Transient Stability Analysis of Synchronous Generator In Multi Machine System Using Time Domain Method, Direct Method and AI Method

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Abstract – *This paper presents transient stability analysis of synchronous generator in multi machine system using time domain method, direct method and artificial intelligence method in MATLAB. A Multi Machine, two generator and nine bus system is used for this analysis. A three line to ground fault is considered for this analysis. Transient stability of multi machine system is analyzed by Critical Clearing Time (CCT) then CCTs of the system are compared for different methods in this paper.*

Key words: Transient stability analysis, Critical Clearing Time, Synchronous Generator, Multi machine system, Direct method, AI method

1. INTRODUCTION

Electricity has important role in the human life. That is why power system should be reliable and stable. Stability of the power system affects directly to the human life, industries production and economy of the country. That is why stability of power system becomes very important. Power system stability can be defined as the ability of a power system to remain in synchronism before, during and after the fault on the system [1][2]. In transient stability point of view, during normal operating conditions of the power systems, synchronism of the system should be maintained and frequency of the all system buses should be same [4]. During steady state condition, input mechanical power and electrical power of each generator should be in balance. But due to occurrence of fault on the system, this power balance is disturbed and system start to accelerate or decelerate. This unbalance of mechanical and electrical power provides the concept of swing equation. If disturbance is small then analysis is known as small signal analysis and if disturbance is large then analysis is known as transient analysis. Power system must have ability to recover and maintain stability after disturbance. 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]

In literature, for transient stability analysis, mainly four methods are given. These methods are:

(i) Time domain method,
(ii) Direct method,
(iii) Approximation method and
(iv) Artificial intelligence method.

Time domain method is a traditional method of transient stability analysis based on time domain numerical integration [3]. Important conclusions and decisions depend on the stability analysis results, So that the stability analysis results should be accurate and within time limit as possible [7]. The stability of the post fault system is analysed based on simulated post fault trajectories. The typical simulation period for the post fault system is about 10 to 15 second.

System simulation takes approx. 10 to 20 second [7]. In time domain method, detail modelling is required of the whole components of the power system for more accuracy. Advantages of time domain method are: this is an accurate method. It can be used directly for any level of modelling. For transient and steady state, all type of information can be determined using this method. This method can provide dynamic parameters of the system using swing curves like rotor angles (δ), speeds (N); accelerations; powers etc[3][7]. Disadvantages of time domain method are: It is a time consuming method (10 to 20 second) No measure of degree of stability and degree of instability are provided by time domain method. No information for preventive control is given. Its cost is higher than direct method [3][7].

Main disadvantage of time domain method is more time consumption in transient stability analysis. To overcome this problem, direct method had come into picture. Direct method is energy based method. This is the extensions of equal area criterion for multi machine system which is shown by the classical model. Advantages of Direct methods are: direct methods without the solution of differential equations can be used to determine the transient stability analysis of power system. It is a faster method than time domain methods. It gives the measurement of the degree of the stability of system. It provides important information related to derivation of preventive control and enhancement action of control. Challenges of direct method are modeling and reliability. Limitation of direct method is accuracy of the analysis [3][7]

Approximation method is the fast method and AI method is fastest method than other methods. Critical clearing time will be compared for all four methods.

2. SYSTEM MODEL

This section presents the system which is considered for transient stability analysis. Two generators, nine bus system is considered here, in which one bus is considered as an infinite bus. Three lines to ground fault is considered near 7 buses on 5-7 line, then after clearing the fault, 5-7 line is removed. All data for generators, lines and power flow are given in [3]. Y bus matrix of initial network for given system is of 9×9 matrix. Two generators connected in network and one infinite bus are the main nodes of system that is why system is converted into 3×3 Y bus matrix using Kron's transformation.

After conversion the system into three node system, generators are considered as classical model.

