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Transient Stability Analysis of Power System Using Matlab

P R Sharma[*1], Narender Hooda[2]
[*1]YMCA University of Science and Technology Faridabad, India
[2]DCR University of Science & Technology, Murthal
prsharma1966@gmail.com

Abstract

This paper presents transient stability assessment of multi-machine system with the help of Simulink based model. Transient stability of a power system is based on the generator relative rotor angles obtained from time domain simulations outputs. A self sufficient model of IEEE nine bus system has been given with full detail and transient stability analysis is done by considering three phase fault at a bus with different Fault Clearing Time (FCT) and the results are found to be more accurate and quiet satisfactory as compared to models simulated in PSPICE and other electromagnetic transient program.

Keywords: MATLAB, Simulink, FCT, transient stability.

Introduction

Modern electric power systems have grown to a large complexity due to interconnections, installation of large generating units and extra high voltage tie-lines etc. Due to increased operations which may cause power system to be highly stressed condition, the need for dynamic stability of power system is arising. Transient stability assessment (TSA) is part of dynamic security assessment of power system which evolves the evolution of the ability of power system to remain in equilibrium when subjected to disturbances. The system response to such disturbances involves large variation of rotor angles, power flows bus voltages and other system variables. Transient stability is a condition that characterizes the dynamics of power system subjected to a fault, the initial state proceeding the fault is balanced one. A system is said to posses transient stability if after the fault it is capable of maintaining synchronous operation and returning to initial state or close to it. The transient stability is a function of both operating condition and the disturbance. This makes the transient stability analysis complicated as the non linear ties of the system cannot be ignored.

In stability assessment the critical clearing time (CCT) is a very important parameter in order maintain the stability of power system. The CCT is maximum time duration that a fault may occur in power system without loss of stability. Fault clearing time is set randomly. If the fault clearing time (FCT) is more than CCT then the relative rotor angles will

go out of step and the system will lose stability. Methods normally employed to find out the TSA are by using time domain simulations, direct and artificial intelligence methods. Time domain simulation method is implemented by solving the state space differential methods. Simulink is an interactive environment for modeling and simulating a wide variety of dynamic systems. A system is built easily using blocks and results can be displayed quickly. Simulink is used for studying the effects of non-linearity of the system and thus is an ideal research tool. Use of Simulink is growing rapidly for research work in the area of power system and also in the other areas. In this paper multi machine nine bus system is modeled in Matlab/simulink and transient stability analysis is done with the fault located in a bus.

System Modeling

The system used is IEEE 9 bus system with three generators, six transmission lines, three load buses and three transformers is shown in Fig 1. The base MVA is 100 and the system frequency is 60 Hz. The system data is given in Appendix 1.The fault is occurring near bus 7 and fault is cleared by opening line 5-7.Fault clearing time is set randomly. The complete system is modeled in Simulink with the mathematical equations. All the buses except the machine buses are eliminated and multi-port representations of the internal nodes of the generators are obtained. Using the self and transfer admittance

parameters of reduced electrical network electric power output of the generators can be obtained. The program to obtain the reduced admittance matrix is given in Appendix.

The admittance matrix $Y_{bus,mod}$ is augmented by including the transient reactance of the generators. Let $Y_{bus,mod}$ after inclusion of load impedances be partitioned as

$$Y_{bus,mod} = \begin{pmatrix} Y_1 & Y_2 \\ Y_3 & Y_4 \end{pmatrix} \qquad (1)$$

Where sub matrix Y_1 is of order m×m and corresponds to the buses where generators are connected and Y_2, Y_3 and Y_4 are the other sub matrices.

Then the augmented bus admittance matrix $Y_{bus,aug}$ with ground as reference would be represented as

$$Y_{bus,aug} = \begin{pmatrix} y & -y & 0 \\ -y & Y_1 + y & Y_2 \\ 0 & Y_3 & Y_4 \end{pmatrix} \qquad (2)$$

