Simulation based on Transient Stability Analysis of Synchronous Generator In Power System Using Direct Method

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ABSTRACT

Transient stability of synchronous generator can be analysed by different methods like time domain method, direct method, approximation method and artificial intelligent method. Transient stability analysis of multi machine system is analysed using time domain method, direct method and approximation method.

Time domain method, direct method and approximation method are compared in this report using Critical Clearing Time (CCT). Time domain method is most accurate method and slowest method. Direct method is less accurate than time domain method but more accurate than approximation method. Approximation method is least accurate but fastest method than other methods. In approximation method, mathematical formulation is done in this report which can be used in parametric analysis. The simulation is performed using MATLAB/ Simulink software.

Keywords: Transient stability, time domain method, MATLAB/ Simulink software.

I.INTRODUCTION

I.I Introduction of Transient Stability

Electricity is the backbone of human life that is why power system should be reliable, stable and qualitative.Power system stability can be defined as the ability of a power system to remain in a synchronism in a normal operating condition and after the occurrence of disturbance in the system [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) Frequency of all generated voltages should be equal [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 remain in synchronism is called rotor angle stability [2]. The ability of the power system to maintain synchronism due to small disturbances is known as small signal stability [2]. The ability of the power system to maintain synchronism due to large disturbances is known as transient stability [2]. Transient stability analysis of synchronous generator can be done using different methods. Power system stability can be classified as shown in figure 1.1

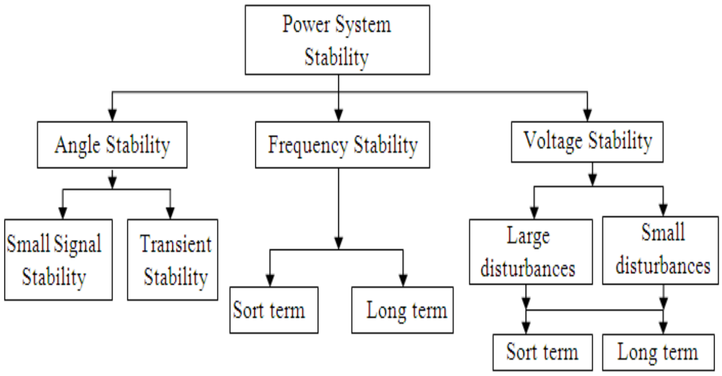


Figure-1.1 Types of power system stability phenomena Adapted from [Kundur and Morisson, 1997a]

I.II Concept of Transient Stability

Prime mover is used to drive the rotor of synchronous generator. So that frequency of the terminal voltage of the generator depends on the speed of rotor. Rotor mechanical speed is synchronized with the frequency of the stator electrical quantities. When two or more synchronous generators are connected, stator voltage and current of each generator must have the same frequency. The rotors of all interconnected synchronous generators must be in synchronism. During normal operating conditions of power system, Mechanical input power (Pm) from prime mover to generator shaft and generated electrical power (Pe) should be in balanced condition.

When large disturbances (like a fault on the network, failure of equipments, sudden change in load, and loss of a line or generator) are developed on power system, the maintenance of stability of rotor angle is known as transient stability. Due to these disturbances the synchronous machines may loss synchronism

For stability, the system oscillations must be damped, therefore the inherent forces in the system start to reduce oscillations.

I.III Swing Equation

The swing equation shows the electromechanical oscillations or dynamics in a power system. This equation provides the relative motion or acceleration.

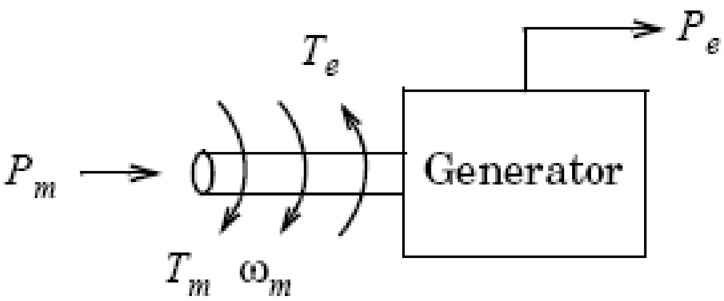


Figure-1.2 Generator-turbine torque balance

- Synchronous generator is considered with torque τ_e and running with synchronous speed.
- During steady state condition, mechanical torque, $\tau_m = \tau_e$
- A disturbance occurred will result in accelerating/decelerating torque.
- As per torque law,

$$J\frac{d^2\delta}{dt} = \tau_m - \tau_e \qquad (1)$$

- If mechanical speed is multiplied both side,

$$J\omega_m\frac{d^2\delta}{dt} = p_m - p_e \qquad (2)$$

- Swing equation in terms of inertial constant M

$$M\frac{d^2\delta}{dt} = p_m - p_e \qquad (3)$$

- If damping is considered then,

$$M\frac{d^2\delta}{dt} - D\frac{d\delta}{dt} = p_m - p_e \qquad (6)$$

- If equation is converted into per unit values, $M = 2H/\omega_0$

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt} - D\frac{d\delta}{dt} = p_m - p_e \qquad (7)$$

- Electrical active power,

$$p_e = \frac{V_1.V_2}{X}sin(\delta) \qquad (8)$$

$$p_e = p_{e.max}sin(\delta) \qquad (9)$$

- From (1) and (2),

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt} - D\frac{d\delta}{dt} = p_m - p_{e.max}sin(\delta) \qquad (10)$$

Where, δ is the power angle

ω = Angular velocity(rad/s)
J = Moment of inertia (kg.m^2)
M = ω.J
H = Inertia constant
D = Damping coefficient

I.IV Factors Affecting Transient Stability

- Generator loading
- Fault type and location (network detail)
- Fault clearing time
- Generator parameter (reactance, inertia etc.)
- Excitation of generator

➢ Infinite bus voltage magnitude

Figure-1.3 shows the characteristic of a synchronous generator which shows the stable and unstable condition. In Case-1, the rotor angle first start to increases and become maximum, then starts to decrease and oscillates with reduced magnitude. This is a transient stable condition. In Case-2, the rotor angle increases and goes to infinite. This is the instability of first swing. In Case-3, for first swing the system is stable but at last due to increasing magnitude system becomes unstable. When the post fault steady state condition is small signal unstable then this form of instability occurs.