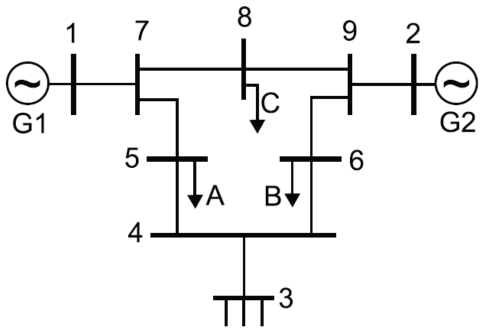

Fig. 1: System considered for analysis [8][3]

3. TIME DOMAIN METHOD

A. Classical Model:

Equation for classical generator model is given by

$$E = \frac{X_d' \times (P - jQ)}{V'} + V \quad (1)$$

Kron's transformation to reduce kth bus is give by,

$$y^{new}_{(i,j)} = y_{(i,j)} - y_{(i,j)} \times \frac{y_{(i,k)} \times y_{(k,j)}}{y_{(k,k)}} \quad (2)$$

After Kron transformation, reduced data for pre fault, fault on and post fault are given in next to next section.

B. Mathematical System Model:

$$\frac{2H}{\omega_0}\frac{d\omega_i}{dt} = p_{mi} - p_{ei} \quad (3)$$

$$p_{ei} = E_i^2.G_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \quad (4)$$

$$\frac{d\delta_i}{dt} = \omega_i \quad (5)$$

C. MATLAB Model

Using above mathematical equations (3 – 5), MATLAB model can be prepared for given system which can be used in time domain for transient stability analysis.[5]

In given system two generators are there that is why two different swing equations are used for each generator which is shown by equation (3). Equation (4) shows the power flow in system lines. Relation between generator rotor speed and rotor angle is shown by equation (5).

In above system MATLAB model, two sub systems are used. These sub systems provide electrical power generated by each generator as per load and circuit condition. During fault and after fault clearing electrical network is changed and its data is given in [3], According to these variable networks due to fault, subsystems in MATLAB are modeled which are shown in next figures.

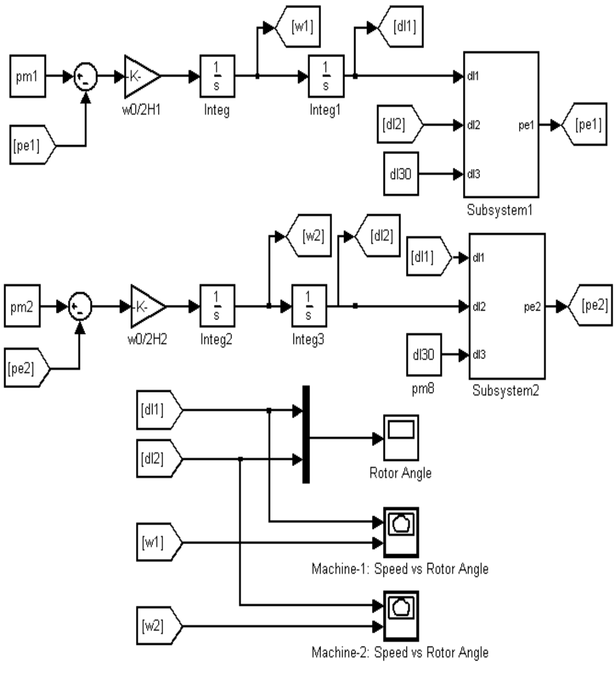

Fig. 2: MATLAB model of considered system.

SIMULATION RESULTS:

Classical (0.0) model of synchronous generator is used for Transient stability analysis. Critical Clearing Time (CCT) can be determined using system simulation.

In below table system network data is given for three different conditions (i) Pre fault Y bus data, (ii) Fault on Y bus system, and (iii) Post fault Y bus system data. Pre fault, fault on, and post fault are considered as steady state condition, during fault condition and after fault clearing condition respectively.

These Y bus matrix for pre fault, fault on and post fault condition can be obtain using Kron;s transformation from considered system.

Using Equation (2), MATLAB programming can be prepared to determine below Y bus.

INPUT DATA [3]