The matrix is reduced by applying Kron's reduction formula eliminating all buses expect the generator buses. For symmetrical three phase to ground at bus k the row and column corresponding to bus k are set to zero before applying network reduction. In stability analysis three reduced matrices are required to be computed pre-fault, during fault and the post fault in power system.
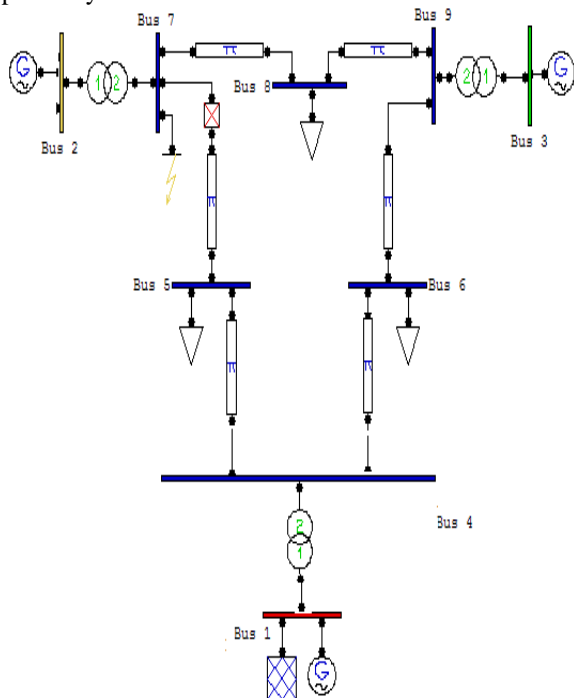

Fig. 1 WSCC 3-machine 9 bus system

The generator electric power output for each machine is computed by following equation

$$P_{ei} = E_{i2}G_{ii} + \sum_{j=1}^{n} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j)$$

(3)
Where

$$Y_{ij} = Y_{ij} \angle \theta_{ij} = G_{ij} + jB_{ij}$$

$$Y_{ii} = Y_{ii} \angle \theta_i = G_{ii} + jB_{ii}$$

The equation of the motion are given by

$$\frac{2H_i d\omega_i}{\omega_R dt} + D_i \omega_i = P_{mi} - \left[E_i^2 G_{ii} + \sum_{j=1}^{n} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \right]$$

(5)
And

$$\frac{d\delta_i}{dt} = \omega_i - \omega_R \qquad (6)$$

It is noted that prior to the fault (t=0) $P_{mi0} = P_{ei0}$
The subscript 0 is used to indicate the pre transient conditions.
As the network changes due to fault, the corresponding values will be changed in the above equation.

Simulink Models

The complete three generator system shown in Fig.1 has been simulated as single integral model in Simulink. Fig 2 shows the complete block diagram of the system for transient stability study. Subsystems 1 is meant to compute the electric power output of each generator. The model also facilitates the choice of simulation parameters like start time, stop time, solver etc.
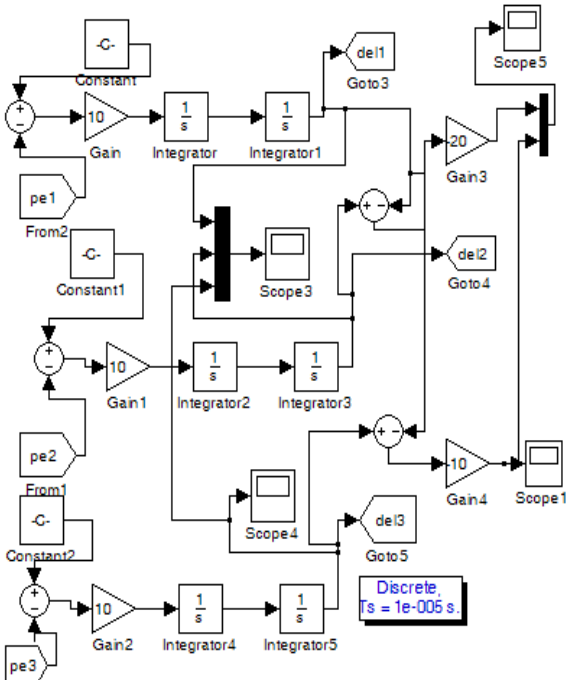
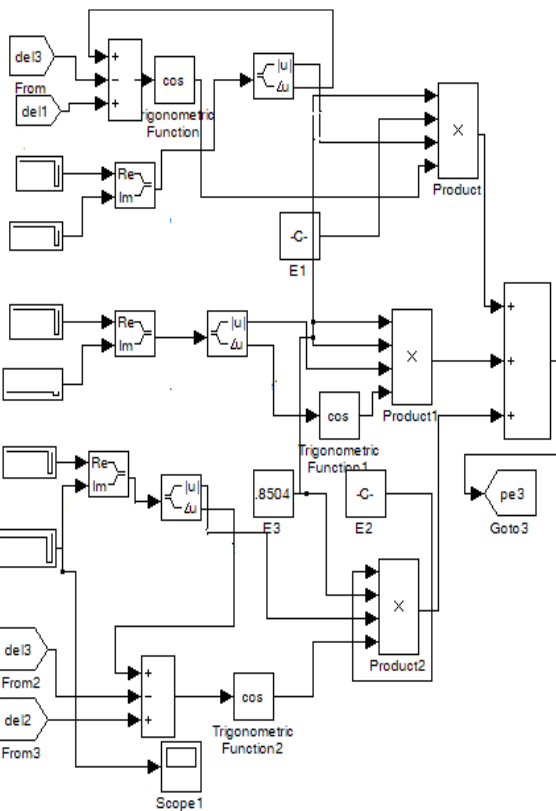**Fig.2 Complete system Model for Transient stability Analysis**

