=1}^{i-1} Y_{ij} V_j^{new} - \sum_{j=i+1}^{n} Y_{ij} V_j^{old} \right)$
Is this the last bus ?
No
B
Yes
At generator buses where Q limits are not violated, adjust the magnitude of the bus voltage to the specified value using the formula
$\bar{V}_i^{new} = (\bar{V}_i^{new} * V_i^{spec}) / |\bar{V}_i^{new}|$
E


E
Yes
No
$|(V_i^{new} - V_i^{old})| \le Tol$?
i = 1 to nb; i ≠ slack bus
Calculate all line power flows, Bus voltage magnitudes, bus voltage angles, total line power losses. Reactive powers generated at P-V buses and slack bus real and reactive powers
Print the Results
STOP
$V_i^{new} = V_i^{old} + \alpha (V_i^{new} - V_i^{old})$
i = 1 to nb ; i ≠ slack bus
$V_i^{old} = V_i^{new}$
i = 1 to nb ; i ≠ slack bus
Iter = Iter +1
C



Bus Specifications:

Bus no	Bus type	V spec	Generation (P.U)		Load (P.U)		Q-min	Q-max
			P	Q	P	Q		
1	Slack	1.06	-	-	-	-	-	-
2	P-V	1.02	0.6	0.25	0.0	0.0	0.25	0.75
3	P-Q	1.0	-	-	0.75	0.35	-	-

Line Data

Line. No	Start bus	End bus	Series impedance	Half-line charging admittance	Capacity [MW]
1	1	2	0.002 + j0.02	0.0001	70
2	2	3	0.003 + j0.032	0.0002	64
3	1	3	0.0015 + j0.0035	0.00015	55

Shunt Element Data

S.No	Bus. No	MVAR
1	3	4.0

RESULT

Load flow study of the given power system using Mi - Power software package is carried out by applying Gauss – Seidal method. The results are presented

LOAD FLOW ANALYSIS BY NEWTON – RAPHSON METHOD

EXERCISE 4

AIM

To conduct load flow analysis of a power system by Newton _ Raphson method using Mi - Power software package.

THEORY:

Load flow study

This study helps in designing the power system network such that there are no overloads or over voltages or under voltages or excessive loss of power.

For each load condition, this analysis may be conducted so that the system performance will be good under all possible load conditions. The load flow analysis program computes the voltage magnitude, phase angles and transmission line power flow for a network under steady state operating condition.

The main objective of the study is to obtain the magnitude and phase angle of the voltage at each bus & Real and Reactive power in each line.

The load flow solution also gives the initial condition of the system when the transient behaviour of the system is to be studied. This study is essential to decide the best operation of the operating system and for planning the future expansion of the system. It is also essential for designing a new power system. This study is used for both Off-line and On-line analysis.

Off-line Analysis : Giving the data to computer as obtained from the data book.

On-line Analysis : Giving data to computer as obtained from the system (current data)

This analysis can be done in any one of the following ways

1. Gauss - Seidal method
2. Newton – Raphson method
3. Fast decoupled method

LOAD FLOW SOLUTION BY NEWTON-RAPHSON METHOD

The N-R technique converges equally fast for small as well as large system, usually less than 4 or 5 iterations but more functional evaluational are required. It is become very popular for large system studies.

The most widely used methods for solving simultaneous non linear algebraic equation is the N-R method. This method is a successive approximation procedure based on initial estimate of the unknown and the use of Taylor series expansion. In this method the Real and Imaginary part of power can be represented as

$$P_i = \sum_{j=1}^{N} |V_i| \left|Y_{ij}\right| \left|V_j\right| \cos(\theta_{ij} + \delta_j - \delta_i) \qquad (1)$$

$$Q_i = - \sum_{j=1}^{N} |V_i| \left|Y_{ij}\right| \left|V_j\right| \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (2)$$

ALGORITHM:

Step 1 : Form Y-bus matrix

Step 2 : Assume flat start for starting voltage solution

$\delta_i^0 = 0.0,$ for i = 1,…..N for all buses except slack bus.

$\left|V_i^0\right| = 1.0,$ for I = M+1, M+2, …N (for all PQ buses)

$|V_i| = \left|V_i^0\right|_{(spec)}$ for all PV buses and slack bus

Step 3 : For load buses, calculate P_i^{cal} and Q_i^{cal}.

Step 4 : For PV buses, check for Q – limit violation.

If $Q_{i\,(min)} < Q_i^{cal} < Q_{i\,(max)}$, then bus acts as PV bus.

If $Q_i^{cal} < Q_{i\,(min)}$, then $Q_{i\,(spec)} = Q_{i\,(min}$

If $Q_i^{cal} > Q_{i\,(max)}$, then $Q_{i\,(spec)} = Q_{i\,(max)}$

The P-V bus will act as P-Q bus.

Step 5 : Compute mismatch vector using

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

$$\Delta Q_i = Q_{i\,spec} - Q_i^{cal}$$

Step : 6 Compute $\Delta P_i = max|\Delta P_i|$; I = 1,2,……,N except slack bus

$\Delta Q_i = max|\Delta Q_i|$; i = M+1…..,N

Step : 7 Compute jacobian matrix using

$$J = \begin{bmatrix} \frac{\partial P_i}{\partial \delta} & \frac{\partial P_i}{\partial |V|} \\ \frac{\partial Q_i}{\partial \delta} & \frac{\partial Q_i}{\partial |V|} \end{bmatrix}$$

Step : 8 Obtain state correction vector

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Step : 9 Update state vector using

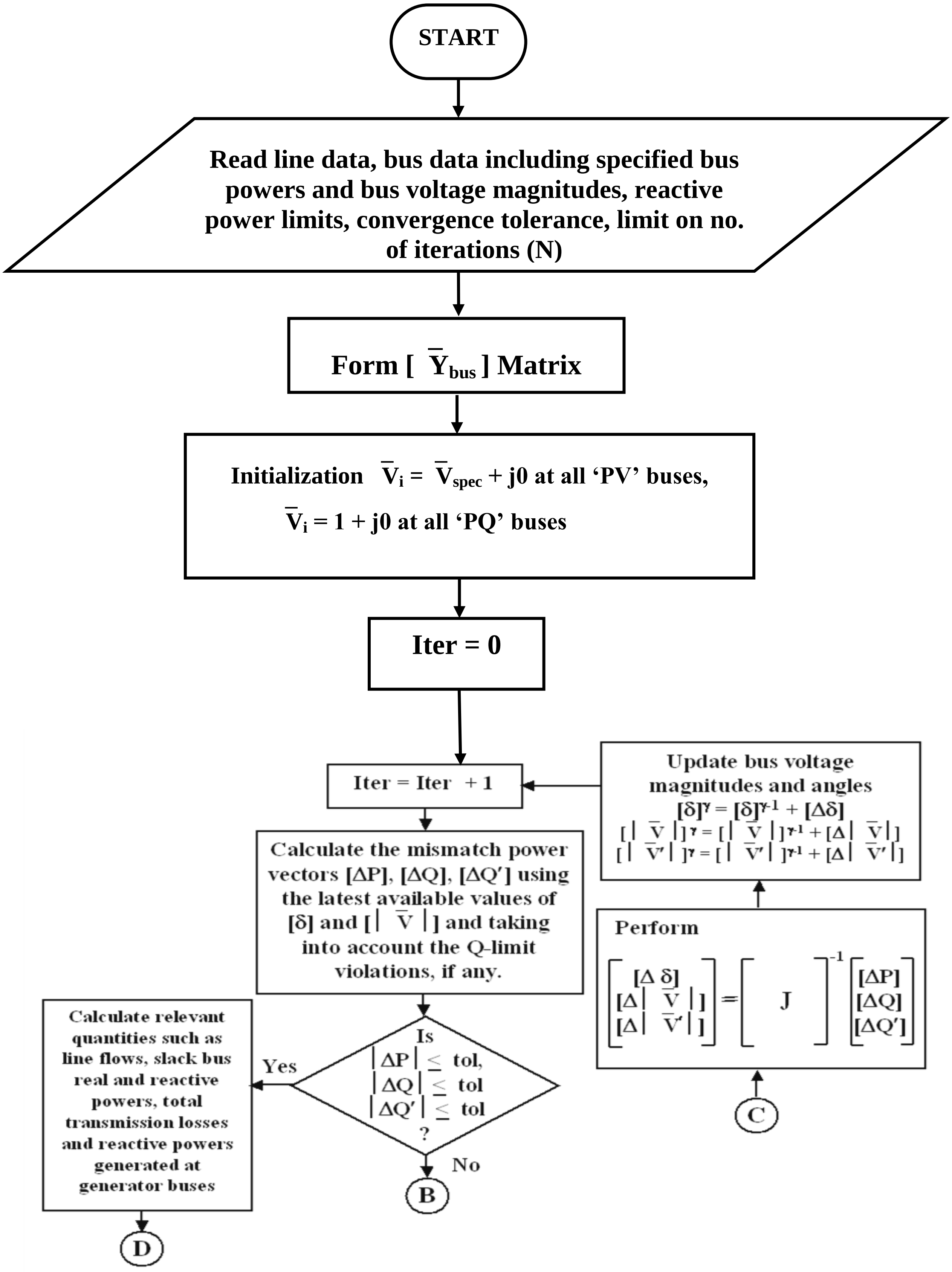
$$V^{new} = V^{old} + \Delta V$$

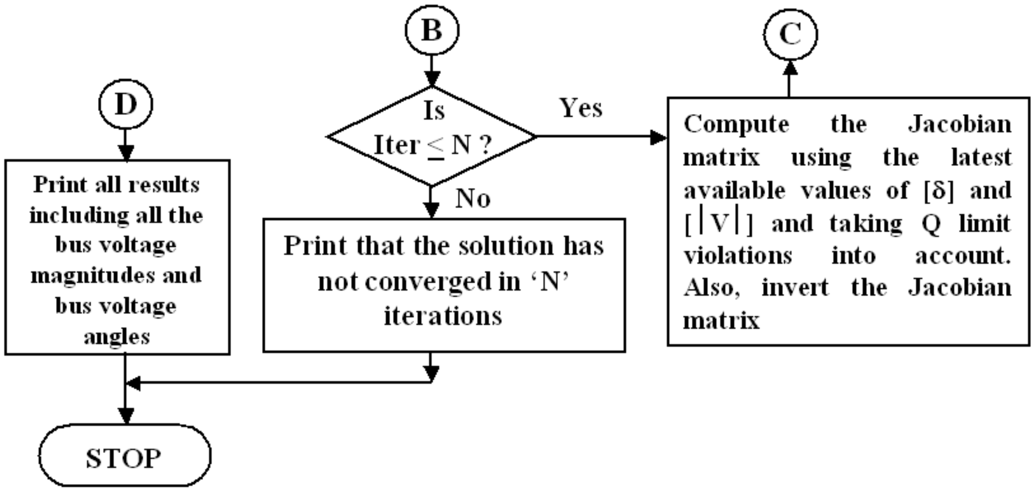
$$\delta^{new} = \delta^{old} + \Delta\delta$$

Step :10 This procedure is continued until

$|\Delta P_i| < \varepsilon$ and $|\Delta Q_i| < \varepsilon$, otherwise go to step 3.