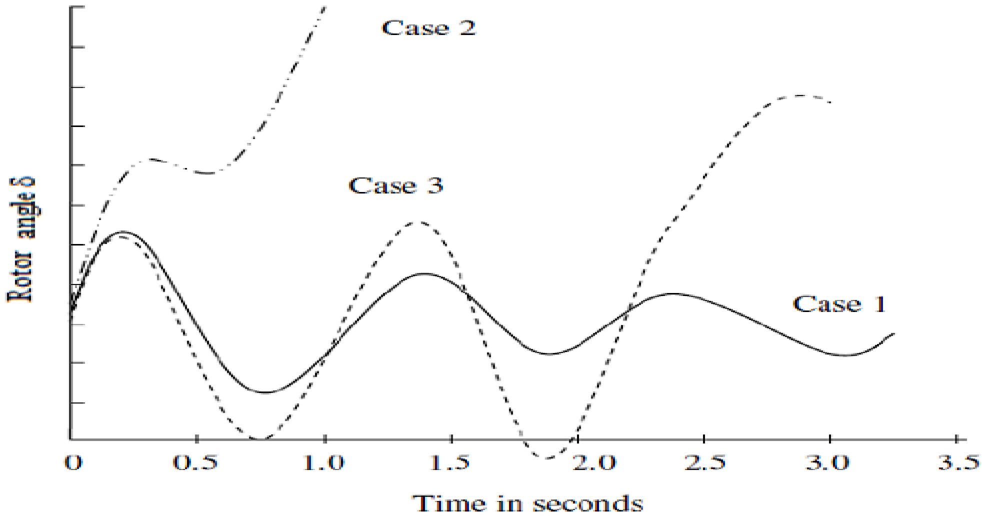


Figure-1.3 Rotor angle response to transient disturbance

In transient stability analysis, variation of rotor angle and speed of rotor of synchronous generator can be determined that shows the relation with time and explains about the stability of the system.

II. Methods of Transient Stability Analysis

Transient stability of synchronous generator in power system can be analysed by swing equation which is a nonlinear differential algebraic equation. In order to solve these equation or to analyse stability, different type of methods are used which are mentioned below

- ➢ Time domain method
- ➢ Direct method
    - Equal area criteria method
    - Energy based Lyapunov's method
        - Closest UEP Method
        - Controlled UEP Method
        - BCU Method
        - PEBS Method
- ➢ Approximate Method
- ➢ Artificial intelligent method

III. Problem Formulation

Transient stability analysis can be done using different methods. Aim of all methods is to determine Critical Clearing Time (CCT).

III.I Objective:

Comparison of "***Critical Clearing Time***" of different methods of transient stability analysis of synchronous generator in power system is the main objective of this work.

- Methods for comparison:

  1. Time Domain Method
  2. Direct Method
  3. Approximation Method

III.II Considered system

In this System, 2 machines, 9 buses (one bus as infinite bus) are considered [3], [9]. For transient stability analysis, in this system, three lines to ground fault is considered near 7th bus, and on 5-7 line. After fault clearing, 5-7 line is removed from the system. In this given system, two synchronous generators are connected; one is connected on 1st bus and second is connected on 2nd bus. All parameters of the considered system are shown in below figure. Three loads are connected on the system; load A is connected on 5thbus, load B is connected on 6th bus and load C is connected on 8th bus. Bus number 3 is considered as a infinite bus.

Table 3.1 Generator Data

Generator Data		
Generator	1	2
Rated MVA	192	128
kV	18	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	5.89
τ_{q0}'	0.535	0.6
Stored energy at rated speed	640 MW.s	301 MW.s

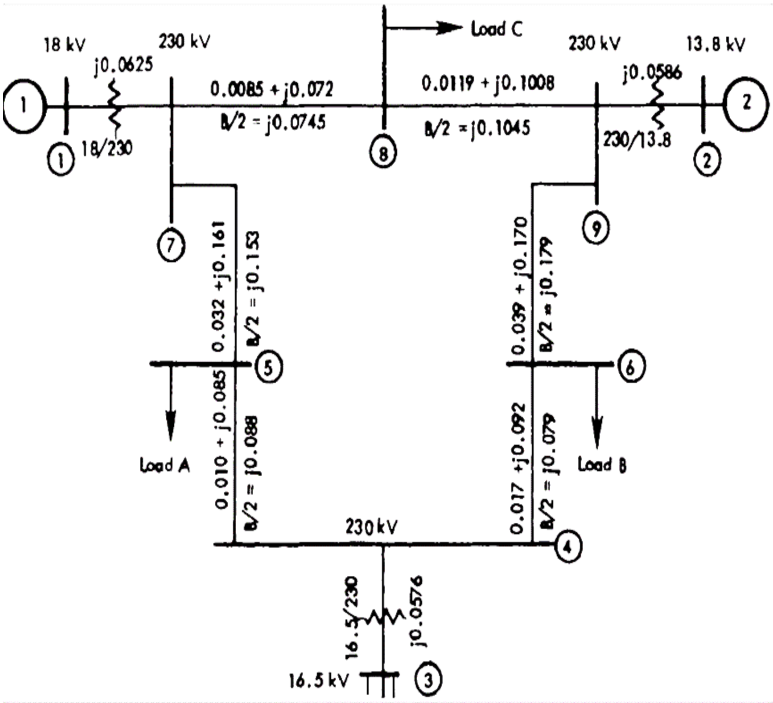


Figure-3.1 Considered system for transient stability analysis

Reactance values are in pu on a 100 MVA base.
Load A: 1.25(0.5), Load B: 0.9(0.3), Load C: 1(0.35), where P(Q) format is taken
Equivalent shunt admittance, for load are given as below,

