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Transient Stability Analysis of Synchronous Generator in Power System

Comparison of Time Domain Method and Direct Method (For Multi Machine System)

Himadri S. Shukla[1], Vishal Thakkar[2], Dipkumar S. Trivedi[3], Parth R. Mishra[4], Arpit R. Joshi [5], Hardik S. Shukla[6]

[1]Student of Master Degree, Department of Electrical Engineering, Kalol Institute Technology, Kalol, Gujarat, India
[2]Assistant Professor, Department of Electrical Engineering, Kalol Institute Technology, Kalol, Gujarat, India
[3/4/5]Lecturer, Department of Electrical Engineering, K.D.Polytechnic, Patan, Gujarat, India
[6]Student, Department of Electrical Engineering, V.G.E.C, Chandhkheda, Gujarat, India

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Abstract - *Transient stability of synchronous generator can be analysed by different methods like time domain method, direct method and artificial intelligent method. This report shows the application of different methods in transient stability analysis of synchronous generator in power system. Problems and issues in application of direct method are listed. Advantages, disadvantages and comparison of different methods are listed in this report. Critical clearing time of Time domain method and Direct method is compared in this report.*

Key words - *Time domain method, direct method, Comparison of time domain and direct method*

1. INTRODUCTION

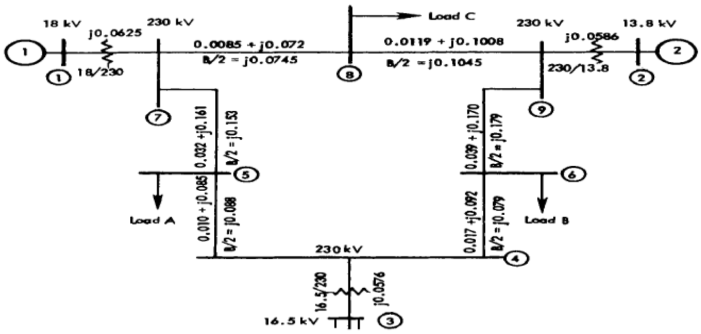
Power system stability can be defined as the ability of a power system to remain in a state of operating equilibrium during normal conditions, and to regain an accepted state of operating equilibrium after a disturbance. [1][2]

During normal operating conditions of the power systems (in steady state), two main conditions should be satisfied for generators: (1) Rotors should be in synchronism. (2) The generated voltages are sinusoidal waveforms with the same frequency. [4] These conditions are violated when any type of disturbances are developed on the power system. Due to these disturbances instability in power system is developed. These disturbances may be small or large. Power system must be able to withstand against these disturbances

The ability of a power system to recover and maintain synchronism is called rotor angle stability. [2] Small signal stability is the ability of the power system to maintain synchronism under small disturbances. [2] Transient stability is the ability of the power system to maintain synchronism under large disturbances. [2]

2. Multi Machine System

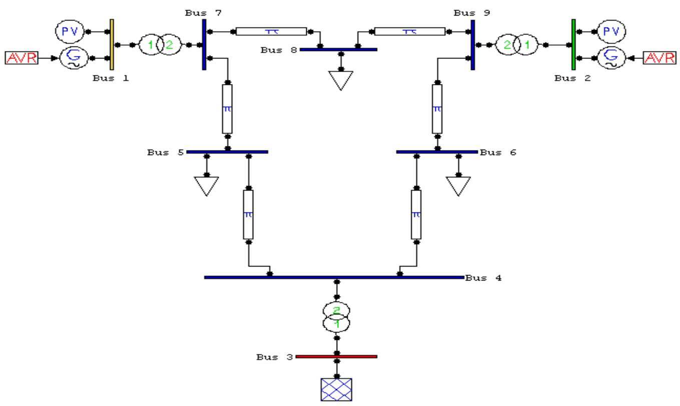
- In this System, 2 machines, 9 buses (one bus infinite bus) are considered. [3], [9]