FLOWCHART FOR THE NEWTON-RAPHSON METHOD





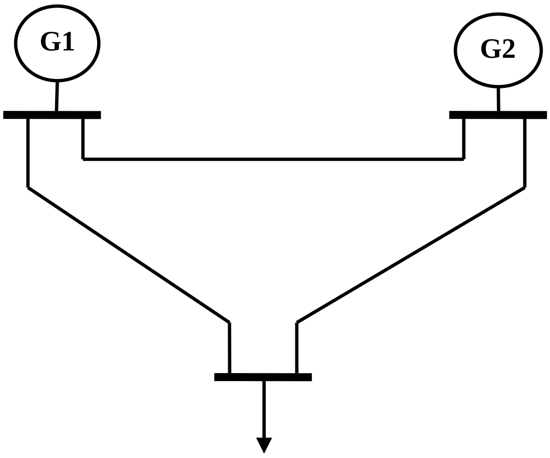
ADVANTAGES

1. On account of its quadratic convergence, Newton- Raphson method is mathematically superior to the Gauss – seidal method and is less prone to divergence with ill conditioned systems
2. More efficient and practical for large power systems
3. Number of iterations is independent of the system size
4. More accuracy and convergence is assured
5. This method is insensitive to factors like slack bus selection, regulating transformers etc.,

DISADVANTAGES

1. Solution technique is difficult
2. More computations are involved and hence computing time per iteration is large
3. Computer memory requirement is more

SINGLE LINE DIAGRAM



Bus Specifications:

Bus no	**Bus type**	**V spec**	**Generation (P.U.)**		**Load (P.U.)**		**Q-min**	**Q-max**
			P	**Q**	**P**	**Q**		
1	**Slack**	**1.06**	**-**	**-**	**-**	**-**	**-**	**-**
2	**P-V**	**1.02**	**0.6**	**0.2**	**0.0**	**0.0**	**0.3**	**0.7**
3	**P-Q**	**1.0**	**-**	**-**	**0.8**	**0.62**	**-**	**-**

Line Data

Line. No	**Start bus**	**End bus**	**Series impedance**	**Half-line charging admittance**	**Capacity [MW]**
1	**1**	**2**	**0.002 + j0.02**	**0.0001**	**70**
2	**2**	**3**	**0.003 + j0.032**	**0.0001**	**64**
3	**1**	**3**	**0.0015 + j0.0035**	**0.00015**	**55**

RESULT

Load flow study of the given power system using Mi - Power software package is carried out by applying Newton - Raphson method. The results are presented.

FAULT ANALYSIS

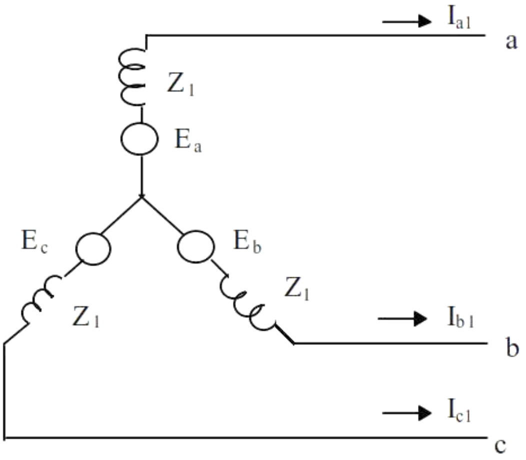
EXERCISE : 5

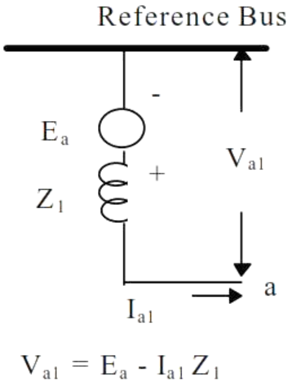
AIM:

To find out the fault current for single line to ground fault.

THEORY:

The single line to ground fault the most common type is caused by lightning or by conductors making contact with grounded structures. Figure shows a three phase generator with neutral grounded through impedance, Zn.





Suppose a LG fault occur on phase ‘a’ connected through impedance Zn.

Assuming the generator is initially on no-load the conduction at the fault bus ‘k’ are expressed by the following relation.

$V_a = ZfI_a$

$I_b = I_c = 0$ (1)

$I_f = I_a$

$$\begin{bmatrix} I_a^0 \\ I_a^+ \\ I_a^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

Substitute $I_b = I_c = 0$ the symmetrical components of current are,

$$\begin{bmatrix} I_a^0 \\ I_a^+ \\ I_a^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

From the equation (3) we find that

$$I_a^0 = I_a/3$$

$$I_a^+ = I_a/3 = I_f/3$$

$$I_a^- = I_a/3$$

$$I_a^0 = I_a^+ = I_a^- = I_a/3 = I_f/3 \tag{4}$$

From the sequence network of the generator the symmetrical voltages are given by

$$\begin{bmatrix} V_a^0 \\ V_a^+ \\ V_a^- \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_{kk}^0 & 0 & 0 \\ 0 & Z_{kk}^+ & 0 \\ 0 & 0 & Z_{kk}^- \end{bmatrix} \begin{bmatrix} I_a^0 \\ I_a^+ \\ I_a^- \end{bmatrix}$$

$$V_a^0 = -Z_{kk}^0 \ I_a^0 = -Z_{kk}^0 \ I_a^+$$

$$V_a^- = -Z_{kk}^- \ I_a^- = -Z_{kk}^- \ I_a^+$$

$$V_a^+ = E_a - Z_{kk}^+ \ I_a^+ \tag{5}$$

The phase voltages are given by

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a^0 \\ V_a^+ \\ V_a^- \end{bmatrix} \tag{6}$$

From equation (6) $\quad V_a = V_a^0 + V_a^+ + V_a^-$

From condition $\quad V_a = Z_f . I_a \qquad (7)$

Sub Symmetrical components of voltages from equation (5) we get

$$-Z_{kk}^0 \ I_a^+ + E_a - Z_{kk}^+ \ I_a^+ - Z_{kk}^- \ I_a^+ = Z_f . I_a$$

$$E_a - I_a^+ \left(Z_{kk}^0 + Z_{kk}^+ + Z_{kk}^- \right) = Z_f . 3 \ I_a^+$$

$$I_a^+ \left(Z_{kk}^0 + Z_{kk}^+ + Z_{kk}^- \right) + Z_f . 3 \ I_a^+ = E_a$$

$I_a^+ (Z_{kk}^0 + Z_{kk}^+ + Z_{kk}^- + 3Z_f) = E_a$

$I_a^+ = \frac{E_a}{(Z_{kk}^0 + Z_{kk}^+ + Z_{kk}^- + 3Z_f)}$ (8)

The fault current $I_f = I_a = 3\ I_a^+ = \frac{E_a}{(Z_{kk}^0 + Z_{kk}^+ + Z_{kk}^- + 3Z_f)}$ (9)

On sub symmetrical components of current in equation (5) and (6) the symmetrical components of voltages and phase voltages at the fault are obtained.

SEQUENCE NETWORK:

From equation (4) and (5), the +ve sequence, -ve sequence and zero sequence network are connected in series as shown in fig. Thus for a LG fault, the thevnin impedance at the fault impedance is obtained for each sequence network and are connected in series.

Mostly $Z_{kk}^+ = Z_{kk}^-$

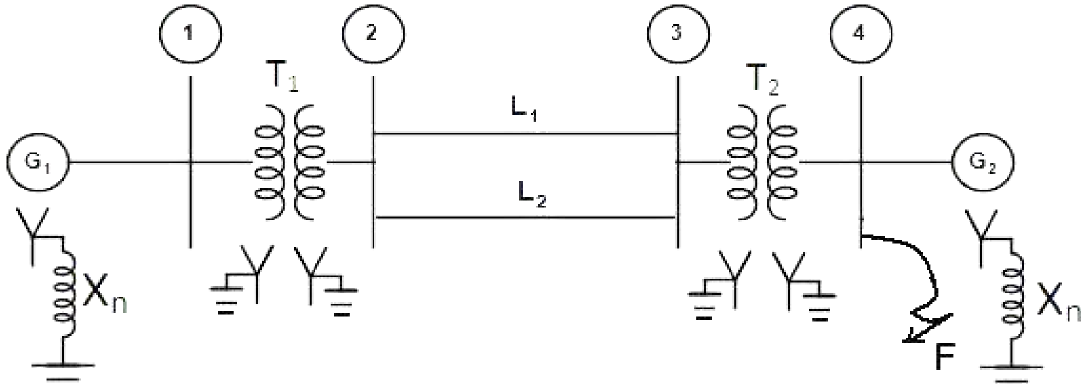
If the generator is solidly grounded, then for solid short circuit fault

$Z_f = 0$.

If the neutral of the generator is ungrounded the zero sequence network is open circuited.

$$\mathbf{I}_a^0 = \mathbf{I}_a^+ = \mathbf{I}_a^- = 0$$

And $I_f = 0$



DATA:

G_1, G_2 : 100 MVA, 11 KV, $X^+ = X^- = 15\%$, $X^0 = 5\%$, $X_n = 6\%$

T_1, T_2 : 100 MVA, IIKV/220 KV, $X_{Leak} = 9\%$

L_1, L_2 : $X^+ = X^- = 10\%$, $X^0 = 5\%$, on a base of 100 MVA

G_1 is connected with bus no.1

G_2 is connected with bus no.4

T_1 is connected between bus no.1 and bus no.2

T_2 is connected between bus no.3 and bus no.4

L_1, L_2 connected between bus no.2 and bus no.3

Assume phase at phase ‘A’ in bus no.4

RESULT

Fault analysis of the given power system using Mi - Power software package is carried out and the results are presented.

COMPUTATION OF TRANSMISSION LINE PARAMETERS

EXERCISE : 6

AIM

To calculate the inductance and capacitance of a given single circuit configuration of a given transmission line through Mi – Power software package.

THEORY

(a). Calculation of Inductance and Capacitance

1). Inductance of 3 phase single circuit symmetrical configuration

If the three conductors A, B, C are placed symmetrically at the corners of an equivalent triangle of side d, then $d_1 = d_2 = d_3 = d$. Under such condition the flux linkage with conductor A become

$$\varphi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - loge^{r}\right) I_A - I_B\ loge^{d} - I_C loge^{d}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - loge^{r}\right) I_A - (I_B + I_C)\ loge^{d}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - loge^{r}\right) I_A + I_A\ loge^{d}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\left(\frac{1}{4} - loge^{r}\right) + loge^{d}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + loge^{d} - loge^{r}\right]$$

$$\varphi_A = \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + loge^{d/r}\right] \textit{ weber – turns/m}$$

Inductance of conductor A

$$L_A = \frac{\varphi_A}{I_A} \textit{ H/m}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + loge^{d/r}\right]$$

$$= \frac{4\pi\ x\ 10^{-7}}{2\pi}\left[\frac{1}{4} + loge^{d/r}\right]$$

$$L_A = 10^{-7}\left[0.5 + 2\ loge^{d/r}\right] \textit{ H/m}$$

2) Capacitance of 3 phase single circuit symmetrical spacing configuration

The overall potential difference between conductor A and infinite neutral plane is

$$V_A = \int_r^\infty \frac{Q_A}{2\pi x\varepsilon_0}\,dx + \int_d^\infty \frac{Q_B}{2\pi x\varepsilon_0}\,dx + \int_d^\infty \frac{Q_C}{2\pi x\varepsilon_0}\,dx$$

$$= \frac{1}{2\pi\varepsilon_0}\left(Q_A loge^{1/r} + Q_B loge^{1/d} + Q_C loge^{1/d}\right)$$

$$= \frac{1}{2\pi\varepsilon_0}\left(\left(Q_A loge^{1/r} + (Q_B + Q_C) loge^{1/d}\right)\right.$$

