SRM VALLIAMMAI ENGINEERING COLLEGE

(An Autonomous Institution)

SRM NAGAR, KATTANKULATHUR – 603203

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

1916108 – POWER SYSTEM SIMULATION LABORATORY

M.E (POWER SYSTEMS ENGINEERING)

SEMESTER – I

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Prepared by,

Mr. T.Santhoshkumar, AP (Sr.G)/ EEE

1916108 – POWER SYSTEM SIMULATION LABORATORY

SYLLABUS

1. Power flow analysis by Newton-Raphson method and Fast decoupled method
2. Transient stability analysis of single machine-infinite bus system using classical machine model
3. Contingency analysis: Generator shift factors and line outage distribution factors
4. Economic dispatch using lambda-iteration method
5. Unit commitment: Priority-list schemes and dynamic programming
6. State Estimation
7. Analysis of switching surge using EMTP: Energisation of a long distributed- parameter line
8. Analysis of switching surge using EMTP: Computation of transient recovery voltage
9. Simulation and Implementation of Voltage Source Inverter
10. Digital Over Current Relay Setting and Relay Coordination using Suitable software packages.
11. Co-ordination of over-current and distance relays for radial line protection

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CYCLE - I

1. Power flow analysis by Newton-Raphson method
2. Power flow analysis by Fast decoupled method
3. Transient stability analysis of single machine-infinite bus system using classical machine model
4. Contingency analysis: Generator shift factors and line outage distribution factors
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CYCLE - II

7. State Estimation
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10. Simulation and Implementation of Voltage source Inverter
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ADDITIONAL EXPERIMENTS

13. Transient behavior of Three-Phase Induction Machine during Starting
14. Small signal stability analysis of a single machine infinite bus system with field circuit, exciter and power system stabilizer

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Exp.No: 1
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POWER FLOW ANALYSIS BY NEWTON-RAPHSON METHOD

Aim:

To develop Newton-Raphson (N-R) method for solving power flow equations. To develop the expressions for the elements of Jacobian matrix. To demonstrate the iterative process of N-R method using the given test system and to check the results with the available load flow programs using MATLAB software.

Development of N-R Method:

Modeling Assumption

- Bus generation and demands are modeled by complex power injections.
- Lines and transformers are modeled by PI equivalent circuit.
- Shunt compensators by shunt susceptance.

Statement of Practical Power Flow Problem

Given

The network configuration, complex bus power injection at all the buses except slack bus and the complex bus voltages at the slack bus.

To Determine

To determine the complex bus voltages at all the buses except slack bus.

Hence only the (n-1) complex power equations are taken and iteratively solved to get the (n-1) unknown complex voltages.

Operating Constraints

- To maintain acceptable voltage profile it is necessary to maintain the voltage magnitude of generator buses distributed throughout the system at values higher than 1.0 per unit.
- In practice “Voltage Control” is achieved by AVR’s and excitation system available at each generating station. At these buses only P-injection and voltage magnitude are specified and hence they are called P-V buses.
- While solving power flow problem the voltage magnitude at the P-V buses are required to be held at specified value provided the reactive power generation at this bus is within the reactive limits QG_{max} and QG_{min}.

Power Flow Model

- Number the PQ buses first then the PV buses and the slack bus is the last bus.
- Let
  - NV be the number of PV bus
  - NP be the number of P equations to find unknown δ (which is equal to $N-1$ equations)
  - NQ be the number of Q equations to find unknown V (which is equal to $N-1-NV$ equations)
- State vector (Dimension NP+NQ)

$$x = \left(\delta_1, \delta_2, \ldots . \delta_{NP}, V_1, V_2, \ldots . . V_{NQ},\right)^t \quad (1)$$

- Number of equations is equal to number of unknowns (NP+NQ). Select the equations as follows
  - Slack bus δ and V known
  - PV bus δ not known only P equation
  - PQ bus and V unknown both P and Q equation

At the k[th] bus the real and reactive power injections are given by

$FP_k = P_k(\delta, V) - PI_{k,sch} = 0$ where $k = 1,2, \ldots .NP$ (2)

$FQ_k = Q_k(\delta, V) - QI_{k,sch} = 0$ where $k = 1,2, \ldots .NQ$ (3)

Where

$P_k(\delta, V) = V_k \sum_{m=1}^{N} V_m [G_{km} \cos \delta_{km} + B_{km} \sin \delta_{km}]$ where $k = 1,2, \ldots .NP$ (4)

$Q_k(\delta, V) = V_k \sum_{m=1}^{N} V_m [G_{km} \sin \delta_{km} - B_{km} \cos \delta_{km}]$ where $k = 1,2, \ldots .NQ$ (5)

The above equations can be compactly represented as

$F(\delta, V) = 0$ (6)

$F(x) = 0$ where $x = (\delta_1, \delta_2, \ldots . \delta_{NP}, V_1, V_2, \ldots . V_{NQ},)^t$ (7)

Compact power flow equation has to be solved using N-R method to obtain the state vector through iterative process. Once the solution is obtained the unknown real and reactive injections and power flow in each line can be computed.

N-R algorithm

To solve $F(x) = 0$

Let $\Delta x^h; h = 0$be the assumed solution.

Let Δx^h be small and be the deviation from the correct solution then

$F(x^h + \Delta x^h) = 0$ (8)

Expanding vector function F by the taylor series around x^h and truncating second and higher order terms we get

$F(x^h + \Delta x^h) = 0 \cong F(x^h) + \left(\frac{\partial F}{\partial x}\right)_{x^h} \Delta x^h$=0 (9)

where h is the iteration number

The above equation can be rearranged as

$\left(\frac{\partial F}{\partial x}\right)_{x^h} \Delta x^h = - F(x^h)$ (10)

Substituting the value for $F(x^h)$ from equations (2) and (3)

$\left(\frac{\partial F}{\partial x}\right)_{x^h} \Delta x^h = \begin{bmatrix} PI_{sch} - P(x^h) \\ QI_{sch} - Q(x^h) \end{bmatrix}$ (11)

The above equation can be expressed as

$\left(\frac{\partial F}{\partial x}\right)_{x^h} \Delta x^h = \begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix}$ (12)

Where

$\left(\frac{\partial F}{\partial x}\right)_{x^h}$ is the jacobian matrix , Δx^h is the state correction matrix and $\begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix}$ is the mismatch vector

The equation (12) can be detailed expressed as

$$\begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\delta P}{\delta V} \\ \frac{\partial Q}{\partial \delta} & \frac{\delta Q}{\delta V} \end{bmatrix} \begin{bmatrix} \Delta \delta^h \\ \Delta V^h \end{bmatrix} = \begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix} \quad (13)$$

Elements of Jacobian

In order to make to computations of Jacobian elements more efficient the equations are modified as shown

$$\begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\delta P}{\delta V} V \\ \frac{\partial Q}{\partial \delta} & \frac{\delta Q}{\delta V} V \end{bmatrix} \begin{bmatrix} \Delta \delta^h \\ \frac{\Delta V^h}{V} \end{bmatrix} = \begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix} (14)$$

Let $H = \frac{\partial P}{\partial \delta}, J = \frac{\partial Q}{\partial \delta}, L = \frac{\delta Q}{\delta V} V$ and $N = \frac{\delta P}{\delta V} V$

The matrix $H, J, L$and Ncan be expressed in terms of $P(x^h)$ and $Q(x^h)$

The off diagonal elements of the above matrices are given by the equations (15) to (18)

$H_{km} = \frac{\partial P_k}{\partial \delta_m} = V_k V_m Y_{km} \sin(\delta_{km} - \theta_{km})$ (15)

$N_{km} = \frac{\partial P_k}{\partial V_m} V_m = V_k V_m Y_{km} \cos(\delta_{km} - \theta_{km})$ (16)

$J_{km} = \frac{\partial Q_k}{\partial \delta_m} = -V_k V_m Y_{km} \cos(\delta_{km} - \theta_{km}) = -N_{km}$ (17)

$L_{km} = \frac{\partial Q_k}{\partial \delta_m} = V_k V_m Y_{km} \sin(\delta_{km} - \theta_{km}) = H_{km}$ (18)

The diagonal elements of the matrices are given by the equations (19) to (22)

$H_{kk} = \frac{\partial P_k}{\partial \delta_k} = -B_{kk} V_k^2 - Q_k(x^h)$ (19)

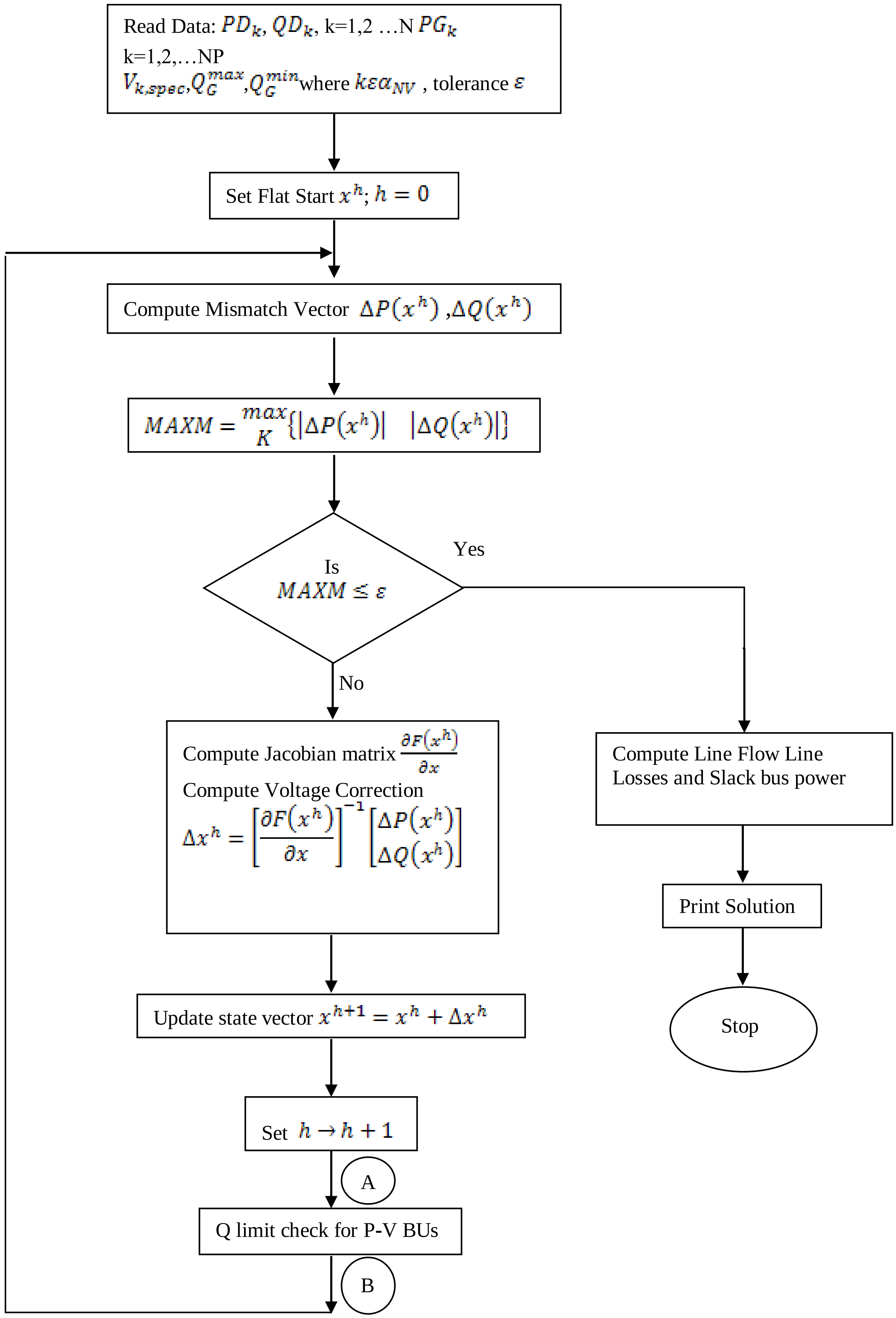
$N_{kk} = \frac{\partial P_k}{\partial V_k} V_k = G_{kk} V_k^2 + P_k(x^h)$ (20)

$J_{kk} = \frac{\partial Q_k}{\partial \delta_k} = -G_{kk} V_k^2 + P_k(x^h)$ (21)

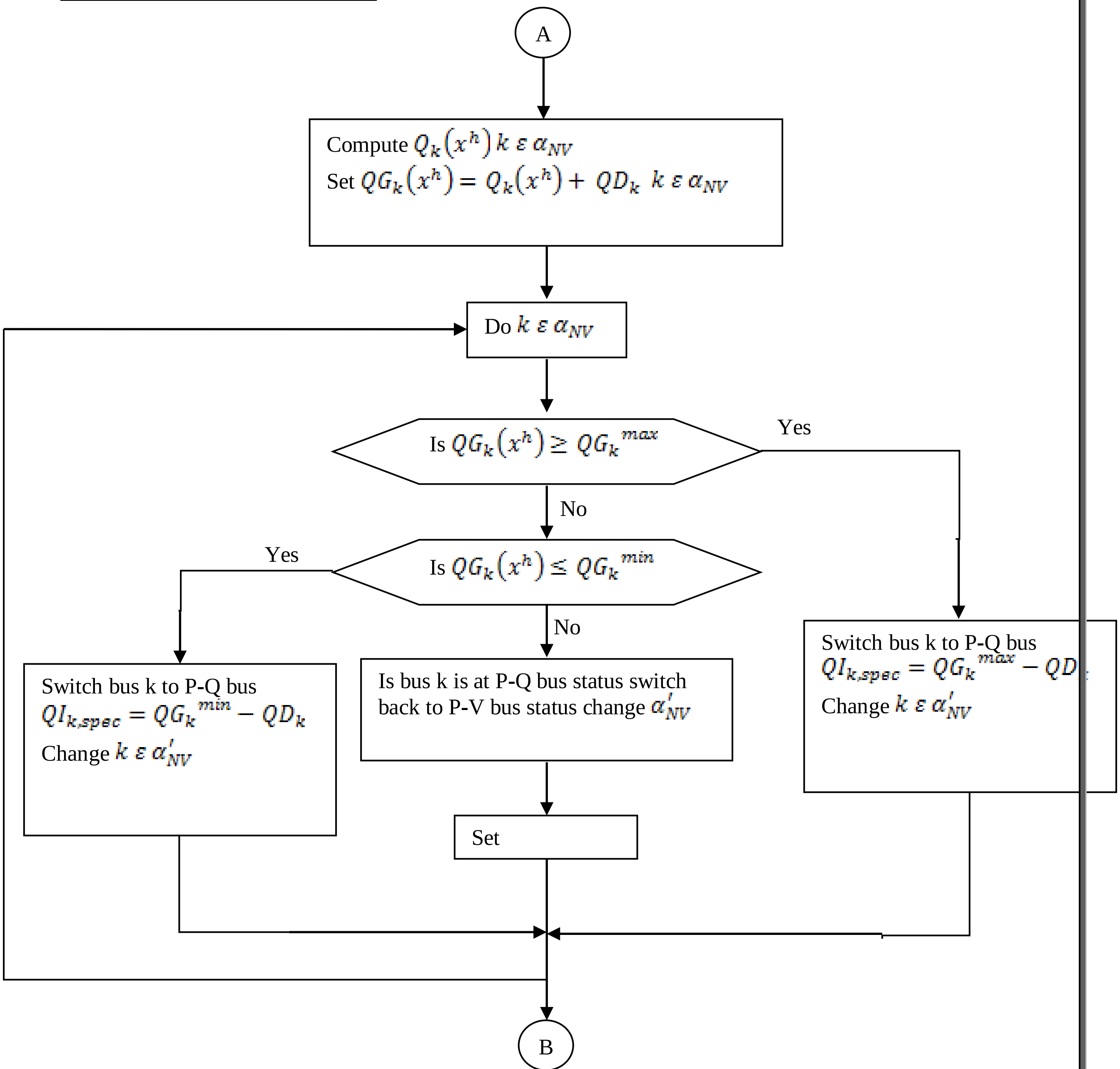
$L_{kk} = \frac{\partial Q_k}{\partial \delta_k} = -B_{kk} V_k^2 + Q_k(x^h)$ (22)

The jacobian elements are functions of latest state vector and bus admittance matrix. The jacobian matrix is real and has symmetric sparse structure, but asymmetric in value.

Flowchart


Read Data: PD_k, QD_k, k=1,2 …N PG_k k=1,2,…NP
$V_{k,spec}$,Q_G^{max},$Q_G^{min}$where $k\varepsilon\alpha_{NV}$, tolerance ε
Set Flat Start x^h; $h = 0$
Compute Mismatch Vector $\Delta P(x^h)$,$\Delta Q(x^h)$
$MAXM = \max_K \{|\Delta P(x^h)| \quad |\Delta Q(x^h)|\}$
Is $MAXM \leq \varepsilon$
Yes
No
Compute Jacobian matrix $\frac{\partial F(x^h)}{\partial x}$
Compute Voltage Correction
$\Delta x^h = \left[\frac{\partial F(x^h)}{\partial x}\right]^{-1} \begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix}$
Compute Line Flow Line Losses and Slack bus power
Print Solution
Stop
Update state vector $x^{h+1} = x^h + \Delta x^h$
Set $h \rightarrow h + 1$
A
Q limit check for P-V BUs
B

Q Limit Check For P-V bus



Exercise:
Consider 3 bus system each has a line of a series impedance of 0.02+j0.02p.u and total shunt admittance of j0.02pu.The specified capacity of buses are tabulated below
Controllable reactive power souce is available at bus 3 with a constraint 0≤QG≤1.5.Find the total flow solution using NR method with power flow mismatch

Bus No	**Real Load Demand(P_D)**	**Reactive load demand (Q_D)**	**Real power generation (P_G)**	**Reactive power Gen. (Q_G)**	**Voltage specification**
1	2.0	1.0	-	-	1.0+j0
2	0	0	0.5	1.0	-
3	1.5	0.6	0.0	QG3?	1.04

PROGRAM

```
clc;
clear;
      %line From to R+jX
ldata=[1    1 2 0.02+0.04i
       2    1 3 0.01+0.03i
       3    2 3 0.0125+0.025i];
        %bus  V d P Q Type
   bdata=[1 1.05 0 0    0 0
          2 1.00 0 -4   -2.5 2
          3 1.04 0 2    0 1];
      nbus=length(bdata(:,1));
      nlines=length(ldata(:,1));
      V=bdata(:,2);
      d=bdata(:,3);
      P=bdata(:,4);
      Q=bdata(:,5);
      type=bdata(:,6);
      y=zeros(nbus);
      for j=1:nlines;
          l=ldata(j,2);
          m=ldata(j,3);
          y(l,l)=y(l,l)+(1/ldata(j,4))+ldata(j,5);
          y(m,m)=y(m,m)+(1/ldata(j,4))+ldata(j,5);
          y(l,m)=-(l/ldata(j,4));
          y(m,l)=y(l,m);
      end
      Y=abs(y);
      t=angle(y);
      poweracc=10^-6;
      DC=1;
      iter=0;
      while poweracc<max(abs(DC));
          iter=iter+1;
          disp('ITERATION');
          disp(iter);
          v=V.*(exp(complex(0,d)));
```

```
    Pcal=real((v).*conj(y*v));
    Qcal=imag((v).*conj(y*v));
    DelP=P-Pcal;
    DelQ=Q-Qcal;
    DX=[DelP;DelQ];
    for j=(1:nbus);
        for k=(1:nbus);
            J1(k,j)=-imag(conj(v(k))*v(j)*y(k,j));
            J2(k,j)=real(conj(v(k))*v(j)*y(k,j))/V(j);
            J3(k,j)=-real(conj(v(k))*v(j)*y(k,j));
            J4(k,j)=-imag(conj(v(k))*v(j)*y(k,j))/V(j);
        end
    end;
    for k=(1:nbus);
        J1(k,k)=-Qcal(k)-imag(V(k)^2*y(k,k));
        J2(k,k)=(Pcal(k)/V(k))+real(V(k)*y(k,k));
        J3(k,k)=Pcal(k)-real(V(k)^2*y(k,k));
        J4(k,k)=(Qcal(k)/V(k))-imag(V(k)*y(k,k));
    end;
    J=[J1 J2;
      J3 J4];
   K=[find(type==0);
      find(type==0)+nbus;
      find(type==1)+nbus];
      DX(K)=[];
      J(K,:)=[];
      J(:,K)=[];
      DC=J\DX;
      d(2)=d(2)+(DC(1));
      d(3)=d(3)+(DC(2));
      V(2)=V(2)+(DC(3));
      V,d
      end;
      i=1:nbus;
      S(i)=v.*conj(y*v);
      for a=1:nbus;
      b=1:nbus;
      LineCurrent(a,b)=-y(a,b)*(v(a)-v(b));
      end;

      for m=1:nbus;
         for n=1:nbus;
      PowerFlow(m,n)=v(m)*conj(LineCurrent(m,n));
      end;
      end;

for i=1:nbus;
    for j=1:nbus;
        Loss(i,j)=PowerFlow(i,j)+PowerFlow(j,i);
    end;
end;
S,LineCurrent,PowerFlow,Loss
```

OUTPUT

Result:

Load flow for the given test system is carried out by Newton Raphson method and the results have been verified by the MATLAB programs.

Viva Questions:

1. What is the need for load flow?
2. What is Voltage controlled bus?
3. How Q limits are considered for PV bus?
4. Compare NR method with other Power flow methods
5. What are the various buses in Power system?

Exp.No:2

Date:

POWER FLOW ANALYSIS BY FAST DECOUPLED METHOD

Aim:

To develop Fast Decoupled (FDPF) method for solving power flow equations. To demonstrate the iterative process of FDPF method using the given test system and to check the results with the MATLAB software

Development of FDPF Method:

FDPF improves the speed and reliability of convergence and to reduce storage requirements.

Decoupling Process

- There is a loose physical interactions between the real and reactive power flow in the power system
- Values of elements of sub matrix $[N]$ and $[J]$ are relatively small when compared to the sub matrix $[H]$ and$[L]$.
- The first step in decoupling process is to neglect the coupling sub matrix $[N]$ and$[J]$.

$$\begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\delta^h \\ \frac{\Delta V^h}{V} \end{bmatrix} = \begin{bmatrix} \Delta P(x^h) \\ \Delta Q(x^h) \end{bmatrix} \qquad (1)$$

$$[H][\Delta\delta] = [\Delta P(x)] \qquad (2)$$

$$[L]\left[\frac{\Delta V}{V}\right] = [\Delta Q(x)] \qquad (3)$$

Where

$$H_{kk} = \frac{\partial P_k}{\partial \delta_k} = -B_{kk}V_k^2 - Q_k(x^h) \qquad (4)$$

$$L_{kk} = \frac{\partial Q_k}{\partial \delta_k} = -B_{kk}V_k^2 + Q_k(x^h) \qquad (5)$$

$$H_{km} = \frac{\partial P_k}{\partial \delta_m} = V_k V_m Y_{km} \sin(\delta_{km} - \theta_{km}) \qquad (6)$$

$$L_{km} = \frac{\partial Q_k}{\partial \delta_m} = V_k V_m Y_{km} \sin(\delta_{km} - \theta_{km}) = H_{km} \qquad (7)$$

and $Q_k(\delta, V) = V_k \sum_{m=1}^{N} V_m [G_{km} \sin\delta_{km} - B_{km}\cos\delta_{km}]$ where $k = 1,2,\ldots..NQ$

(8)

Assumptions:

Physically justifiable assumptions can be made which are always valid

- δ_{km} is very small and hence $\cos\delta_{km} \cong 1$and $G_{km}\sin\delta_{km} \ll B_{km}\cos\delta_{km} \cong B_{km}$

  Invoking the following in (7) and (8)

  $$L_{km} = H_{km} = -V_k V_m B_{km} \; k \neq m \qquad (9)$$

  $$Q_k(\delta, V) = -B_{kk}V_k^2 - \sum_{m\varepsilon\alpha_k} V_k B_{km} V_m \qquad (10)$$

- Assuming all values of V to be equal to 1 and comparing the value of $Q_k(\delta, V)$ with $B_{kk}V_k^2$it is found $Q_k(\delta, V) \ll |-B_{kk}V_k^2|$ and hence

  $$H_{kk} = L_{kk} = -B_{kk}V_k^2 \qquad (11)$$

- $L_{km} = H_{km} = -V_k B_{km} V_m \; k \neq m$ and $L_{kk} = H_{kk} = V_k B_{kk} V_k$ can be expressed in matrix form as

  $$[V[-B]V]\Delta\delta = \Delta P \qquad (12)$$

$[V[-B]V]\frac{\Delta V}{V} = \Delta Q$ (13)

$[-B]$ in (12) and (13) is negative bus susceptance matrix.

- Three step process to improve decoupling
  - Divide the i[th] equation of (12) and (13) by V_i thereby removing the L.H.S V terms to the denominator of the R.H.S terms.
  - Remove the influence of Q-flow on the calculation of δ
    - By setting all the R.H.S V terms to $1.0\ p.u$ in (12)
    - By omitting shunt reactance's and off nominal tap ratio from $[-B]$ in (12)
    - By neglecting series resistance while calculating $[-B]$ in (12) which makes it a D.C load flow matrix.