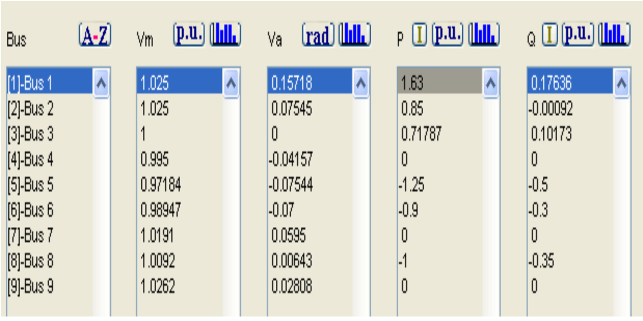
Generator	1	2
Rated MVA	192.0	128.0
kV	18.0	13.8
Power factor	0.85	0.85
Type	steam	steam
Speed	3600 r/min	3600 r/min
x_d	0.8958	1.3125
x'_d	0.1198	0.1813
x_q	0.8645	1.2578
x'_q	0.1969	0.25
x_ℓ (leakage)	0.0521	0.0742
τ'_{d0}	6.00	5.89
τ'_{q0}	0.535	0.600
Stored energy at rated speed	640 MW·s	301 MW·s

Load A: 1.25(0.5), Load B: 0.9(0.3), Load C: 1(0.35)

2.1 Initial system using PSAT TOOL BOX



2.2 Power flow



Bus	Vm (p.u.)	Va (rad)	P (p.u.)	Q (p.u.)
[1]-Bus 1	1.025	0.15718	1.63	0.17636
[2]-Bus 2	1.025	0.07545	0.85	-0.00092
[3]-Bus 3	1	0	0.71787	0.10173
[4]-Bus 4	0.995	-0.04157	0	0
[5]-Bus 5	0.97184	-0.07544	-1.25	-0.5
[6]-Bus 6	0.98947	-0.07	-0.9	-0.3
[7]-Bus 7	1.0191	0.0595	0	0
[8]-Bus 8	1.0092	0.00643	-1	-0.35
[9]-Bus 9	1.0262	0.02808	0	0

2.3 Classical Model

Classical model is also known as voltage behind reactance. Equation for classical generator model is given by

$$E = \frac{X_d^{'} \times (P - jQ)}{V'} + V$$

Program for Classical model Voltage
p1= 1.63
q1= 0.17636
v1= 1.025*[cos(0.15718)+sin(0.15718)*i]
xdd1=0.1198i

p2= 0.85
q2=-0.00092
v2=1.025*[cos(0.07545)+sin(0.07545)*i]
xdd2= 0.1813i

E1=v1+(xdd1)*(p1-q1*i)/(v1)'
magE1 = abs(E1)
angE1 = angle(E1)

E2=v2+(xdd2)*(p2-q2*i)/(v2)'
magE2=abs(E2)
angE2 = angle(E2)

Result for Classical model voltage
E1 = 1.0029 + 0.3518i
magE1 = 1.0628
angE1 = 0.3374
E2 = 1.0106 + 0.2272i
magE2 = 1.0358
angE2 = 0.2211

2.4 Kron Transformation [9]

Equation to remove kth node or raw and column.

$$y^{new}{}_{(i,j)} = y_{(i,j)} - y_{(i,j)} \times \frac{y_{(i,k)} \times y_{(k,j)}}{y_{(k,k)}}$$

2.5 Network Data of Reduced System

Type of Network	Node	1	2	3
Pre Fault	1	0.420 - j2.724	0.213 + jl.088	0.287 + j1.513
	2	0.213 + jl.088	0.277 - j2.368	0.2 10 + j1.226
	3	0.287 + j1.513	0.2 10 + j1.226	0.846 - j2.988
Fault	1	0.000 - j5.486	0.000 + j0.000	0.000 + j0.000
	2	0.000 + j0.000	0.174 - j2.796	0.070 + j0.631
	3	0.000 + j0.000	0.070 + j0.631	0.657 - j3.816
Post fault	1	0.389 - j1.953	0.199 + j1.229	0.138 + j0.726
	2	0.199 + j1.229	0.273 - j2.342	0.191 + j1.079
	3	0.138 + j0.726	0.191 + j1.079	1.181 - j2.229