Assume balnced supply $Q_A = Q_B = Q_C = 0$

$Q_B + Q_C = - Q_A$

$$= \frac{1}{2\pi\varepsilon_0}\left(Q_A loge^{1/r} - Q_A loge^{1/d}\right)$$

$$= \frac{Q_A}{2\pi\varepsilon_0}\left(loge^{1/r} - loge^{1/d}\right)$$

$$V_A = \frac{Q_A}{2\pi\varepsilon_0}\left(loge^{d/r}\right)$$

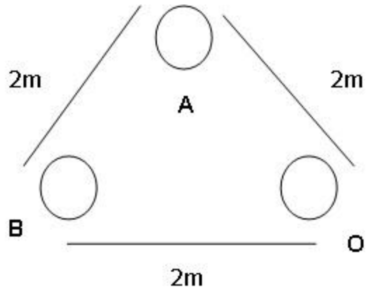
Capacitance of a conductor A with respect to neutral

$$C_A = \frac{Q_A}{V_A}$$

$$C_A = \frac{2\pi\varepsilon_0}{loge^{d/r}}\,F/m$$

DATA:

(i) Symmetrical Spacing

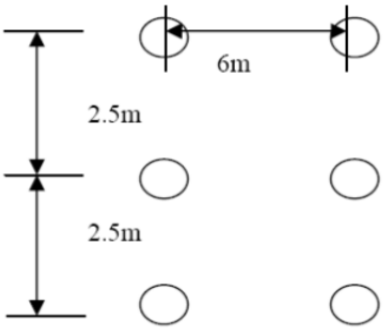


1. Diameter of the conductor = 0.125 m

2. Spacing between conductor = 2 m

3. GMR (Inductance) = 0.00486 m

4. GMR (Capacitance) = 0.00625 m



(ii) Asymmetrical Spacing

1. Diameter of the conductor = 1.5 cm

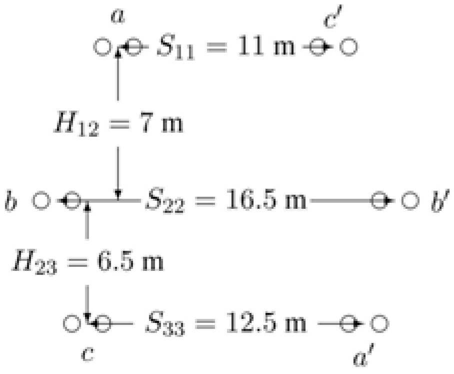
2. GMR = 0.00386 cm

(iii) Bundled Conductor

1. Diameter of the conductor = 1.427 inch

2. Spacing between conductor = 18 inch

3. GMR = 0.564 inch



RESULT

The Inductance and capacitance of a given transmission determined using Mi - Power software package

MODELING OF TRANSMISSION LINE

EXERCISE : 7

AIM:

To determine the voltage and current of receiving end of a given transmission line through Mi – Power software package.

THEORY:

The line models are classified by their length. These classifications are

- Short line approximation for lines that are less than 80 km long.
- Medium line approximation for lines whose lengths are between 80 km to 250 km.
- Long line model for lines that are longer than 250 km.

These models will be discussed in this chapter. However before that let us introduce the ABCD parameters that are used for relating the sending end voltage and current to the receiving end voltage and currents.

Consider the power system shown in Fig. 2.1. In this the sending and receiving end voltages are denoted by $\left(\overrightarrow{V_S}\right)$ and $\left(\overrightarrow{V_R}\right)$ respectively. Also the currents $\left(\overrightarrow{I_S}\right)$ and $\left(\overrightarrow{I_R}\right)$ are entering and leaving the network respectively.

$$\overrightarrow{V_S} = A\,\overrightarrow{V_R} + B\,\overrightarrow{I_R} \qquad (1)$$

$$\overrightarrow{I_S} = C\,\overrightarrow{V_R} + D\,\overrightarrow{I_R} \qquad (2)$$

From (2) we see that where

$$A = \frac{V_S}{V_R}\,at(I_R = 0) \qquad (3)$$

This implies that A is the ratio of sending end voltage to the open circuit receiving end voltage. This quantity is dimension less. Similarly,

$$B = \frac{V_S}{I_R}\,at(V_R = 0)\text{ ohm} \qquad (4)$$

i.e., B, given in Ohm, is the ratio of sending end voltage and short circuit receiving end current. In a similar way we can also define

$C = \frac{I_S}{V_R} at(I_R = 0)$ mho (5)

$D = \frac{I_S}{I_R} at(V_R = 0)$ (6)

The parameter D is dimension less.

Nominal-π Representation

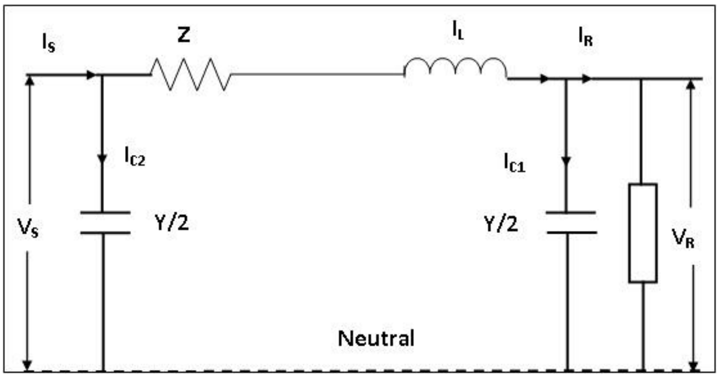


Fig. 1 Short transmission line representation.

In this representation the lumped series impedance is placed in the middle while the shunt admittance is divided into two equal parts and placed at the two ends. The nominal-π representation is shown in Fig. 1. This representation is used for load flow studies, as we shall see later. Also a long transmission line can be modeled as an equivalent π-network for load flow studies.

Let us define three currents I_1, I_2 and I_3 as indicated in Fig. Applying KCL at nodes M and N we get

$I_S = I_1 + I_2 = I_1 + I_3 + I_R$

$= \frac{Y}{2} V_S + \frac{Y}{2} V_S + I_R$ (7)

Again

$V_S = Z I_2 + V_R$

$= Z\left(V_R \frac{Y}{2}\right) + V_R$

$= \left(\frac{YZ}{2} + 1\right) V_R + ZI_R$ (8)

Substituting (7) in (8) we get

$$\mathrm{I_S} = \frac{Y}{2}\left[\left(\frac{YZ}{2}+1\right)\, V_{R+}\, \mathrm{Z}I_R\,\right] + \frac{Y}{2}\, V_R + I_R$$

$$= \mathrm{Y}\left(\frac{YZ}{4}+1\right) V_R + \mathrm{Y}\left(\frac{YZ}{2}+1\right) I_R \qquad (9)$$

Therefore from (8) and (9) we get the following ABCD parameters of the nominal-π representation

$\mathrm{A} = \mathrm{D} = \left(\frac{YZ}{2}+1\right)$

B = Z ohm

$\mathrm{C} = \left(\frac{YZ}{4}+1\right)$mho

The constants A, B, C and D are generally complex numbers.

The constants A and D are dimensionless where as the dimensions of B and C are ohm and mho respectively.

For a given transmission line

A = D

For a given transmission line

AD – BC = 1

DATA:

Transmission line length = 100 Km

Resistance of transmission line = 0.124 Ω/Km

Inductance of transmission line = 0.497 Ω/Km

Suspectance = 3.3 x 10^{-6} mho/Km

Transmission line length = 220 KV

Real power load/ demand = 40 MW

Reactive power demand = 19.37 MVAR

RESULT

The ABCD parameters of a given transmission determined using Mi - Power software package and the results are presented.

LOAD FREQUENCY CONTROL OF SINGLE AREA SYSTEM

EXERCISE: 8

AIM:

To develop a single area load frequency control through Mi-power software package.

THEORY:

The real power in a power system is being controlled by controlling the driving torques of the individual turbines of the system. The speed governor is the main primary tool for the load frequency control.

Fly ball speed governor

It is purely mechanical speed sensitive device coupled directly to the hydraulic amplifier which adjust the control valve opening via for the fine linkage mechanism.

As the load increases speed of the turbine decreases, and the speed changer gives raise command, so the fly balls move outwards and the point B moves downwards and the reverse happens with the increased speed.

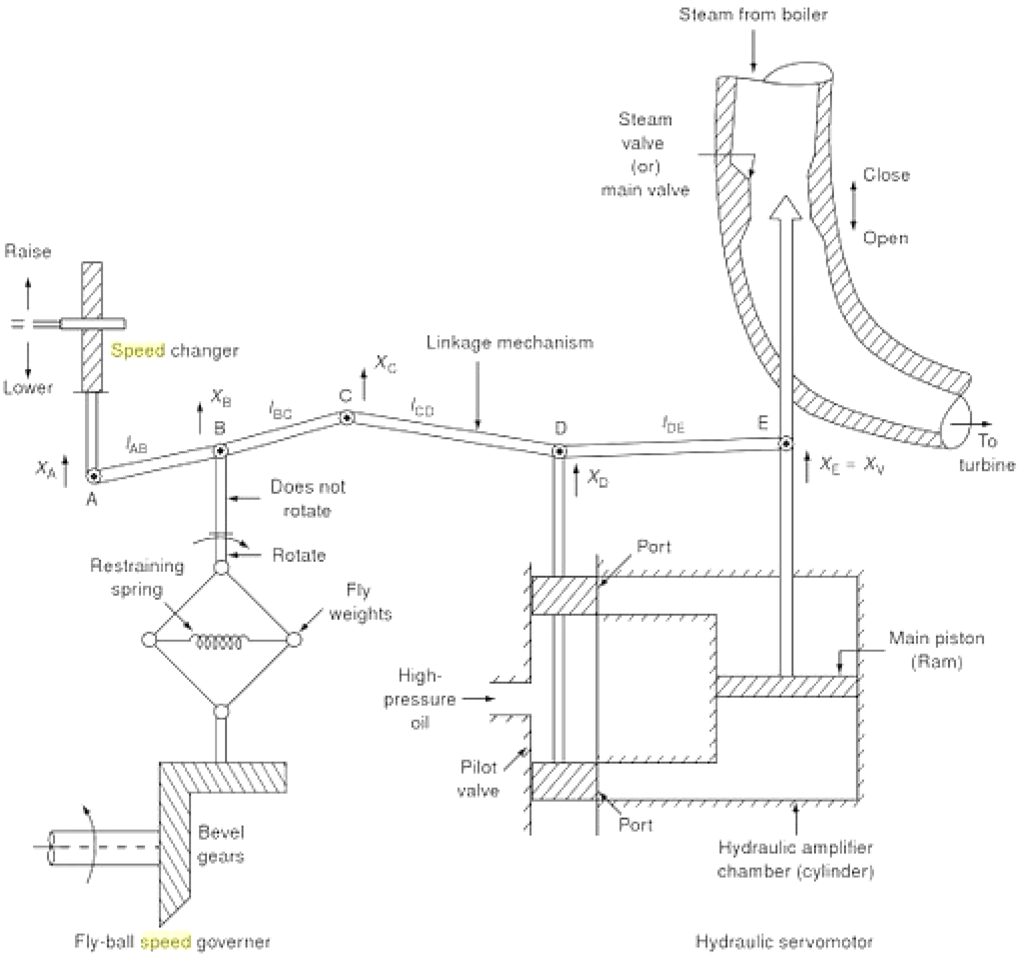
Speed Changer

It makes it possible to restore the frequency to the initial (nominal) value after the operation of the speed governor which has steady state.

characteristics corresponds to an increase ΔP_C in the reference power setting.

Hydraulic Amplifier

It consists of pilot valve and main piston with this arrangement, a low power pilot valve movement is converted into high level movement of the oil, servomotor piston. The input to the amplifier is the position X_D of the pilot valve. The output is the position X_E of the main piston. Hydraulic amplification is necessary so that steam valve or gate could be operated against high pressure steam.



Linkage Mechanism

ABC is rigid link pivoted at B and ODE is another rigid link pivoted at D. The functions of link mechanism is to control the steam valve or gate. We get feedback from the movement of the steam valve via link CD.