Load-A: y_{L5}= 1.261 – j0.5044

Load-2: y_{L6}= 0.8777 – j0.2926

Load-3: y_{L8}= 0.969- j0.3391

IV.I Transient stability analysis methods

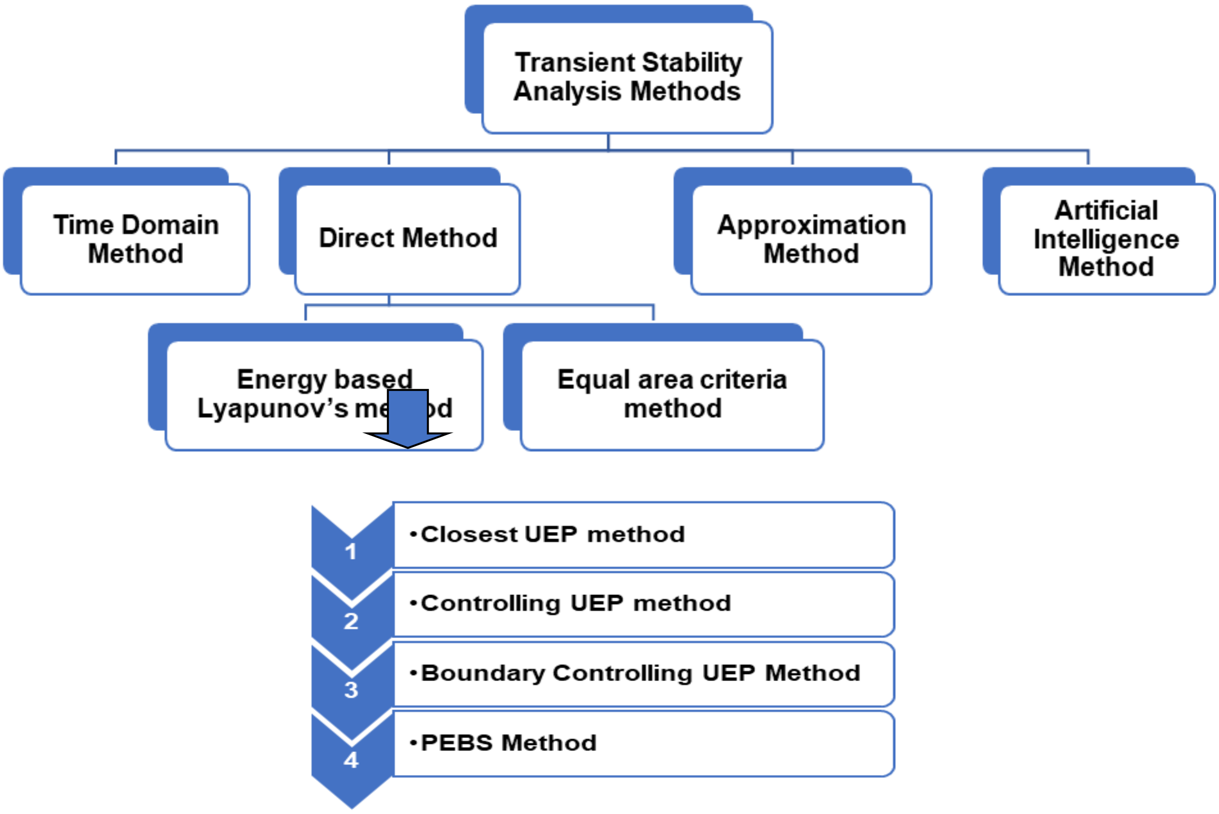


Figure- IV .1 Transient Stability Analysis Methods

V. Simulation and result

V.I Time domain method

During transient analysis of power system, numbers of dynamic equations are there for speed and acceleration of synchronous generators. These equations are also known as swing equations. These equations are non linear differential equations. To solve these equations numerical integrations techniques are used.The time domain numerical integration technique is not suitable for on line security analysis due to the long run timesfor simulation. In numerical integration method step size of time is used. This run time depend on step size. If step size is large then run time is small but accuracy is less. Different numerical integration methods are

- Euler method
- Trapezoidal rule

- Runge kutta method
- Point by point method

➢ At present, stability analysis programs are based on step by step numerical integrations technique.

➢ Modelling of components is required in time domain method.

➢ Modelling components:

- Synchronous generator modelling
- Excitation system modelling
- Transformer and transmission line modelling
- Different types of load modelling
- Facts controller modelling
- Turbine and speed control scheme modelling

➢ As per 1986 IEEE task force report, Different types of models are possible in case of synchronous generator that are given as below,[16]

- Model 0.0 (Classical model)
- Model 1.0 (Only field circuit)
- Model 1.1 (One field circuit on d-axis and one damper circuit on q-axis)
- Model 2.1 (One field and one damper circuit on q axis, one damper on d axis)
- Model 2.2 (Two circuit on d-axis and two circuit on q-axis)
- Model 3.2 (Three circuit on d-axis and two circuit on q-axis)
- Model 3.3 (Three circuit on d-axis and three circuit on q-axis)

➢ Mostly 1.1 and 2.1 model is used in practice as detail model.