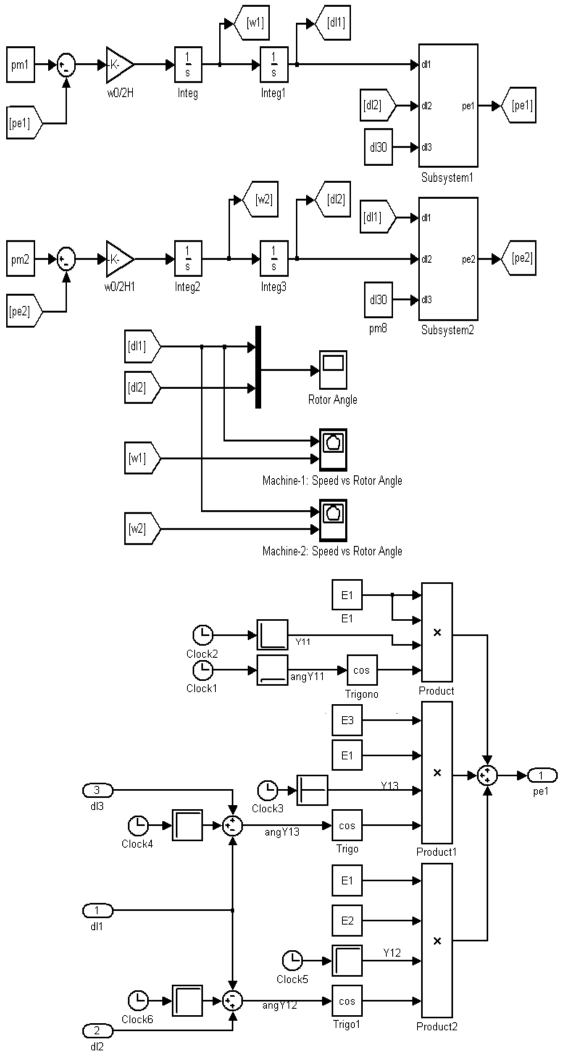
2.6 Mathematical model

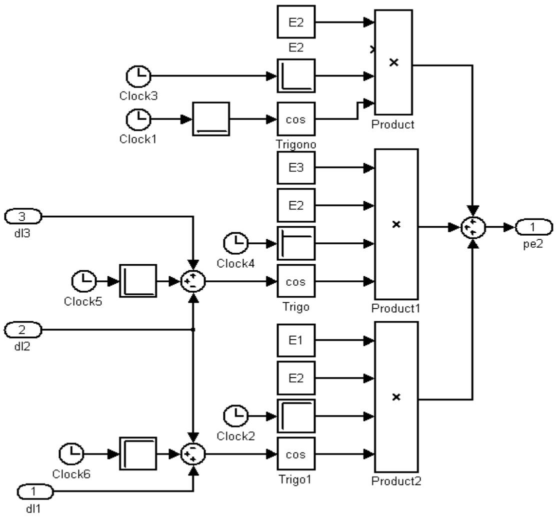
$$\frac{2H}{\omega_0}\frac{d\omega_i}{dt} = p_{mi} - p_{ei}$$

$$p_{ei} = E_i^2.G_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^{n} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j)$$