Working

As load increases the speed of the turbine decreases, the speed changer gives raise command and the fly ball move outwards and point B moves downwards and D moves upwards and high pressure oil enters in to the upper pilot valve and presses the main piston downwards and opens the valve or gate i.e increases the flow of steam to the turbine.

MODEL OF SPEED GOVERNING MECHANISM:

We shall develop the mathematical model based on small deviations around a nominal steady state. Consider the steam is operating under steady state and is delivering power P_G^0 from the generator at nominal frequency f^0.

Let X_S^0 be the steam valve setting. Let us assume that raise command $\Delta P_{C,}$ to the speed changer, the point A moved downwards, by a small amount ΔX_A which cause the turbine power output to change,

$$\Delta X_A = K_C \Delta P_C$$

Let us assume positive direction for downward movement and negative direction for upward movement.

Movement of C:

(i) ΔX_A contributes $\left(\frac{-l_2}{l_1}\right) \Delta X_A = - K_1 \Delta X_A = -K_1 K_C \Delta P_C$

(ii) Increase in frequency Δf cause the fly balls to move outwards so that b moves downwards by a proportional amount $K_2 \Delta f$.

$$\Delta X_C = -K_1 K_C \Delta P_C + K_2 \Delta f \quad (1)$$

Movement of D:

It is contributed by ΔX_C and ΔX_T. The movement of ΔX_D is the amount by which the pilot valve open, thereby moving the main piston and opening the steam valve by ΔX_E.

$$\Delta X_D = \left(\frac{l_1}{l_3+l_4}\right) \Delta X_C + \left(\frac{l_3}{l_3+l_4}\right) \Delta X_E$$

$$= K_3 \Delta X_C + K_4 \Delta X_E \quad (2)$$

Movement of ΔX_E :

The volume of oil admitted to the cylinder is thus proportional to the line integral of ΔX_D.

$$\Delta X_E = K_5 \int_0^t (-\Delta X_D) \; dt \quad (3)$$

Taking Laplace transform of equ (1), (2) and (3)

$$\Delta X_C(S) = -K_1 K_C \Delta P_C(S) + K_2 \Delta F(S) \quad (4)$$

$$\Delta X_D(S) = K_3 \Delta X_C(S) + K_4 \Delta X_E(S) \quad (5)$$

$$\Delta X_E(S) = \frac{-K_5}{S} \Delta X_D(S) \quad (6)$$

Substituting equation (5) in (6) we get,

$$\Delta X_E(S) = \frac{-K_5}{S}(K_3\ \Delta X_C(S) + K_4 \Delta X_E(S))$$

$$\Delta X_E(S)\left(1 + \frac{K_4K_5}{S}\right) = \frac{-K_5K_3}{S}\Delta X_C(S) \qquad (7)$$

Substituting equ (4) in (7) we get,

$$\Delta X_E(S)\left(1 + \frac{K_4K_5}{S}\right) = \frac{-K_5K_3}{S}(-K_1K_C\Delta P_C(S) + K_2\Delta F(S))$$

$$\Delta X_E(S)\left(\frac{S+K_4K_5}{S}\right) = \left(\frac{K_5K_3K_1K_C\Delta P_C(S) - K_2K_5K_3\Delta F(S)}{S}\right)$$

$$\Delta X_E(S) = \left(\frac{K_5K_3K_1K_C\left(\Delta P_C(S) - \frac{K_2}{K_1K_C}\Delta F(S)\right)}{K_4K_5\left(1+\frac{S}{K_4K_5}\right)}\right)$$

$$\Delta X_E(S) = \frac{K_3K_1K_C}{K_4}\left(\frac{\Delta P_C(S) - \frac{K_2}{K_1K_C}\Delta F(S)}{1+\frac{S}{K_4K_5}}\right)$$

This equation can be written as,

$$\Delta X_E(S) = \left[\Delta P_C(S) - \frac{1}{R}\Delta F(S).\frac{K_G}{1+ST_G}\right] \qquad (8)$$

Where,

$R_1 = \frac{K_1K_C}{K_2}$ – speed regulation of the governor in Hz/MW

$K_G = \frac{K_3K_1K_C}{K_4}$ – gain of the governor

$T_G = \frac{1}{K_4K_5}$ – time constant of speed governor

- Value of $T_G < 100$ msec

The output of a generating unit at a given system frequency can be varied only by changing it's " Load reference or control point" which is integrated with the speed governing mechanism.

Turbine model

We are integrated in the increased power generation ΔP_G due to the increased steam valve opening. There is incremental increase in turbine power ΔP_T due to the change in valve position ΔX_E, which will result in an increase generator power ΔP_G. If the generator incremental loss is neglected then

$$\Delta P_T = \Delta P_G$$

The figure for non- reheat turbine is shown in fig.

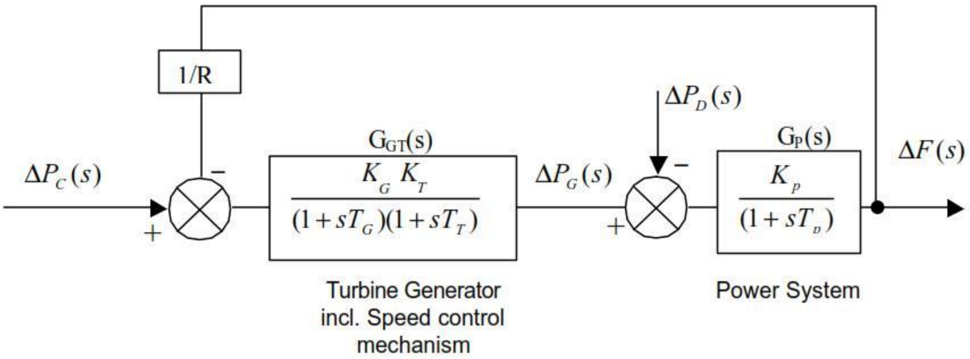
T_t = Time constant of turbine

K_t = Gain constant

ΔP_V = Per unit change in valve position from nominal value

Generator Load Model:

To develop the mathematical model of an isolated generator, which is only supplying local load and is not supplying power to another area. Suppose there is a real load change of ΔP_D. The net surplus power (ΔP_G - ΔP_D) will be absorbed by system in two ways.



1. By increasing the kinetic energy stored in the rotor at the rate $\frac{d}{dt}(W_{KE})$

W_{KE}^0 = H.P_r KW seconds

$$W_{KE}^0 = \frac{J\omega_0^2}{2} = W_{KE}^0 \propto f_0^2 \tag{9}$$

$$W_{KE} \propto (f_0 + \Delta f)^2 \tag{10}$$

Dividing equ (10) by (9) we get

$$W_{KE} = W_{KE}^{0}\left(\frac{f_0+\Delta f}{f_0}\right)^2 = W_{KE}^{0}\left(1+\frac{\Delta f}{f_0}\right)^2$$

$$= W_{KE}^{0}\left(1+\frac{2\,\Delta f}{f_0}+\frac{\Delta f^2}{f_0^2}\right)$$

$$= W_{KE}^{0}\left(1+\frac{2\,\Delta f}{f_0}\right)$$ neglect second order term.

Substituting W_{KE}^{0},

$$W_{KE} = H.P_r\left(1+\frac{2\,\Delta f}{f_0}\right) \qquad (11)$$

Rate of change of kinetic energy,

$$\frac{dW_{KE}}{dt} = \frac{2HP_r}{f_0}\frac{d}{dt}\,\Delta f \qquad (12)$$

2. As the frequency changes, the motor load changes being sensitive to speed

   Rate of change of load with respect to frequency $\frac{\partial P_D}{\partial f}$ = B

   Where,

   B = damping co-efficient in MW/Hz.

Values of damping co-efficient is positive for motor load.

$\Delta P_G - \Delta P_D = B\Delta f$

Writing power balance equation,

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f_0}\frac{d}{dt}(\Delta f) + B\Delta f$$

Dividing by P_r,

$$\Delta P_{G_{p.u}} - \Delta P_{D_{p.u}} = \frac{2H}{f_0}\frac{d}{dt}(\Delta f) + B_{p.u}\Delta f$$

Taking laplace transform,

$\Delta P_G(S) - \Delta P_D(S) = \Delta F(S)\left(\frac{2H(S)}{f_0} + B\right)$

$\Delta F(S) = \frac{\Delta P_G(S) - \Delta P_D(S)}{B\left(1 + \frac{2H(S)}{f_0}\right)}$

$\Delta F(S) = \Delta P_G(S) - \Delta P_D(S)\left(\frac{K_P}{1 + ST_p}\right)$

Where,

$K_P = \frac{1}{B}$ = Power system gain

$T_P = \frac{2H}{f_0}$ = Power system time constant

Combining the governor model, turbine model and generator model, we get the complete block diagram representation of LFC of an isolated power which is shown in fig.

DATA:

Rated capacity of the area	= 2000 MVA
Normal operating load	= 1000 MW
Nominal frequency	= 60 Hz
Inertia Constant (H)	= 5.0
Governor droop for all regulating generators	= 4 %
Governor time constant	= 0.05 sec
Turbine time constant	= 0.30 sec
Sudden rise in load value	= 20 MW
Rate of change of load (D_{PL})	= 1.0
D_{PF}	= 1.0
D_T	= 0.01
T_{max}	= 20.0

RESULT:

Thus for given single area system, load frequency control dynamics analysis was carried out using Mi-Power software package and LFC pattern were presented.

LOAD FREQUENCY CONTROL OF TWO AREA SYSTEM

EXERCISE 8

AIM:

To develop a two area load frequency control through Mi-power software package.

THEORY

An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generating, we shall consider a two area case connected by a single tie line as illustrated in fig.

The control objective now is to regulate the frequency of each area and to regulate the tie line power as per inter area power contracts. As in the case of frequency proportional plus integral controller will be installed so as to give zero steady state error in the tie line flow as compare to the contracted power.

It is assumed that each control area can be represented by equivalent turbine generator and governor system. Symbols used with suffix ‘1’ refers to area ‘1’.

In an isolated control area case, the incremental power (ΔP_G - ΔP_D) was accounted for the rate of increase in area load, caused by increase in frequency. Since, a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area.

Power transported out of area 1 is given by,

$$P_{tie,1} = \frac{|V_1||V_2|}{X_{12}}\sin(\delta_1^0 - \delta_2^0) = P_{max}\sin(\delta_1^0 - \delta_2^0)$$

Where,

δ_1^0, δ_2^0 = Power angle of equivalent machines of the two area

For incremental changes in δ_1 and δ_2 the incremental tie line can be expressed as,

Apply partial differentiation with respect to $'\delta'$

$$\frac{\partial P_{tie,1}}{\partial \delta_{12}} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^0 - \delta_2^0)(\Delta\delta_1 - \Delta\delta_2)$$

$$\Delta P_{tie,1_{p.u}} = \frac{|V_1||V_2|}{X_{12}P_{r_1}}\cos(\delta_1^0 - \delta_2^0)(\Delta\delta_1 - \Delta\delta_2)$$

$$\Delta P_{tie,1_{p.u}} = T_{12}(\Delta\delta_1 - \Delta\delta_2)$$

Where

$$T_{12} = \frac{|V_1||V_2|}{X_{12}P_{r_1}}\cos(\delta_1^0 - \delta_2^0)$$

Synchronizing power co-efficient or electric or dielectric (i.e) slope of the power angle curve at the initial stiffness operating angle δ_{12}^0.

T_{12} is defined as the differential power increase obtained per differential power angle increase obtained per differential power angle increase.