FDPF Method

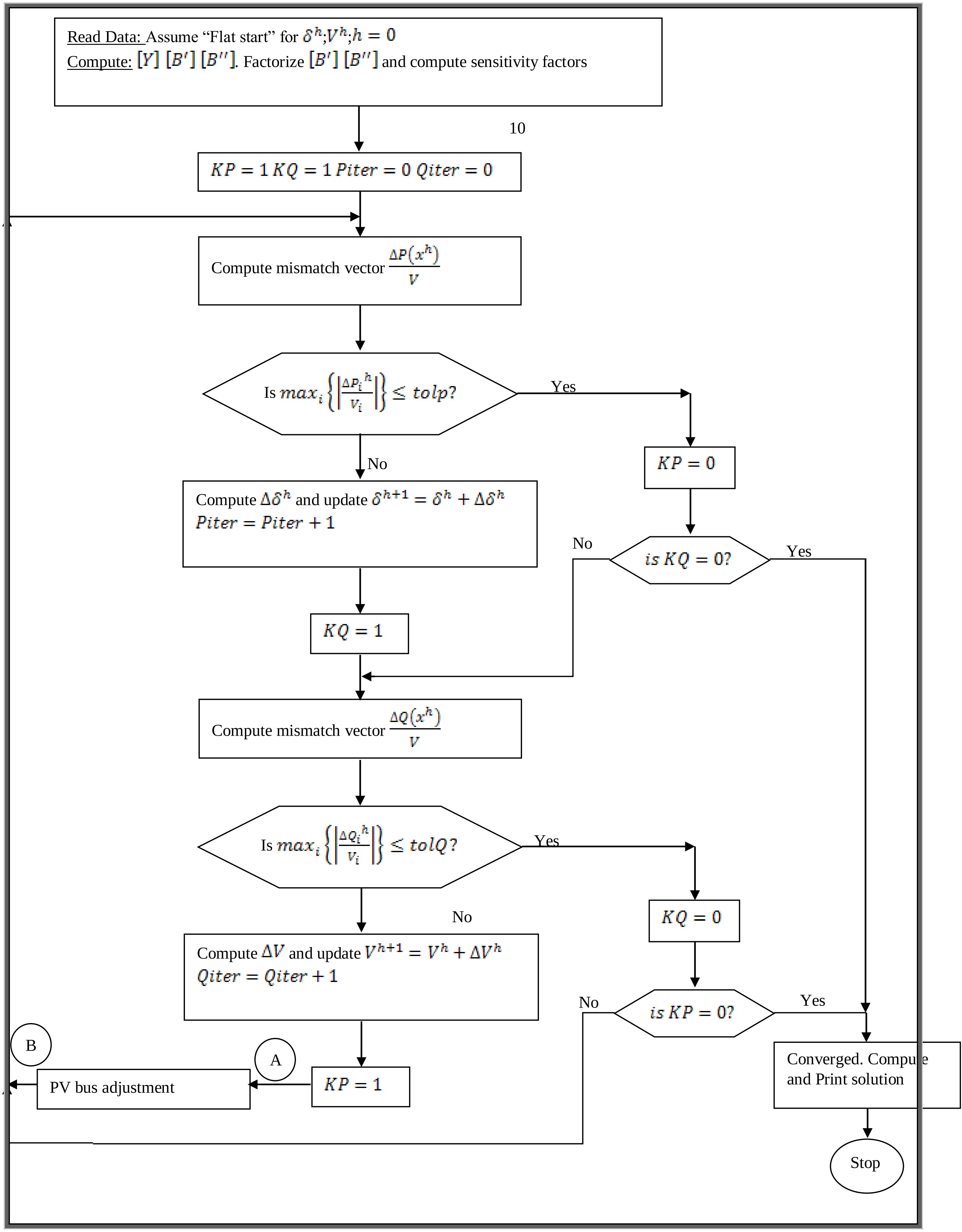
Neglect the angle shifting effects of phase shifter in $[-B]$ in (13). With all the above modification the FDPF scheme becomes

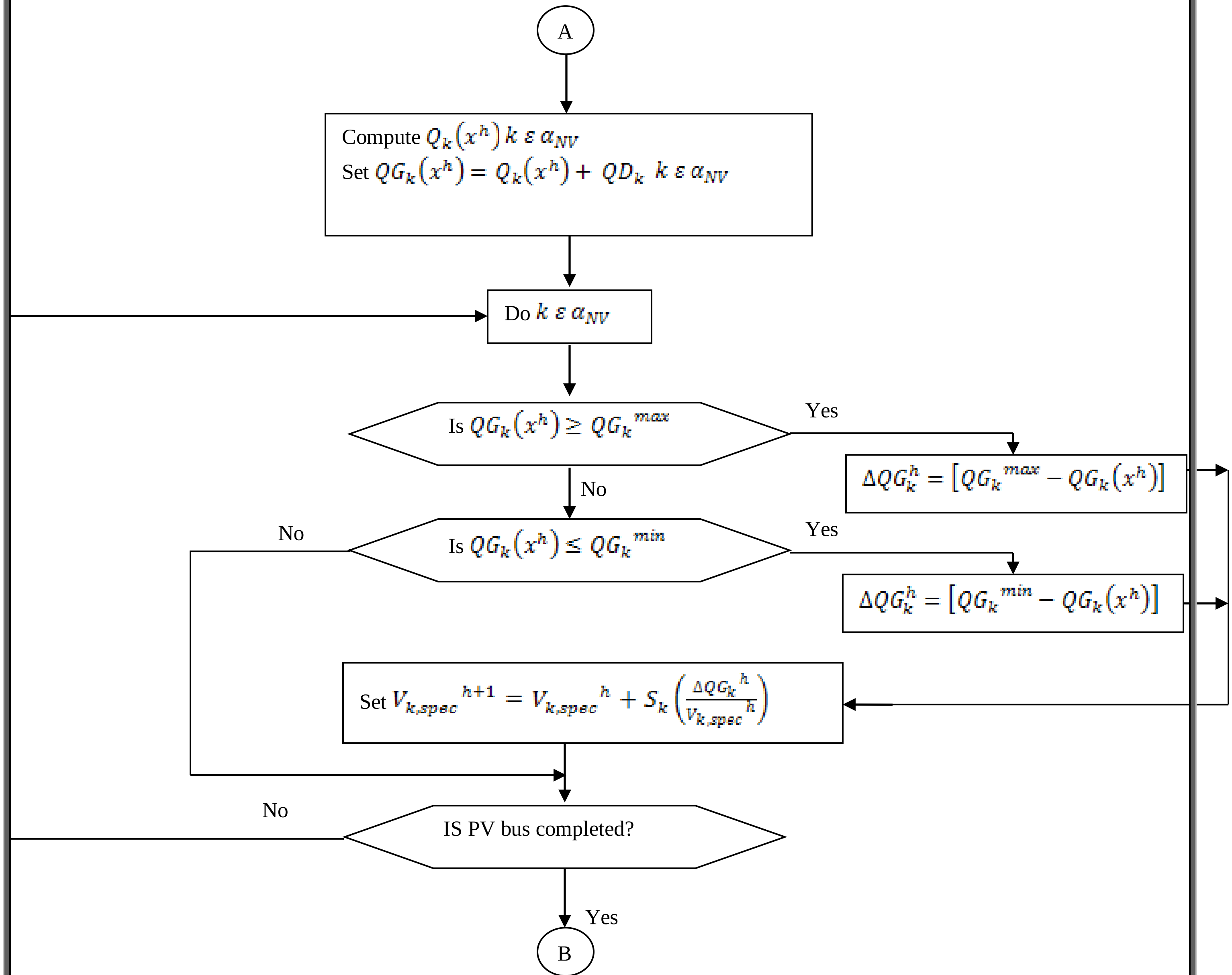
$[B^{'}]\Delta\delta = \left[\frac{\Delta P}{V}\right]$ (14)

$[B^{''}]\Delta V = \left[\frac{\Delta Q}{V}\right]$ (15)

$[B^{'}]$ and $[B^{''}]$ are real, sparse, symmetric constant matrix. They are computed and factorized only once at the beginning of iterations and are not recomputed and refactorized

Flowchart: Flowchart for the decoupled power flow is given below


Read Data: Assume "Flat start" for $\delta^h; V^h; h = 0$
Compute: $[Y]$ $[B']$ $[B'']$. Factorize $[B']$ $[B'']$ and compute sensitivity factors
10
$KP = 1$ $KQ = 1$ $Piter = 0$ $Qiter = 0$
Compute mismatch vector $\frac{\Delta P(x^h)}{V}$
Is $max_i \left\{ \left| \frac{\Delta P_i{}^h}{V_i} \right| \right\} \leq tolp?$
Yes
No
$KP = 0$
Compute $\Delta\delta^h$ and update $\delta^{h+1} = \delta^h + \Delta\delta^h$
$Piter = Piter + 1$
No
$is\ KQ = 0?$
Yes
$KQ = 1$
Compute mismatch vector $\frac{\Delta Q(x^h)}{V}$
Is $max_i \left\{ \left| \frac{\Delta Q_i{}^h}{V_i} \right| \right\} \leq tolQ?$
Yes
No
$KQ = 0$
Compute ΔV and update $V^{h+1} = V^h + \Delta V^h$
$Qiter = Qiter + 1$
No
$is\ KP = 0?$
Yes
B
A
Converged. Compute and Print solution
PV bus adjustment
$KP = 1$
Stop



bus does not find a place in $[B^{''}]$. Augment $[B^{''}]$ with a new row and column corresponding to P-V bus, say the k^{th} bus and the sensitivity $S_k = X_{kk}{}^{''}$ is found as shown

$$\left[\left(\begin{array}{c|c} B^{''} & \begin{matrix} x \\ \vdots \\ x \end{matrix} \\ \hline x \cdots x & X \end{array}\right)\right] \begin{bmatrix} \Delta V \\ \Delta V_{NQ+1} \end{bmatrix} = \begin{bmatrix} \frac{\Delta Q}{V} \\ \frac{\Delta Q_{max}}{V} \end{bmatrix} \qquad (16)$$

$$\begin{bmatrix} \Delta V \\ \Delta V_k \end{bmatrix} = \begin{bmatrix} \ddots & \vdots \\ \cdots & X_{kk}{}^{''} \end{bmatrix} \begin{bmatrix} \frac{\Delta Q}{V} \\ \frac{\Delta Q_k}{V_k} \end{bmatrix} \qquad (17)$$

Exercise

For the two bus test system perform two iterations of N-R method using flat start and obtain δ^2, V^2. Using this solution determine the real and reactive power mismatches at bus 2. Compute the line flow (MW, Mvar) and line losses. Compute slack bus generation. Verify your results with available MATLAB programs.

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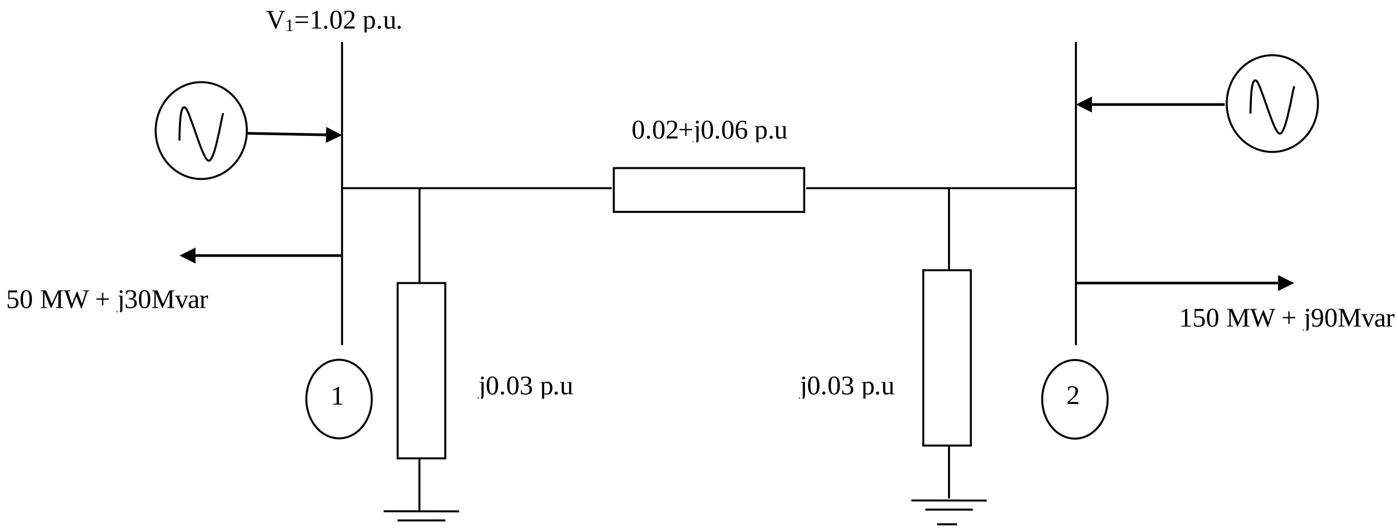


EXTRA PROBLEMS

Carry out a FDPF method for same two bus system with different specifications given below

$P_{D2} + jQ_{D2} = 150 + j90$

$P_{G2} = 75\ MW\ V_{2,spec} = 1.0\ p.u. -50Mvar \leq Q_{G2} \leq 105\ Mvar$

PROGRAM

```
clc;
clear all;
  %Line  From   To  R+jX   Adm
  ldata=[1   1  2  0.0+0.025i  0.0i
     2  1  3  0.0+0.025i  0.0i
     3  2  3  0.0+0.05i  0.0i];
  %Bus   V  d  P  Q  Type
  bdata=[1   1.025  0  0  0  0
     2  1.00   0  -4  -2  2
     3  1.03   0  3  0  1];
  nbus=length(bdata(:,1));nlines=length(ldata(:,1));
  V=bdata(:,2);d=bdata(:,3);
  type=bdata(:,6);P=bdata(:,4);Q=bdata(:,5);
  y=zeros(nbus);
  for j=1:nlines;
     l=ldata(j,2);
     m=ldata(j,3);
     y(l,l)=y(l,l)+(1/ldata(j,4))+ldata(j,5);
     y(m,m)=y(m,m)+(1/ldata(j,4))+ldata(j,5);
     y(l,m)=-(1/ldata(j,4));y(m,1)=y(l,m);
  end
```

```
BPr=imag(y);BPr(1,:)=[];BPr(:,1)=[];
INVBPr=inv(BPr);
BDPr=imag(y);K=[find(type==0);find(type==0)];
BDPr(K,:)=[];BDPr(:,K)=[];
INVBDPr=inv(BDPr);
Poweracc=0.0000025;
Deld=10;iter=0;
while Poweracc<abs(Deld);
   iter=iter+1;
   disp('iteration:');
   disp(iter);
   v=V.*(exp(complex(0,d)));
   Pcal=real((v).*conj(y*v));
   Qcal=imag((v).*conj(y*v));
   DP=P-Pcal;DelP=DP;DelP(1)=[];
   DQ=Q-Qcal;DelQ=DQ;DelQ(K)=[];
   Deld=-INVBPr*DelP;DelV=-INVBDPr*DelQ;
   d(2)=d(2)+(Deld(1)*V(2));d(3)=d(3)+(Deld(2)*V(3));
   V(2)=V(2)+(DelV(1)*V(2));
   iter,V,d
end;
i=1:nbus;
S(i)=v.*conj(y*v);
P(i)=real(S(i));Q(i)=imag(S(i));
for a=1:nbus;
   for b=1:nbus;
      Linecurrent(a,b)=-y(a,b)*(v(a)-v(b));
      PowerFlow(a,b)=v(a)*conj(Linecurrent(a,b));
   end;
end;
for i=1:nbus;
   for j=1:nbus;
      Loss(i,j)=PowerFlow(i,j)+PowerFlow(j,i);
   end;
end;
V,d,S,PowerFlow,Linecurrent,Loss
```

OUTPUT

P_{iter}	Q_{iter}	V_2	δ_2	$\lvert\Delta P_2\rvert$	$\lvert\Delta Q_2\rvert$
0	0	1	0.0	0.65	-
1	0	1	-2.2345	-	0.480400
1	1	0.9679	-	0.075759	-
2	1	-	-1.965	-	0.006451
2	2	0.9675	-	0.008923	0.012617

Result: FDPF for the given test system is carried out ant the results have been verified by using MATLAB programs

Viva questions:

1. What is PQ decoupling?
2. What are the assumptions made in FDLF method?
3. What are the advantages of FDLF over NR method?
4. What are the applications of Load flow?

Exp.No:3

Date:

TRANSIENT STABILITY ANALYSIS OF SINGLE MACHINE-INFINITE BUS SYSTEM USING CLASSICAL MACHINE MODEL

AIM:

To carry out transient stability analysis of an interconnected power system and obtain the swing curves.

THEORY:

Transient stability of a power system is the ability of the system to maintain synchronism among the generators when it is subjected to sudden, large transient disturbance. The transient disturbance may be,

1. Sudden fault or short - circuit followed by opening of breakers
2. Sudden application or rejection of large load or sudden tripping of generators.
3. Switching operations

If the individual machine in a multi - machine power system are operating in steady - state equilibrium and a disturbance of the kind mentioned above is imposed on the system, then the system is said to be stable, if each machine oscillates around and ultimately settles to a new equilibrium condition. This equilibrium condition is characterized by constant speed of the machine.

Transient stability analysis is one of the essential simulation studies conducted by power system engineers. The purpose of this is to find out the dynamic behaviour of the system following a transient disturbance such as a fault on a high voltage line.

Critical clearing time has to be determined by conducting this study. This time is defined as the maximum permissible fault clearing time for the system to remain stable under the given conditions of disturbances. This involves the computation of swing curves by solving the non - linear swing equation of the system using suitable numerical method.

Swing equation of multi - machine power system is,

$$\frac{H_i^1}{\Pi f}\frac{d^2\delta}{dt^2} + D_i\frac{d\ \delta}{dt} = P_{mi}{}^1 - P_{ai}^1$$

$$H_i = \frac{\mathrm{H_i\ * MVA\ rating\ of\ i^{th}\ generator}}{\mathrm{Base\ MVA\ for\ the\ given\ system}}$$

H_i = Inertia constant of i^{th} generator in seconds based on its own rating.

δ_I = the load angle of the i^{th} machine in electrical radians.

P_{mi}' = per - unit mechanical power of the i^{th} machine.

P_{ei}' = per - unit electrical power of the i^{th} machine.

D_i = Damping factor of the i^{th} machine.

f = nominal system frequency.

t = time in seconds.

In the above expressions, i vary from 1 to g, where g is the total number of synchronous machines in the system.

Runge - Kutta Algorithm for Computation of Swing Curves:

Runge - Kutta method of fourth order is one of the best numerical method's used for the purpose of solving the swing equation. The damping of the rotors must also be taken into account to get the results in an accurate form.

According to this algorithm, the total transient period is typically of the order of one second is divided into a large number of small intervals, each of Δt second duration. During each Δt duration, the value of parameters K_1, K_2, K_3, K_4, and l_1, l_2, l_3, l_4, are calculated. Thus, these parameters are used to determine the changes in δ_I , ω_i.

$\omega_I(0)$ = value of ω of the i^{th} machine at the end of previous interval Δt .

f = nominal system frequency.

i = number of the machine.

$$I_i = \frac{\Pi f_0}{H_i^1}(P_{mi}^1 - P_{ei}^1(0) - D_i \omega_i^{\ 1})\Delta t \qquad \text{where,}$$

$H_I^{'}$ = per - unit inertia constant of the i^{th} machine referred t the system base.

$P_{mi}^{'}$ = per - unit mechanical power of the i^{th} generator.

$P_{ei}^{'}$ = per - unit electrical power supplied by the i^{th} generator.

$\omega_i^{'} = (\omega_i(0) - 2\Pi f_0)/2\Pi f_0$ = per - unit disturbance velocity of the i^{th} machine

$$K_{2i} = [\omega_i(0) + I_i/2] - 2\Pi f_0]\Delta t$$

$$I_{2i} = \frac{\Pi f_0}{H_i}\left(P_{mi}^{'} - P_{ei}^{'}(0) - D_I(\omega_I^{'} + I_I/2/2\Pi f_0\right)\Delta t$$

Where,

$P_{ei}^{'}(0)$ = electrical power of the i^{th} generator calculated using δ_i at the end of previous Δt.

$$K_{3i} = [\omega_i(0) + I_{2I}/2] - 2\Pi f_0]\Delta t$$

$$I_{2i} = \frac{\Pi f_0}{H_i}\left(P_{mi}^{'} - P_{ei}^{''}(0) - D_I(\omega_I^{'} + I_I/2/2\Pi f_0\right)\Delta t$$

Where,

$P_{ei}^{''}(0)$ = electrical power of the i^{th} generator calculated by using $\delta_i(0) + K_2/2$

$$K_{4i} = [\omega_i(0) + I_{3I}] - 2\Pi f_0]\Delta t$$

$$I_{4i} = \frac{\Pi f_0}{H'_i}\left(P_{mi}^{'} - P_{ei}^{''}(0) - D_I(\omega_I^{'} + I_{3I}/2/2\Pi f_0\right)\Delta t$$

Where,

$P_{ei}^{''}(0)$ = electrical power of the i^{th} generator calculated by using $\delta_i(0) + K_3$

$\delta_i(\text{new}) = \delta_i(0) + 1/6 * (K_i + 2K_{2I} + 2K_{3i} + K_{4i})$

$\omega_I(\text{new}) = \omega_I(0) + 1/6 * (l_i + 2l_{2i} + 2l_{3i} + l_{4i})$

ALGORITHM:

1. Read inertia constant, machine transient reactance, tie - line reactance, voltages at generator buses, bus powers, system frequency, type of fault.
2. Conduct load flow analysis.
3. Calculate the machine currents.
4. Calculate the voltage behind transient reactance E' is given by

   $E' = V_t + j I_t X_d$
5. Assume mechanical powers are constant since governor action is not taken into consideration.
6. The angle for E' is taken as initial value of δ and initial value of $\omega = 2\Pi f_o$.
7. Compute reduced Y_{BUS} for faulted and post faulted systems.
8. Calculate first estimates of phase angle K_1 and speed l_1

$$k_1 = \left(\frac{d\delta}{dt}\right)|0\Delta t = (\omega_i(0) - 2\Pi f_0)\Delta t \quad \text{----------- (1)}$$

$$I_1 = \left(\frac{d\omega}{dt}\right) | \, 0\Delta t = \Pi f_0 \, / \, H(P_m - P_e^{'}(0))\Delta t \quad \text{-----------} \ (2)$$

9. To calculate second estimate K_2 and l_2

$$K_2 = [(\omega(0) + I_1 \, / \, 2) - 2\Pi f_0]\Delta t \quad \text{-----------} \ (3)$$

$$I_2 = \Pi f_0 \, / \, H(P_m - P_e^{1}(0))\Delta t \quad \text{-----------} \ (4)$$

10. To calculate third estimate K_3 and l_3

$$K_3 = [(\omega(0) + I_2 \, / \, 2) - 2\Pi f_0]\Delta t \quad \text{-----------} \ (5)$$

$$I_3 = \Pi f_0 \, / \, H(P_m - P_e^{''}(0))\Delta t \quad \text{-----------} \ (6)$$

11. To calculate fourth estimate K_4 and l_4

$$K_4 = [(\omega(0) + I_3 \, / \, 2) - 2\Pi f_0]\Delta t \quad \text{-----------} \ (7)$$

$$I_4 = \Pi f_0 \, / \, H(P_m - P_e^{''}(0))\Delta t \quad \text{-----------} \ (8)$$

12. Find the phase angle and speed at the end of the first interval

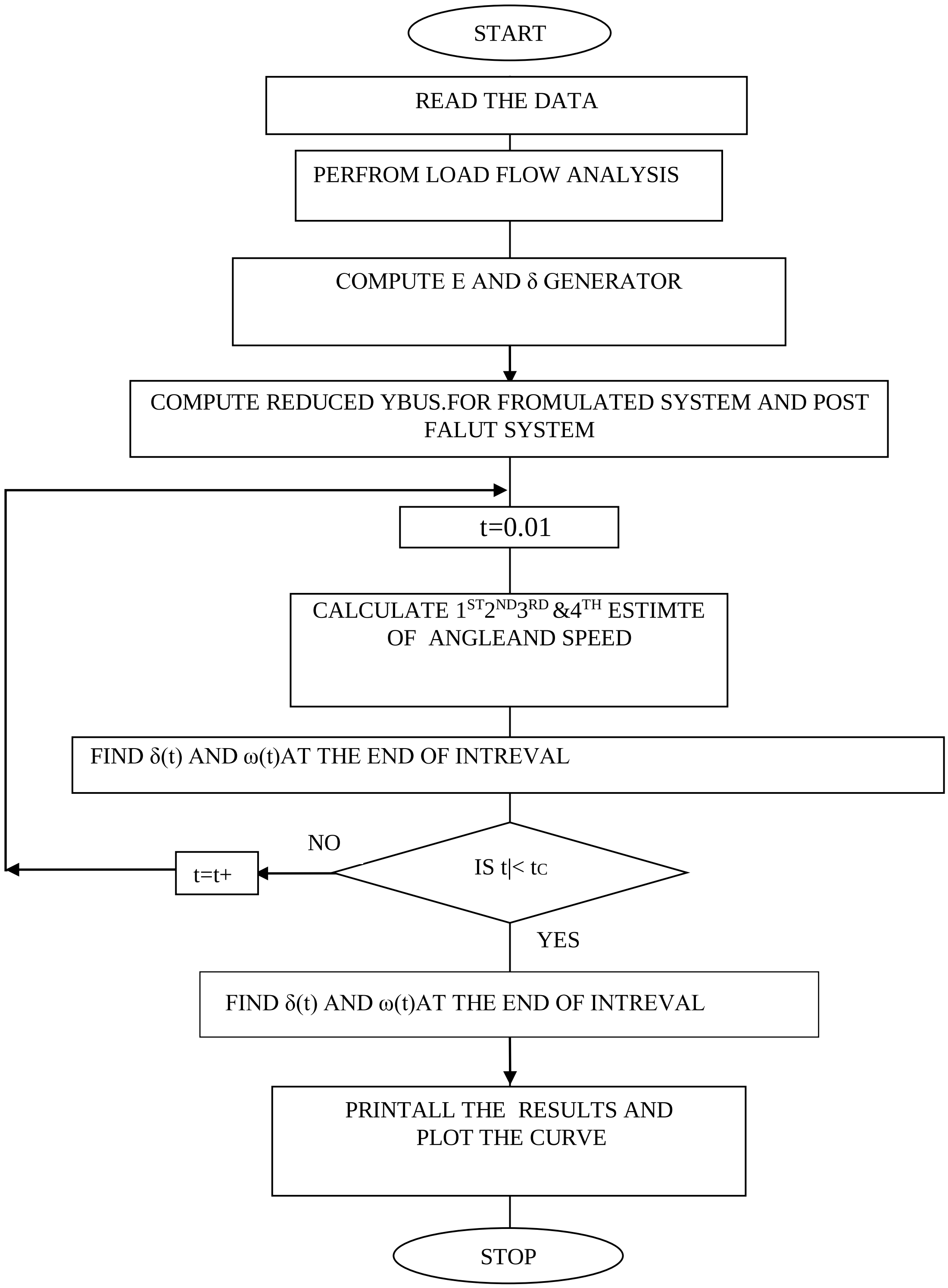
$\delta (t) = \delta (t - 1) + 1/ 6 (K_1 + 2K_2 + 2K_3 + K_4)$ ----------- (9)

$\omega(t) = \omega(t -1) + 1/ 6 (l_1 + 2l_2 + 2l_3 + l_4)$ ----------- (10)

13. Repeat from step (8) and calculate the phase angle and speed during the subsequent time interval till t = 0.3seconds. All these calculations should be done using reduced Y_{BUS} matrix corresponding to faulted system.