Table 1: Y Bus System Results Of System Simulation

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

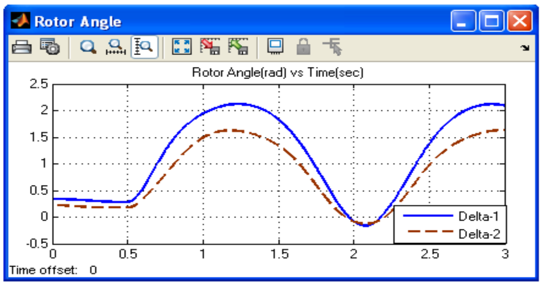

Fig. 3: Simulation results where Fault Clearing Time is 0.1 second

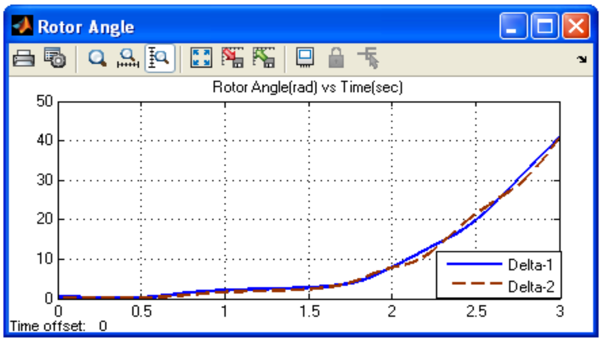

Fig. 4: Simulation results where Fault Clearing Time is 0.11 second

4. DIRECT METHOD

Steps for transient stability analysis using direct method:

1. Using post fault system, critical energy (E_c) is determined. Critical Energy formula is given by,

$$E_c = \sum_{i=1}^{n} \frac{1}{2} M_i.\omega_i^2 - \sum_{i=1}^{n} (P_{mi} - P_{ai}).\delta_i - \sum_{\substack{i=1 \\ k>i}}^{n} \bar{P}_{ik}.\cos(\delta_i - \delta_k)$$

2. Critical energy is determined with respect to stable equilibrium point (SEP) of post fault system, that is why first stable equilibrium point of post fault system is determined. Formula of critical energy with respect to SEP is given by,

$$E_c = \sum_{i=1}^{n} \frac{1}{2} M_i.\omega_i^2 - \sum_{i=1}^{n} (P_{mi} - P_{ai}).(\delta_i - \delta_{is})$$
$$- \sum_{\substack{i=1 \\ k>i}}^{n} \bar{P}_{ik}.[\cos(\delta_i - \delta_k) - \cos(\delta_{is} - \delta_{ks})]$$

3. Critical energy is the total energy at Unstable Equilibrium Point (UEP). Speed of synchronous generator rotor at unstable equilibrium point is zero means kinetic energy of the system is zero at UEP. Critical energy at UEP is given by

$$E_c = -\sum_{i=1}^{n} (P_{mi} - P_{ai}).(\delta_i - \delta_{is})$$
$$- \sum_{\substack{i=1 \\ k>i}}^{n} \bar{P}_{ik}.[\cos(\delta_i - \delta_k) - \cos(\delta_{is} - \delta_{ks})]$$

4. Using Fault on system, Total energy (Es) just after the fault clearing time is determined.

$$E_s = KE + PE$$

5. Total energy (E_s) and Critical energy (E_c) is compared,

If, $E_s > E_c$ => System is unstable

$E_s < E_c$ => System is stable

4.1 Direct Method Result

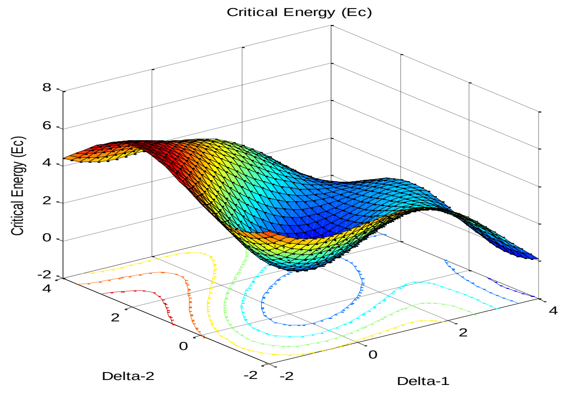

Figure-5: Critical Energy (Ec)