Since incremental frequency Δf is related to the phase angle of deviation,

$$\omega = 2\pi f$$

$$f = \frac{\omega}{2\pi}$$

$$= \frac{1}{2\pi}\frac{d\delta}{dt}$$

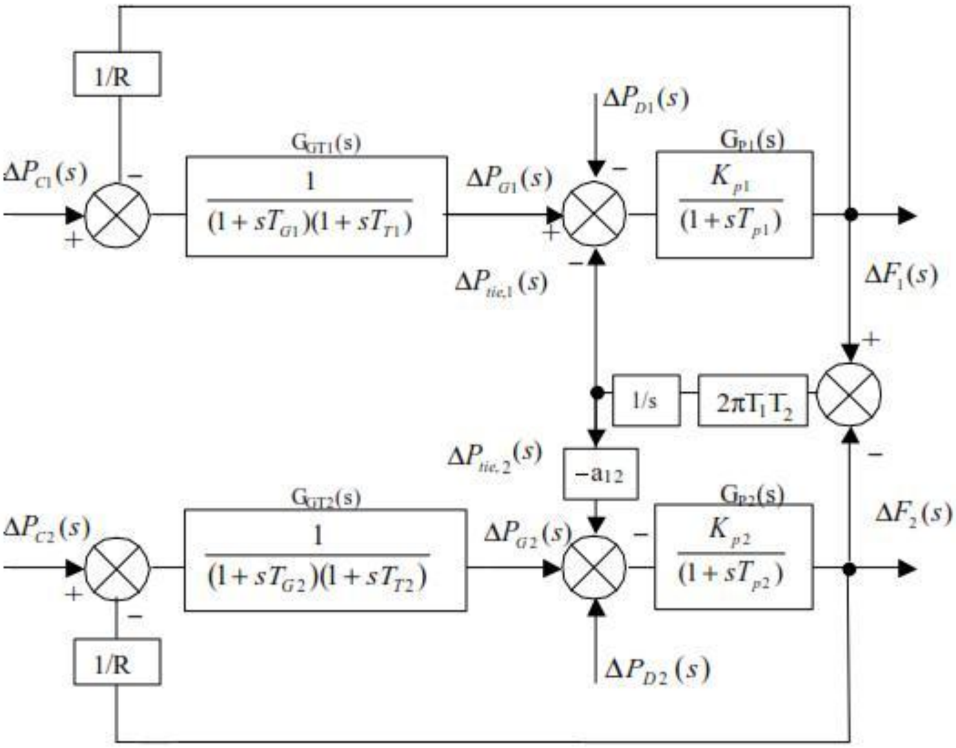
(i.e) $$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta)$$

$$\Delta\delta = 2\pi \int \Delta f . dt$$

We can equ T_{12} as,

$$\Delta P_{tie,1} = 2\pi T_{12}[\int \Delta f_1 . dt - \int \Delta f_2 . dt]$$

Where Δf_1 and Δf_2 are incremental frequency changer of areas ‘1’ and ‘2’ respectively.



Similarly,

$$\Delta P_{tie,1} = 2\pi \mathrm{T}_{21}[\int \Delta \mathrm{f}_2 .dt - \int \Delta \mathrm{f}_1 .dt]$$

$$\mathrm{T}_{12} = \frac{|V_2||V_1|}{X_{12}P_{r_2}} \cos(\delta_2^0 - \delta_1^0). \frac{P_{r_1}}{P_{r_1}}$$

$$\mathrm{P}_{21} = \left(\frac{P_{r_1}}{P_{r_2}}\right) T_{12} = a_{12}T_{12}$$

Where,

$$a_{12} = \left(\frac{P_{r_1}}{P_{r_2}}\right)$$

The incremental power balance equation for area ‘1’ can be written as,

$$\Delta P_{G_1} - \Delta P_{D_1} = \frac{2H}{f_0}\frac{d}{dt}(\Delta f_1) + B_1 \Delta f_1 + \Delta P_{tie,1}$$

Taking LT on equation of above and rearranging we get,

$$\Delta P_{G_1}(S) - \Delta P_{D_1}(S) - \Delta P_{tie,1}(S) = \Delta f_1(S)\left[B_1 + \frac{2H_1 S}{f_0}\right]$$

$$\Delta f_1(S) = \frac{\Delta P_{G_1}(S) - \Delta P_{D_1}(S) - \Delta P_{tie,1}(S)}{B_1 + \frac{2H_1 S}{f_0}}$$

$$= \left[\Delta P_{G_1}(S) - \Delta P_{D_1}(S) - \Delta P_{tie,1}(S)\right] \frac{1/B_1}{1 + \frac{2H_1 S}{f_0 B_1}}$$

$$\Delta f_1(S) = \left[\Delta P_{G_1}(S) - \Delta P_{D_1}(S) - \Delta P_{tie,1}(S)\right] \frac{K_P S_1}{1 + ST_P S_1}$$

Where,

$K_P S_1 = \frac{1}{B_1}$ = Power system gain for area ‘1’

$T_P S_1 = \frac{2H_1}{f_0 B_1}$ = Power system time constant for area ‘1’

Taking LP transform of equation,

$$\Delta P_{tie,1}\,(S) = \frac{2\pi T_{12}}{S}\left[\Delta f_1(S) - \Delta f_2(S)\right]$$

For the control area ‘2’,

$$\Delta P_{tie,2}\,(S) = \frac{2\pi T_{21}}{S}\left[\Delta f_2(S) - \Delta f_1(S)\right]$$

$$\Delta P_{tie,2}\,(S) = \frac{-2\pi a_{12} T_{21}}{S}\left[\Delta f_1(S) - \Delta f_2(S)\right]$$

DATA:

Number of areas	= 2
Rated capacity of the area	= 2000 MVA
Normal operating load	= 1000 MW
Nominal frequency	= 60 Hz
Inertia Constant (H)	= 5.0
Governor droop for all regulating generators	= 4 %
Governor time constant	= 0.08 sec
Turbine time constant	= 0.30 sec
Sudden rise in load value (D_{PD})	= 0 MW (for Area 1); 20 MW (for Area 2);
Rate of change of load (D_{PL})	= 1.0
D_{PF}	= 1.0
D_T	= 0.01
T_{max}	= 20.0

RESULT:

Thus for given two area system, load frequency control dynamic analysis was carried out using Mi-Power software package and LFC pattern were presented.

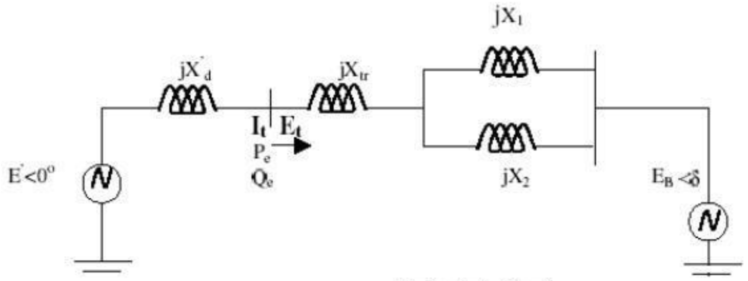
TRANSIENT STABILITY ANALYSIS OF SINGLE MACHINE INFINITE BUS SYSTEM

EXERCISE 10

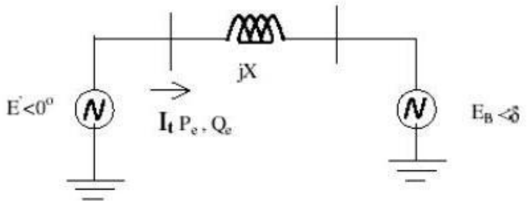
AIM

Analyze the transienet stability analysis of a single machine infinite bus system through Mi-Power software package.

THEORY:



Equivalent circuit



Simplified Equivalent Circuit

For the purpose of analysis fig (a) is reduced to fig (b) using thevnin's equivalent of the transmission network external to the machine and the adjacent transmission.

Because of the relative size of the system to which the machine is supplying power dynamics associated with the machine will cause virtually no change in the voltage and frequency of thevnin's volatage E_B . Such a source of constant voltage and constant frequency is referred to an infinite bus.

For any given system condition, the magnitude of infinite bus voltage E_B remains constant. However as the steady state condition change, the magnitude of E_B may change represent a changed generating condition of the external network.

We will analyze the small signal stability of the system with the synchronous machine represented by models of varying degree of detail. We will begin with the classical model and gradually increase the model detail by accounting for the effects of the dynamics of the field, circuits and excitation system.

In each case we will develop the expressions for the elements of state matrix as explicit function of the system parameters. This will help make clear the effects of various factor associated with a synchronous machine on system stability. In addition to the state space representation and model analysis we will use the block diagram representation and torque angle relationship to analyze the system stability characteristics.

CALCULATION:

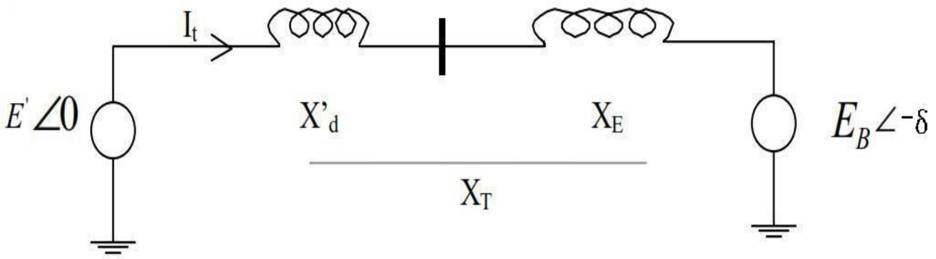


Figure: 6.5.1 Classical Model

Let E' = Voltage behind X'd

δ = Angle by which E' leads the infinite bus voltage E_B.

With E' as reference phasor

$$I_t = \frac{E'\angle 0 - E_B\angle -\delta}{jX_T}$$

$$= \frac{E'\angle 0 - E_B(\cos\delta - j\sin\delta)}{jX_T}$$

The complex power behind X_d' is given by

$$S' = P + jQ' = E'I_t^*$$

$$= \frac{E'E_B\sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T}$$

In p.u the air gap torque is equal to the air gap power

Here,

$T_e \quad = \frac{E' E_B}{X_T} \sin\delta$

Linearizing about an initial operating condition represented by $\delta = \delta_0$ yields

$\Delta T_e \quad = \frac{\partial T_e}{\partial \delta} \Delta\delta = \frac{E' E_B}{X_T} \cos\delta_0 (\Delta\delta)$

The equation of motion in p.u are

$P\,\Delta\omega_r \quad = \frac{1}{2H}(T_m - T_e - K_D.\,\Delta\omega_r)$

$P\,\delta \quad = \omega_0 \Delta\omega_r$

Also

$P\,\Delta\omega_r \quad = \frac{1}{2\pi}(\Delta\,T_m - K_S\,\Delta\delta - K_D.\,\Delta\omega_r)$

Where K_S is synchronizing torque co-efficient and is given by

$K_S \quad = \frac{E' E_B}{X_T} \cos\delta_0$

Linearizing the (6) we get,

$P\,\Delta\delta \quad = \omega_0 \Delta\omega_r$

Writing the (7) & (9) in vector matrix, we obtain

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta\end{bmatrix} = \begin{bmatrix}\frac{-K_D}{2H} & \frac{-K_S}{2H} \\ \omega_0 & 0\end{bmatrix}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta\end{bmatrix} + \begin{bmatrix}\frac{1}{2H} \\ 0\end{bmatrix}\Delta T_m$$