Fig.3 Simulink model for Computation of electric power output of generator 1

Simulation Results

System Responses are given for different values of FCT. Fault is created near bus 7 and it is cleared at different clearing time by opening line 5-7. Fig 4 (a) and (b) shows the relative angular positions of the generators taking generator one as reference and individuals angles of each generator. Fig(c) and (d) shows the accerlating powers and angular velocities of each generator for the FCT equal to 0.1sec Fig shows that the rotors angles are in synchronism with each other making the system stable when the fault clearing time is 0.1sec.As the FCT increases the system will move towards instability as the FCT will become greater that the CCT. When the FCT in 0.3 sec. the system is unstable.
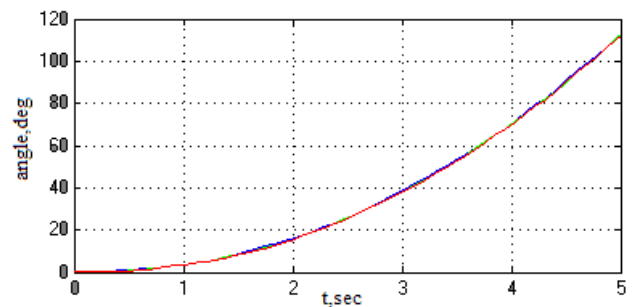
Fig 5(a)-(d) shows the accerlating powers, Relative angular positions and angular velocities of the generators and Fig 5(b) shows as the fault clearing time is increased the rotor angles of the generators go out of synchronism and the system is losing stability.
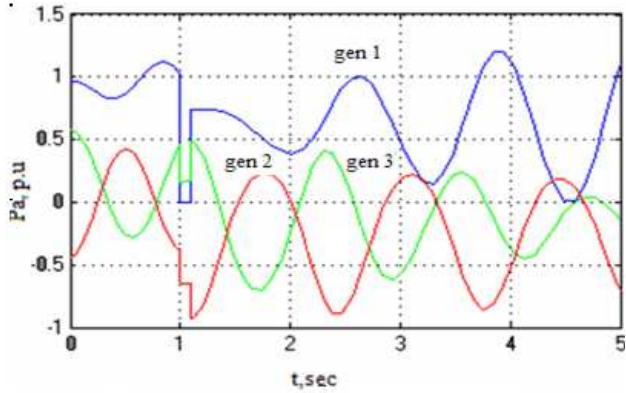
(Fault cleared at 0.1s)
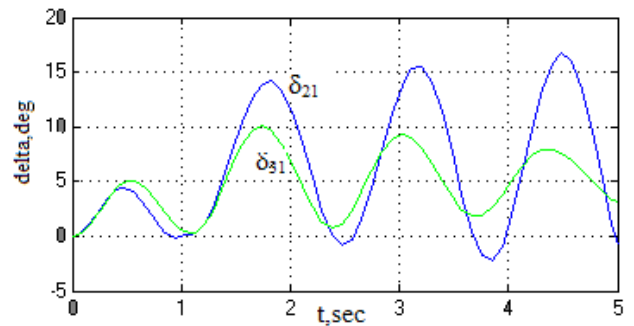
(a) Relative angular positions of angles
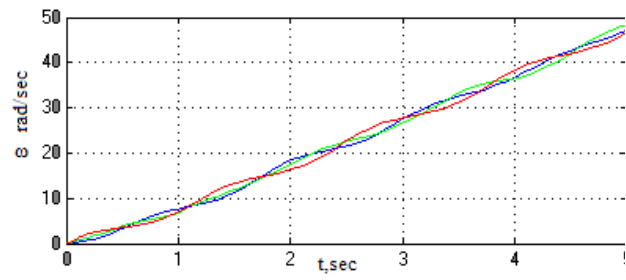
(Fault cleared at 0.1s)