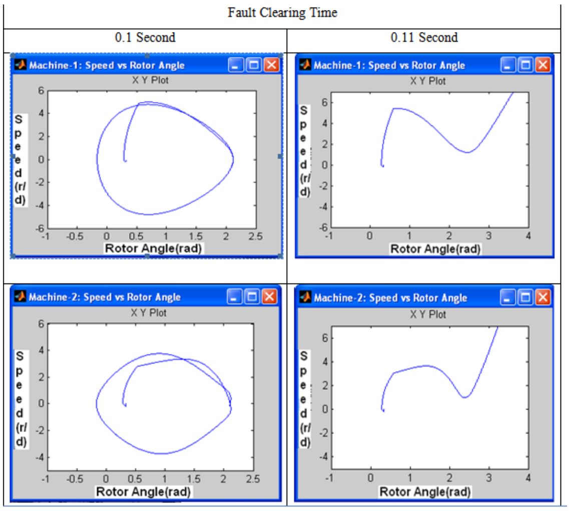
$$\frac{d\delta_i}{dt} = \omega_i$$

2.7 MATLAB Model:





2.8 Result



3. Direct Method

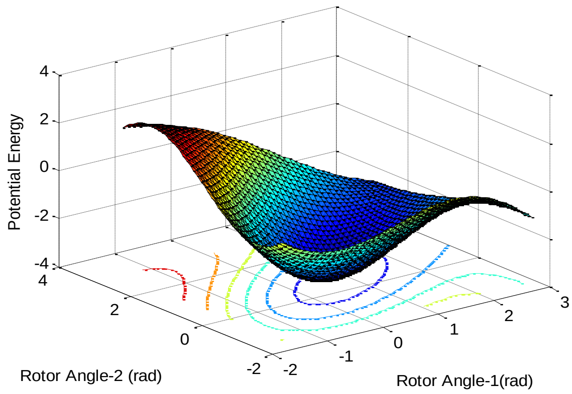
3.1 Program in Direct Method

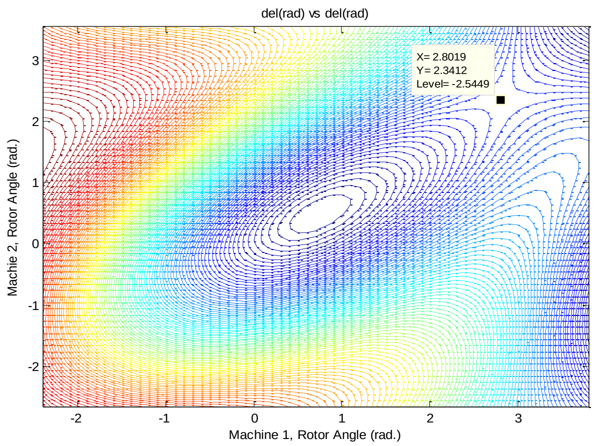
```
%Potential Energy For Post Fault System
clc; clear all;
H1 = 6.4 ;
H2 = 3.01 ;
f = 60 ;
w0 = 2*pi*f ;
M1 = 2*H1/w0
M2 = 2*H2/w0
pm1= 1.63 ;
pm2= 0.85 ;
pm3= 0.7162 ;
%Post fault stable point
dl1s = 0.7435;
dl2s = 0.4828 ;
dl3s = 0 ;
dl3=0 ;
E1 = 1.0628 ;
E2 = 1.0358 ;
E3 = 1 ;
%Post fault
B12= 1.229;
B13= 0.726;
B23= 1.079;
G12= 0.199;
G13= 0.138;
G23= 0.191;
G11= 0.389;
G22= 0.273;
pa1 = E1*E1*G11 + E1*E2*G12*cos(dl1s-dl2s) + E1*E3*G13*cos(dl1s-dl3s);
pa2 = E2*E2*G22 + E1*E2*G12*cos(dl2s-dl1s) + E2*E3*G23*cos(dl2s-dl3s);
dl1 = -1.5:0.1:3 ;
dl2 = -1.5:0.1:3 ;
[dl1,dl2]=meshgrid(dl1,dl2);
Epot = -[(pm1-pa1)*(dl1) + (pm2-pa2)*(dl2)] - E1*E2*B12*cos((dl1)-(dl2)) -
E1*E3*B13*cos(dl1-dl3) - E2*E3*B23*cos(dl2-dl3)
surfc(dl1,dl2,Epot);
contour(dl1,dl2,Epot,100);
```