Where

K_S = Synchronising torque co-efficient

K_D = Damping torque co-efficient in p.u torque/p.u speed deviation

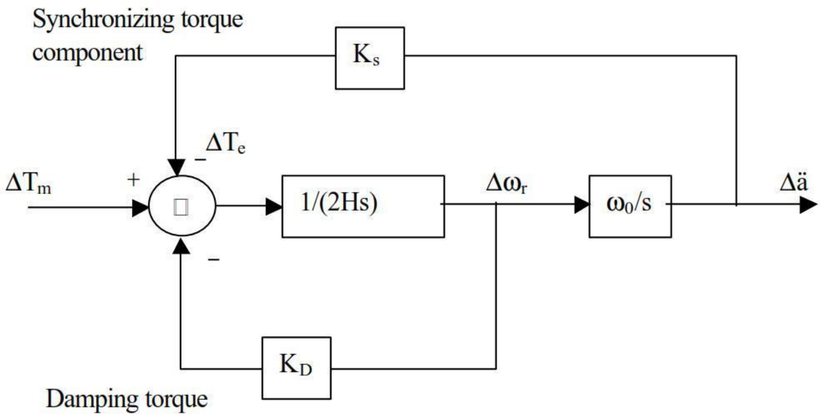
H = Inertia constant in MW. S/MVA

$\Delta\omega_r$ = Speed deviation in p.u

$\Delta\delta$ = Rotor angle deviation in electrical radii

Δ = Laplace operator

ω = rated speed in electrical rad/s



From the block diagram, we have

$$\Delta\delta = \frac{\omega_0}{S}\left[\frac{1}{2HS}(-K_S\Delta\delta - K_D\,\Delta\omega_r + \Delta T_m)\right]$$

$$= \frac{\omega_0}{S}\left[\frac{1}{2HS}\left(-K_S\Delta\delta - K_D S\,\frac{\Delta\delta}{\omega_0} + \Delta T_m\right)\right]$$

Rearranging we get,

$$S^2(\Delta\delta) + \frac{K_D}{2H}\,S(\Delta\delta) + \frac{K_S}{2H}\omega_0(\Delta\delta) = \frac{\omega_0}{2H}\Delta T_m$$

Therefore the characteristic equation is given by

$$S^2 + \frac{K_D}{2H}\,S + \frac{K_S}{2H}\omega_0 = 0$$

This is of the general form

$$S^2 + 2\,S\,\omega_n + \omega_n^2 = 0$$

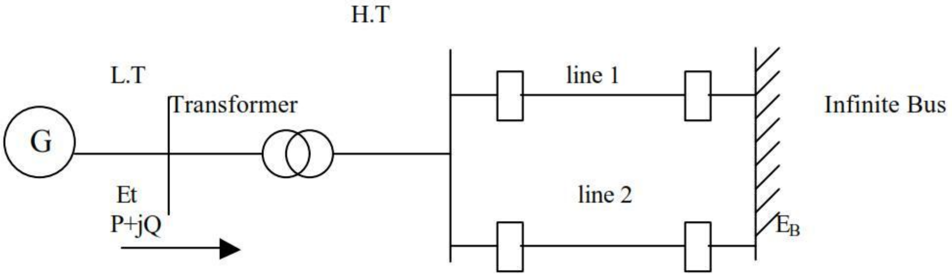
Therefore the un-damped natural frequency is

$\omega_n = \sqrt{\frac{K_S}{2H}\omega_0}$ rad/sec

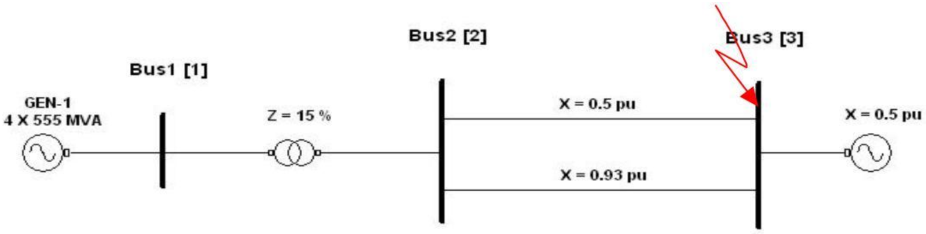
and the damping ratio is

$$S = \frac{1}{2}\frac{K_D}{2H\omega_n}$$

SINGLE LINE DIAGRAM:



DETAILED DIAGRAM:



Note: All the values are in pu on 2220MVA, 24kV base

DATA:

Generator:

555 MVA x 4 Units

X_d' = 0.3 p.u

H = 3.5 Mw-s/MVA

Voltage = 24 KV, 60 Hz

Transformer:

Voltage Ratio = 24/220 KV

Reactance = 0.15 p.u

Line:

Reactance of line 1 = 0.5 p.u

Reactance of line 2 = 0.93 p.u

Reactance of infinite bus = 0.5 p.u

Fault:

Three phase to ground fault at end of line 2 occur at t = 0 sec;

clearing at t = 0.07 sec

E_t = 1.0 p.u;

PF = 0.9

Plant operating condition P = 0.9 pu

RESULT:

Thus for a given single bus infinite system, transient stability analysis was carried out using Mi-Power software package.

ECONOMIC DISPATCH IN POWER SYSTEM

EXERCISE 11

AIM:

To solve economic dispatch and unit commitment problem of a given power system using Mi – Power package.

THEORY:

ECONOMIC DISPATCH PROBLEM:

The purpose of economic dispatch (or) optimal dispatch is to reduce fuel costs for the power system. By economic load scheduling, we mean to find the generation of the different generators (or) plants, so that the total fuel cost is minimum and at the same time the total demand and losses at any instant must be met by total generation. The economic dispatch problem involves the solution of two different problems.

We know that $F_T = F_1 + F_2 + \ldots\ldots + F_N$

Equality Constraint: $\sum_{i=1}^{N} P_{G_i} - P_D = 0$

Inequality Constraint: $P_{G_{i,min}} \leq P_{G_i} \leq P_{G_{i,max}}$

The necessary condition, for the existence of a minimum cost operating condition is that the incremental cost rates of all the units will be equal to some undetermined value □□

$$\frac{dF_i}{dP_{G_i}} = \lambda$$

The power balance equation is $\sum_{i=1}^{N} P_{G_i} = P_D$. There are two inequalities that must be satisfied for each of the units.

$$P_{G_{i,min}} \leq P_{G_i} \leq P_{G_{i,max}}$$

The necessary conditions may be expanded slightly as shown in the set of equation.

$$\frac{dF_i}{dP_{G_i}} = \lambda : \text{for } P_{G_{i,min}} \leq P_{G_i} \leq P_{G_{i,max}}$$

$$\frac{dF_i}{dP_{G_i}} \leq \lambda : P_{G_i} = P_{G_{i,min}}$$

$$\frac{dF_i}{dP_{G_i}} \geq \lambda : P_{G_i} = P_{G_{i,max}}$$

The net saving cost ΔF_t = ΔF_1 +ΔF_2

Where

ΔF_1 = Increase in cost for unit 1.

ΔF_2 = Increase in cost for unit 2.

$\Delta F_i = \int \frac{dF_i}{dP_{G_i}}. dP_{G_i}$

The possible observation concerned to ΔF_t are,

1. If ΔF_t < 0, the fuel input to the system is decreased by increasing generation on source 1 and consequently, the intial generation schedule was not optimum.
2. If ΔF_t > 0, the fuel input to the system is increased by increasing the generation of source 1 and in this case it would not be desirable to increase the output of source 1.

Solution by λ - iteration method without loss

Step: 1 Assign initial trial value of $\boldsymbol{\lambda}$ or calculate $\boldsymbol{\lambda}$ using

$$\lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_i}{2a_i}}{\sum_{i=1}^{N} \frac{1}{2a_i}}$$

Step: 2 Compute P_{G_i} corresponding to $\boldsymbol{\lambda}$ using equations

P_{G_i} = α_i + β_i (IC) + γ_i $(IC)^2$

P_{G_i} = α_i + β_i λ + γ_i λ^2 (or)

$\gamma_{G_i} = \frac{\lambda - b_i}{2a_i}$

Step: 3 Compute $\sum_{i=1}^{N} P_{G_i}$

Step: 4 Check the power balance equation $\sum_{i=1}^{N} P_{G_i} = P_D$

Step: 5 If $\sum_{i=1}^{N} P_{G_i} < P_D$

Assign $\lambda = \lambda + \Delta\lambda$

If $\sum_{i=1}^{N} P_{G_i} > P_D$

Assign $\lambda = \lambda - \Delta\lambda$

Where $\Delta\lambda = \frac{(\Delta P}{\sum_{i=1}^{N} \frac{1}{2a_i}}$ $(\Delta P - Change\ in\ demand)$

DATA

(i) Total Demand = 850MW

Operating limits:

$150\ \text{MW} \leq P_1 \leq 600\ \text{MW}$
$100\ \text{MW} \leq P_2 \leq 400\ \text{MW}$
$50\ \text{MW} \leq P_3 \leq 200\ \text{MW}$

Production cost function in Rs / hr

$F_1 = 459 + 6.48\ P_1 + 0.00128\ P_1^2$ Rs./Hr

$F_2 = 310 + 7.85\ P_2 + 0.0019\ P_2^2$ Rs./Hr

$F_3 = 78 + 7.97\ P_3 + 0.00482\ P_3^2$ Rs./Hr

(ii) Total Demand = 150 MW

Operating limits:

$10\ \text{MW} \leq P_1 \leq 100\ \text{MW}$
$10\ \text{MW} \leq P_2 \leq 100\ \text{MW}$

Production cost function in Rs / hr

$F_1 = 0.05\ P_1^2 + 20\ P_1 + 800$ Rs./Hr
$F_2 = 0.06\ P_2^2 + 15\ P_2 + 1000$ Rs./Hr
$B_{11} = 0.01$; $B_{12} = B_{21} = 0.01$; $B_{22} = 0.024$

(iii) Total Demand = 200 MW

Operating limits:

$10\ \text{MW} \leq P_1 \leq 100\ \text{MW}$
$10\ \text{MW} \leq P_2 \leq 100\ \text{MW}$

Incremental cost function in Rs / hr

$dF_1 = 0.2\ P_1^2 + 20\ P_1$ Rs./Hr
$dF_2 = 0.2\ P_2^2 + 30\ P_2$ Rs./Hr

RESULT:

Thus solution for economic dispatch and unit commitment problem for a given power system was solved using Mi – Power package and the results were presented.

STATE ESTIMATION USING WEIGHTED LEAST SQUARE ESTIMATION

EXERCISE 12

AIM

To obtain the bests possible estimate of state of the power system for the given set of Measurement by weighted least squares method.

THEORY

State estimation plays a very important role in the monitoring and control of modern power system. The main aim of this is to obtain the voltages and bus angles by processing the available system data. State estimation is defined as the data processing algorithm for converting redundant meter reading and other available information into as estimate of the state of electrical power system. Real time measurement is collected in power system through SCADA system. Typical data includes real and reactive line flows and real and reactive bus injections and bus voltage magnitude. This telemetered data may contain errors.

These errors render the output useless. It is for this reason that, power system state estimation techniques have been developed. A commonly used criterion is that of minimizing the sum of the squares of the differences between estimated measurement quantities and actual measurement. This is known as “weighted least squares” criterion.

The mathematical model of state estimation is based on the relation between the measurement variable and the state variable.