14. Repeat the steps (8) to (12) for t =0.3seconds upto t = 1.0seconds by using reduced Y_{BUS} matrix corresponding to faulted system.

15. Plot the swing curves and state the system is stable or not.


START
READ THE DATA
PERFROM LOAD FLOW ANALYSIS
COMPUTE E AND δ GENERATOR
COMPUTE REDUCED YBUS.FOR FROMULATED SYSTEM AND POST FALUT SYSTEM
t=0.01
CALCULATE 1ST2ND3RD &4TH ESTIMTE OF ANGLEAND SPEED
FIND δ(t) AND ω(t)AT THE END OF INTREVAL
NO
IS t|< tC
t=t+
YES
FIND δ(t) AND ω(t)AT THE END OF INTREVAL
PRINTALL THE RESULTS AND PLOT THE CURVE
STOP

PROBLEM STATEMENT

1) A 60 Hz Synchronous generator having inertia constant H= 5MJ/MVA and a direct axis transient reactance Xd''= 0.3pu is connected to an infinite bus through a purely resistive circuit. Reactance's are marked on the diagram with a common base .The generator is delivering real power Pe = 0.8pu and Q = 0.074pu to infinite bus at a voltage of 1 pu.

(a) A temporary 3 phase fault occurs at sending end of the line at point F When the fault is cleared both lines are intact. Determine the critical clearing angle and fault clearing time.

(b) A 3 phase fault occurs at middle of one line the fault is cleared and the faulted line is isolated Determine the critical Clearing angle.

(c) The fault is cleared at 0.3 sec .Obtain the numerical solution of swing equation for 1 sec using modified Euler's method with step size d(t) = 0.01 sec. Obtain simulink model for swing equation and simulate for Tc of 0.3 & 0.5 sec.

PROGRAM

```
clc;
clear;
h=0.005;
del0=21.64*pi/180;
omega0=1;
ti=0;
tf=0.5;
n=round((tf-ti)/h);
t(1)=ti;
del(1)=del0;
omega(1)=omega0;
tc=0.15;
for i=1:n
   if(t(i)==ti)
      status=0;
   end
   if(t(i)==tc)
      status=1;
   end
   if (t(i)>ti && t(i)<tc)
      status=2;
   end
   if (t(i)>tc)
      status=3'
   end
   l1=h*swing(del(i),omega(i),status);
   k1=h*omega(i);
   l2=h*swing(del(i)+0.5*k1,omega(i)+0.5*l1,status);   %R-K algorithm
   k2=h*(omega(i)+0.5*l1);
   l3=h*swing(del(i)+0.5*k2,omega(i)+0.5*l2,status);
   k3=h*(omega(i)+0.5*l2);
   l4=h*swing(del(i)+k3,omega(i)+l3,status);
   k4=h*(omega(i)+l3);
   k=(k1+2*(k2+k3)+k4)/6;
   l=(l1+2*(l2+l3)+l4)/6;
   omega(i+1)=omega(i)+1;
   del(i+1)=del(i)+k;
   t(i+1)=t(i)+h;
end
plot(t,del*180/pi);
grid on;
xlable('time----->');
ylable('del(degrees)------->');
title('Plot of del various time');
swing
swing(del,omega,status)
[diffomega]=swing(del,omega,status)
M=2.52/(pi*50);
Pm=0.9;
Pmaxbf=2.44;
Pmaxdf=0.88;
Pmaxaf=2.00;
```

```
switch status
   case 0
      diffomega=((Pm-Pmaxbf*sin(del))+(Pm-Pmaxdf*sin(del)))/(2*M);
   case 1
      diffomega=((Pm-Pmaxdf*sin(del))+(Pm-Pmaxaf*sin(del)))/(2*M);
   case 2
      diffomega=(Pm-Pmaxdf*sin(del))/M;
   case 3
      diffomega=(Pm-Pmaxaf*sin(del))/M;
end
```

OUTPUT

```
enter the reactance between bus 1 and 20.6
enter the reactance between bus 2 and 30.4
enter the reactance between bus 1 and 30.8
enter the generated power40
enter the power demand130
enter the base100

xo =

    0.4444    0.1778
    0.1778    0.3111


del =

   -0.0533
   -0.3333


p =

         0    0.4667   -0.0667
   -0.4667         0   -0.8333
    0.0667    0.8333         0


a =

         0    0.4444    0.5556
   -0.4444         0    0.4444
   -0.5556   -0.4444         0



L12 =    1.0000

L23 =    1.0000

L13 =    1.0000

L23 =    0.5000
L12 =    1.0000
```

```
L13 =    1.0000
P12 =    0.2889
P13 =   -0.2889
P23 =   -1.0111
po =
        0
   -1.3000

xo =

    0.4444    0.1778
    0.1778    0.3111

del =

   -0.2311
   -0.4044


limp =

    1.4000    0.6000    0.8000
    0.6000    1.0000    0.4000
    0.8000    0.4000    1.2000

p12 =    0.2889


P13 =   -0.2889


 P23 =   -1.0111
```

RESULT:

The Transient stability analysis has been carried out and simulated on a given power system network.

VIVA Questions

1. What is the need of transient stability analysis?
2. Specify the value of power angle for the power system to remain in stability?
3. Define Synchronous coefficient.
4. Define steady state stability/
5. Define critical clearing angle and time

Exp.No:4

DATE:

CONTINGENCY ANALYSIS: GENERATOR SHIFT FACTORS AND LINE OUTAGE DISTRIBUTION FACTORS

AIM:

To write a program in MATLAB to perform contingency analysis of the given 3- bus system and to calculate the distribution factors for various line outages.

ALGORITHM:

STEP1: Start the program.

STEP2: Get the various values of line reactance, generated power, power demand, base MVA values.

STEP3: Calculate the B coefficient matrix.

STEP4: Determine the line flows for the three bus system.

STEP5: Calculate the generation shift factors using

$$A_{li} = \frac{(Xmi - Xni)}{(xl)}$$

Xmi= m^th^ element from from Δδ vector.

Xni = n^th^ element from from Δδ vector.

xl = Line reactance for the line.

STEP6: Calculate the generation outages of various lines using

$$L_{l,k} = \frac{xk(Xni - Xnj - Xmi + Xmj)}{xl(xk - (Xnn + Xmm - 2Xnm))}$$

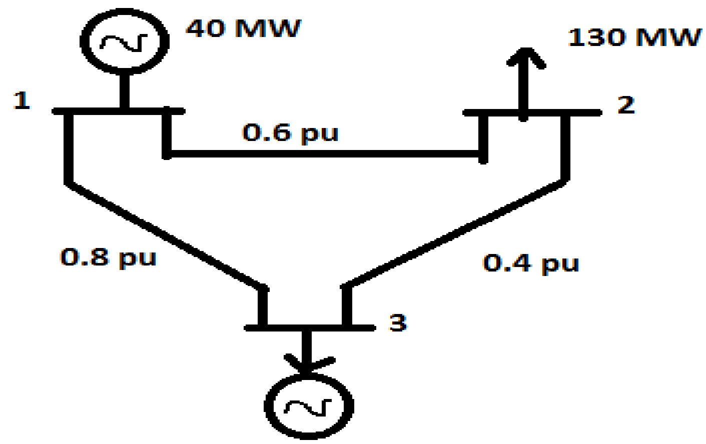
STEP7: Calculate the new line flows after the various generation outages as

$$P_{nm} = P_{nm(old)} + a_{li} * p$$

STEP8: Conduct the DC load flow to check the generation values match the calculated line flows.

Problem:

Calculate the generation shift factors, line outages, generator outages for the given circuit diagram. Take base MVA as 100.



PROGRAM

```
clear all;
clc;
r1=input('enter the reactance between bus 1 and 2');
r2=input('enter the reactance between bus 2 and 3');
r3=input('enter the reactance between bus 1 and 3');
limp=[(r1+r3) r1 r3;r1 (r1+r2) r2;r3 r2 (r3+r2)];
pg=input('enter the generated power');
pd=input('enter the power demand');
b=input('enter the base');
bo=[(1/r1)+(1/r3) -(1/r1);-(1/r1) (1/r1)+(1/r2)];
bo;
xo=inv(bo)
p=[(pg/b) -(pd/b)];
po=transpose(p);
del=(xo*po)
%line flows
del(3)=0;
p=[0 0 0;0 0 0;0 0 0];
 for i=1:3
 for j=1:3
  if(i~=j)
  p(i,j)=(del(i)-del(j))/limp(i,j);
  end
  end
  end
   p
  %generation shift factors
  a=[0 0 0;0 0 0;0 0 0];
  xo(3)=0;
   for i=1:3
   for j=1:3
   if(i~=j)
   a(i,j)=(xo(i)-xo(j))/limp(i,j);
   end
   end
   end
    a
  xo=inv(bo)
 r1
 r2
 r3
 L12=(xo(1,1)-xo(2,1))*r3/((r3-xo(1,1))*r1)
 L23=(xo(2,1)*r3)/((r3-xo(1,1))*r2)
 %outage of line 1-2
```

```
L13=(xo(1,1)-xo(1,2))*r1/((r1-((xo(1,1)-xo(1,2))-(xo(2,1)-xo(2,2))))*r3)
L23=-(xo(2,1)-xo(2,2))*r1/((r1-((xo(1,1)-xo(1,2))-(xo(2,1)-xo(2,2))))*r3)
%Outage of line 2-3
L12=(-(xo(1,2)-xo(2,2))*r2)/((r2-xo(2,2))*r1)
L13=(xo(1,2)*r2)/((r2-xo(2,2))*r3)
%The new line flows after outage of generator 1'
delp=-.4;
P12=p(1,2)+a(1,2)*delp
P13=p(1,3)+a(1,3)*delp
P23=p(2,3)+a(2,3)*delp
%'dc load flow'
po=[0;-1.3]
xo
del=xo*po
    limp
    p12=(del(1,1)-del(2,1))/limp(1,2)
    P13=del(1,1)/limp(1,3)
    P23=del(2,1)/limp(2,3)
```

RESULT:

Thus the program to perform contingency analysis of the given 3- bus system and to calculate the distribution factors for various line outages was completed.

Viva Questions:

1. What is the need for contingency analysis?
2. What are the various contingencies that occur in power system?
3. What is generator shift factor?
4. What is line outage distribution factor?

OUTPUT

```
enter the reactance between bus 1 and 20.6
enter the reactance between bus 2 and 30.4
enter the reactance between bus 1 and 30.8
enter the generated power40
enter the power demand130
enter the base100
xo =
    0.4444    0.1778
    0.1778    0.3111
del =
   -0.0533
   -0.3333
p =
         0    0.4667   -0.0667
   -0.4667         0   -0.8333
    0.0667    0.8333         0
a =
         0    0.4444    0.5556
   -0.4444         0    0.4444
   -0.5556   -0.4444         0
xo =
    0.4444    0.1778
    0.1778    0.3111

r1 =    0.6000
r2 =    0.4000
r3 =    0.8000
L12 =    1.0000
L23 =    1.0000
L13 =    1.0000
L23 =    0.5000
L12 =    1.0000
L13 =    1.0000
P12 =    0.2889
P13 =   -0.2889
P23 =   -1.0111
po =
         0
   -1.3000
xo =
    0.4444    0.1778
    0.1778    0.3111
del =
   -0.2311
   -0.4044
limp =
    1.4000    0.6000    0.8000
    0.6000    1.0000    0.4000
    0.8000    0.4000    1.2000
p12 =    0.2889
P13 =   -0.2889
P23 =   -1.0111
```

Exp.No:5

Date:

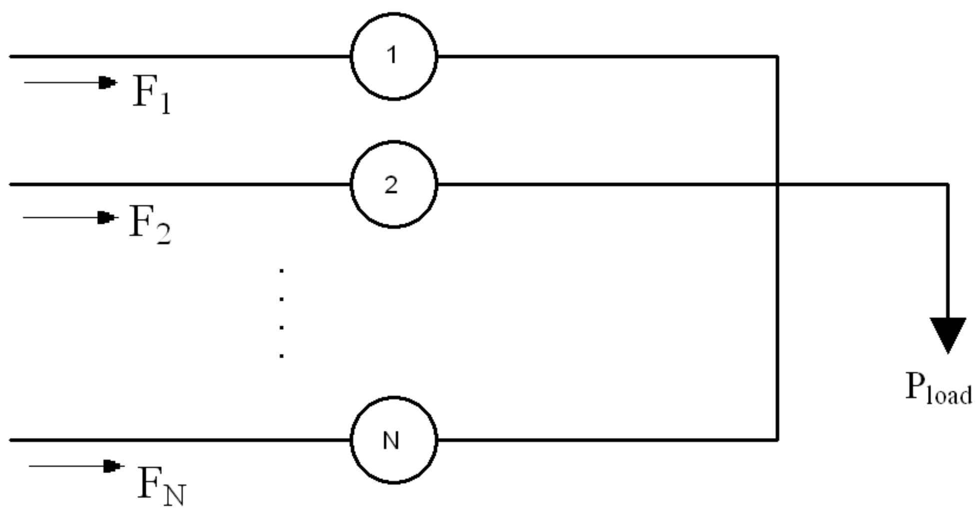
ECONOMIC DISPATCH USING LAMBDA-ITERATION METHOD

AIM : **To compute the optimal economical scheduling of the generators with & without considering the network losses for the given system**

THEORY :

ECONOMIC DESPATCH WITHOUT LOSSES

Consider a system of N – generating units connected to a single bus bar serving a received electrical load P_{load}. The input of each unit, F_i represents the cost rate (Rs./Hr). The output of each unit P_i is the electrical power generated by that particular unit. The total cost rate (F_T) subject to the constraint that the sum of the output powers must equal the reactive load.



Objective Function:Min $F_T = \sum_{i=1}^{N} F_i\left(P_i\right)$

Where $F_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2$

Subjected to the following constraints,
Equality Constraint,

$$P_{LOAD} = \sum_{i=1}^{N} P_i, Where\ \ F_T = F_1 + F_2 + \ldots\ldots\ldots\ldots + F_N$$

N – Number of generating units
Here the transmission losses are neglected
In Equality Constraint,

$P_{i,\,min} \le P_i \le P_{i,\,max}$

$P_{i,\,min}$ --- **Minimum Power generation from plant i.**

$P_{i,\,max}$ -- Maximum Power generation from plant i.

Let $\phi = P_{LOAD} - \sum_{i=1}^{N} P_i = 0$

By making use of Lagrangian multiplier the auxiliary function is obtained as

$$L = F_T + \lambda\phi, \quad i.e, \quad L = F_T + \lambda\left(P_{LOAD} - \sum_{i=1}^{N} P_i\right)$$

λ – *Lagrangian Multiplier*

differentiating L wrt P_i and equating to zero

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_i(P_i)}{\partial P_i} + \lambda(0-1) = 0$$

$$\frac{\partial F_i}{\partial P_i} = \lambda$$

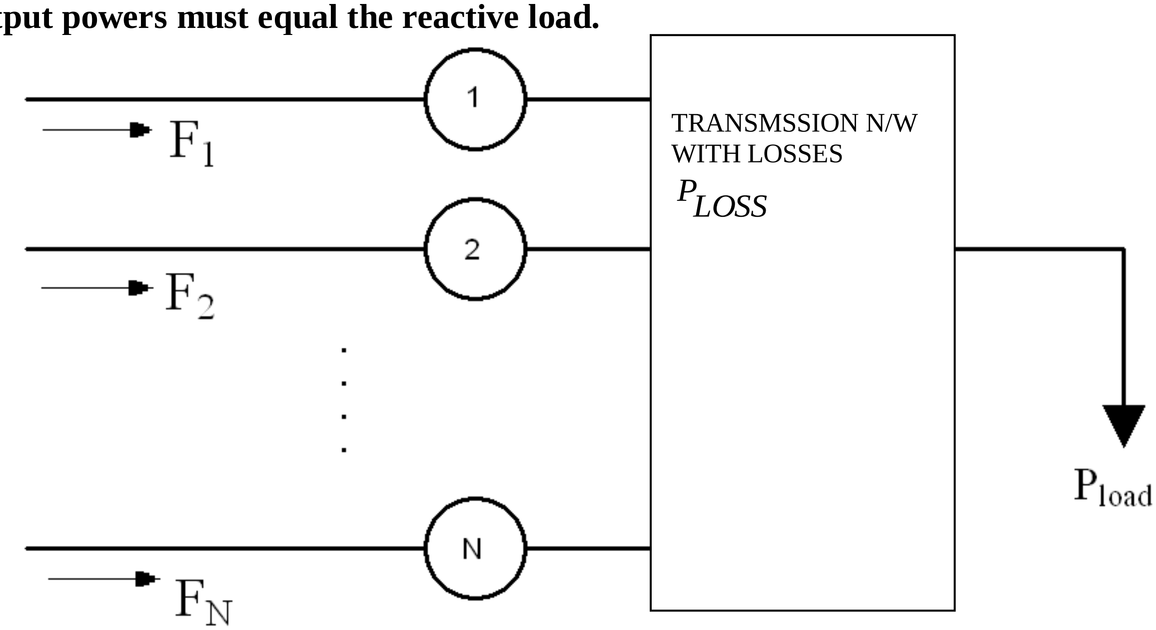
the condition for optimum operation is

$$\frac{\partial F_1}{\partial P_1} = \frac{\partial F_2}{\partial P_2} = \ldots\ldots\ldots\ldots\ldots = \frac{\partial F_N}{\partial P_N} = \lambda$$

$\frac{\partial F_i}{\partial P_i}$ **is the Incremental production cost of the unit i**

ECONOMIC DESPATCH WITHOUT LOSSES

Consider a system of N – generating units connected to a single bus bar serving a received electrical load P_{load}. The input of each unit, F_i represents the cost rate (Rs./Hr). The output of each unit P_i is the electrical power generated by that particular unit. The total cost rate (F_T) subject to the constraint that the sum of the output powers must equal the reactive load.



Objective Function Min $F_T = \sum_{i=1}^{N} F_i(P_i)$

Subjected to the following constraints

Equality Constraint,

$$P_{LOAD} + P_{LOSS} - \sum_{i=1}^{N} P_i$$

N – Number of generating units

P_{LOAD} **-Total load of the system**

P_{LOSS} **-Total Network losses of the system.**

In Equality Constraint,

$P_{i,\,min} \le P_i \le P_{i,\,max}$

$P_{i,\,min}$--- **Minimum Power generation from plant i.**

$P_{i,\,max}$ -- **Maximum Power generation from plant i.**

The Lagrangian function was formulated by adding the constraints to the objective function by using lagrangian multiplier and is given below,

Let $\phi = P_{LOAD} + P_{LOSS} - \sum_{i=1}^{N} P_i$

P_{LOSS} **is the total system loss**

Making use of the Lagrangian multiplier, the auxiliary function is

$$L = F_T + \lambda\phi$$

$$L = F_T + \lambda\left(P_{LOAD} + P_{LOSS} - \sum_{i=1}^{N} P_i \right)$$

differentiating L wrt P_i and equating to zero

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_i}{\partial P_i} + \lambda\left(\frac{\partial P_{LOAD}}{\partial P_i} + \frac{\partial P_{LOSS}}{\partial P_i} + \sum_{i=1}^{N}\frac{\partial P_i}{\partial P_i}\right) = 0$$

$$\frac{\partial F_i}{\partial P_i} + \lambda\left(0 + \frac{\partial P_{LOSS}}{\partial P_i} - 1\right) = 0$$

$$\frac{\partial F_i}{\partial P_i} + \lambda\left(\frac{\partial P_{LOSS}}{\partial P_i}\right) = \lambda \text{ -----} \; Coordination \;\; Equation$$

$\frac{\partial P_{LOSS}}{\partial P_i}$ = **Incremental Transmission loss at plant i**

λ = **Incremental production cost (Rs/MWHr)**

WITH OUT CONSIDERING LOSSES

1.Find the initial value of λ by using the formula given below,

$$\lambda = \frac{P_{load} + \sum_{i=1}^{N} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{N} \frac{1}{2\gamma_i}}$$

2.Find the value of power output of all the generators by using the formula given below

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i}$$

3.Check the value of power residue .If it is zero then stop the iteration and print the optimal schedule otherwise go to next step.

$$\Delta P = P_{load} - \sum_{i=1}^{N} P_i$$

4.Calculate the change in λ and update the value of λ by using the equations given below,

$$\Delta\lambda = \frac{\Delta P}{\sum \frac{1}{2\gamma_i}}$$

$$\lambda^{new} = \lambda + \Delta\lambda$$

5.Go to step 2

WITH CONSIDERING LOSSES

1.Find the initial value of λ by using the formula given below,

$$\lambda = \frac{P_{load} + \sum_{i=1}^{N} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{N} \frac{1}{2\gamma_i}}$$

2.Find the value of power output of all the generators by using the formula given below

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i}$$

3.Check the value of power residue .If it is zero then stop the iteration and print the optimal schedule otherwise go to next step.

$$\Delta P = P_{load} - \sum_{i=1}^{N} P_i + P_{loss}$$

4.Calculate the change in λ and update the value of λ by using the equations given below,

$$\Delta\lambda = \Delta P \Big/ \sum \left(\delta P_i \big/ \delta\lambda\right)$$

$$\lambda^{new} = \lambda + \Delta\lambda$$

5.Go to step 2

PROBLEM

1.The given cost function of the 3 Generating units are given below,

$C1 = 561+7.92+0.001562P_1^2$ Rs/Hr

$C2 = 310+7.85P_2+0.00194P_2^2$ Rs/Hr

$C3 = 78+7.97P_3+0.00482P_3^2$ Rs/Hr

where P_1, P_2, P_3 are in MW. The total system load is P_D = 975MW. The MW limits of the generating units are given below,

$150 \leq P_1 \leq 600$

$100 \leq P_2 \leq 400$

$50 \leq P_3 \leq 200$

The fuel cost of all the unit is 1 Rs/MBtu.The generating units contribute to satisfy a load demand of 850 MW. The loss expression is given as $P_{loss} = 0.00003P_1^2 + 0.0000982P_2^2 + 0.00012P_3^2$ in MW.