V.II Synchronous generator modelling (2.1 model) [13]

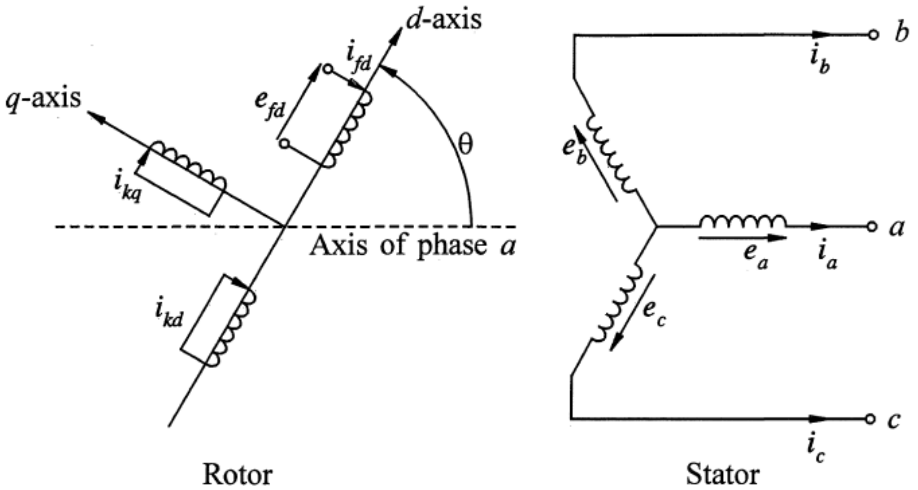


Figure-5.1 Synchronous generator stator rotor circuits

- Steps for modelling:
  - Forming mathematical equations from circuit in abc form.
  - Park's transformation is used to change time variant quantities into time invariant quantities.
  - Forming mathematical equations in dq0 form.
- Equations in abc parameter from circuits,

$$v_s = \frac{d\psi_s}{dt} + [R_s]i_s \tag{11}$$

$$v_r = \frac{d\psi_r}{dt} + [R_r]i_r \tag{12}$$

Here,

$$v^t{}_s = [v_a \quad v_b \quad v_c]$$

$$v^t{}_s = [v_f \quad 0 \quad 0 \quad 0]$$

- Relation between flux and current,

$$\psi = [L]i \tag{13}$$

Inductance matrix in abc parameter,

$$[L] = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix} \tag{14}$$

Park's transformation,

$$f_{abc} = [C_p]f_{dq0}$$

$$f_{dq0} = [C_p]^{-1}f_{abc}$$

Where,

$$[C_p] = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\theta & sin\theta & \frac{1}{\sqrt{2}} \\ cos\left(\theta - \frac{2\pi}{3}\right) & sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ cos\left(\theta + \frac{2\pi}{3}\right) & sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix}$$

Voltage equations in dq0 form after applying park's transformation,

$$v_d = \frac{1}{\omega_0}\frac{d\psi_d}{dt} - \frac{\omega_m}{\omega_0}\psi_q + R_a i_d \quad (15)$$

$$v_q = \frac{1}{\omega_0}\frac{d\psi_q}{dt} + \frac{\omega_m}{\omega_0}\psi_q + R_a i_d \quad (16)$$

$$v_0 = \frac{1}{\omega_0}\frac{d\psi_0}{dt} + R_a i_0 \quad (17)$$

$$v_f = \frac{1}{\omega_0}\frac{d\psi_f}{dt} + R_f i_f \quad (18)$$

$$0 = \frac{1}{\omega_0}\frac{d\psi_h}{dt} + R_h i_h \quad (19)$$

$$0 = \frac{1}{\omega_0}\frac{d\psi_g}{dt} + R_g i_g \quad (20)$$

Flux equations in dq0 form after applying park's transformation,

$$\psi_d = L_{ls} i_d + L_{md}\left(i_d + i_f + i_h\right) (21)$$

$$\psi_q = L_{ls} i_q + L_{md}\left(i_q + i_g\right) (22)$$

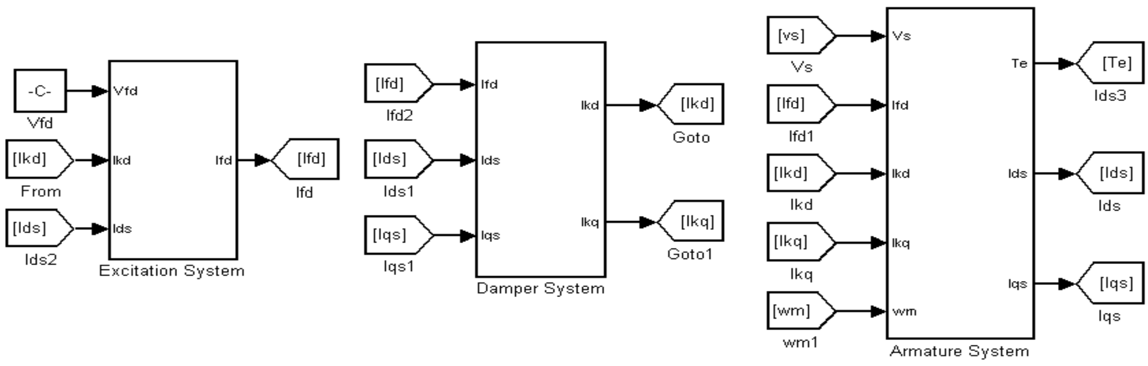
$$\psi_0 = L_{ls} i_0 (23)$$

$$\psi_f = L_{lf} i_f + L_{md}\left(i_d + i_f + i_h\right) (24)$$

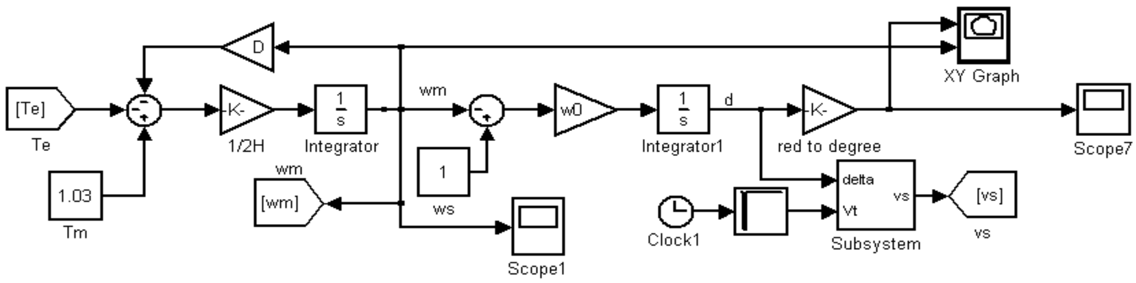
$$\psi_h = L_{lh} i_h + L_{md}\left(i_d + i_f + i_h\right) (25)$$

Using above mathematical equations, MATLAB model can be prepared which can be used in time domain for transient stability analysis.