Let [Z] = Set of measurements
[X] = The vector of state variables
[f(X] = The equation relating measurement variables to the state variable
[e] = The measurement error vector

We have
[Z] = [f(x)+[e]

Line Data

Line Number	Start Bus	End Bus	Reactance in p.u.
1	1	2	0.2
2	2	3	0.4
3	1	3	0.25

Measurement Data

S. No.	Measurement Quantities	Values (p.u)	Weightages
1	P1	0.72	1.0
2	P1, 2	0.68	1.0
3	P3, 2	-0.405	0.1
4	P1, 3	-0.04	0.2

RESULT

The state of the given system has estimated using weighted least square method and the results are found to be correct

PERFORMANCE ANALYSIS OF OVER CURRENT RELAY

EXERCISE 13

AIM

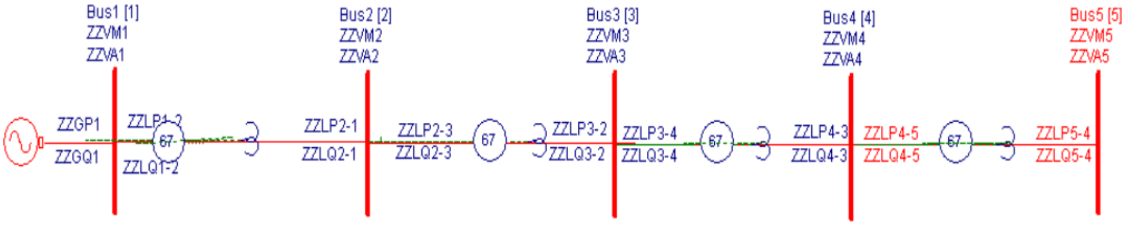
To study the performance analysis of over current relay.

THEORY

The over current relays are used to sense the fault currents and over-load currents and trips off the system. Micro controller is used for the control operation. The programming is done in such a way that when the fault current value is above the set value the relay is closed/ opened (depends on connection) and it trips the circuit. The tripping of the relay is indicated by the LED. The LCD displays the set time, set current, fault current and tripping time. Relays are of many types. Some Depend on the operation of an armature by some form of electromagnet. A very large numbers of relays operate on the induction principle.

When a relay operates it closes contacts in the trip circuit which is normally connected across 110 V D.C. supply from a battery. The passage of current in the coil of the trip circuit actuates the plunger, which causes operation of the circuit breaker, disconnecting the faulty system. In the laboratory, a 3-phase contactor simulates the operation of the circuit breaker. The closure of the relay contacts short-circuits the 'no volt ' coil of the contactor, which, in turn, disconnects the faulty system.

The protective relaying which responds to a rise in current flowing through the protected element over a pre-determined value is called 'overcurrent protection' and the relays used for this purpose are known as over current relays. The operating time of all overcurrent relays tends to become asymptotic to a definite minimum value with increase in the value of current.



DATA

Table 1 : Transmission Line Data on 100 MVA base

Bus Code	Line Impedance	Line Charging Admittance
1-2	j0.1	0
2-3	j0.1	0
3-4	j0.1	0
4-5	j0.1	0
5-6	j0.1	0

Generator Details :

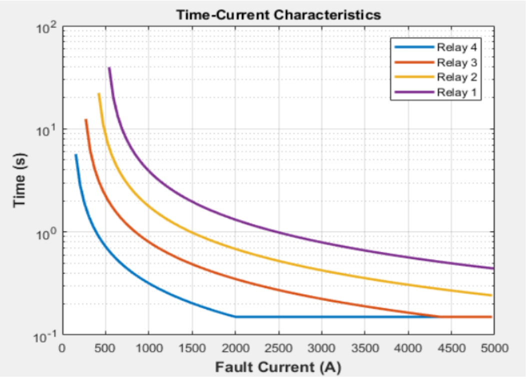
G1 = 100 MVA, 11 kV

Maximum fault level = 1000 MVA

Relay Manufacturer : ABB REB 670, IEC Normal Inverse characteristics

Relay Details :

Relay Name	R1	R2	R3	R4
Primary Rating (1,2,3,4)	800	400	200	100
Secondary Rating in Amps	5	5	5	5
Load Current in Amps	800	400	200	100
Relay Type	IEC NI	IEC NI	IEC NI	IEC NI



PERFORMANCE CURVE FOR OVER CURRENT RELAY COORDINATION

RESULT

Thus, the performance analysis of over current relay is studied.

PERFORMANCE ANALYSIS OF IMPEDANCE RELAY

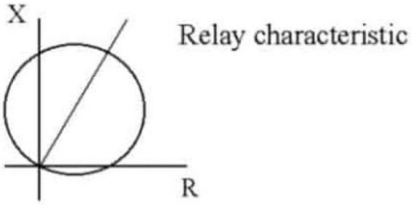
EXERCISE 14

AIM

To study the performance analysis of impedance relay.

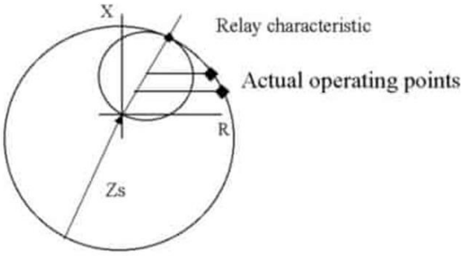
THEORY

A mho impedance relay generally has an operating characteristic which is a circle passing through the origin. Actually, all modern mho impedance relays for phase, ground and 3-phase protection have an expanded characteristic that includes the origin.



Only the case in which the mho characteristic does pass through the origin is when the source impedance (Zs) is zero. However, this case would never happen since all real-world sources have some finite non-zero impedance.

The simple explanation is that the relay sees the source impedance from the drop in the voltage from prefault conditions during the fault. It has been shown that traditional fixed voltage or fixed current testing methods actually present a power system to the relay has the following special characteristics:



- ❖ It is a radial system (no load).
- ❖ The zero sequence source impedance is equal to the positive sequence source impedance.

- The angle of the zero-sequence line impedance is equal to the angle of the positive sequence line impedance.
- The angle of the fault is equal to the line impedance angle and to the source impedance angle.

The real impedance operates times actually vary with source to line impedance ratio (SIR). Generally, the operation times are higher with higher source to line impedance ratio values.

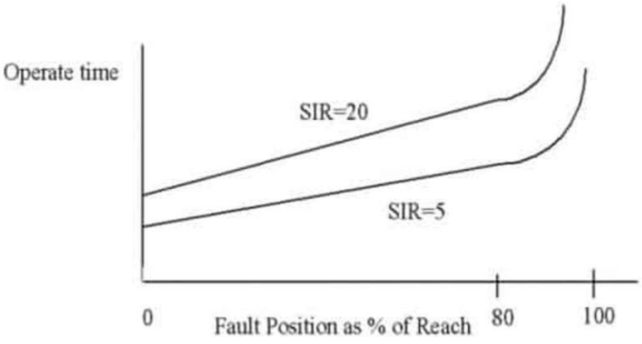
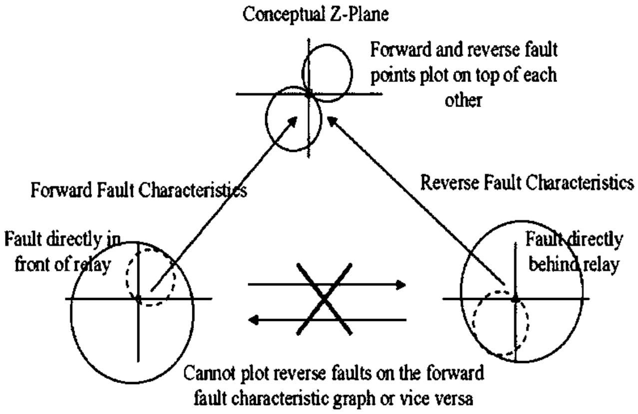


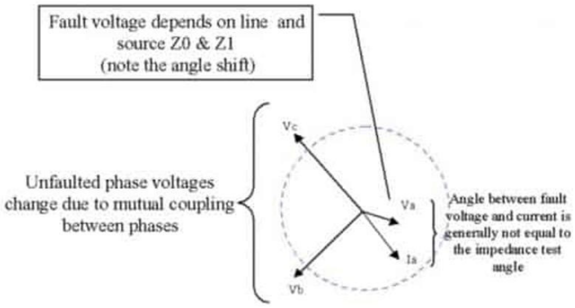
Fig. Typical variation of operate time for different SIR values

The fault directly in front of the relay can only be plotted on the forward fault characteristic graph. The fault directly behind the relay can only be plotted on the reverse fault characteristic graph. The fault directly in front of the relay cannot be plotted on the reverse fault characteristic graph or vice versa.



- The unfaulted phase voltages change. This is due to the mutual coupling between phases.
- The angle of the faulted phase voltage (Va) shifts. The value of Va depends on the line and source positive as well as zero sequence impedances.

- The angle between the fault voltage and current is not necessarily equal to the impedance test angle.



Fault phasors for a typical system

In order to determine the appropriate voltages and currents to simulate a given fault condition, it is necessary to also decide on the power system being simulated. That is:

Fault condition + Power system — Determine -> Voltages & Currents

The power system is defined by:

The circuit configuration (radial, 2-terminal, parallel line etc.)

Source + line impedances (positive, negative and zero sequence)

Source voltages (magnitude and angle)

The fault condition is defined by:

Fault section (forward, reverse, adjacent line, beyond remote end)

Position (% of line)

Fault phase(s) and type

Fault impedance (magnitude & angle)

The relay input voltages and currents include:

Faulted phase voltage and currents

Unfaulted phase voltages and currents

(Prefault voltages and currents)

Without consciously deciding on power system, some arbitrary assumption must be made about either the voltage or the current or both and we end up with an unknown power system.

Example:

Fault condition + — Determine -> Voltages & Currents+ unknown power system

Of course, what an impedance relay does is use some knowledge (read assumption) of the power system which is the line impedances, and the voltages and currents to determine the fault condition. That is:

Fault condition <– Determine — Voltages & Currents+ power system

Note that the voltages and currents include both the prefault and unfaulted phase voltages and currents.

In actuality:

- Any point on the R-X plane corresponds to an infinite number of possible fault conditions even for the same power system.
- Impedance relays use not only the faulted phase voltages and currents, but also the prefault and unfaulted phase voltages and currents to determine operation.
- All must be calculated properly with the same power system model that the relay is set for to simulate the desired fault condition.

RESULT

Thus, the performance analysis of over current relay is studied.

TESTING OF CT, PR AND INSULATOR STRING

EXERCISE 15

AIM

To study the performance of CT,PT and Insulator String.

THEORY

Current transformers reduce high voltage currents to a much lower value and provide a convenient way of safely monitoring the actual electrical current flowing in an AC transmission line using a standard ammeter. The principal of operation of a basic current transformer is slightly different from that of an ordinary voltage transformer. Current transformers can reduce or “step- down” current levels from thousands of amperes down to a standard output of a known ratio to either 5 Amps or 1 Amp for normal operation. Thus, small and accurate instruments and control devices can be used with CT’s because they are insulated away from any high-voltage power lines. There are a variety of metering applications and uses for current transformers such as with Wattmeter’s, power factor meters, watt-hour meters, protective relays, or as trip coils in magnetic circuit breakers, or MCB’s.

Potential transformer or voltage transformer gets used in electrical power system for stepping down the system voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage. This is a simplest form of potential transformer definition. Potential transformer theory is just like a theory of general-purpose step-down transformer. Primary of this transformer is connected across the phase and ground. Just like the transformer used for stepping down purpose, potential transformer i.e. PT has lower turns winding at its secondary. The system voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT.

The secondary voltage of the PT is generally 110 V. In an ideal potential transformer or voltage transformer, when rated burden gets connected across the secondary; the ratio of primary and secondary voltages of transformer is equal to the turns ratio and furthermore, the two terminal voltages are in precise phase opposite to each other. But in actual transformer, there must be an error in the voltage ratio as well as in the phase angle between primary and secondary voltages.