Write the program in C/ MATLAb to calculate the optimum dispatch scheduling for the above problem

PROGRAM

```
clc;
clear all;
n=input('Enter the number of generating units');
for i=1:n
   disp('Enter the details for the unit');
   disp(i);
   a(i)=input('Enter the coefficient of Pg^2');
   b(i)=input('Enter the coefficient of Pg');
   pmin(i)=input('Enter the pmin value');
   pmax(i)=input('Enter the pmax value');
end
pd=input('Enter the demand value');
lam=input('Enter the starting value of lambda');
delp=-1;
iteration=0;
q=input('Enter 1 for ED without losses & 2 for ED with losses');
if q==1
   while delp~=0
      pp=0;
      x=0;
      for i=1:n
         p(i)=(lam-b(i))/(2*a(i));
         if p(i)<pmin(i)
            p(i)=pmin(i);
         end
         if p(i)>pmax(i)
            p(i)=pmax(i);
         else
            p(i)=p(i);
         end
         x=x+(1/(2*a(i)));
         pp=pp+p(i);
      end
      delp=pd-pp;
      dellam=delp/x;
      lam=lam+dellam;
      iteration=iteration+1;
      if iteration==1000
         break;
      end
      disp('iteration=');
      disp(iteration);
      disp('Power of the unit');
      disp(p);
      disp('Lambda=');
      disp(lam);
   end
```

```
else
   for i=1:n
      for j=1:n
         B(i,j)=input('Enter the value');
      end
   end
   while delp~=0
      pp=0;
      x=0;
      ploss=0;
      for i=1:n
         p(i)=(lam-b(i))/(2*(a(i)+(lam*B(i,i))));
         if p(i)<pmin(i)
            p(i)=pmin(i);
         end
         if p(i)>pmax(i)
            p(i)=pmax(i);
         else
            p(i)=p(i);
         end
         pp=pp+p(i);
         x=x+(a(i)+(B(i,i)*b(i)))/(2*(a(i)+(lam*B(i,i)))^2);
      end
      ploss=(p*B*transpose(p));
      delp=ploss+pd-pp;
      dellam=delp/x;
      lam=lam+dellam;
      iteration=iteration+1;
      if iteration==1000
         break;
      end
      disp('iteration=');
      disp(iteration);
      disp('Power of the unit');
      disp(p);
      disp('lambda');
      disp(lam);
   end
end
```

OUTPUT

OUTPUT:

WITH LOSSES:

Enter the number of generating units3

Enter the details for the unit 1

Enter the coefficient of Pg^2 0.001562

Enter the coefficient of Pg 7.92

Enter the pmin value 150

Enter the pmax value 600

Enter the details for the unit 2

Enter the coefficient of Pg^2 0.00194

Enter the coefficient of Pg 7.85

Enter the pmin value 100

Enter the pmax value 400

Enter the details for the unit 3

Enter the coefficient of Pg^2 0.004823

Enter the coefficient of Pg 7.97

Enter the pmin value 50

Enter the pmax value 200

Enter the demand value 850

Enter the starting value of lambda 7

Enter 1 for ED without losses & 2 for ED with losses 1

iteration= 999

Power of the unit

393.2055 334.6325 122.1619

Lambda= 9.1484

WITHOUT LOSSES:

Enter the number of generating units 3

Enter the details for the unit 1

Enter the coefficient of Pg^2 0.001562

Enter the coefficient of Pg 7.92

Enter the pmin value 150

Enter the pmax value 600

Enter the details for the unit 2

Enter the coefficient of Pg^2 0.00194

Enter the coefficient of Pg 7.85

Enter the pmin value 100

Enter the pmax value 400

Enter the details for the unit 3

Enter the coefficient of Pg^2 0.00482

Enter the coefficient of Pg 7.97

Enter the pmin value 50

Enter the pmax value 200

Enter the demand value 850

Enter the starting value of lambda 7

Enter 1 for ED without losses & 2 for ED with losses 2

Enter the value0.00003

Enter the value0

Enter the value0

Enter the value0

Enter the value0.00009

Enter the value0

Enter the value0

Enter the value0

Enter the value0.00012

```
iteration=99
Power of the unit
  435.1984  299.9700  130.6606
lambda
    9.5284
```

RESULT: **The optimal economical scheduling of the generators with & without losses are obtained for the given system.**

VIVA Questions

1. **What is Equal incremental cost?**
2. **What are the various constraints in ED Problem?**
3. **What is Power Balance constraint?**
4. **What is loss Coefficients in ED problem?**

Exp.No:6
Date:

UNIT COMMITMENT: PRIORITY-LIST SCHEMES AND DYNAMIC PROGRAMMING

AIM : To obtain the optimal Unit commitment schedule by priority listing method for the given problem using MATLAB/C program

ALGORITHM:

Priority-List Method:
It consist of a simple shut-down rule obtained by an exhaustive enumeration of all unit combinations at each load level or obtained by noting the full-load average production cost of each unit The full-load average production cost is the net heat rate at full load multiplied by the fuel cost .Various enhancements can be made to the priority-list scheme by the grouping of units to ensure that various constraints are met.
Typical shut-down rules:

1. At each hour when load is dropping, determine whether dropping the next unit on the list leaves sufficient generation to supply the load plus the spinning-reserve requirements
2. If the supply is not sufficient, keep the unit committed.
3. Determine the number of hours before the unit is needed again.
4. If the time is less than the minimum shut-down time for the unit, keep it committed.
5. Perform a cost comparison for the sum of the hourly production costs for the next number of hours with the next unit to be dropped being committed and the sum of the restart costs for the next unit based on the minimum cost of cooling the unit or banking the unit ‘

THEORY:
Unit Commitment, further abbreviated as UC, refers to the strategic choice to be made in order to determine which of the available power plants should be considered to supply electricity. UC is not the same as *dispatching*. Dispatching consists of fitting a given set of power plants into a certain electric demand. UC appoints the set of plants from which dispatching can choose. The difference between both issues is time. In dispatching decisions, there is no time to rapidly activate a power plant because the inertia of most plants will not allow this. UC therefore prepares a set of plants and stipulates in which time period they have to be on-line and ready for dispatching.

UC chooses plants taking into account a wide variety of parameters, technological aspects (such as minimal operation point, minimum up and down time and transient behavior) as well as economical considerations (such as start-up costs and operational costs) and social elements (such as availability of staff and work-schemes). UC optimization enables utilities to minimize electricity generation costs.

THREE EXISTING METHODS
Many strategies have already been developed to tackle the UC economic optimization.
Brute Force Method: The most evident method is what we call *brute force* in which all possible combinations of power plants to provide a given demand are calculated. The possibilities conflicting with the boundary conditions are struck off the list. Finally, the most economic of all remaining possibilities is withheld. This method is not only scientifically clumsy but will also amount in the largest possible calculation time.

DP Method: Dynamic programming (DP) is a name used for methods in which a-priori impossible or improbable possibilities are left out. This Method starts from a previously determined optimal UC planning and gradually adds power plants to obtain optimal solutions for higher demand.

Decomposition Method: In this method the main problem is decomposed into several sub-problems that are easier to solve. In order to take into account uncertainties combine the DP with fuzzy logic. The neural networks can be used to enable the model to learn from previously made decisions. · It is possible to decompose UC into a master problem and sub-problems that can be solved separately. The master problem is optimized (minimal cost), linking the sub-problems by Lagrange multipliers.

Priority Listing Method: A very simple method is based on Priority Listing in which power plants are logically ranked. Originally, the plants were ranked according to full load cost. All plants are initially activated. Then they are shut down one at a time to check whether or not the overall costs are reduced.

Next to these *conservative* methods, also some unconventional methods like genetic algorithms can be used. This is a stochastic adaptive search based on "survival of the fittest".

Exercise

Obtain the optimal Unit Commitment for the given generators using Priority list technique

Unit1:Pmin=150MW ;Pmax=600MW

Fuel Cost function $H_1=510+7.2P_1+0.00142P_1^2$ MBtu/Hr

Unit2:Pmin=100MW ;Pmax=400MW

Fuel Cost function $H_2=310+7.85P_2+0.00142P_2^2$ MBtu/Hr

Unit1:Pmin=150MW ;Pmax=600MW

Fuel Cost function $H_3=78+7.97P_3+0.004822P_3^2$ MBtu/Hr

With

Fuel cost 1=1.1 R/MBtu

Fuel cost 2=1.0 R/MBtu

Fuel cost 3=1.2 R/MBtu

PROGRAM

```
clc;
clear all;
n=input('Enter the number of generating units');
for i=1:n
   disp('Enter the details for unit');
   disp(i);
   a1(i)=input('Enter the coefficient of Pg^2');
   b1(i)=input('Enter the coefficient of Pg');
   c1(i)=input('Enter the coefficient ');
   pmin(i)=input('Enter the Pmin value');
   pmax(i)=input('Enter the Pmax value');
   k(i)=input('Enter the fuel cost');
   a(i)=(k(i)*a1(i));
   b(i)=(k(i)*b1(i));
   c(i)=(k(i)*c1(i));
end
for i=1:n
  FLAPC(i)=(k(i)*(c1(i)+(b1(i)*pmax(i))+(a1(i)*pmax(i)^2)))/pmax(i);
end
FLAPC
for i=1:n
   for j=i+1:n
      if FLAPC(j)<FLAPC(i)
         temp1=FLAPC(i);
         FLAPC(i)=FLAPC(j);
         FLAPC(j)=temp1;
         temp2=pmin(i);
         pmin(i)=pmin(j);
         pmin(j)=temp2;
         temp3=pmax(i);
         pmax(i)=pmax(j);
         pmax(j)=temp3;
         temp4=a(i);
         a(i)=a(j);
         a(j)=temp4;
         temp5=b(i);
         b(i)=b(j);
         b(j)=temp5;
         temp7=c(i);
         c(i)=c(j);
         c(j)=temp7;
      end
   end
end
FLAPC
u=n;
for i=1:n
   m1=0;
   m2=0;
```

```
    for k=1:u
    m1=m1+pmin(k);
    m2=m2+pmax(k);
    end
    u=u-1;
    psmin(i)=m1;
    psmax(i)=m2;
end
psmin
psmax
lam=input('Enter the initial value of lambda');
pd=input('Enter the Pd value');
u=n;
for i=1:n
    if psmax(i)>pd
delp=-1;
iteration=0;
while delp~=0
    pp=0;
    x=0;
    for i=1:u
        p(i)=(lam-b(i))/(2*a(i));
        if p(i)<pmin(i)
            p(i)=pmin(i);
        end
        if p(i)>pmax(i)
            p(i)=pmax(i);
        else
            p(i)=p(i);
        end
        x=x+(1/(2*a(i)));
        pp=pp+p(i);
    end
    for i=1:u
        for j=i+1:u
            if FLAPC(j)<FLAPC(i)
            temp6=p(i);
            p(i)=p(j);
            p(j)=temp6;
            end
        end
    end
    for k=1:u
        f(k)=(c(k)+(b(k)*p(k))+(a(k)*p(k)^2));
    end
    tot=0;
    for k=1:u
        tot=tot+f(k);
    end
    delp=pd-pp;
    dellam=delp/x;
```

```
    lam=lam+dellam;
    if iteration==100
        break;
    end
    iteration=iteration+1;
end
u=u-1;
    end
    disp('For the combination ');
    disp(i);
    disp('Total Fuel Cost=');
    disp(tot);
    disp('At the end of Iteration=');
    disp(iteration);
    disp('Power of the units');
    disp(p);
    disp('lambda=');
    disp(lam);
    p=zeros(1,n);
    lam=0;
    tot=0;
end
```

RESULT:
Thus the optimal unit commitment Schedule is obtained using priority listing method
Viva Questions:
1. What is Unit Commitment?
2. What are the various constraints in unit commitment?
3. Define spinning reserve constraint.
4. What are crew constraints?
5. What is priority listing?

OUTPUT

```
Enter the number of generating units3

Enter the details for unit     1
Enter the coefficient of Pg^2=0.006
Enter the coefficient of Pg=7
Enter the constant coefficient=600
Enter the Pmin value=100
Enter the Pmax value=400
Enter the fuel cost=1.1

Enter the details for unit     2
Enter the coefficient of Pg^2=0.01
Enter the coefficient of Pg=8
Enter the constant coefficient=400
Enter the Pmin value=50
Enter the Pmax value=300
Enter the fuel cost=1.2

Enter the details for unit     3
Enter the coefficient of Pg^2=0.008
Enter the coefficient of Pg=6
Enter the constant coefficient=500
Enter the Pmin value=150
Enter the Pmax value=500
Enter the fuel cost=1

FLAPC =   11.9900   14.8000   11.0000
FLAPC =   11.0000   11.9900   14.8000
u =     3
psmin =   300   250   150
psmax =        1200         900         500
Enter the PD value     800
Enter the starting value of lambda     8
At the end of combination     3
iteration=     3
Power of the unit=  313.8298  335.1064  151.0638
lamda=   11.0213
Total cost=  8.6271e+003
```

Exp.No: 7
Date:

State Estimation

Aim:

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

State Estimation BY WLSE method

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 are 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. Theseerrors render the outputuseless. 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] → (1)

The errors [e1,e2,….em]T are assumed to be independent random variable with Gaussian distribution whose mean is zero. The variationmeasurement errorσiprovides an indication of the certainity about the particular measurements. A large variance indicates that the corresponding measurement accurate.

The objective function to be minimsed

$$J(X) = \sum_{i=1}^{m} \frac{(Zi - fi)^2}{\sigma i} \rightarrow \qquad (2)$$

Here m is the number of measurements

Minimise

J(x)={[f(x)-[Z]}T [W}[f(X/]-[Z]}

Linearsing equation (1) and simultaneously minimizing the objective function (3), We get state correction vector as

[ΔX]={[H][W][H]-1[H][W]{[Z]-F9X)]}} (4)

Where

$$[W] = \begin{bmatrix} w1\ 0\ 0\ 0\ 0\ 0 \\ 0\ W2\ 0\ 0\ 0\ 0 \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ 0\ 0\ 0\ 0\ 0\ 0\ Wm \end{bmatrix} = \begin{bmatrix} \frac{1}{\sigma 1^2}\ 0\ 0\ 0\ 0 \\ 0\ \frac{1}{\sigma 2^2}\ 0\ 0\ 0 \\ \cdots\cdots\cdots\cdots \\ 0\ 0\ 0\ 0\ 0\ \frac{1}{\sigma m^2} \end{bmatrix}$$

[W]=Diagonal matrix which contain weightage value of each measurement
[H]=Matrix of partial differential derivatives of measurement functions with respect to state variables

$$Hij = \frac{\partial fi}{\partial Xi}$$

The correction vector [ΔX] should be computed using the latest available system state must be checked for convergence.

Algorithm:

Read all the relevant data

Initialize the state vector

Compute measurement function [f(x)] and Jocobian matrix [H] using latest known system state variable

Check weather all the elements of [ΔX] are within the tolerance value, if so latest [X] is the present system state or else go to next step.

Update the state vector

[X]=[X0]+[ΔX] and go to step 3

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 Quanities	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

Program:

```
num = 3;
ybus = ybusppg(num);
zdata = zdatas(num);
bpq = bbusppg(num);
nbus = max(max(zdata(:,4)),max(zdata(:,5)));
type = zdata(:,2);
z = zdata(:,3);
fbus = zdata(:,4);
tbus = zdata(:,5);
Ri = diag(zdata(:,6));
V = ones(nbus,1);
del = zeros(nbus,1);
E = [del(2:end); V];
G = real(ybus);
B = imag(ybus);
```

```
vi = find(type == 1);
ppi = find(type == 2);
qi = find(type == 3);
pf = find(type == 4);
qf = find(type == 5);
nvi = length(vi);
npi = length(ppi);
nqi = length(qi);
npf = length(pf);
nqf = length(qf);
iter = 1;
tol = 5;

while(tol> 1e-4)

    h1 = V(fbus(vi),1);
    h2 = zeros(npi,1);
    h3 = zeros(nqi,1);
    h4 = zeros(npf,1);
    h5 = zeros(nqf,1);

fori = 1:npi
        m = fbus(ppi(i));
for k = 1:nbus
            h2(i) = h2(i) + V(m)*V(k)*(G(m,k)*cos(del(m)-del(k)) + B(m,k)*sin(del(m)-del(k)));
end
end

fori = 1:nqi
        m = fbus(qi(i));
for k = 1:nbus
            h3(i) = h3(i) + V(m)*V(k)*(G(m,k)*sin(del(m)-del(k)) - B(m,k)*cos(del(m)-del(k)));
end
end

fori = 1:npf
        m = fbus(pf(i));
        n = tbus(pf(i));
        h4(i) = -V(m)^2*G(m,n) - V(m)*V(n)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-
del(n)));
end

fori = 1:nqf
        m = fbus(qf(i));
        n = tbus(qf(i));
        h5(i) = -V(m)^2*(-B(m,n)+bpq(m,n)) - V(m)*V(n)*(-G(m,n)*sin(del(m)-del(n)) +
B(m,n)*cos(del(m)-del(n)));
end

    h = [h1; h2; h3; h4; h5];

        r = z - h;


    H11 = zeros(nvi,nbus-1);

    H12 = zeros(nvi,nbus);
```

```
for k = 1:nvi
for n = 1:nbus
if n == k
H12(k,n) = 1;
end
end
end

        H21 = zeros(npi,nbus-1);
fori = 1:npi
        m = fbus(ppi(i));
for k = 1:(nbus-1)
if k+1 == m
for n = 1:nbus
                    H21(i,k) = H21(i,k) + V(m)* V(n)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-
del(n)));
end
H21(i,k) = H21(i,k) - V(m)^2*B(m,m);
else
                H21(i,k) = V(m)* V(k+1)*(G(m,k+1)*sin(del(m)-del(k+1)) - B(m,k+1)*cos(del(m)-
del(k+1)));
end
end
end


    H22 = zeros(npi,nbus);
fori = 1:npi
        m = fbus(ppi(i));
for k = 1:(nbus)
if k == m
for n = 1:nbus
                    H22(i,k) = H22(i,k) + V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
end
H22(i,k) = H22(i,k) + V(m)*G(m,m);
else
                H22(i,k) = V(m)*(G(m,k)*cos(del(m)-del(k)) + B(m,k)*sin(del(m)-del(k)));
end
end
end

% H31 - Derivative of Reactive Power Injections with Angles..
    H31 = zeros(nqi,nbus-1);
fori = 1:nqi
        m = fbus(qi(i));
for k = 1:(nbus-1)
if k+1 == m
for n = 1:nbus
                    H31(i,k) = H31(i,k) + V(m)* V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-
del(n)));
end
H31(i,k) = H31(i,k) - V(m)^2*G(m,m);
else
                H31(i,k) = V(m)* V(k+1)*(-G(m,k+1)*cos(del(m)-del(k+1)) - B(m,k+1)*sin(del(m)-
del(k+1)));
end
end
end
```

```
   H32 = zeros(nqi,nbus);
fori = 1:nqi
       m = fbus(qi(i));
for k = 1:(nbus)
if k == m
for n = 1:nbus
                H32(i,k) = H32(i,k) + V(n)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
end
H32(i,k) = H32(i,k) - V(m)*B(m,m);
else
            H32(i,k) = V(m)*(G(m,k)*sin(del(m)-del(k)) - B(m,k)*cos(del(m)-del(k)));
end
end
end


   H41 = zeros(npf,nbus-1);
fori = 1:npf
       m = fbus(pf(i));
       n = tbus(pf(i));
for k = 1:(nbus-1)
if k+1 == m
            H41(i,k) = V(m)* V(n)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
elseif k+1 == n
            H41(i,k) = -V(m)* V(n)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
else
H41(i,k) = 0;
end
end
end
end

% H42 - Derivative of Real Power Flows with V..
   H42 = zeros(npf,nbus);
fori = 1:npf
       m = fbus(pf(i));
       n = tbus(pf(i));
for k = 1:nbus
if k == m
            H42(i,k) = -V(n)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-del(n))) -
2*G(m,n)*V(m);
elseif k == n
            H42(i,k) = -V(m)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-del(n)));
else
H42(i,k) = 0;
end
end
end
end

   H51 = zeros(nqf,nbus-1);
fori = 1:nqf
       m = fbus(qf(i));
       n = tbus(qf(i));
for k = 1:(nbus-1)
if k+1 == m
            H51(i,k) = -V(m)* V(n)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-del(n)));
elseif k+1 == n
            H51(i,k) = V(m)* V(n)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-del(n)));
```

```
else
H51(i,k) = 0;
end
end
end
end


   H52 = zeros(nqf,nbus);
fori = 1:nqf
      m = fbus(qf(i));
      n = tbus(qf(i));
for k = 1:nbus
if k == m
            H52(i,k) = -V(n)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n))) -
2*V(m)*(-B(m,n)+ bpq(m,n));
elseif k == n
            H52(i,k) = -V(m)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
else
H52(i,k) = 0;
end
end
end
end


   H = [H11 H12; H21 H22; H31 H32; H41 H42; H51 H52];

   Gm = H'*inv(Ri)*H;
   J = sum(inv(Ri)*r.^2);

dE = inv(Gm)*(H'*inv(Ri)*r);
   E = E + dE;
del(2:end) = E(1:nbus-1);
   V = E(nbus:end);
iter = iter + 1;
tol = max(abs(dE));
end

CvE = diag(inv(H'*inv(Ri)*H));
Del = 180/pi*del;
E2 = [V Del];
disp('-------- State Estimation ------------------');
disp('--------------------------');
disp('| Bus |    V   |  Angle  | ');
disp('| No  |   pu   |  Degree | ');
disp('--------------------------');
for m = 1:n
fprintf('%4g', m); fprintf('  %8.4f', V(m)); fprintf('   %8.4f', Del(m)); fprintf('\n');
end
disp('---------------------------------------------');
```

```
functionbbus = bbusppg(num)
linedata = linedatas(num);
fb = linedata(:,1);
tb = linedata(:,2);
b = linedata(:,5);
nbus = max(max(fb),max(tb));
nbranch = length(fb);
bbus = zeros(nbus,nbus);

for k=1:nbranch
bbus(fb(k),tb(k)) = b(k);
bbus(tb(k),fb(k)) = bbus(fb(k),tb(k));
end
functionybus = ybusppg(num)  % Returns ybus

linedata = linedatas(num);
fb = linedata(:,1);
tb = linedata(:,2);
r = linedata(:,3);
x = linedata(:,4);
b = linedata(:,5);
a = linedata(:,6);
z = r + i*x;
y = 1./z;
b = i*b;

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

for k=1:nbranch
ybus(fb(k),tb(k)) = ybus(fb(k),tb(k))-y(k)/a(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)/(a(n)^2) + b(n);
elseiftb(n) == m
ybus(m,m) = ybus(m,m) + y(n) + b(n);
end
end
end


function [rho theta] = rect2pol(x)
rho = sqrt(real(x).^2 + imag(x).^2);
theta = atan(imag(x)./real(x));

functionrect = pol2rect(rho,theta)
rect = rho.*cos(theta) + j*rho.*sin(theta);
```

RESULT:

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

Exp.No:8
Date

ANALYSIS OF SWITCHING SURGE USING PSCAD: ENERGISATION OF A LOAD

AIM

To study and understand the electromagnetic transient phenomenon in power system caused by switching and fault by using electromagnetic transient program [EMTP]

To become proficient in the image of EMTP to address problems in the areas of over voltages protection and mitigation and insulation coordination of EHV systems.

Objective:
The study of transients due to energization of a long distributed parameters line from an ideal 230kV source.

Software Required :
PSCAD

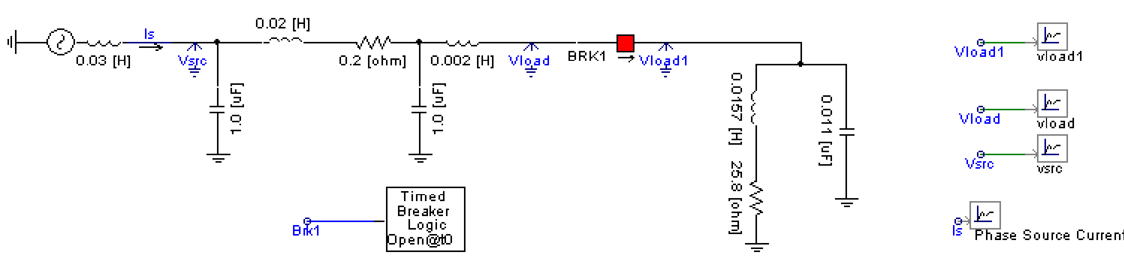
Theory:
Solution method for electromagnetic transient analysis Intentional and inadvertent switching operations in EHV system initiate over voltages, which might obtain dangerous value resulting in distinction of observation.

Accurate Computation of these over voltages is essential for proper sizing co ordination of insulation of various equipments and specification of protection devices.

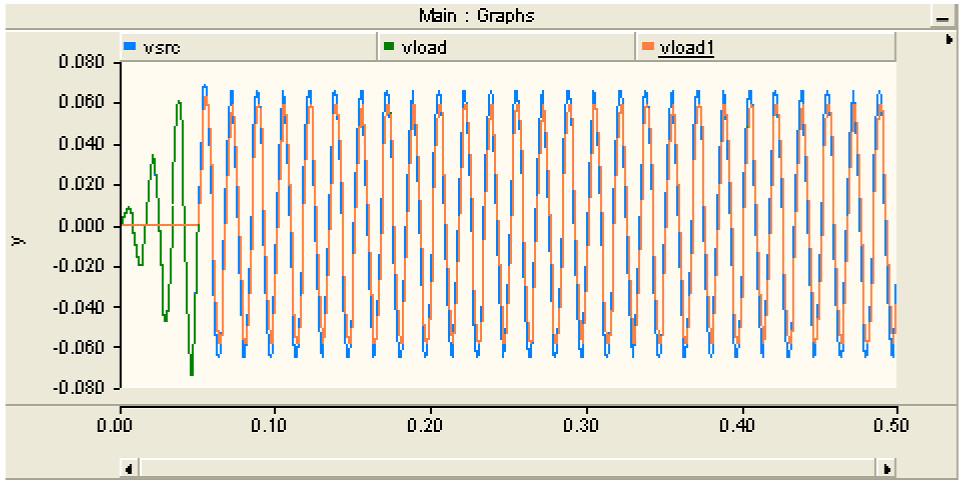
The Models of equipment must be detailed enough to reproduce actual condition successfully an important aspect where a general purpose digital computers program source are transient network analysis.

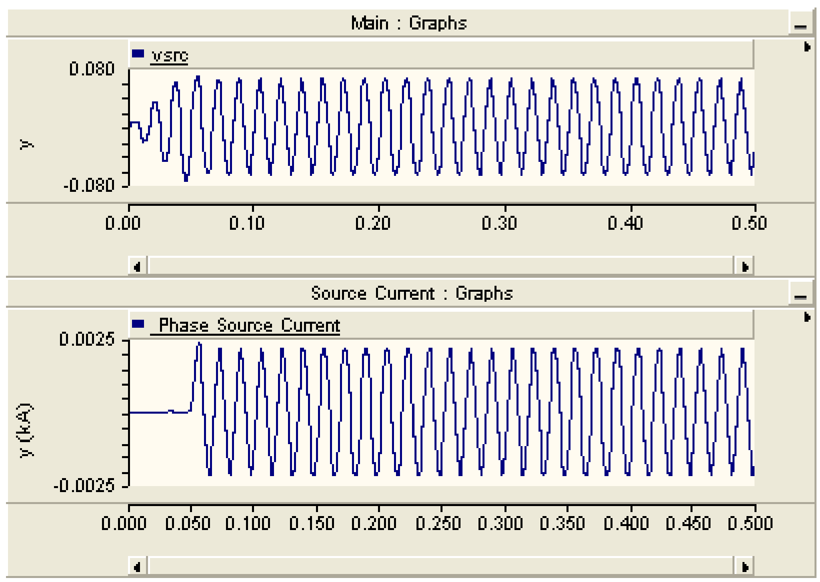
Any network which consists of inter connection of resistance, Inductance circuits distributed parameters line and other certain elements can be solved.