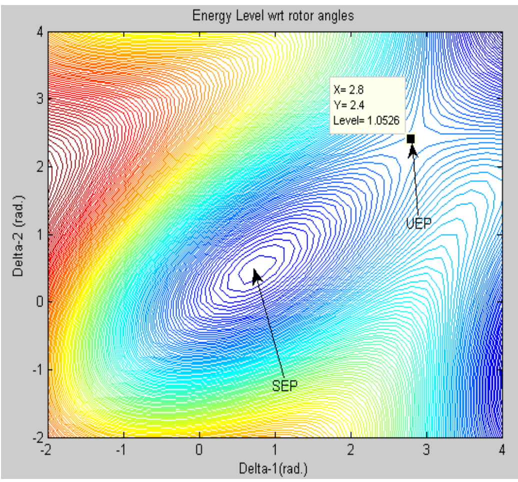

Figure-6: Energy Level

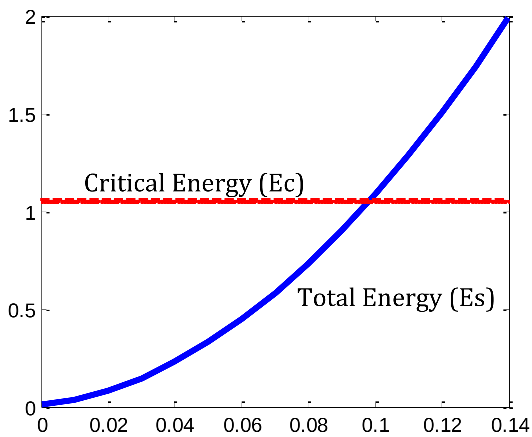

Figure-7: Total energy and critical energy

5. ARTIFICIAL INTELLGENCE- NEURAL NETWORK (ANN) METHOD

Artificial Neural Network (ANN) is a data-driven approach that can be used for transient stability assessment and Critical Clearing Time (CCT) prediction. Unlike conventional methods, ANN does not require repeated numerical integration of swing equations after training. The ANN learns the relationship between system operating conditions and stability status from previously generated simulation data.

In the present work, a Feed-Forward Neural Network (FFNN) is employed to estimate the transient stability of the considered two-machine nine-bus system. Training data are generated using the Time-Domain Simulation Method. Different fault clearing times are applied to the system, and the corresponding stability status is recorded. The fault clearing time is varied from 0.01 s to 0.25 s with a step size of 0.01 s.

MATLAB ANN Model

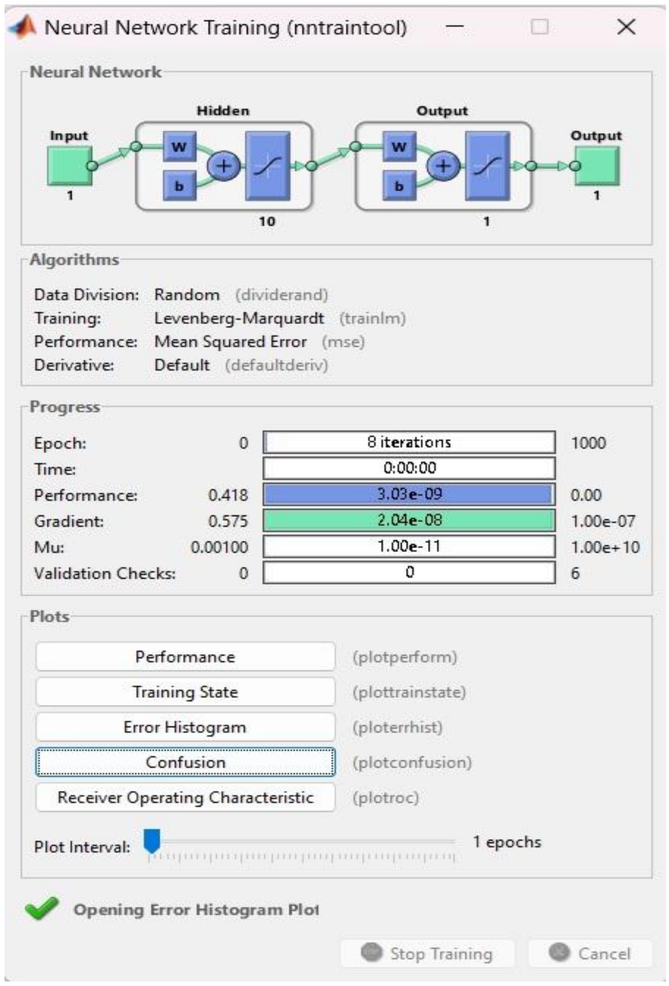

Figure-8: MATLAB ANN Model

6. Comparison of methods

Sr. No.	Method	CCT(S)
1	Time Domain Method	0.10
2	Direct Method	0.99
3	Artificial Intelligence ANN Method	0.103

7. CONCLUSION

Transient stability analysis of multi machine system using time domain method is more accurate and slower than direct method. Artificial Intelligence method result shows near to time domain method which is more accurate. This comparison becomes possible using Critical Clearing Time (CCT) for the system.

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