V.III 2.1 Model in MATLAB

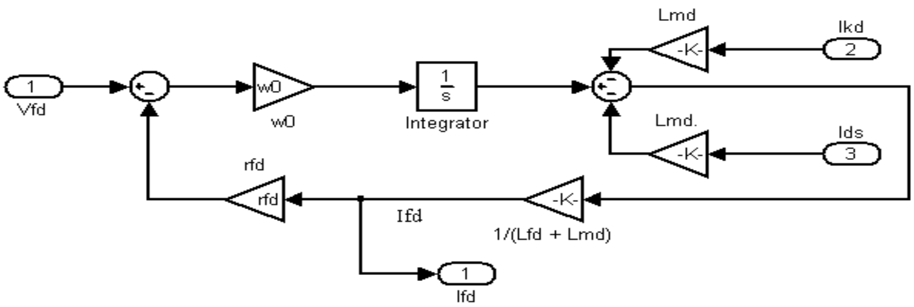


(a)



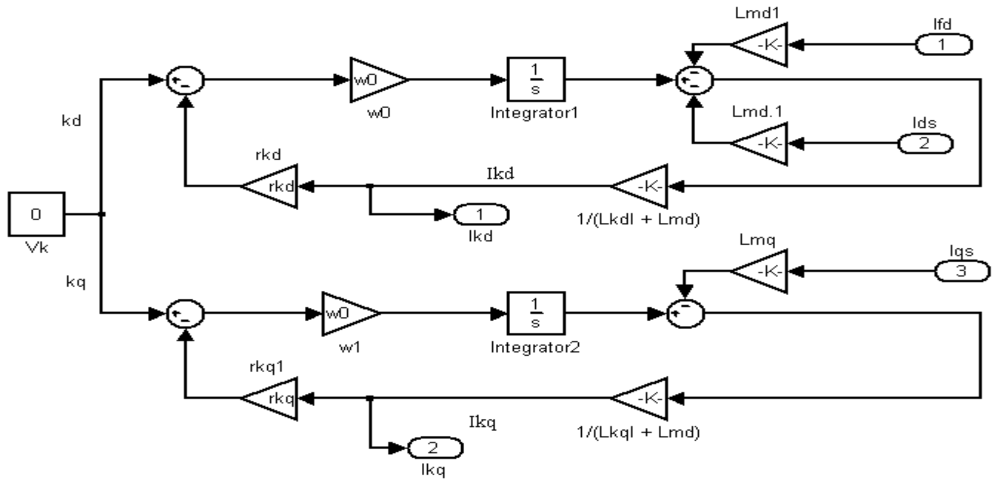
(b)

Field Circuit Model



(c)

Damper Circuit Model



(d)

Armature Circuit Model

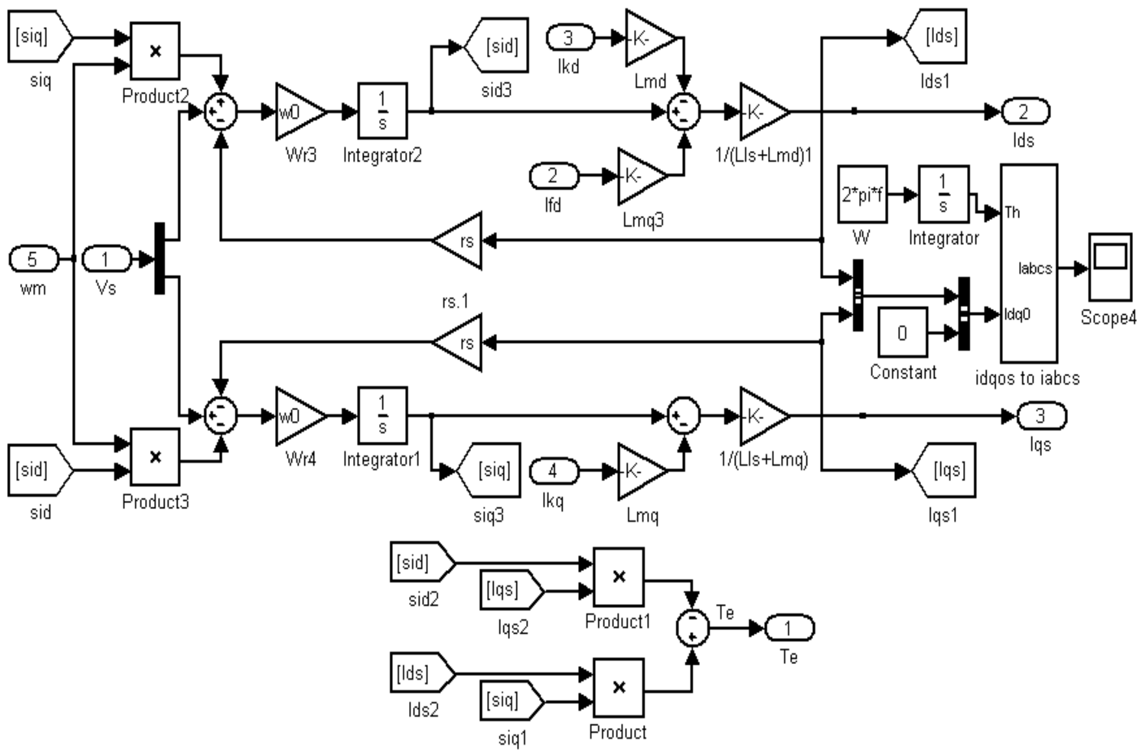


Figure-5.2 Synchronous generator 2.1 model in MATLAB including (a),(b),(c) and (d)

V.III Time Domain Method

Two machines, nine buses system is considered. In transient stability analysis classical model of synchronous machine is used. To determine classical model, initial power flow of system is required that is why PSAT tool box is used as shown in figure.