Single Line Diagram :



Simulation:





Result:

The study of transient due to energization of a long distributed parameter line has been performed.

Exp.No:9
Date

ANALYSIS OF SWITCHING SURGE USING PSCAD: COMPUTATION OF TRANSIENT RECOVERY VOLTAGE

AIM
To study and understand the electromagnetic transient phenomenon in power system caused by switching and fault by using electromagnetic transient program [EMTP]

To become proficient in the image of EMTP to address problems in the areas of over voltages protection and mitigation and insulation coordination of EHV systems.

Objective:
The study the transients Recovery Voltage (TRV) associated with a breaker for a 3 phase fault.

Software Required :
PSCAD

Theory:
Solution method for electromagnetic transient analysis:
Intentional and inadvertent switching operations in EHV system initiate over voltages, which might obtain dangerous value resulting in distinction of apparatus.

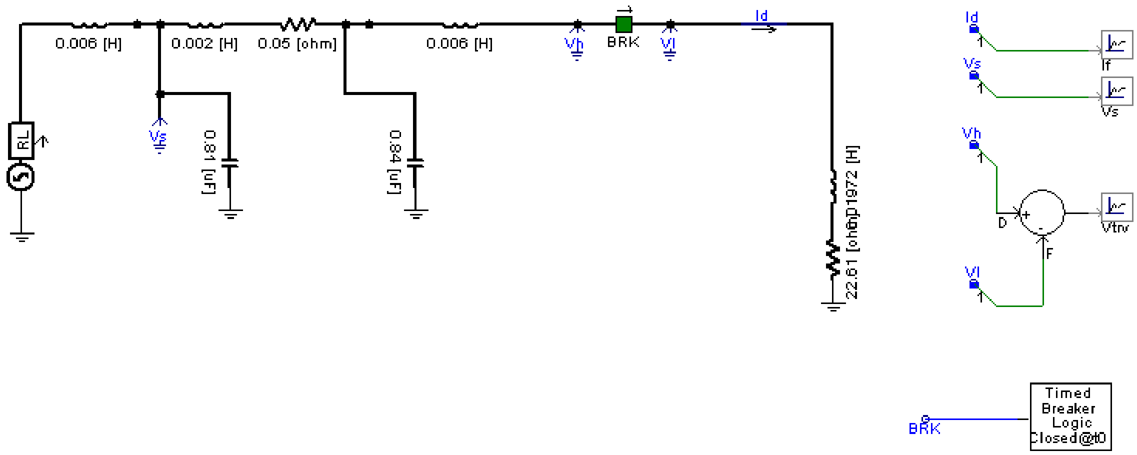
Accurate Computation of these over voltages is essential for proper sizing co ordination of insulation of various equipments and specification of protection devices.

Meaningful design of EHV system is dependent on Modeling philosophy built in to a computer program.
The Models of equipment must be detailed enough to reproduce actual condition successfully an important aspect where a general purpose digital computers program source over transient network.

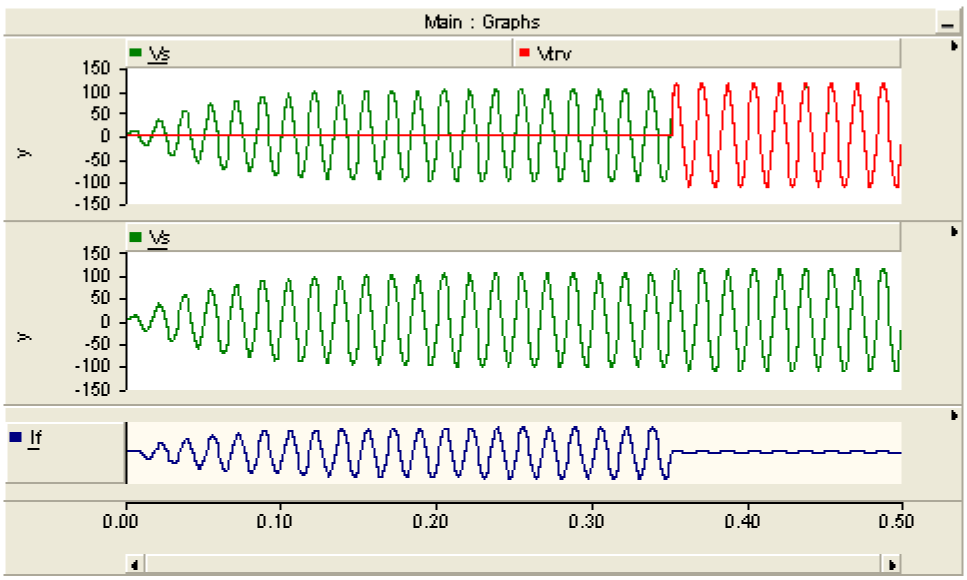
The program emphasis a direct integration time domain technique. The Essence of this method is discrimination of differential equation associated with network elements using trapezoidal rate of integration and solution of the resulting difference equation for the unknown voltages.

Any network which consists of interconnection of resistance, Inductance, Capacitance single and multiphase circuits distributed parameters line and other certain elements can be solved.

Single Line Diagram:



Simulation :



Result:

The the transient recovery voltage in each phase for a 3 phase fault was obtained by PSCAD.

Exp.No:10
Date:

DESIGN OF VOLTAGE SOURCE INVERTER USING MATLAB SIMULINK

AIM:

To design and study of voltage source inverter by using a MATLAB Simulink.

Theory:

DC to AC converters is known as converters. The function of an inverter is to change a DC input voltage to a symmetric AC input voltage of desired magnitude and frequency. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input DC voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse wudth modulation control within the inverter. The inverter gain may be defined as the ratio of the AC output voltage to the DC input voltage.

The output voltage waveform of the ideal inverter should be sinusoidal. However ,the waveform of practical inverters are non sinusoidal.

Inverters are widely used in industrial applications. The input may be battery etc.,

They are broadly classified as

1. Single phase inverters
2. Three phase inverters

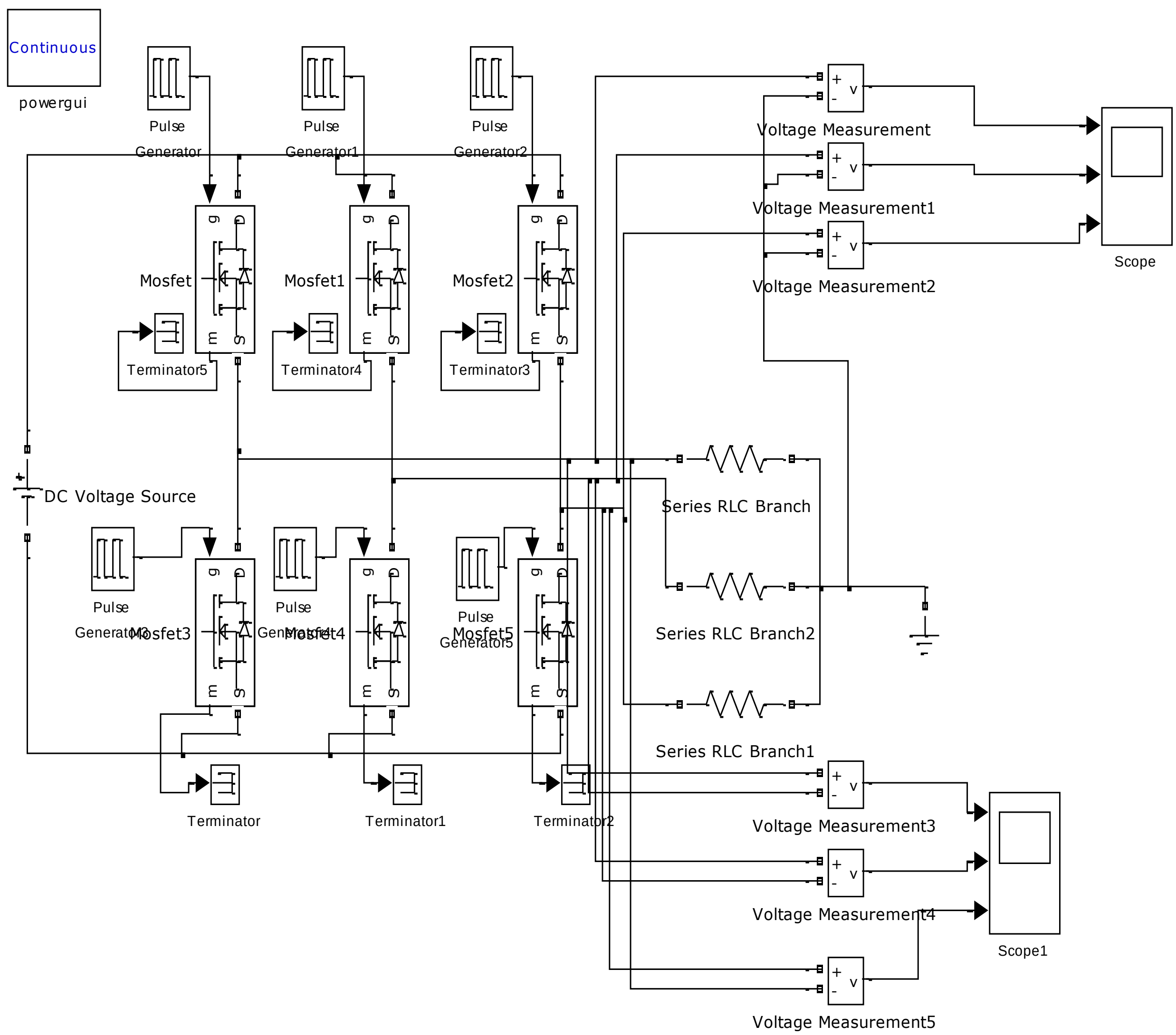
Each type can use controlled turn ON and OFF devices. These inverters generally use PWM control signal for producing an AC output voltage. An inverter called voltage fed inverter, if input voltage remains constant and called current fed inverters, if current remains constant.

Circuit demonstration:

The system consists of three independent circuits illustrating various PWM DC/DC and DC/AC inverters. All converters are controlled in open loop with the Discrete PWM Generator block available in the Extras/Discrete Control Blocks library. The three circuits use the same DC voltage (Vdc = 400V), carrier frequency (1080 Hz) and modulation index (m = 0.8) . From top to bottom, the three circuits are:

1. DC/DC, two-quadrant converter (one-arm; two-switches) 2. DC/AC, half-bridge, bipolar converter (one-arm; two-switches) 3. DC/AC, full-bridge, monopolar converter (two-arms; four-switches)

CIRCUIT:



OUTPUT:

Demonstration

Run the simulation and observe the following two waveforms on the three Scope blocks: current into the load (trace 1), voltage generated by the PWM inverter (trace 2).

Once the simulation is completed, open the Powergui and select "FFT Analysis" to display the 0 - 5000 Hz frequency spectrum of signals saved in the three "psb1phPWMx_str" structures. The FFT will be performed on a 2-cycle window starting at t = 0.1 - 2/60 (last 2 cycles of recording). For each circuit, select Input labeled "V inverter" . Click on "Display" and observe the frequency spectrum of last 2 cycles.

The fundamental component of V inverter (DC component in case of circuit 1) is displayed above the spectrum window. Compare the magnitude of the fundamental or DC component of the inverter voltage with the theoretical values given in the circuit. Compare also the harmonic contents in the inverter voltage for the half-bridge and the full-bridge DC/AC inverters.

The half-bridge inverter generates a bipolar voltage (-200V or +200V) . Harmonics occur around the carrier frequency (1080 Hz +- k*60 Hz), with a maximum of 103% at 1080 Hz.

The full-bridge inverter generates a monopolar voltage varying between 0 and+400V for one half cycle and then between 0 and -400V for the next half cycle. For the same DC voltage and modulation index, the fundamental component magnitude is twice the value obtained with the half-bridge. Harmonics generated by the full-bridge are lower and they appear at double of the carrier frequency (maximum of 40% at 2*1080+-60 Hz) As a result, the current obtained with the full-bridge is "cleaner".

If you now perform a FFT on the signal "Iload" you will notice that the THD of load current is 7.3% for the half-bridge inverter as compared to only 2% for the full-bridge inverter.

Result:

Thus the voltage source inverter was studied and designed.

Exp.No:11
Date:

Digital Over Current Relay Setting and Relay Coordination using Suitable software packages.

Aim:
In this laboratory you will use the PSCAD example case provided to study and verify the following:

1. Settings of the Time Overcurrent Relays.
2. Verification of Primary, Backup Protection and their Coordination.
3. Effect of CT saturation on the operating times.

Introduction

The case provided shows a 230 kV substation feeding a 33 kV radial distribution network. Coordinated over-current (inverse time) relays at the breakers B12, B23 and B34 are used to discriminate the faults at different locations and provide backup protection.

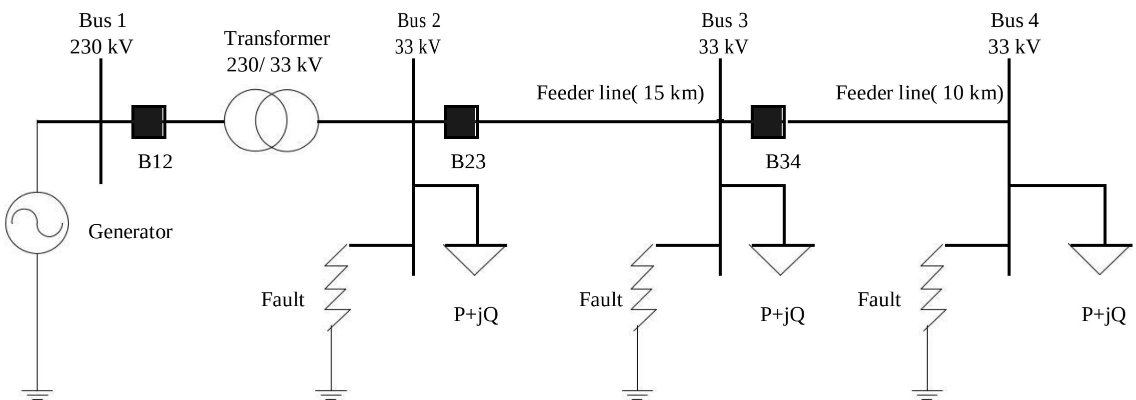


Figure 1: A radial distribution network.

You may recall that the settings of the time overcurrent relays are adjusted in such a way that the breaker nearest to the fault is tripped in the shortest possible time, and then the remaining breakers are tripped in succession using longer time delays, moving backwards towards the source. We will use the following principle for coordinated operation of the overcurrent relays:

For any relay X, backing up the next downstream relay Y, is that X must pick up

1) For one third of the minimum fault current seen by Y and
2) For the maximum fault current seen by Y but no sooner than 0.3 s after Y should have picked up for that current.

All the relays in the PSCAD case provided use the IEC standard inverse current characteristics and the curves are provided at the end of instruction sheet. As explained in the class the inverse time relays can be adjusted by selecting two parameters- the pick-up or the plug settings (tap settings) and the time dial settings (or time multiplier settings – TMS).

The pick-up settings

The pick-up settings are used to define the pick up current of the relay. For example, the tap settings of the electromechanical overcurrent relay that was discussed in the class was 1.0, 1.2, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 10.0, 12.0 A. We will use these discrete values in the PSCAD simulation case provided as well. This way we can make a comparison with the hand calculated values from the characteristic curves shown in the graph paper. However, you should be aware of the fact that the modern relays are of the digital type and the pick-up settings of IEC characteristics can be varied in a continuous fashion.

Time dial settings

The time dial setting adjusts the time delay before the relay operates whenever the fault current reaches a value equal to, or greater than, the relay current setting. In electromechanical relays, the time delay is usually achieved by adjusting the physical distance between the moving and fixed contacts, and is also specified as discrete settings. In Figure 2, a time-dial setting of 0.1 produces the fastest operation of the relay, whereas a setting of 1 produces the slowest operation for a given current. For digital relays, similar to the pick-up settings, the time-dial settings can be used in a continuous fashion but we will assume in this laboratory that the time multiplier settings are discrete.

Settings of the Time Overcurrent Relays

Study and familiarize with the PSCAD simulation case provided.

<u>Laboratory Exercise</u>

1. Bypass all relays using the bypass switches on the control panel. Record the maximum fault currents seen at the Bus 2, 3 and 4. Use the timed fault logic to apply the fault at 2.0s for a period longer than the simulation run to record the fault currents. Keep the fault resistance at 0.001 □.
2. Again bypass all relays using the bypass switches on the control panel and this time apply line-line and line-to-ground permanent fault at Bus 2, 3 and 4. Record the fault currents seen by the relays for the two types and note the minimum value (note that the minimum fault currents are obtained for line-line or line-ground faults). Use the timed fault logic to apply the fault at 2.0s for a period longer than the simulation run to record the fault currents. Keep the fault resistance at 0.001 □.
3. Use the obtained fault currents to determine the appropriate CT ratios and the relay settings for the three breakers (follow the method that was explained to you in the class).

Verification of Primary, Backup Protection, and their Coordination

Apply the settings that you just determined to the CT models and the overcurrent relay models in the simulation.

<u>Laboratory Exercise</u>

1. Put all relays back into operation by reverting the position of the bypass switches. Apply a solid permanent three-phase fault on Bus-4. Examine the fault current values, primary relay operation and its operating time. Check whether the operation of primary protection is as expected and according to your settings.
2. Repeat step 1 with fault resistance of 20 □.
3. Repeat step 1 with A-B and A-G faults. Keep the fault resistance at 0.001 □.
4. Remove the fault at Bus-4. Repeat step 1 for faults at Bus-3 and Bus-2.
5. Bypass the relay at breaker (B34) and apply a solid three-phase fault on Bus-4. Examine whether the backup protection (B23) clears the fault. Record the operating time of the backup relay and verify it with it with hand calculations using the graph provided.
6. Bypass the relay at breaker (B23) and study the operation of backup protection (relay at breaker B12) by applying a solid three-phase fault on Bus-3. Examine whether the backup protection clears the fault. Record the operating time of the backup relay.

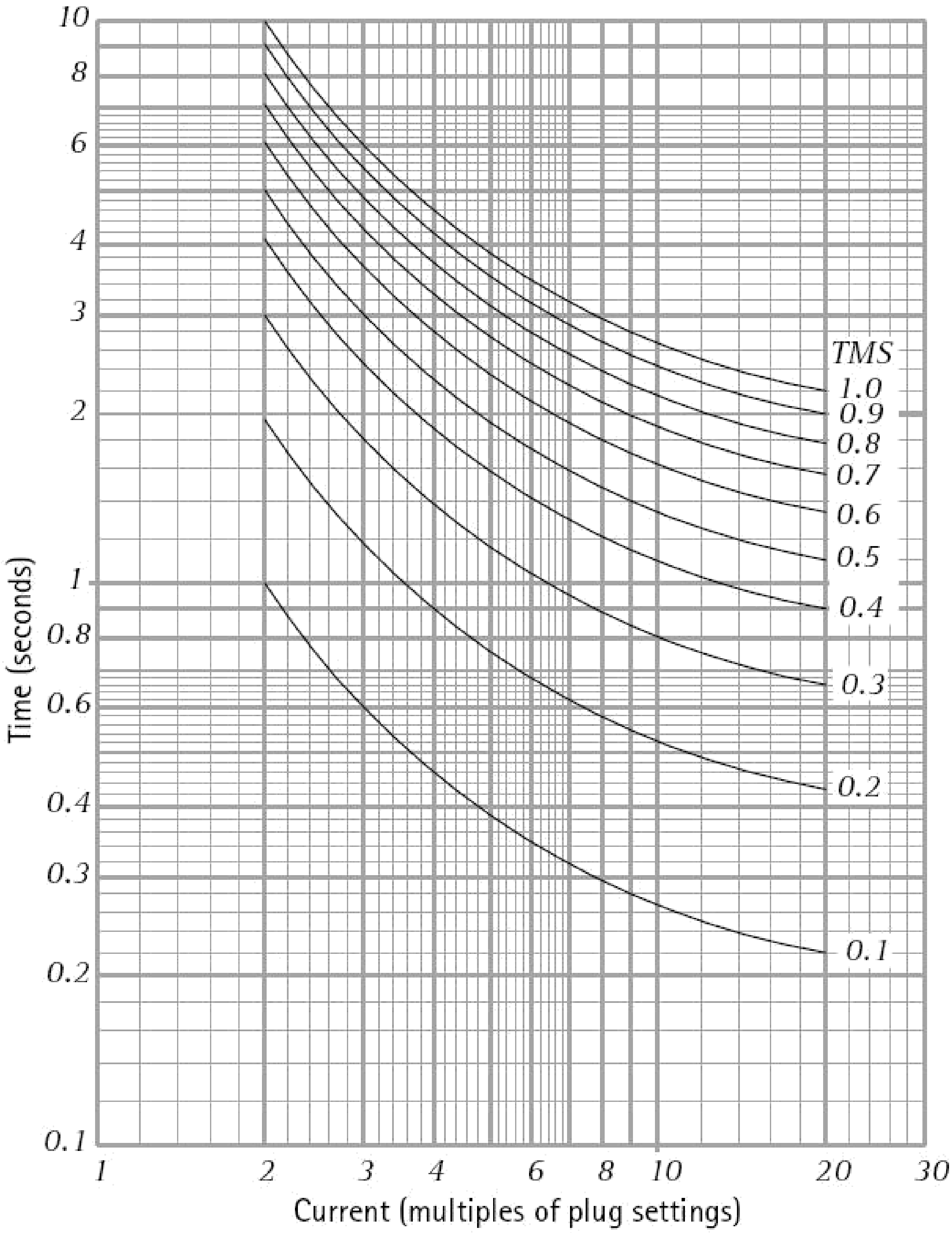
Effect of CT Saturation

In this part of the laboratory we will briefly investigate the effect of CT saturation on the operating times of the overcurrent relays. CT saturation strongly depends on the fault current levels, CT secondary burden and the presence of dc offset currents in the waveform, size of the CT core.

Laboratory Exercise

a) Revert all relays back into operation. Change the burden of the CTs of relay at B34 to 5 □. Apply a solid three-phase fault at Bus-4. Observe the primary and secondary currents of the CT at B34. Observe the relay operating time and compare with the values obtained in Section 3. Comment on your observation.

b) Change the fault type to an asymmetrical type of fault (A-G). Apply the fault at 2.0s and record the relay operating time. Repeat the simulation now with fault applied at 2.0042 s and compare the relay operating time with the previous case. Comment on your observation – discuss with your instructor.



Characteristic curves of type IEC standard inverse overcurrent relays.

Result:

Exp.NO:12
DATE:

CO-ORDINATION OF OVER-CURRENT AND DISTANCE RELAYS FOR RADIAL LINE PROTECTION

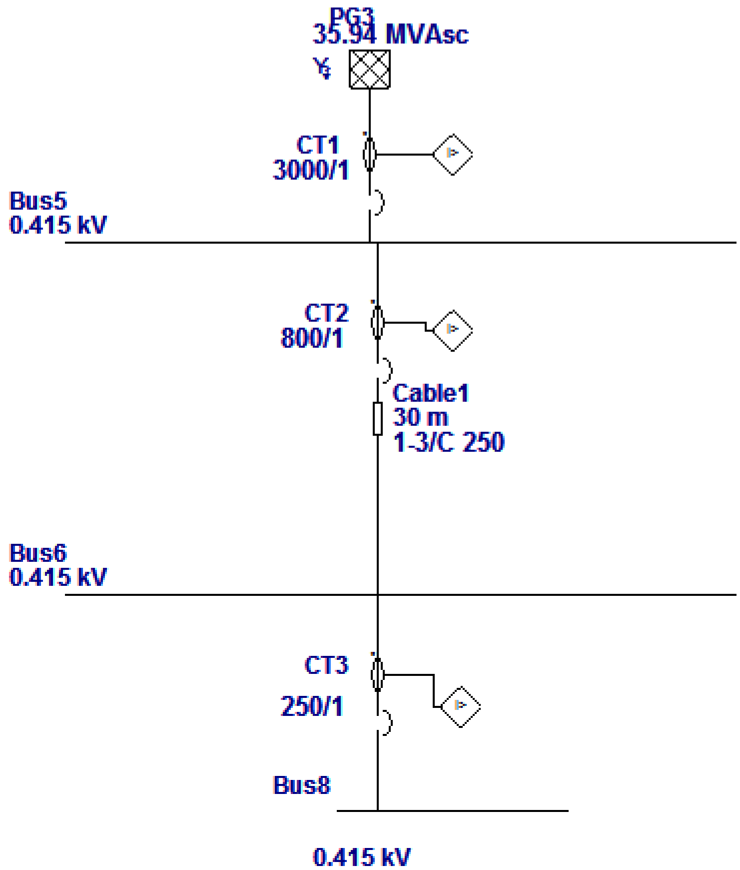
AIM:

To analyse the relay coordination for radial line protection using ETAP 7.5.0.