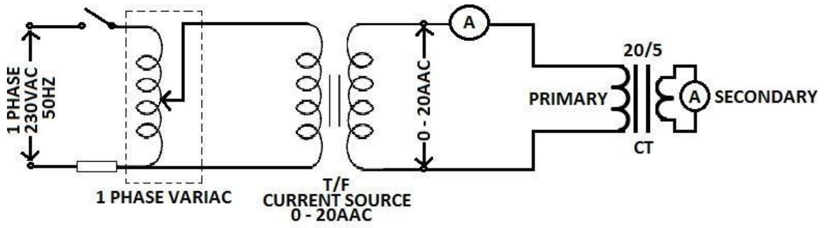


Fig. Current Transformer Circuit

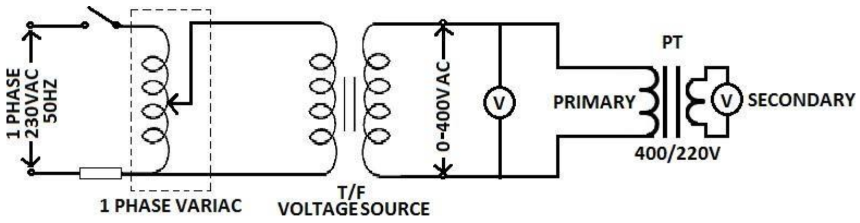


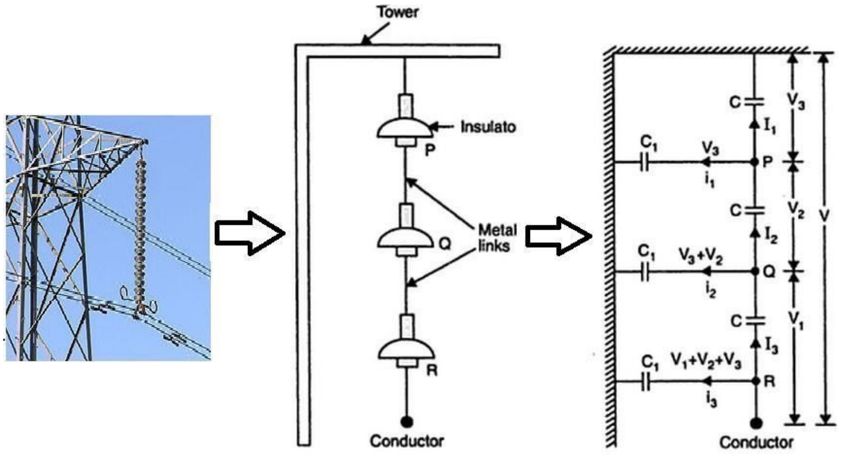
Fig. Potential Transformer Circuit

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. 1 (i) shows string of suspension insulators. The porcelain portion of each disc is in between two metal links as shown in Fig. 1 (ii). Therefore, each disc forms a capacitor C as shown in Fig. 1 (iii). This is known as mutual capacitance or self capacitance.

However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same throu1gh all the discs of the string Fig. 1 (i) shows string of suspension insulators. The porcelain portion of each disc is in between two metal links as shown in Fig. 1 (ii). Therefore, each disc forms a capacitor C as shown in Fig. 1 (iii). This is known as mutual capacitance or self capacitance. However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string [See Fig. 1 (iii)]. Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum voltage. Thus referring to Fig. 1 (iii), V1 will be much more than V2 or V3.

The following points may be noted regarding the potential distribution over string of suspension insulators:

i. The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.
ii. The disc nearest to the conductor has maximum voltage across it. As we move towards the Cross-arm, the voltage across each disc goes on decreasing.
iii. The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.
iv. If the voltage impressed across the string were d.c, then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.



(i) (ii) (iii)

String Efficiency:

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency.

$$String\ Efficiencey = \frac{Voltage\ across\ the\ string}{n\ x\ voltage\ across\ nearest\ to\ the\ conductor}$$

where n – number of discs in the string

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

Methods to Improve String Efficiency:

i. By using longer cross-arms
ii. By grading the insulators.
iii. By using a guard ring

The potential across each unit in a string can be equalized by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator. The guard ring introduces capacitance between metal fittings and the line conductor. The guard rings contoured in such a way that shunt capacitance currents i1, i2 etc. are equal to metal fitting line capacitance currents i′1, i′2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

CIRCUIT DIAGRAM:

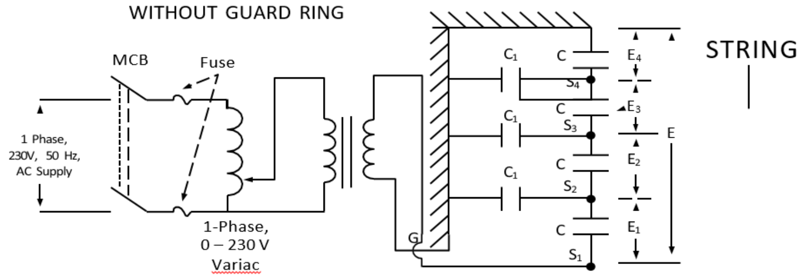
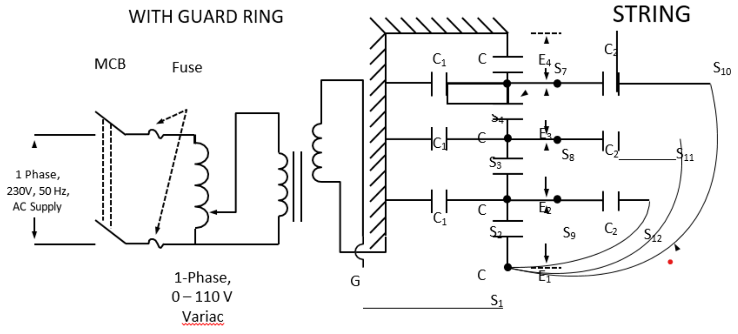


Fig 3: Without Guard Ring



PROCEDURE:

Without Guard Ring:

i. Connect the circuit as per the Fig. 3. From one of the Variac output terminals connect to terminals S1 and other Variac output terminal to G as shown in Fig. 3.
ii. Apply voltage from the Variac across the string in steps of 20V starting from 30V to 110V.
iii. Measure the voltage across S1 and S2(which is to be noted as E1); S2 and S3(which is to be noted as E2); S3 and S4(which is to be noted as E3); S4 to G (which is to be noted as E4)
iv. Tabulate the voltages E1 to E4 in the tabular column 1.
v. Calculate the string efficiency without guard ring.

With Guard Ring:

i. Connect the circuit as per the Fig. 4.From one of the Variac output terminals connect to terminals S1 and other Variac output terminal to G. To connect the guard ring to the string,
ii. connect the terminals S4-S7, S3-S8, S2-S9 and also make connections between S1-S10, S1-S11 and S1-S12
iii. Apply voltage from the Variac across the string in steps of 20V starting from 30V to 110V.
iv. Measure the voltage across S1 and S2(which is to be noted as E1); S2 and S3(which is to be noted as E2); S3 and S4(which is to be noted as E3) ; S4 to G(which is to be noted as E4)
v. Tabulate the voltages E1 to E4 in the tabular column 2.
vi. Calculate the string efficiency with guard ring.

CALCULATIONS:

$$String\ Efficiencey = \frac{Voltage\ across\ the\ string}{n\ x\ voltage\ across\ nearest\ to\ the\ conductor}$$

TABULAR COLUMN:

Without Guard Ring:

E	E1	E2	E3	E4	String Efficiency

With Guard Ring:

E	E1	E2	E3	E4	String Efficiency

RESULT:

Thus, testing of CT, PT and Insulator string is studied.

RELAY COORDINATION IN RADIAL FEEDER PROTECTION

EXERCISE 16

AIM

To study the performance of relay coordination in radial feeder protection.

THEORY

Whole of the power system can be subdivided in to number of radial feeders fed from one end. Generally such radial feeders are protected by over current and earth fault relays used as primary relays for 11 kV and 66 kV lines. For lines of voltage rating beyond 66 kV, distance protection is applied as a primary protection whereas over current and earth fault relays are used as back up relays.

A simplified radial feeder network without transformers (in actual practice transformers do exist at substations) is shown in single line diagram of fig. below.

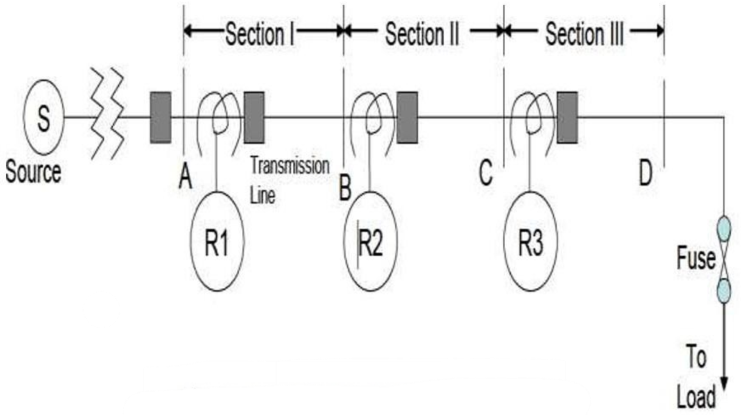


Fig. Typical Radial Transmission Line

If the fault occurs in distribution network, fuse should isolate the faulty section. Should the fuse fail, relay R3 shall give back-up protection. Relays R1, R2, and R3 act as primary relays for faults in section I, section I, and section III respectively.

If fault in section III is not cleared by relaying scheme at relaying point R3, relay R2 will act as a back-up. Similarly back-up protection is provided by relay R1 for faults in section II. A,B, C and D are substations in fig.

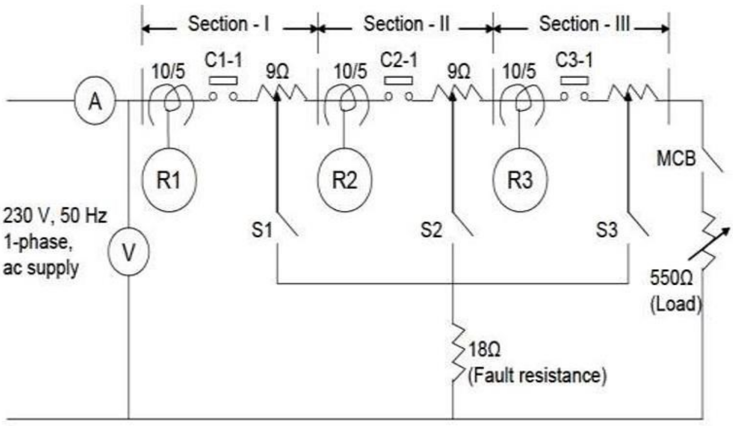
Generally Inverse time over current relays with Definite Minimum Time feature (IDMT relays) are used in practice. There are many types of such relays available in relay market, viz. normal inverse relays, very inverse relays and extremely inverse relays.

The other types of o/c relays are 3 second relay and 1.3 second relay. This means the time of operation of the relay is either 3 or 1.3 second at Plug Setting Multiplier (PSM) equal to 10. Long time inverse relays are used for o/c cum overload application. Voltage restrains o/c relays have their own application.

Very inverse relays are less prone to the ratio ZS/ZL. Extremely inverse relays are yet better. Very inverse relays are faster in operation for close-in faults yet maintaining the discrimination with fuse and other relays. Extremely inverse relays are more meritorious in this aspect too. Instantaneous o/c relays are not immune to ZS/ZL ratio. Definite time o/c relays are 100 % immune to this ratio.

Very inverse relays can be used with an additional advantage while protecting a machine or a transformer as they match with the heating characteristic of equipment better than their normal inverse equivalent.

LIVE MODELOF AC CIRCUIT



This is only a single phase version of a radial feeder. Faults in different sections can be created by switches S1, S2 and S3. Fault limiting resistance of 18 ohms is used for practical purposes only. Here C.T. secondary rating is 5 Amp and relay rating is 1 Amp. This is contradicting the practice for practical purpose.

RESULT:

Thus, the relay coordination in radial feeder protection is studied