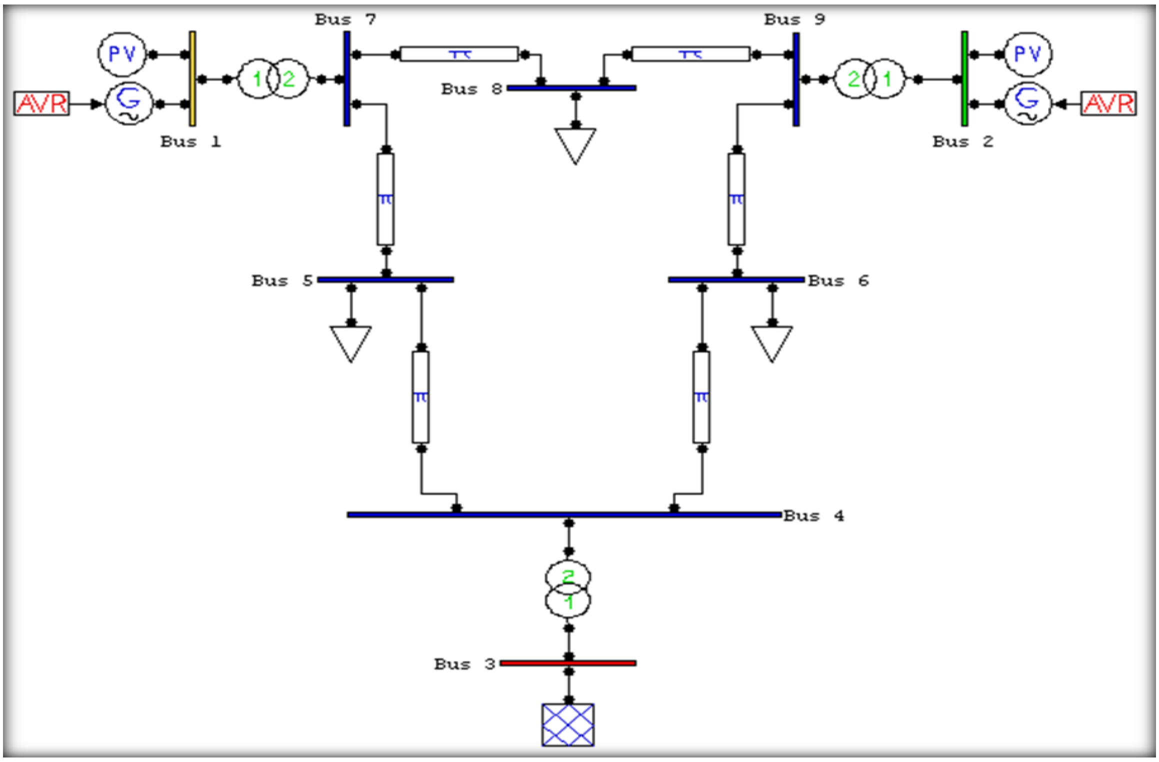


Figure-5.4 System in PSAT tool box

Power flow Result

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

MATLAB Model

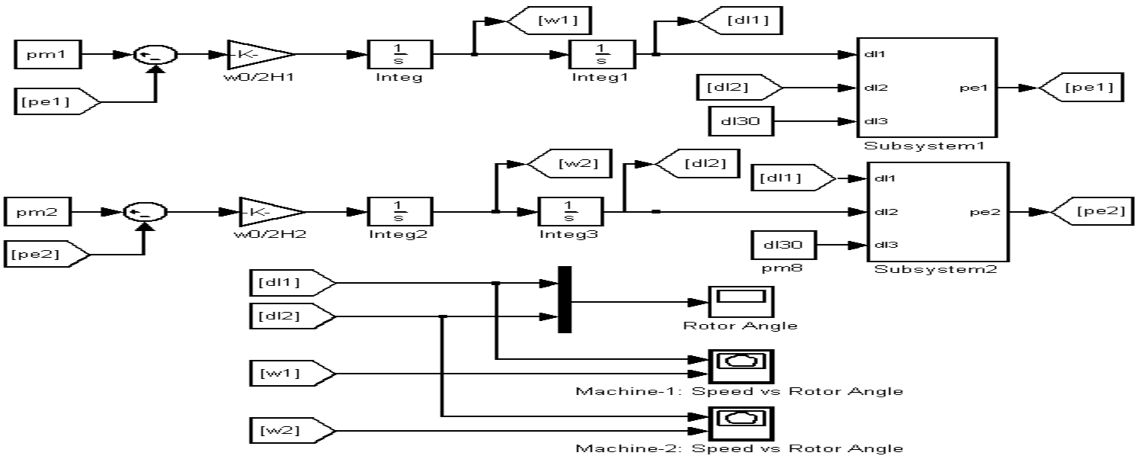


Figure-5.4 System MATLAB model

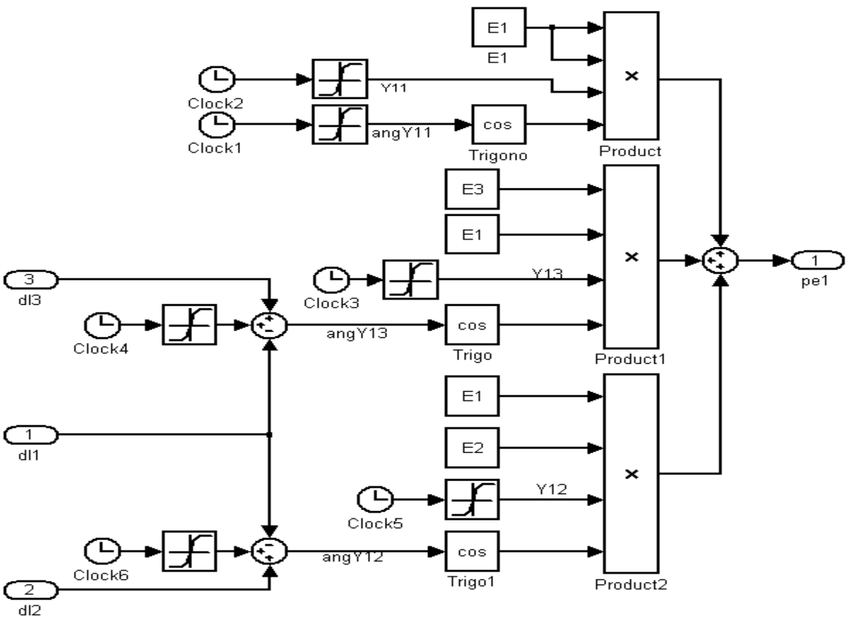


Figure-5.4 System subsystem-1 MATLAB model

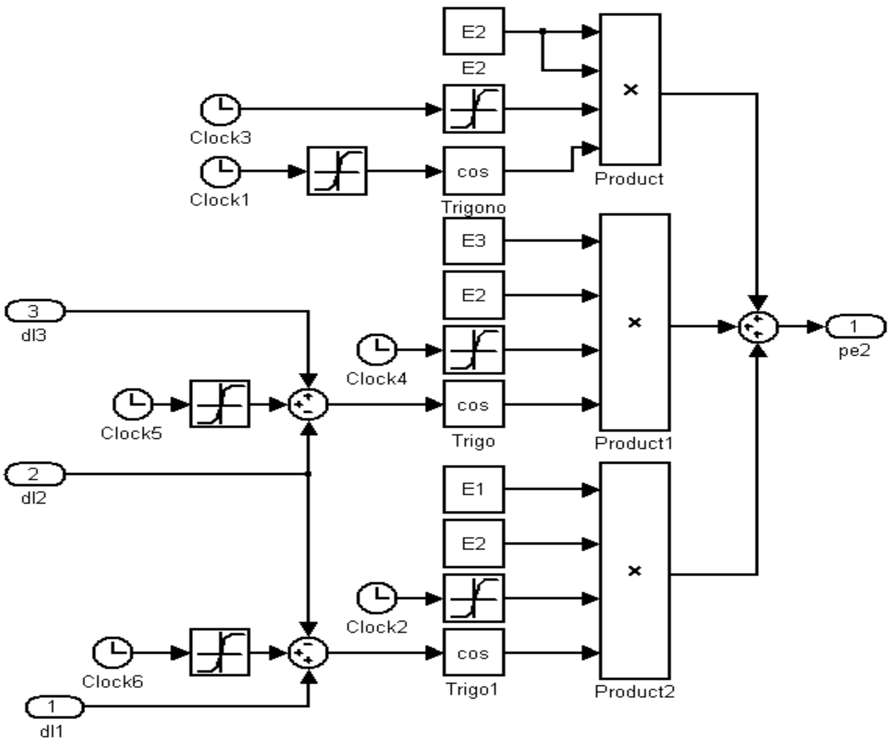


Figure-5.4 System subsystem-2 MATLAB model

Results for Fault Clearing Time = 0.1 second

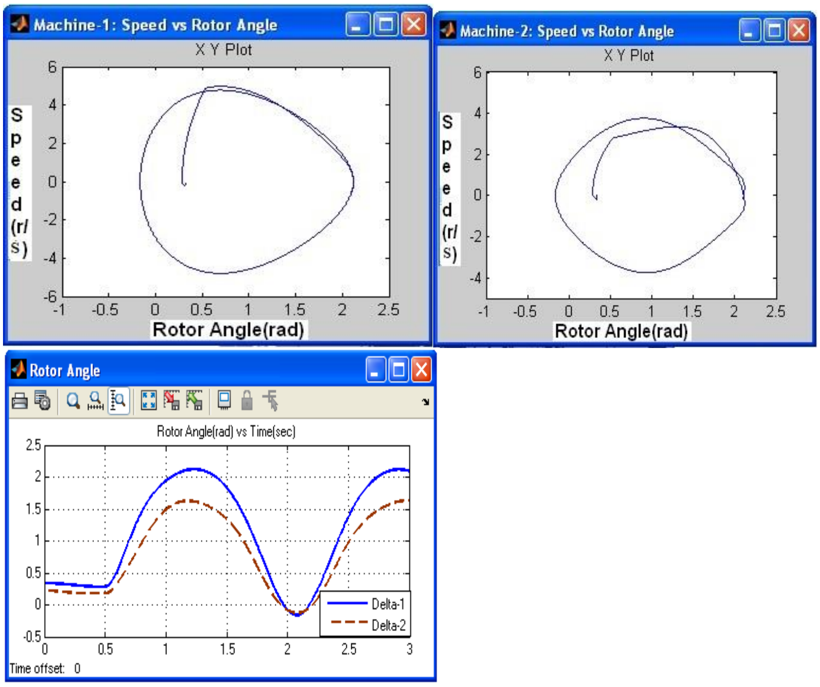


Figure-5.5 Results for fault clearing time 0.1 second

Results for Fault Clearing Time = 0.11 second

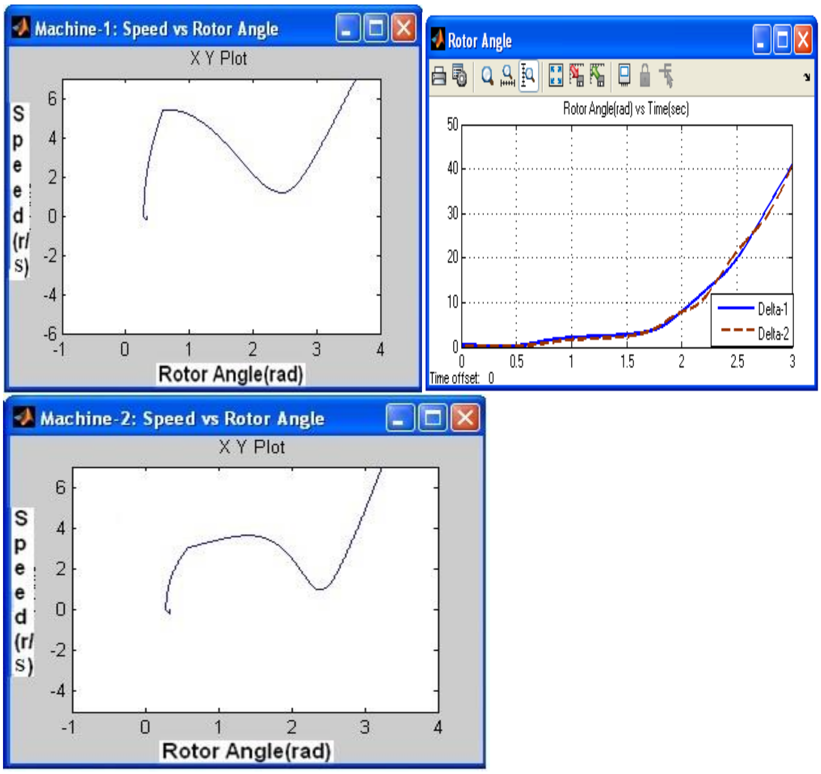


Figure-5.6 Results for fault clearing time 0.11 second

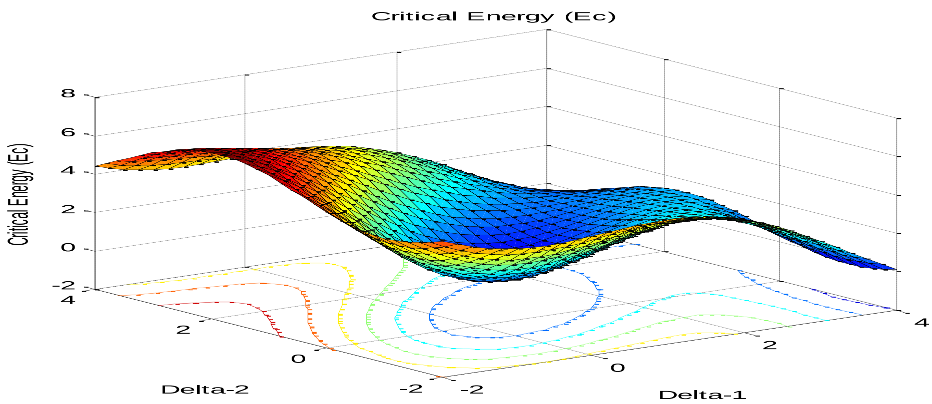