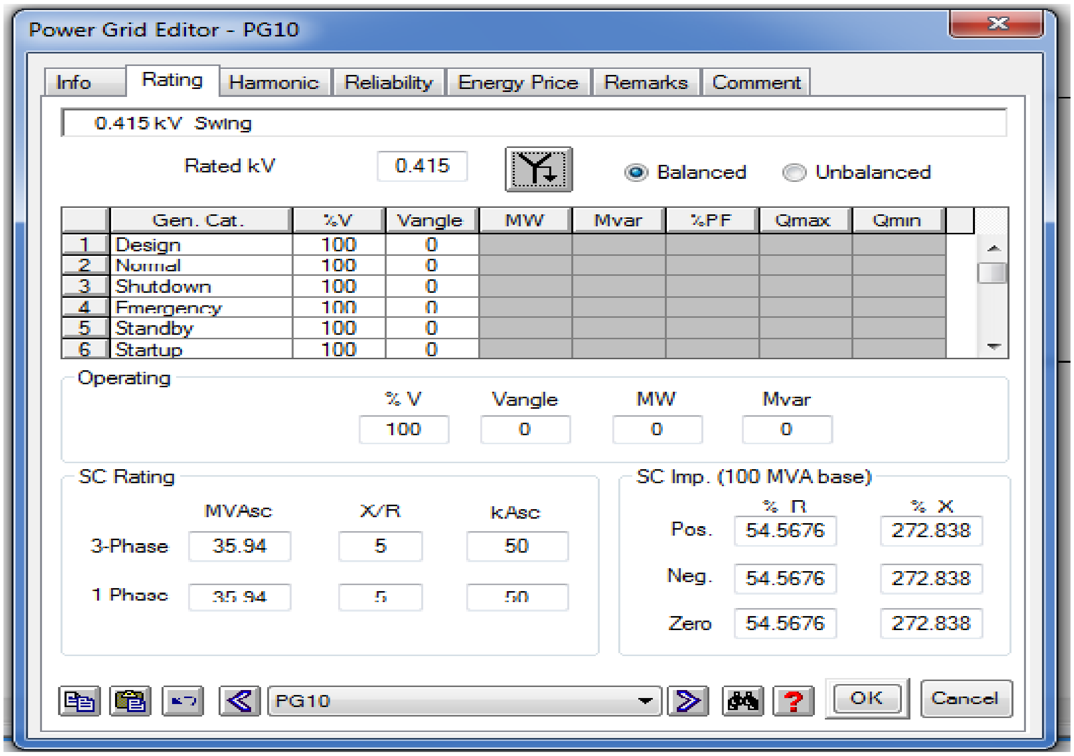
THEORY:

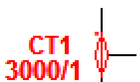
Power system protection performs the function of fault detection and clearing as soon as possible, isolating whenever possible only the faulted component or a minimal set of components in any other case. Since the main protection system may fail (relay fault or breaker fault), protections should act as backup either in the same station or in the neighboring lines with time delay according to the selectivity requirement. The determination of the time delays of all backup relays is known as coordination of the protection system.

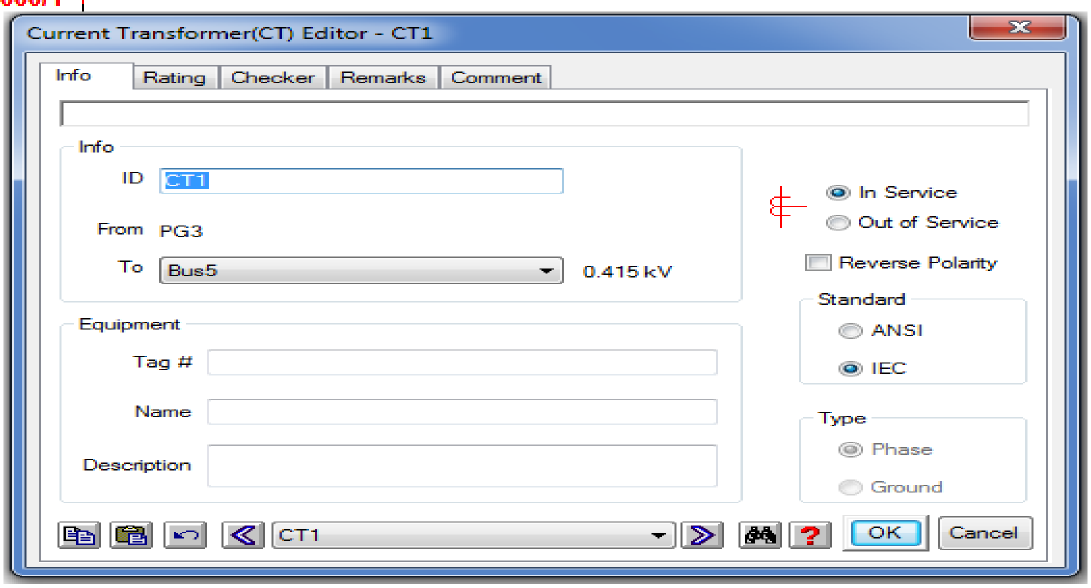
Coordination of protective relays is necessary to obtain selective tripping. The first rule of protective relaying is that the relay should trip for a fault in its zone. The second rule is that the relay should not trip for a fault outside its zone, except to back up a failed relay or circuit breaker. To coordinate this backup protection with the primary relay characteristic will ensure that the backup relay has sufficient time delay to allow the primary relay (and its breaker) to clear the fault. Several methods have been proposed for the coordination of over current relays.



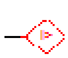
Single line diagram of radial distribution system

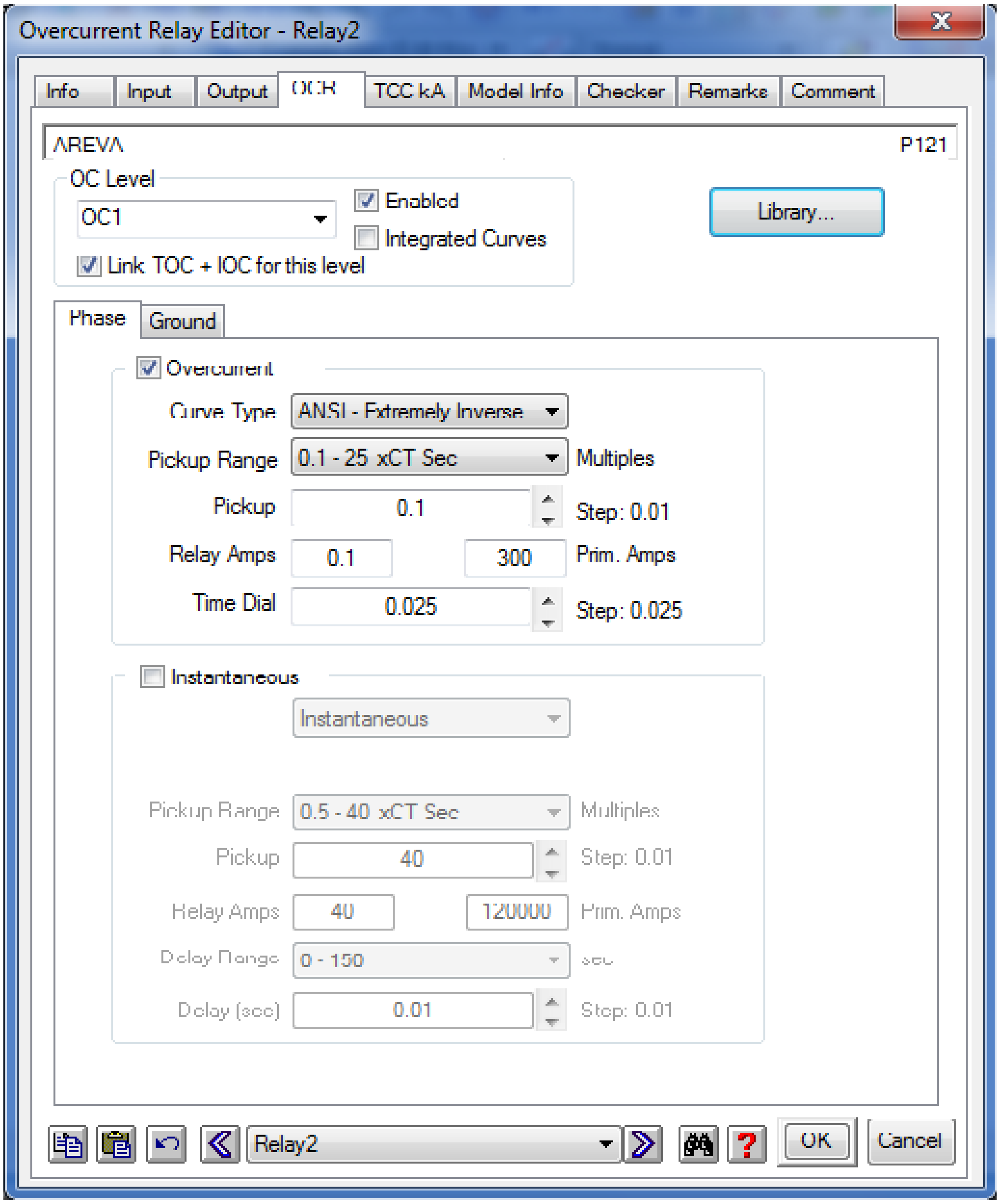

Power Grid Editor - PG10
Info
Rating
Harmonic
Reliability
Energy Price
Remarks
Comment
0.415 kV Swing
Rated kV
0.415
Balanced
Unbalanced
Gen. Cat.
%V
Vangle
MW
Mvar
%PF
Qmax
Qmin
1 Design 100 0
2 Normal 100 0
3 Shutdown 100 0
4 Emergency 100 0
5 Standby 100 0
6 Startup 100 0
Operating
% V
Vangle
MW
Mvar
100
0
0
0
SC Rating
MVAsc
X/R
kAsc
3-Phase
35.94
5
50
1-Phase
35.94
5
50
SC Imp. (100 MVA base)
% R
% X
Pos.
54.5676
272.838
Neg.
54.5676
272.838
Zero
54.5676
272.838
PG10
OK
Cancel

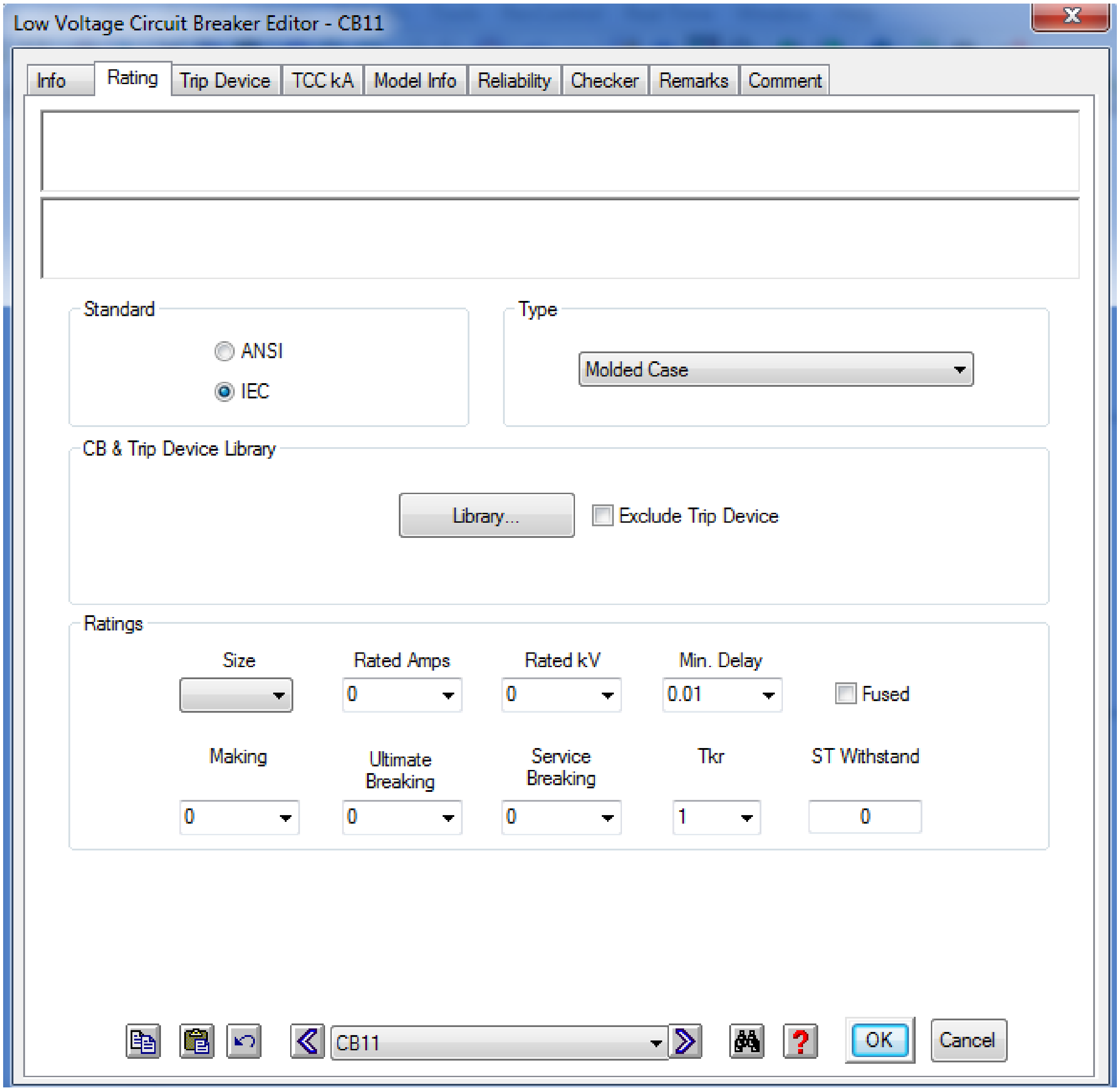

CT1
3000/1


Current Transformer(CT) Editor - CT1
Info
Rating
Checker
Remarks
Comment
Info
ID
CT1
From
PG3
To
Bus5
0.415 kV
In Service
Out of Service
Reverse Polarity
Standard
ANSI
IEC
Equipment
Tag #
Name
Description
Type
Phase
Ground
CT1
OK
Cancel

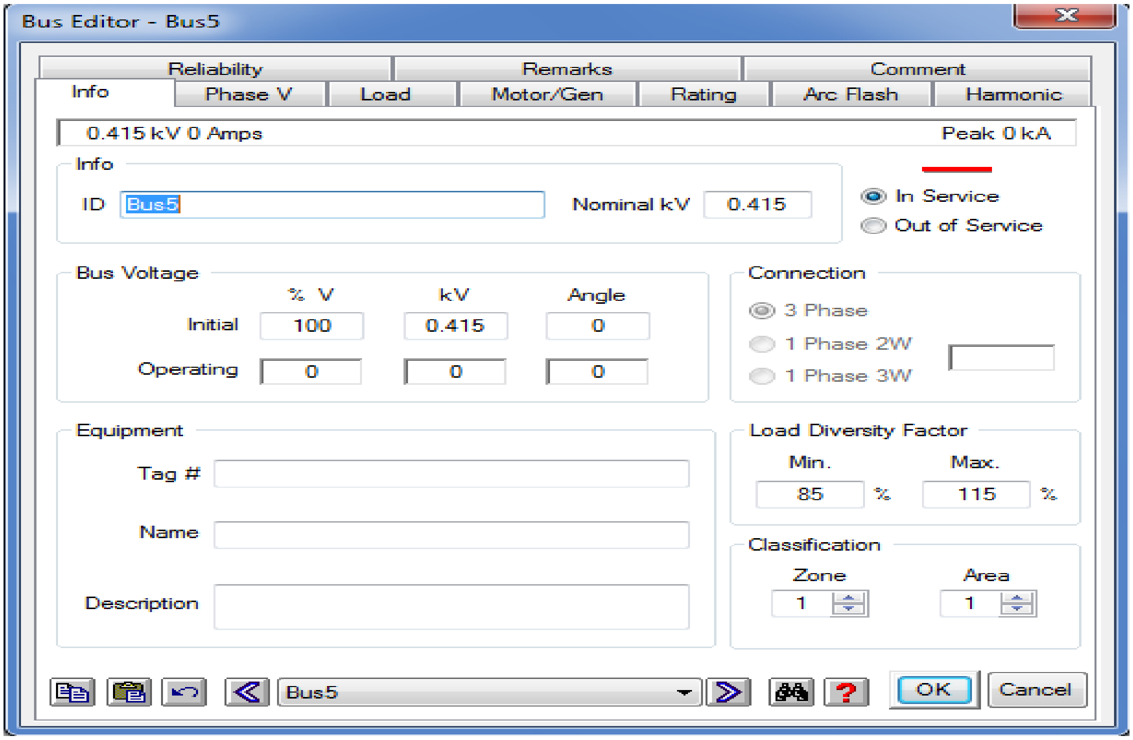
OC RELAY

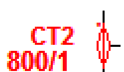


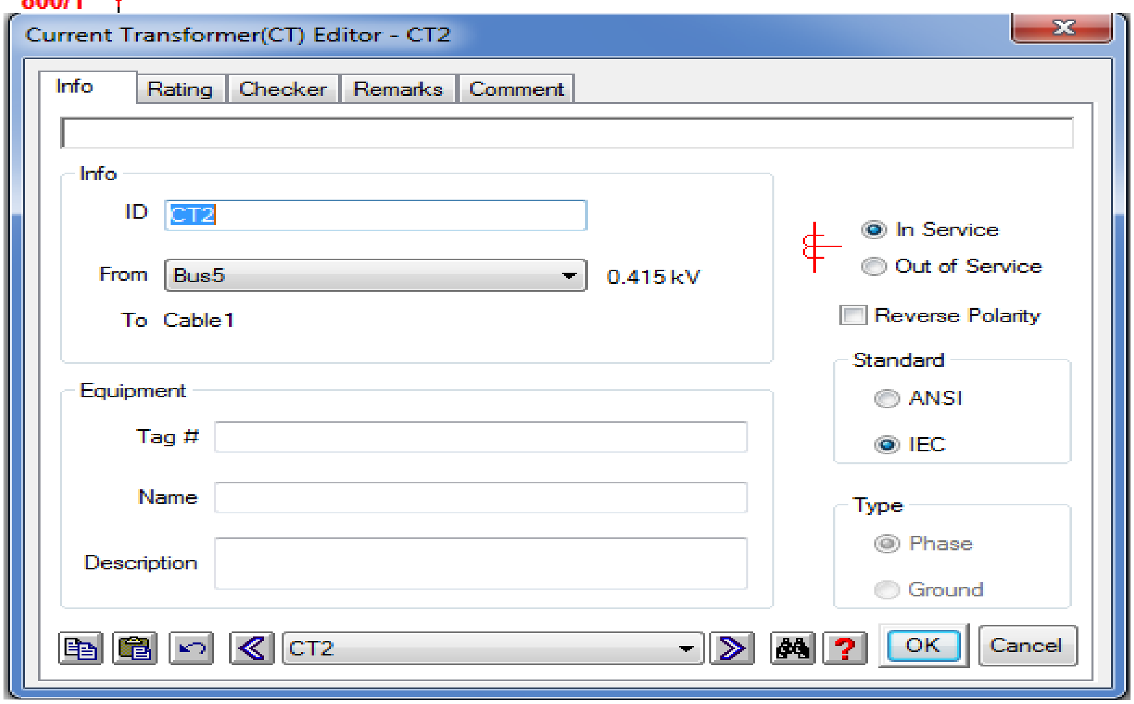

Overcurrent Relay Editor - Relay2
Info
Input
Output
OCR
TCC kA
Model Info
Checker
Remarks
Comment
AREVA
P121
OC Level
OC1
Enabled
Integrated Curves
Link TOC + IOC for this level
Library...
Phase
Ground
Overcurrent
Curve Type
ANSI - Extremely Inverse
Pickup Range
0.1 - 25 xCT Sec
Multiples
Pickup
0.1
Step: 0.01
Relay Amps
0.1
300
Prim. Amps
Time Dial
0.025
Step: 0.025
Instantaneous
Instantaneous
Pickup Range
0.5 - 40 xCT Sec
Multiples
Pickup
40
Step: 0.01
Relay Amps
40
120000
Prim. Amps
Delay Range
0 - 150
sec
Delay (sec)
0.01
Step: 0.01
Relay2
OK
Cancel

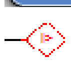

Low Voltage Circuit Breaker Editor - CB11
Info
Rating
Trip Device
TCC kA
Model Info
Reliability
Checker
Remarks
Comment
Standard
ANSI
IEC
Type
Molded Case
CB & Trip Device Library
Library...
Exclude Trip Device
Ratings
Size
Rated Amps
Rated kV
Min. Delay
0
0
0.01
Fused
Making
Ultimate Breaking
Service Breaking
Tkr
ST Withstand
0
0
0
1
0
CB11
OK
Cancel

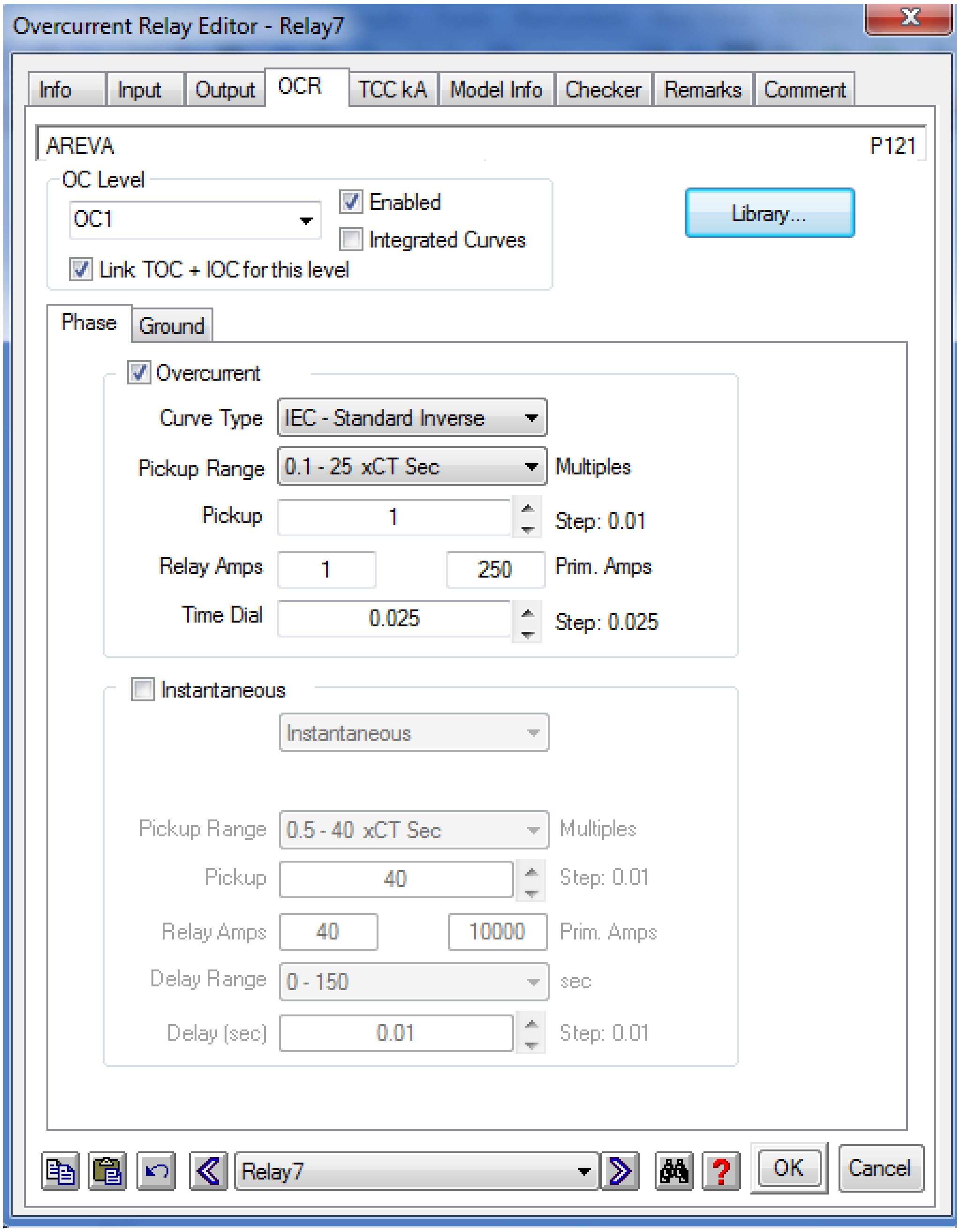

Bus5
0.415 kV

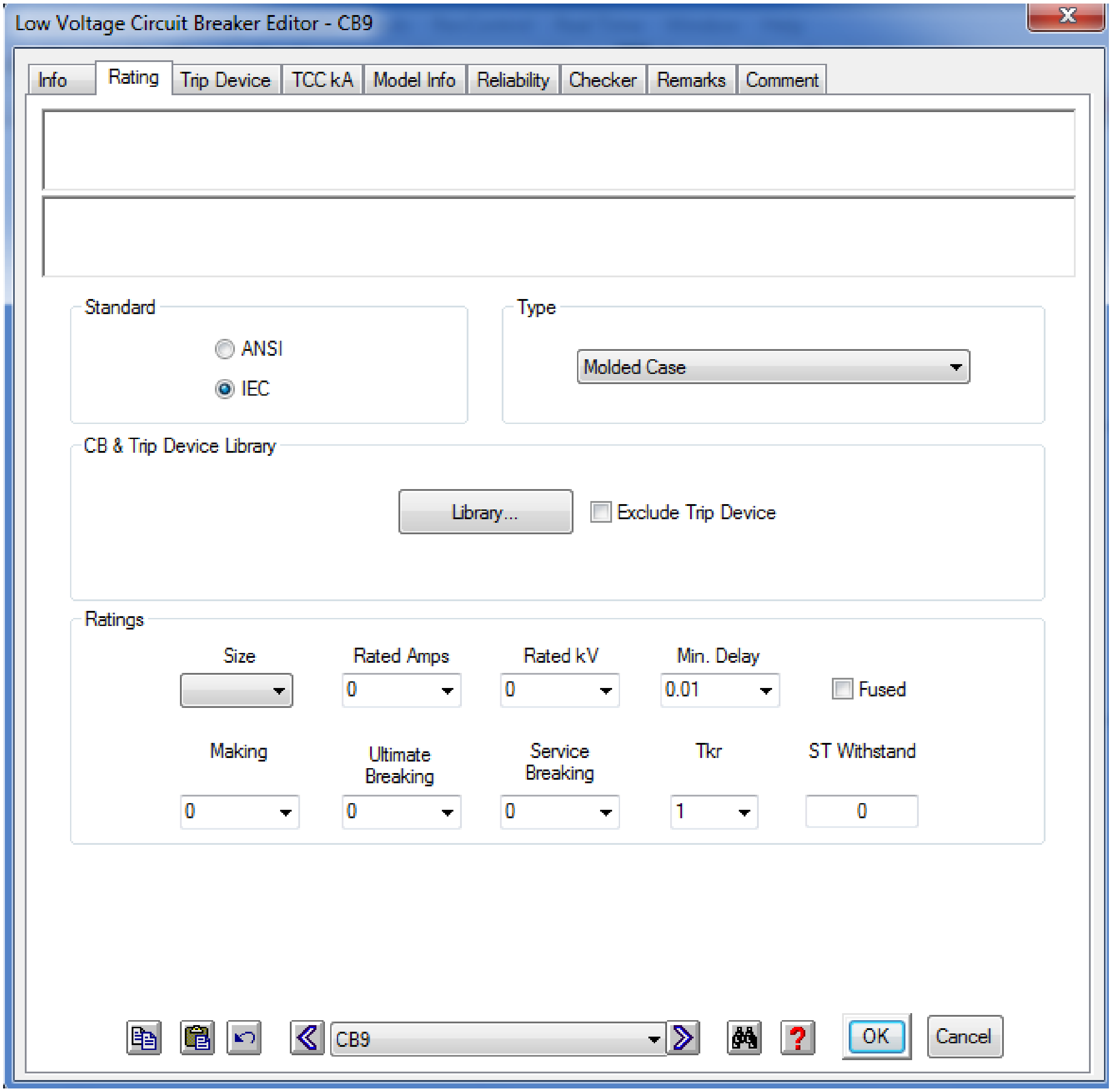

Bus Editor - Bus5
Reliability
Remarks
Comment
Info
Phase V
Load
Motor/Gen
Rating
Arc Flash
Harmonic
0.415 kV 0 Amps
Peak 0 kA
Info
ID Bus5
Nominal kV 0.415
In Service
Out of Service
Bus Voltage
% V
kV
Angle
Initial 100 0.415 0
Operating 0 0 0
Connection
3 Phase
1 Phase 2W
1 Phase 3W
Equipment
Tag #
Name
Description
Load Diversity Factor
Min. 85 %
Max. 115 %
Classification
Zone 1
Area 1
Bus5
OK
Cancel