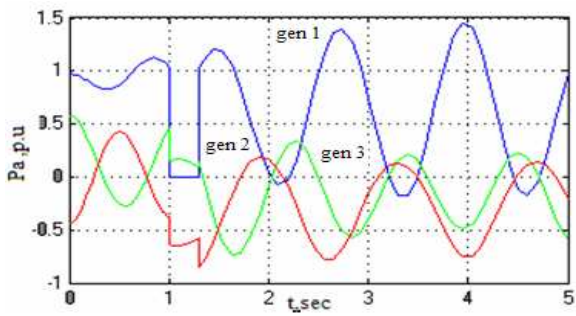**(b) Angular positions of individual generators**

(Fault cleared at 0.1s)
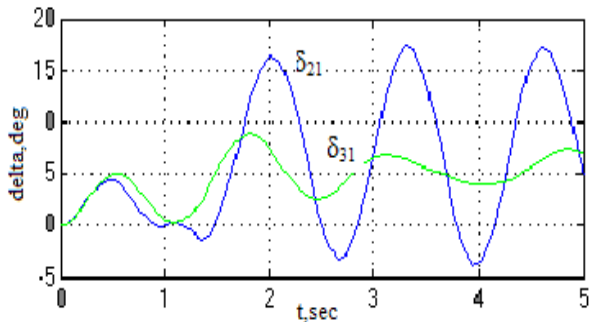
(c) Generator accelerating Powers
(Fault cleared at 0.1s)

(d) Angular velocities of generators
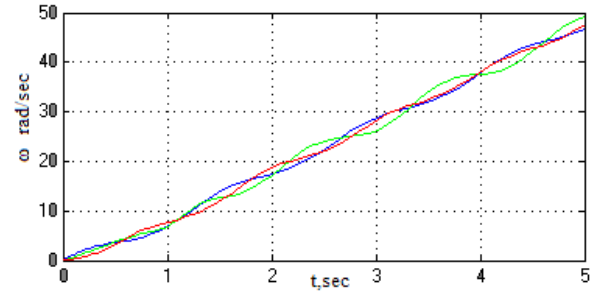**Fig 4 (a) – (d)**

(Fault cleared at 0.3sec)

(a)   Accerlating power of generators
(Fault cleared at 0.3sec)

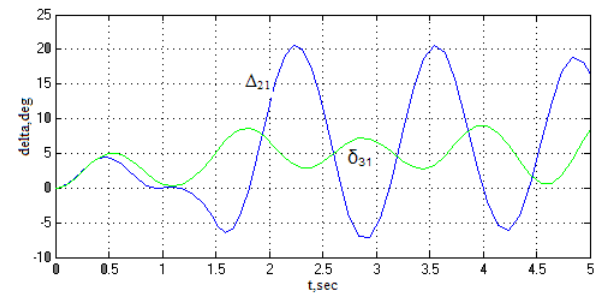**(b)   Relative angular positions of generators**

(Fault cleared at 0.3 sec)

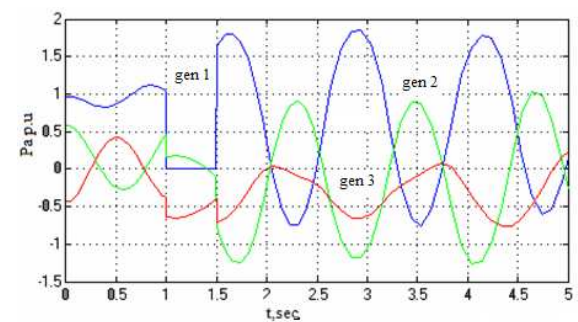**(c) Angular velocities of individual generators**
Fig 5(a)-(c)

Fig 6(a)-(b) shows the relative rotor angles and the accelerating powers of the generators. Fig 6(a) shows that the rotor angles synchronism making the system unstable.

(Fault cleared at 0.5sec)

(a) Relative angles in degree
(Fault cleared at 0.5sec)

(c)   Accerlating powers of the generators
Fig.6 (a) - (b)

Conclusion
A complete model to study the transient behavior of Multi-machine system was developed using Simulink. It is basically a transfer function and block diagram representation of system equations. The system was simulated for different FCT and the results are highly satisfactory. A Simulink model is very user friendly and for transient stability analysis the model facilitates the fast and precise solution of nonlinear differential equation.

Appendix

```
n=9;
Y=zeros(n);
n=n-1;
i=1;
k=1;
for ii=1:locs;
   add=loc(ii+1)-loc(ii);
   for kk=1:add;
     J=c(k);
     Y(i,i)=Y(i,i)+1/e(k);
     if J==0;
        disp('branch')
        k=k+1;
     else
        Y(J,J)=Y(J,J) +1/e(k);
        Y(i,J)=Y(i,J) -1/e(k);
        Y(J,i)=Y(i,J);
        k=k+1;
     end
   end
   i=i+1;
end
Y
```

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