Figure- Critical Energy (Ec)

Formula of critical energy (E_c) with respect to SEP is given as equation. Using this equation, MATLAB coding is prepared as given in Appendix-A.

Result of critical energy (E_c) is shown in figure in which energy variation is shown with respect to both generator rotor angles.

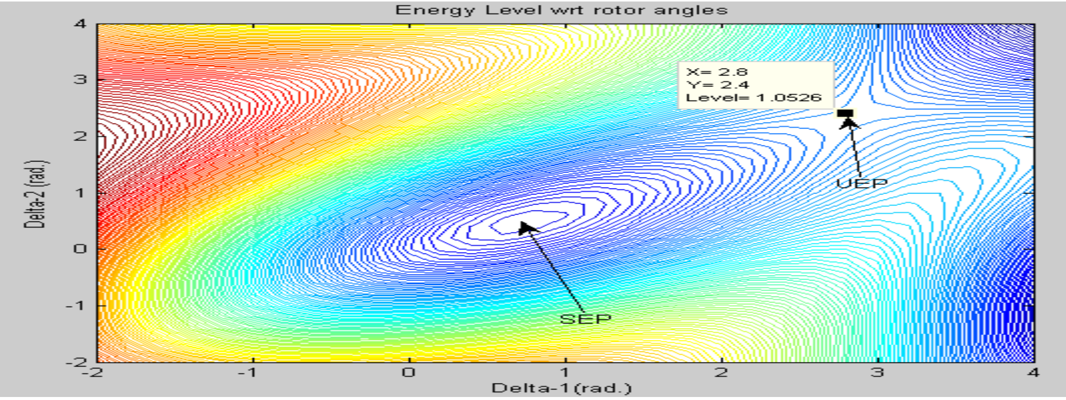
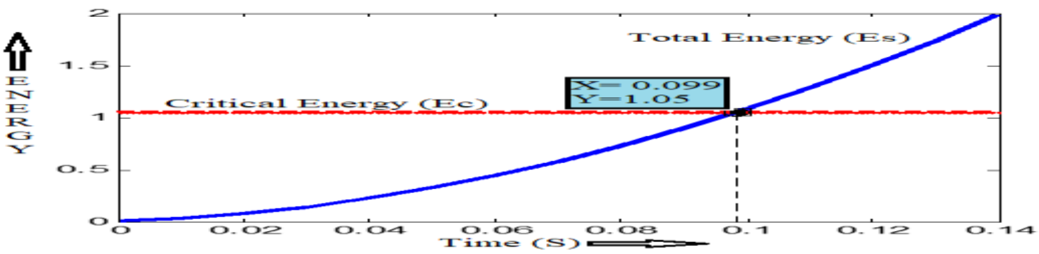


Figure- Energy Level

Critical energy can be obtain by contour graph as shown in figure-5.8, in which critical energy is given by E_c= 1.0525

Total energy of fault on condition can be determined using equation. MATLAB coding for total energy of fault on system is given in Appendix-A.

Fault on system is dynamic system, energy of this system increases due to fault occurred. Here total energy and critical energy are compared. Result can be obtained as shown in below figure.



From figure, it can be said that Critical Clearing Time (CCT) is 0.099 second.

From figure-, CCT, t_D= 0.099 second

From figure-, CCT, t_T= 0.1 second

VI. Conclusion

- Time domain method is most accurate method among other methods, and it is slowest method than other methods.
- Direct method is less accurate method than time domain method but particularly in this case its accuracy almost same as time domain method. This method is faster than time domain method.
- Approximation method is least accurate method and fastest than other methods.

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