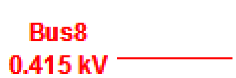

CT2
800/1

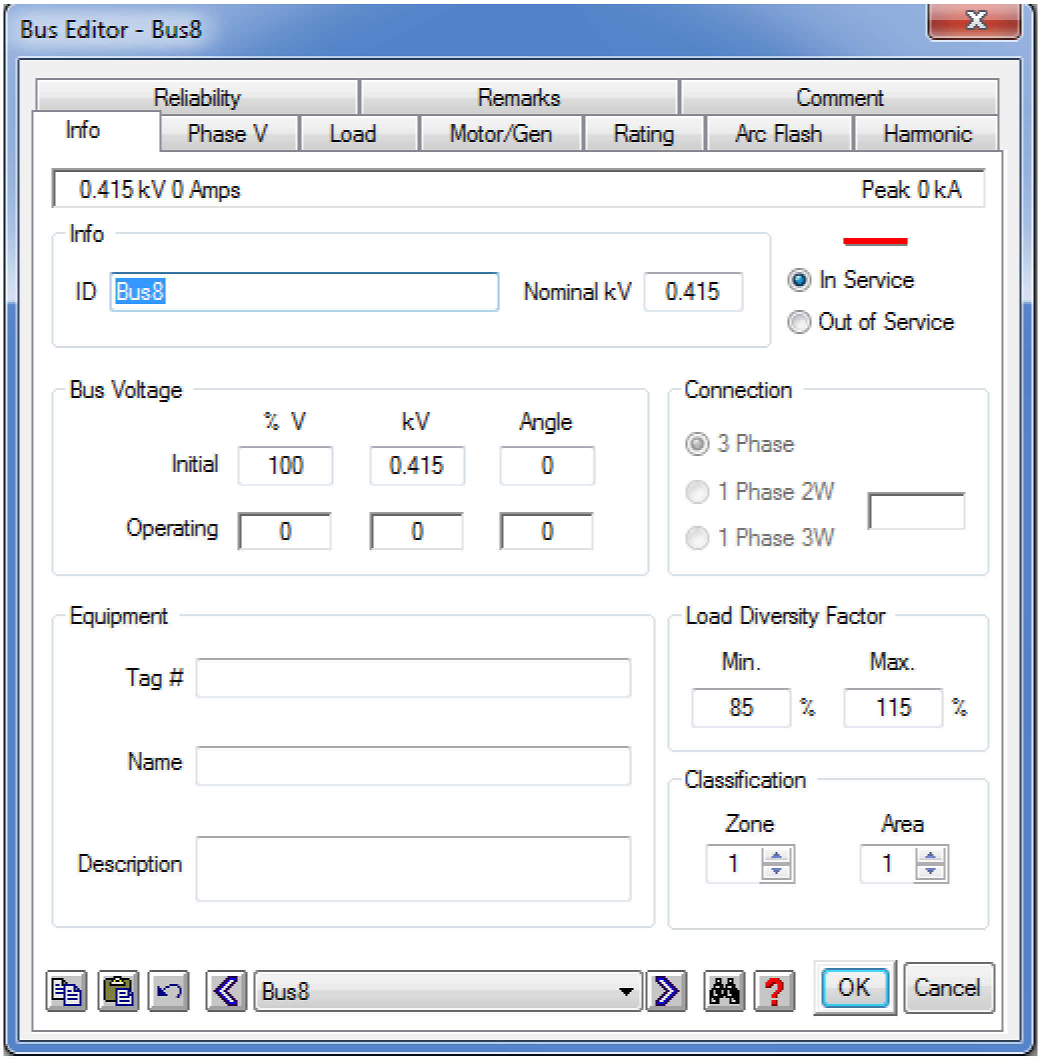

Current Transformer(CT) Editor - CT2
Info
Rating
Checker
Remarks
Comment
Info
ID CT2
From Bus5
0.415 kV
To Cable1
In Service
Out of Service
Reverse Polarity
Standard
ANSI
IEC
Equipment
Tag #
Name
Description
Type
Phase
Ground
CT2
OK
Cancel




Overcurrent Relay Editor - Relay7
Info
Input
Output
OCR
TCC kA
Model Info
Checker
Remarks
Comment
AREVA
P121
OC Level
OC1
Enabled
Integrated Curves
Link TOC + IOC for this level
Library...
Phase
Ground
Overcurrent
Curve Type
IEC - Standard Inverse
Pickup Range
0.1 - 25 xCT Sec
Multiples
Pickup
1
Step: 0.01
Relay Amps
1
250
Prim. Amps
Time Dial
0.025
Step: 0.025
Instantaneous
Instantaneous
Pickup Range
0.5 - 40 xCT Sec
Multiples
Pickup
40
Step: 0.01
Relay Amps
40
10000
Prim. Amps
Delay Range
0 - 150
sec
Delay (sec)
0.01
Step: 0.01
Relay7
OK
Cancel


Low Voltage Circuit Breaker Editor - CB9
Info
Rating
Trip Device
TCC kA
Model Info
Reliability
Checker
Remarks
Comment
Standard
ANSI
IEC
Type
Molded Case
CB & Trip Device Library
Library...
Exclude Trip Device
Ratings
Size
Rated Amps
Rated kV
Min. Delay
0
0
0.01
Fused
Making
Ultimate Breaking
Service Breaking
Tkr
ST Withstand
0
0
0
1
0
CB9
OK
Cancel


Bus8
0.415 kV


Bus Editor - Bus8
Reliability
Remarks
Comment
Info
Phase V
Load
Motor/Gen
Rating
Arc Flash
Harmonic
0.415 kV 0 Amps
Peak 0 kA
Info
ID Bus8
Nominal kV 0.415
In Service
Out of Service
Bus Voltage
% V
kV
Angle
Initial 100 0.415 0
Operating 0 0 0
Connection
3 Phase
1 Phase 2W
1 Phase 3W
Equipment
Tag #
Name
Description
Load Diversity Factor
Min.
Max.
85 %
115 %
Classification
Zone
Area
1
1
Bus8
OK
Cancel

GUIDELINES FOR RELAY SETTINGS

Relays for breakers on the primaries of CT transformers:

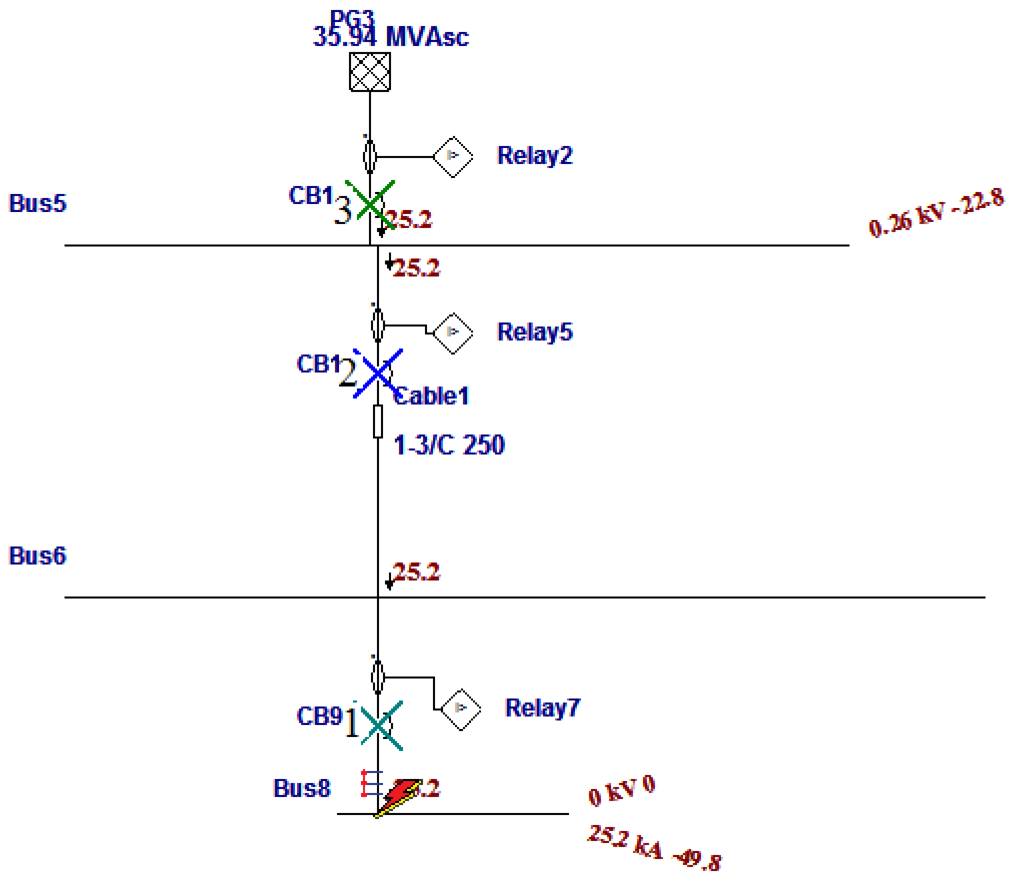
1. Pickup is typically chosen at approximately 140% of nominal CT transformer current or higher if coordination considerations dictate that. Values up to600% are allowed by the IEC, depending on system parameters and what other protective devices are used.

2. Instantaneous pickup is greater than or equal to 160% of short circuit current for maximum fault downstream of the transformer to avoid tripping of the primary breaker for an asymmetrical secondary fault.160% is used for larger transformers.

COORDINATION EVALUATION

ETAP's STAR module was used to coordinate the time-current curves associated with the P121-s protective relays. In this study, there is a maximum of three protective devices needing to be coordinated at any given time. This occurs when a fault happens in any of the feeders tied in with the ct transformers. Since all these feeders are identical, the settings associated with the respective relays will also be identical. There are guidelines in coordinating these devices. There must be adequate time for the relay to sense the fault, transmit to the breaker, and open the breaker. If this does not occur in the downstream device, then the upstream device must perform this function

SIMULATION OUTPUT:



RESULT:

Hence, analysis on the relay coordination for radial line protection using ETAP 7.5.0. has been executed.

Viva Questions:

1. Explain the circuit of the experiment.
2. What is the function of semaphore indicator?
3. Why are the settings of the earth-fault relays lower than the settings of the overcurrent relays?
4. Draw an a.c. circuit and d.c. control circuit for two overcurrent and one earth-fault scheme of protection of a feeder used in practice. How does our experimental scheme differ from that? Why?
5. What do you understand by time discrimination?
6. What do you understand by overshoot of a relay?
7. What is the significance of resetting time of a relays?
8. What do you understand by back-up protection? Explain remote back-up protection.
9. How does the source impedance affect the choice of relay to be used in radial feeder protection?
10. Why are the IDMT relays popular in practice?
11. What are the factors to be considered for deciding settings of phase relays and ground relays?

Exp.No:13
Date:

TRANSIENT BEHAVIOUR OF THREE-PHASE INDUCTION MACHINE DURING STARTING

AIM:

To analyse the study of transient behaviour of three-phase induction machine during starting using PSCAD

SOFTWARE REQUIRED:

Power system module of PSCAD

THEORY:

Three-phase induction machines are generally used as motors for many industrial applications and all this is due to its simple construction and other advantages in contrast to other machines. Popularity of these motors has resulted into a lot of research including the transient behaviour of the machine.

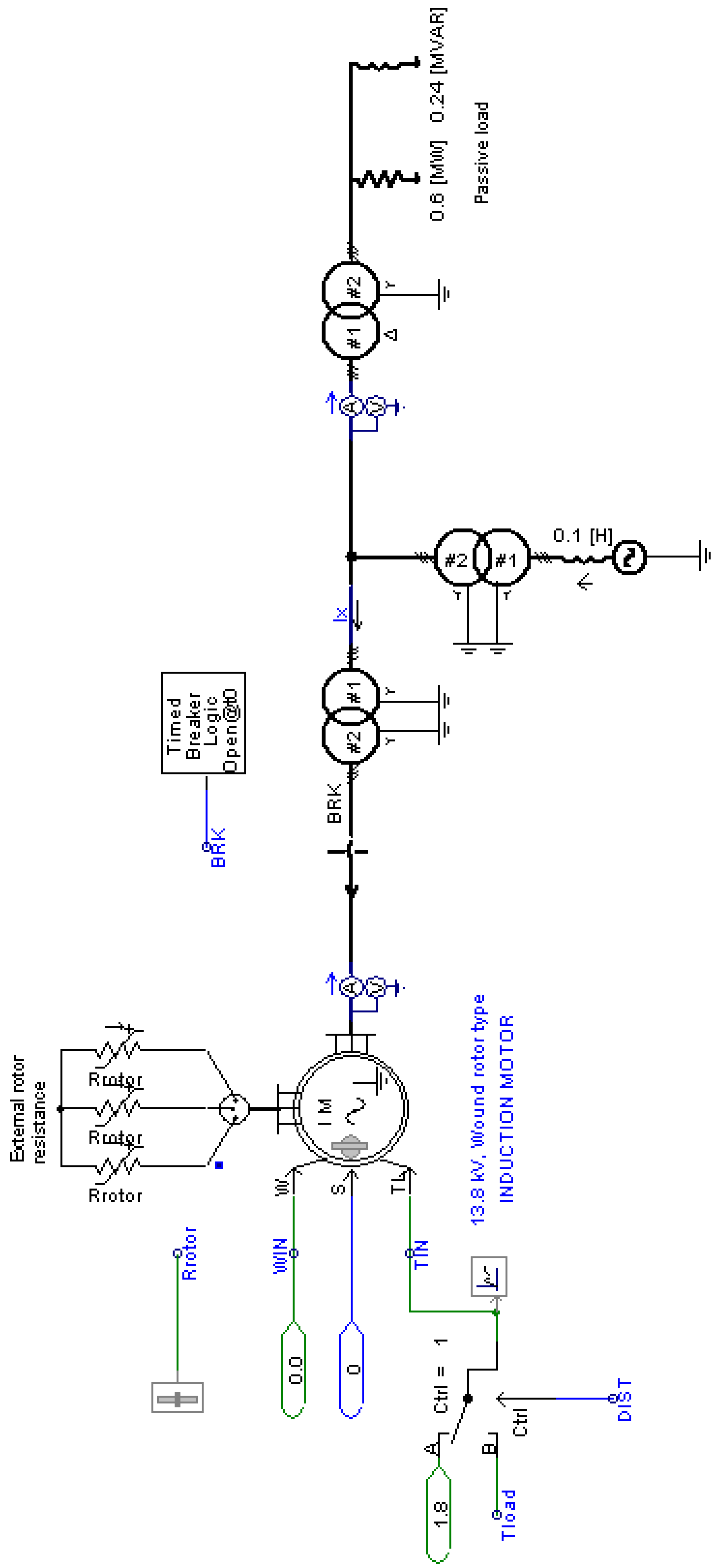


FIG 1: SLD OF INDUCTION MOTOR STARTING ANALYSIS

1. Enter the component data.

<u>Motor</u>

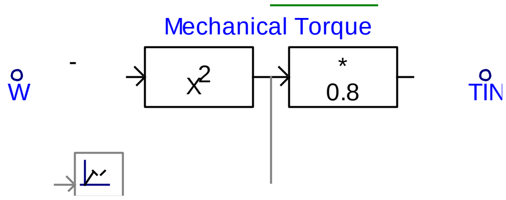
500 kVA Induction machine.
Wound rotor Type.
13.8 kV(L-L) 7.697 kV (Phase)
Irated = 0.02804 [kA]
Inertia = 0.7267 [s]
Stator resistance = 0.005 PU
Rotor Resistance = 0.008 PU

<u>Short Line</u>

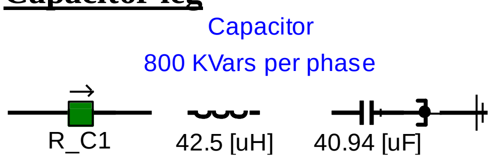
Short line of 7.4 km
Z+ = 0.2 E-4 + j0.3 E-3 Ohms/m
Z0 = 0.3 E-3 + j0.1 E-2 Ohms/m
Use default values for the capacitances

<u>Mechanical Load model</u>

This block models the mechanical
characteristics of a typical load.



<u>Capacitor leg</u>



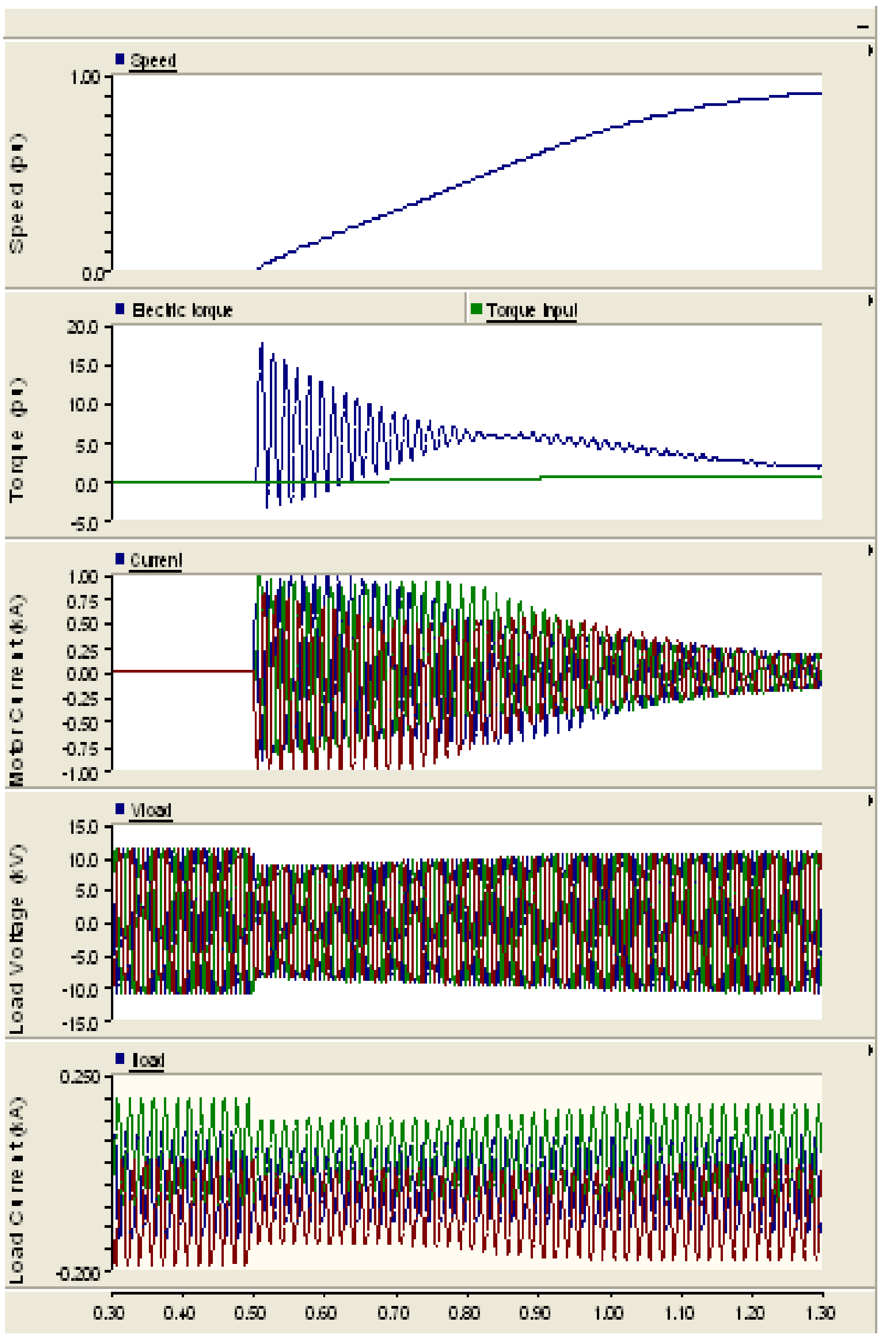
Note:
1. Use 'typical' data for the machine.
2. Plot the currents on either side of the transformer (ia and ib).
3. The input torque to the machine is equal to 80% of the square of the speed.
Derive this signal using control blocks. i.e

$$T_m = 0.8 \cdot w^2$$

Use control blocks to implement the above equation.
The wound rotor machine is used.
The motor is started from zero speed.
The mechanical torque applied, Tm, is varied as a function of speed.
ie. Tm = Tload = k*w*w + b
w = speed
k,b = constants.
The machine accelerates if Te>Tm

At 3s, the mechanical torque is switched to 1.8 pu using a 'controlled' switch. The machine goes through a transient state and settles at a new speed.
The start up characteristics depends on the external resistance, Rrotor, connected to the rotor. This value can be changed using a 'slider'. Parameters such as machine inertia, damping can also be changed inside the component to study their impact on start up.

Output



Result :

This experiment was chosen with the intention of learning PSCAD and using it effectively in obtaining transient behaviour of three-phase induction machine during starting. Simulated results have been compared and verified with experimental results on a test machine

Exp.No:14
Date:

SMALL SIGNAL STABILITY ANALYSIS OF A SINGLE MACHINE INFINITE BUS SYSTEM WITH FIELD CIRCUIT, EXCITER AND POWER SYSTEM STABILIZER

AIM:

To write a MATLAB program for analyzing the small signal stability of a single machine infinite bus system with field circuit, exciter and power system stabilizer.

SOFTWARE REQUIRED:

Power system module of MATLAB.

THEORY:

Effect of Synchronous Machine Field Circuit Dynamics:

We now consider the system performance including the effect of field flux variations. The amortisseur effects will be neglected and the field voltage will be assumed constant (manual excitation control).

Synchronous machine equations:

As in the case of the classical generator model, the acceleration equations are

$$p\Delta\omega_r = \frac{1}{2H}\left(T_m - T_e - K_D\Delta\omega_r\right) \quad (1)$$

$$p\delta = \omega_0\Delta\omega_r$$

where

Network equations:

The machine terminal and infinite bus voltages in terms of the d and q components are

$$\tilde{E}_t = e_d + je_q \quad (2)$$

$$\tilde{E}_B = E_{Bd} + jE_{Bq} \quad (3)$$

The network constraint equation for the system

$$\tilde{E}_t = \tilde{E}_B + \left(R_E + jX_E\right)\tilde{I}_t \quad (4)$$

$$\left(e_d + je_q\right) = \left(E_{Bd} + jE_{Bq}\right) + \left(R_E + jX_E\right)\left(i_d + ji_q\right) \quad (5)$$

Resolving into d and q components gives

$$e_d = R_E i_d - X_E i_q + E_{Bd} \quad (6)$$

$$e_q = R_E i_q + X_E i_d + E_{Bq} \quad (7)$$

Where,

$$E_{Bd} = E_B \sin\delta \quad (8)$$

$$E_{Bq} = E_B \cos\delta \quad (9)$$

The expressions for i_d and i_q in terms of the state variables ψ_{fd} and δ is given by

$$i_d = \frac{X_{Tq}\left[\psi_{fd}\left(\frac{L_{ads}}{L_{ads}+L_{fd}}\right) - E_B\cos\delta\right] - R_T E_B\sin\delta}{D} \quad (10)$$

$$i_q = \frac{R_T\left[\psi_{fd}\left(\frac{L_{ads}}{L_{ads}+L_{fd}}\right) - E_B\cos\delta\right] + X_{Td} E_B\sin\delta}{D} \quad (11)$$

$$\mathbf{R_T = R_a + R_E} \quad \textbf{(12)}$$

$$\mathbf{X_{Tq} = X_E + \left(L_{aqs} + L_l\right) = X_E + X_{qs}} \quad \textbf{(13)}$$

$$\mathbf{X_{Tqd} = X_E + \left(L'_{ads} + L_l\right) = X_E + X'_{ds}} \quad \textbf{(14)}$$

$$\mathbf{D = R_T^2 + X_{Tq}\ X_{Td}} \quad \textbf{(15)}$$

The reactance's L_{ads} and L_{aqs} are saturated values. In per unit they are equal to the corresponding inductances.
These equations are nonlinear and have to be linearized for small signal analysis.