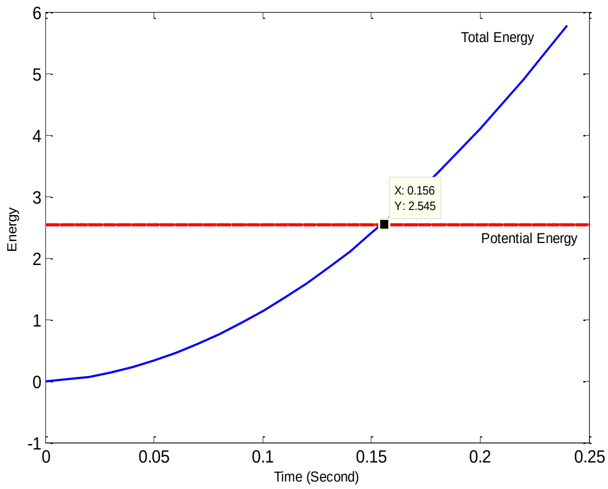
```
%Total Energy in Faulted System
clc; clear all;
% Data given
H1 = 6.4 ;
H2 = 3.01 ;
H3 = 23.64 ;
f = 60 ;
w0 = 2*pi*f ;
M1 = 2*H1/w0
M2 = 2*H2/w0
pm1= 1.63 ;
pm2= 0.85 ;
pm3= 0.7162 ;
% Pre fault stable point
dl1s = 0.3116;
dl2s = 0.1949;
dl3s = 0;
dl3=0 ;
E1 = 1.0628 ;
E2 = 1.0358 ;
E3 = 1 ;
%Fault on
B12= 0;
B13= 0;
```

```
B23= 0.631;
G12= 0;
G13= 0;
G23= 0.07;
G11= 0;
G22= 0.174;
pa1 = E1*E1*G11 + E1*E2*G12*cos(dl1s-dl2s) + E1*E3*G13*cos(dl1s-dl3s)
pa2 = E2*E2*G22 + E1*E2*G12*cos(dl2s-dl1s) + E2*E3*G23*cos(dl2s-dl3s)
t=0;
dt=0.01;
dl1=0.3116;
dl2=0.1949;
dl3=0;
w1=0 ;
w2=0 ;
for i=1:25
k11 = (1/M1)*(pm1-G11*E1^2-E1*E2*G12*cos(dl1-dl2) - E1*E3*G13*cos(dl1-dl3) -E1*E3*B13*sin(dl1) - E1*E2*B12*sin(dl1-dl2))*dt;
k21 = [w1]*dt;
r11 = (1/M2)*(pm2-G22*E2^2-E1*E2*G12*cos(dl2-dl1) - E2*E3*G23*cos(dl2-dl3) -E2*E3*B23*sin(dl2) - E1*E2*B12*sin(dl2-dl1))*dt;
r21 = (w2)*dt;
k12 = (1/M1)*(pm1-G11*E1^2-E1*E2*G12*cos(dl1+k21-dl2-r21) - E1*E3*G13*cos(dl1+k21-dl3) -E1*E3*B13*sin(dl1+k21) - E1*E2*B12*sin(dl1+k21-dl2-r21))*dt;
k22 = (w1 + k11)*dt ;
r12 = (1/M2)*(pm2-G22*E2^2-E1*E2*G12*cos(dl2+r21-dl1-k21) - E2*E3*G23*cos(dl2+r21-dl3) -E2*E3*B23*sin(dl2+r21) - E1*E2*B12*sin(dl2+r21-dl1-k21))*dt;
r22 = (w2 + r11)*dt;
w1 = w1 + (k11 + k12)/2;
dl1 = dl1 + (k21 + k22)/2;
w2 = w2 + (r11 + r12)/2;
dl2 = dl2 + (r21 + r22)/2;
v = (1/2)*M1*w1^2 + (1/2)*M2*w2^2 +([(pm1-pa1)*(dl1) + (pm2-pa2)*(dl2)] - E1*E2*B12*cos((dl1)-(dl2)) - E1*E3*B13*cos(dl1-dl3) - E2*E3*B23*cos(dl2-dl3));
Epot= [(pm1-pa1)*(dl1) + (pm2-pa2)*(dl2)] - E1*E2*B12*cos((dl1)-(dl2)) - E1*E3*B13*cos(dl1-dl3) - E2*E3*B23*cos(dl2-dl3);
T(i,:) = t;
t = t + dt;
D1(i,:) = dl1;
Dw1(i,:) = w1;
D2(i,:) = dl2;
Dw2(i,:) = w2;
V(i,:) = v;
E(i,:) = Epot;
end
Ec=2.5449
plot(T,V)
hold on
n=0:0.001:0.25
plot(n,Ec,'r')
```

3.2 Result







3.3 Comparison of Direct Method and Time Domain Method (For Multi Machine System)

Sr. No.	Method	CCT
1	Time Domain	0.1sec
2	Direct Method	0.15sec

4. Conclusion

We can conclude for time domain method critical clearing time in between 0.1 to 0.11 second using Model 2.1 in MATLAB Modelling and solving problem using Direct method critical clearing time is 0.15 seconds. Transient stability of synchronous generator in power system can be analyzed by different methods like Time Domain methods and Direct Methods. Each method has its own advantages. Time domain method is time consuming method. That is why now a days, Energy based direct method is used for stability analysis.

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