Linearized system equations

Expressing equations (11) and (13) in terms of perturbed values, we may write

$$\mathbf{\Delta i_d = m_1 \Delta\delta + m_2 \Delta\psi_{fd}} \quad \textbf{(16)}$$

$$\mathbf{\Delta i_q = n_1 \Delta\delta + n_2 \Delta\psi_{fd}} \quad \textbf{(17)}$$

$$m_1 = \frac{E_B\left(X_{Tq}\sin\delta_o - R_T\cos\delta_o\right)}{D} \quad \textbf{(18)}$$

$$n_1 = \frac{E_B\left(R_T\sin\delta_o + X_{Td}\cos\delta_o\right)}{D} \quad \textbf{(19)}$$

$$m_2 = \frac{X_{Tq}}{D}\frac{L_{ads}}{(L_{ads} + L_{fd})} \quad \textbf{(20)}$$

$$n_2 = \frac{R_T}{D}\frac{L_{ads}}{(L_{ads} + L_{fd})} \quad \textbf{(21)}$$

By linearizing ψ_{ad} and ψ_{aq}, and substituting them in the above expressions and , we get

$$\Delta\psi_{ad} = L'_{ads}\left(-\Delta i_d + \frac{\Delta\psi_{fd}}{L_{fd}}\right) \quad \textbf{(22)}$$

$$= \left(\frac{1}{L_{fd}} - m_2\right)L'_{ads}\Delta\psi_{fd} - m_1 L'_{ads}\Delta\delta \quad \textbf{(23)}$$

$$\Delta\psi_{aq} = -L_{aqs}\Delta i_q \quad \textbf{(24)}$$

$$= -n_2 L_{aqs}\Delta\psi_{fd} - n_1 L_{aqs}\Delta\delta \quad \textbf{(25)}$$

Linearizing i_{fd} and substituting for $\Delta\psi_{ad}$ from equation (19) gives

$$\Delta i_{fd} = \frac{\Delta\psi_{fd} - \psi_{ad}}{L_{fd}} \quad \textbf{(26)}$$

$$= \frac{1}{L_{fd}}\left(1 - \frac{L'_{ads}}{L_{fd}} + L'_{ads}\right)\Delta\psi_{fd} + \frac{1}{L_{fd}} m_1 L'_{ads}\Delta\delta \quad \textbf{(27)}$$

The linearized form of air gap torque $\mathbf{T_e}$ is given by

$$\Delta T_e = \psi_{ad0}\Delta i_q + i_{q0}\Delta\psi_{ad} - \psi_{aq0}\Delta i_d - i_{d0}\Delta\psi_{aq} \quad (28)$$

$$\Delta T_e = K_1\Delta\delta + K_2\Delta\psi_{fd} \quad (29)$$

$$K_1 = n_1\left(\psi_{ad0} + L_{aqs} i_{d0}\right) - m_1\left(\psi_{aq0} + L'_{ads} i_{q0}\right) \quad (30)$$

$$K_2 = n_2\left(\psi_{ad0} + L_{aqs} i_{d0}\right) - m_2\left(\psi_{aq0} + L'_{ads} i_{q0}\right) + \frac{L'_{ads}}{L_{aqs}} i_{q0} \quad (31)$$

The system equation in the desired final form :

$$\begin{bmatrix} \Delta\dot{\omega}_r \\ \Delta\dot{\delta} \\ \Delta\dot{\psi}_{fd} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & 0 & 0 \\ 0 & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\psi_{fd} \end{bmatrix} \quad (32)$$

Where,

$$a_{11} = -\frac{K_D}{2H} \quad (33)$$

$$a_{12} = -\frac{K_1}{2H} \quad (34)$$

$$a_{13} = -\frac{K_2}{2H} \quad (35)$$

$$a_{21} = \omega_0 = 2\pi f_0 \quad (36)$$

$$a_{32} = \frac{\omega_0 R_{fd}}{L_{fd}} m_1 L'_{ads} \quad (37)$$

$$a_{33} = -\frac{\omega_0 R_{fd}}{L_{fd}}\left[1 - \frac{L'_{ads}}{L_{fd}} + m_2 L'_{ads}\right] \quad (38)$$

$$b_{11} = \frac{1}{2H} \quad (39)$$

$$b_{32} = \frac{\omega_0 R_{fd}}{L_{adu}}$$

And ΔT_m and ΔE_{fd} depend on prime mover and excitation controls. With constant mechanical input torque, ΔT_m =0; with constant exciter output voltage, ΔE_{fd} =0.

Summary of procedure for formulating the state matrix

(a)The following steady state operating conditions , machine parameters and network parameters are given below:

P_t Q_t E_t R_E X_E

L_d L_q L_l R_a L_{fd} A_{sat} B_{sat} Ψ_{Tl}

Alternatively E_B may be specified instead of Q_t or E_t

(b)The first step is to compute the initial steady state values of system variables:

I_t , power factor angle ,Total saturation factors K_{sd} and K_{sq} .

$$X_{ds} = L_{ds} = K_{sd}L_{adu} + L_l \quad (40)$$

$$\mathbf{X_{qs} = L_{qs} = K_{sq}L_{aqu} + L_l} \quad (41)$$

$$\delta_1 = \tan^{-1}\left(\frac{I_t X_{qs} \cos j - I_t R_a \sin j}{E_t + I_t R_a \cos j + I_t X_{qs} \sin j}\right) \quad (42)$$

$$\mathbf{e_{d0} = E_t \sin\delta_i} \quad (43)$$

$$\mathbf{e_{q0} = E_t \cos\delta_i} \quad (44)$$

$$\mathbf{i_{d0} = I_t \sin(\delta_i + j)} \quad (45)$$

$$\mathbf{i_{q0} = I_t \cos(\delta_i + j)} \quad (46)$$

$$\mathbf{E_{Bd0} = e_{d0} - R_E i_{d0} + X_E i_{q0}} \quad (47)$$

$$a_{32} = \frac{\omega_0 R_{fd}}{L_{fd}} m_1 L'_{ads} \quad (48)$$

$$\delta_0 = \tan^{-1}\left(\frac{E_{Bd0}}{E_{Bq0}}\right) \quad (49)$$

$$E_B = \left(E_{Bd0}^2 + E_{Bq0}^2\right)^{1/2} \quad (50)$$

$$i_{fd0} = \frac{e_{q0} + R_a i_{q0} L_{ds} i_{d0}}{L_{ads}} \quad (51)$$

$$\mathbf{E_{fd0} = L_{adu} i_{fd0}} \quad (52)$$

$$\mathbf{\psi_{ad0} = L_{ads}(-i_{d0} + i_{fd0})} \quad (53)$$

$$\mathbf{\psi_{aq0} = -L_{aqs} i_{q0}} \quad (54)$$

(c) The next step is to compute incremental saturation factors and the corresponding saturated values of L_{ads} ,L_{aqs} ,L'_{ads} , and then

$\mathbf{R_T, X_{Tq}, X_{Td}, D}$

$\mathbf{m_1, m_2, n_1, n_2}$

$\mathbf{K_1, K_2}$

is calculated from the equations (11) and (14).

(d) Finally, compute the elements of matrix A.

Block diagram representation

Fig.1 shows the block diagram representation of the small signal performance of the system. In this representation; the dynamic characteristics of the system are expressed in terms of the so called K constants. The basis for the block diagram and the expressions for the associated constant are developed

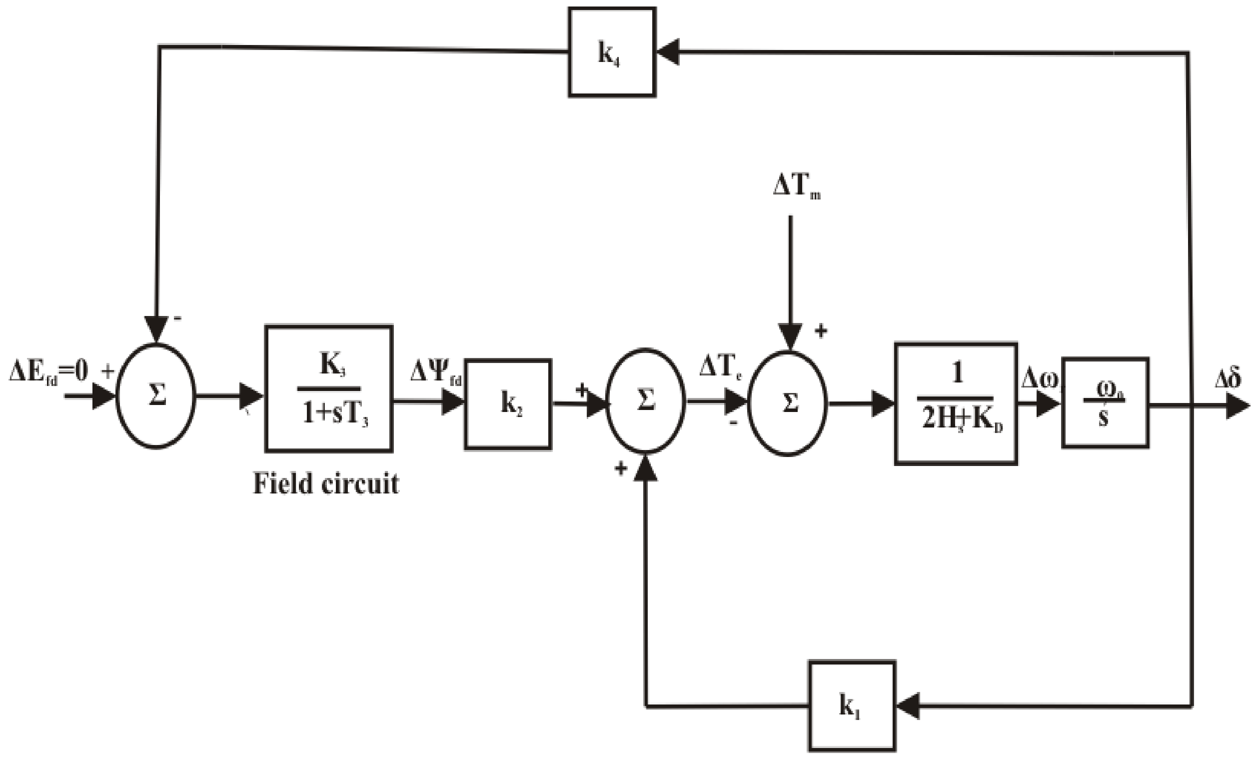


Fig.1-BLOCK DIAGRAM REPRESENTATION WITH CONSTANT Efd

EFFECTS OF EXCITATION SYSTEM:

We will examine the effect of the excitation system on the small signal stability performance of the single machine infinite bus system.

The input control signal to the excitation system is normally the generator terminal voltage E_t. In the generator model E_t is not a state variable. Therefore, E_t has to be expressed in terms of the state variables $\Delta\ \omega_r$, $\Delta\delta$, and$\Delta\psi_{fd}$.

$\tilde{E}$ May be expressed in complex form:

$$\tilde{\mathbf{E}}_t = \mathbf{e}_d + j\mathbf{e}_q \qquad \textbf{(55)}$$

Hence,

$$\mathbf{E}_t^2 = \mathbf{e}_d^2 + \mathbf{e}_q^2 \qquad \textbf{(56)}$$

Applying a small perturbation, we may write

$$(\mathbf{E}_{t0} + \Delta\mathbf{E}_t)^2 = (\mathbf{e}_{d0} + \Delta\mathbf{e}_d)^2 + (\mathbf{e}_{q0} + \Delta\mathbf{e}_q)^2 \qquad \textbf{(57)}$$

By neglecting second order terms involving perturbed values , the above equation reduces to

$$\mathbf{E}_{t0}\Delta\mathbf{E}_t = \mathbf{e}_{d0}\Delta\mathbf{e}_d + \mathbf{e}_{q0}\Delta\mathbf{e}_q \qquad \textbf{(58)}$$

Therefore,

$$\Delta\mathbf{E}_t = \frac{\mathbf{e}_{d0}}{\mathbf{E}_{t0}}\Delta\mathbf{e}_d + \frac{\mathbf{e}_{q0}}{\mathbf{E}_{t0}}\Delta\mathbf{e}_q \qquad \textbf{(59)}$$

In terms of the perturbed values, Equations

$\mathbf{\Delta e_d = -R_a\Delta i_d + L_l\Delta i_q - \Delta\psi_{aq}}$

$\mathbf{\Delta e_q = -R_a\Delta i_q + L_l\Delta i_d - \Delta\psi_{ad}}$ **(60)**

Use of Equations to eliminate $\Delta i_d, \Delta i_q, \Delta\psi_{ad}$ and $\Delta\psi_{aq}$ from the above equations in terms of the state variables and substitution of the resulting expressions for Δe_d and Δe_q in equation yield

$\mathbf{\Delta E_t = K_5\Delta\delta + K_6\Delta\psi_{fd}}$ **(61)**

Where

$$K_5 = \frac{e_{d0}}{E_{t0}}\left[-R_a m_1 + L_1 n_1 + L_{aqs} n_1\right] + \frac{e_{q0}}{E_{t0}}\left[-R_a n_1 - L_1 m_1 - L'_{ads} m_1\right] \quad (62)$$

$$K_6 = \frac{e_{d0}}{E_{t0}}\left[-R_a m_2 + L_1 n_2 + L_{aqs} n_2\right] + \frac{e_{q0}}{E_{t0}}\left[-R_a n_2 - L_1 m_2 - L'_{ads}\left(\frac{1}{L_{fd}} - m_2\right)\right] \quad (63)$$

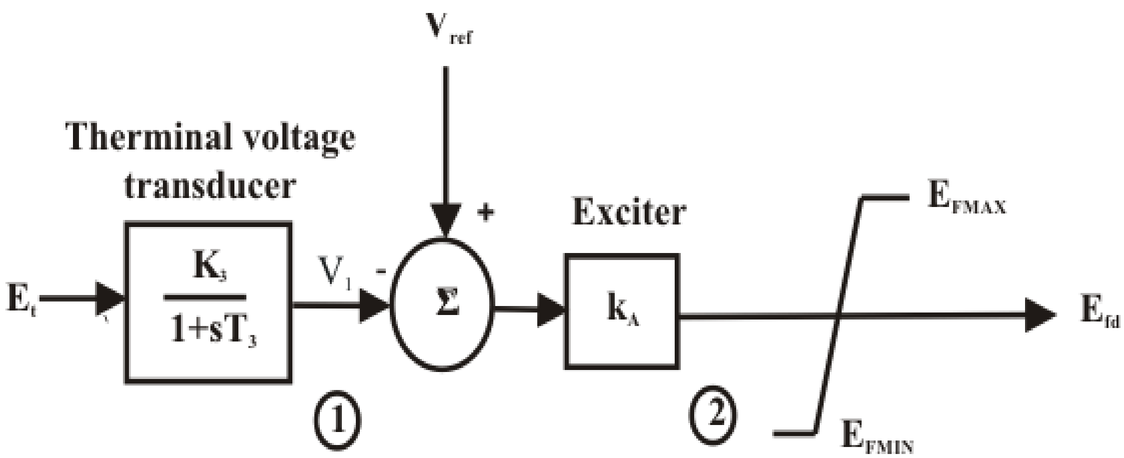


Fig.2 THYRISTOR EXCITATION SYSTEM WITH AVR

$\mathbf{a_{34} = -b_{32}K_A}$

$\mathbf{a_{41} = 0}$

$$a_{42} = \frac{K_5}{T_R}$$

$$a_{43} = \frac{K_6}{T_R}$$

$$a_{44} = -\frac{1}{T_R} \quad (64)$$

The complete state space model for the power system, including the excitation system is given by

$$\begin{bmatrix} \Delta\dot{\omega}_r \\ \Delta\dot{\delta} \\ \Delta\dot{\psi}_{fd} \\ \Delta\dot{v}_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\psi_{fd} \\ \Delta v_1 \end{bmatrix} + \begin{bmatrix} b_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \Delta T_m \qquad (65)$$

Block diagram including the excitation system:

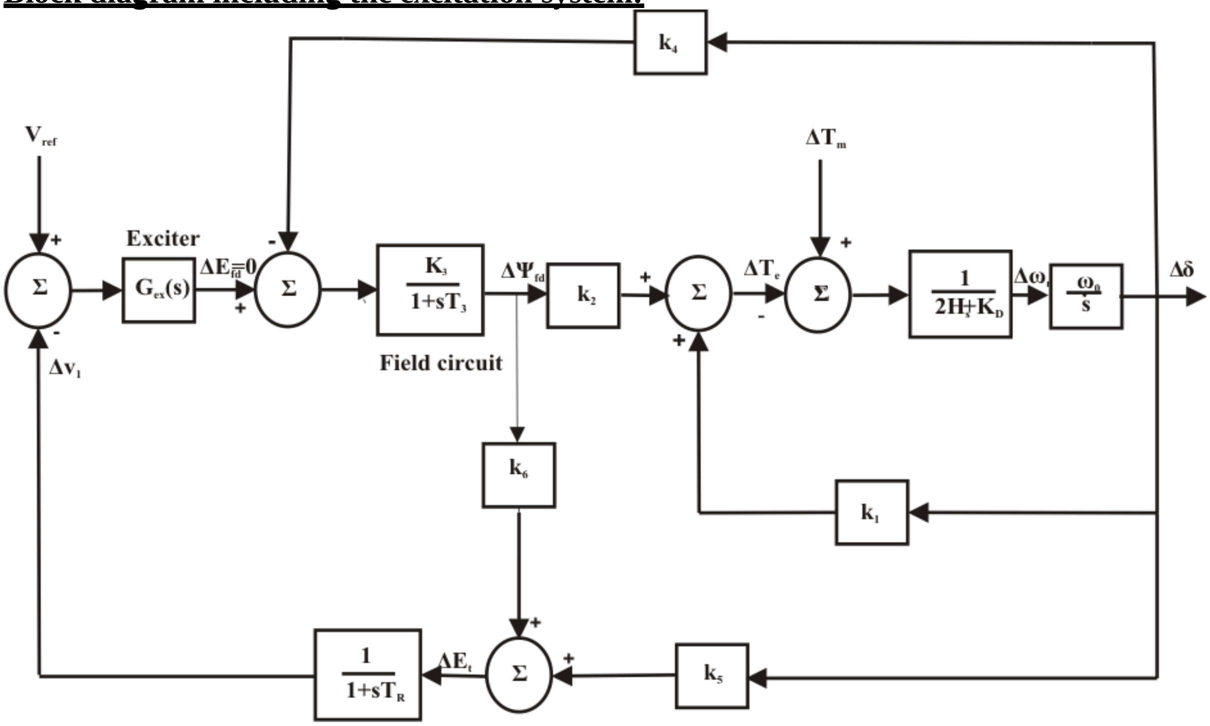


Fig 3- BLOCK DIAGRAM REPRESENTATION WITH EXCITER AND AVR

POWER SYTEM STABILIZER:

The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

The theoretical basis for a PSS may be illustrated with the aid of the block diagram shown below.

Since the purpose of a PSS is to introduce a damping torque component, a logical signal to use for controlling generator excitation is the speed deviation $\Delta\omega_r$.

If the exciters transfer function $G_{ex}(s)$ and the generator transfer function between ΔE_{fd} and ΔT_e were pure gains, a direct feedback of $\Delta\omega_r$ would result in a damping torque component. However, in practice both the generator and the exciter (depending on its type) exhibit frequency dependent gain and phase characteristics. Therefore, the PSS transfer function, GPSS(s), should have appropriate phase compensation circuits to compensate for the phase lag between the exciter input and the electrical torque. In the ideal case, with the phase characteristics of GPSS(S) being an exact inverse of the exciter and generator phase characteristics to be compensated, the PSS would result in a pure damping torque at all oscillating frequencies.

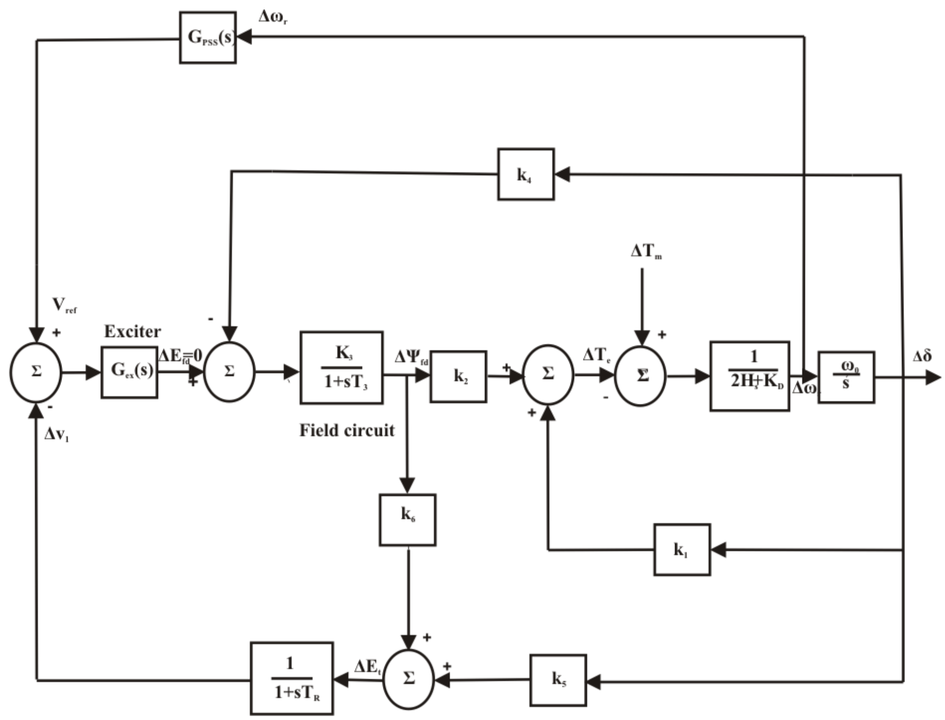


Fig 4- BLOCK DIAGRAM REPRESENTATION WITH AVR AND PSS.

The PSS representation in figure shown below consists of three blocks: a phase compensation block, a signal washout block, and a gain block.

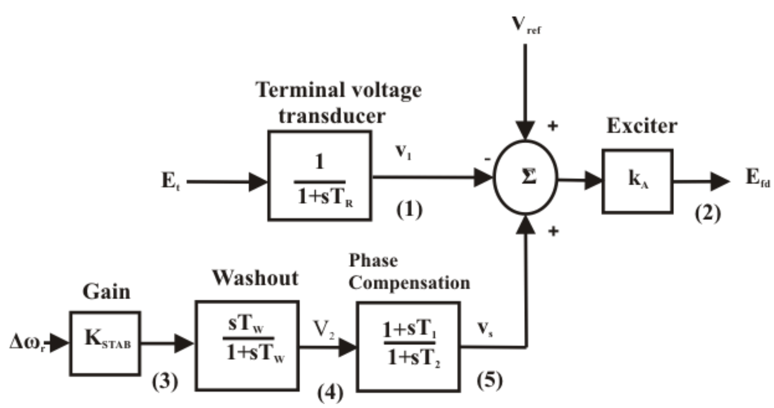


Fig 5- THYRISTOR EXCITATION SYSTEM WITH AVR AND PSS

System state matrix including PSS

$a_{51} = K_{STAB} a_{11}$
$a_{52} = K_{STAB} a_{12}$
$a_{53} = K_{STAB} a_{13}$

$$a_{55} = -\frac{1}{T_w}$$

$$a_{61} = \frac{T_1}{T_2} a_{51}$$

$$a_{62} = \frac{T_1}{T_2} a_{52}$$

$$a_{63} = \frac{T_1}{T_2} a_{53}$$

$$a_{65} = \frac{T_1}{T_2} a_{55} + \frac{T_1}{T_2}$$

$$a_{36} = \frac{\omega_0 R_{fd}}{L_{adu}} K_A \qquad \textbf{(66)}$$

The complete state space model, including the PSS, has the following form

$$\begin{bmatrix} \Delta \dot{\omega}_r \\ \Delta \dot{\delta} \\ \Delta \dot{\psi}_{fd} \\ \Delta \dot{v}_1 \\ \Delta \dot{v}_2 \\ \Delta \dot{v}_s \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & 0 \\ a_{21} & 0 & 0 & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} & 0 & a_{36} \\ 0 & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & 0 & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & 0 & a_{65} & a_{66} \end{bmatrix} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\psi_{fd} \\ \Delta v_1 \\ \Delta v_2 \\ \Delta v_s \end{bmatrix} \qquad \textbf{(67)}$$

RESULT:

A MATLAB program was written to analyze the small signal stability of single machine infinite bus system with field circuit, exciter and power system stabilizer.