International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

Transient Stability Analysis of Synchronous Generator in Power System

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

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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. *Time domain method (For SMIB System)*

- *At present, stability analysis programs are based on step by step numerical integrations.*
- *Modelling of components is required in this 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*
- *Different type of models is possible in case of synchronous generator.*
  - *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 d axis, one damper on q-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.*

2.1 Synchronous generator modelling (2.1 model) [13]

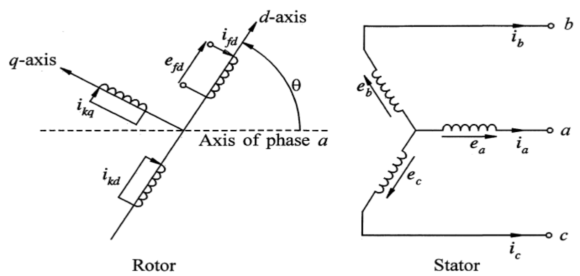


Figure-1 Synchronous generator stator rotor circuits

- ***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 and forming mathematical equations in dq0 form.*

- *Forming MATLAB Model from mathematic equation*

Step-1: Forming Mathematical Equations

- *Equations in abc form from circuits,*

$$v_s = -\frac{d\psi_s}{dt} - [R_s]i_s$$

$$v_r = -\frac{d\psi_r}{dt} - [R_r]i_r$$

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

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

- *Relation between flux and current*
-

$$\psi = [L]i$$

Inductance matrix in abc form,

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

Step-2: 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,

$$v_d = -\frac{d\psi_d}{dt} - \omega\psi_q - R_a i_d$$

$$v_q = -\frac{d\psi_d}{dt} + \omega\psi_d - R_a i_q$$

$$v_0 = -\frac{d\psi_0}{dt} + R_a i_0$$

$$v_f = \frac{d\psi_f}{dt} + R_f i_f$$

$$0 = \frac{d\psi_h}{dt} + R_h i_h$$

$$0 = \frac{d\psi_g}{dt} + R_g i_g$$

- *lux equations in dq0 form after applying park's transformation,*

$$\psi_d = -L_{ls} i_d + L_{md}(-i_d + i_f + i_h)$$
$$\psi_q = -L_{ls} i_q + L_{md}(-i_q + i_g)$$
$$\psi_0 = -L_{ls} i_0$$
$$\psi_f = -L_{lf} i_f + L_{md}(-i_d + i_f + i_h)$$
$$\psi_h = -L_{lh} i_h + L_{md}(-i_d + i_f + i_h)$$
$$\psi_g = -L_{lg} i_g + L_{md}(-i_q + i_g)$$

Step-3: Forming MATLAB Model from mathematic equation

- *using mathematical equations, MATLAB model can be prepared which can be used in time domain method for transient stability analysis.*

2.2 Synchronous generator (2.1 Model) in MATLAB

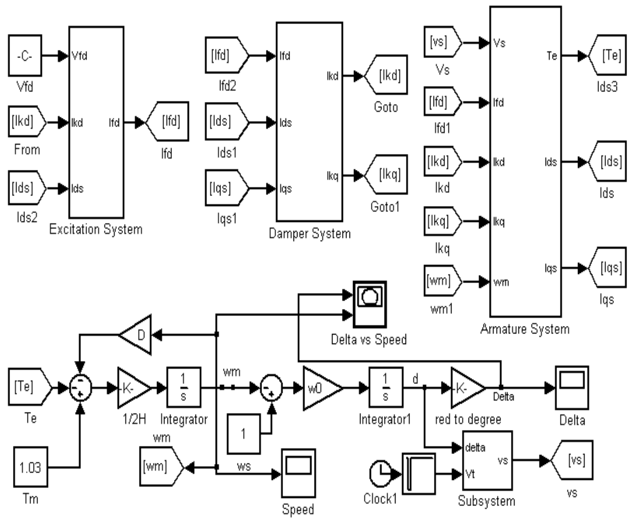
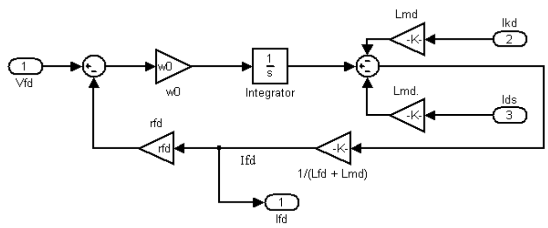


Figure-2: Synchronous generator 2.1 model

Field Circuit Model



Damper Circuit Model

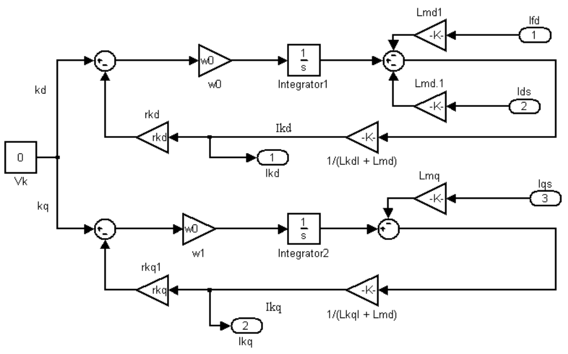


Figure-3: Field and Damper circuits model of 2.1 Synchronous Generator

Armature Circuit Model

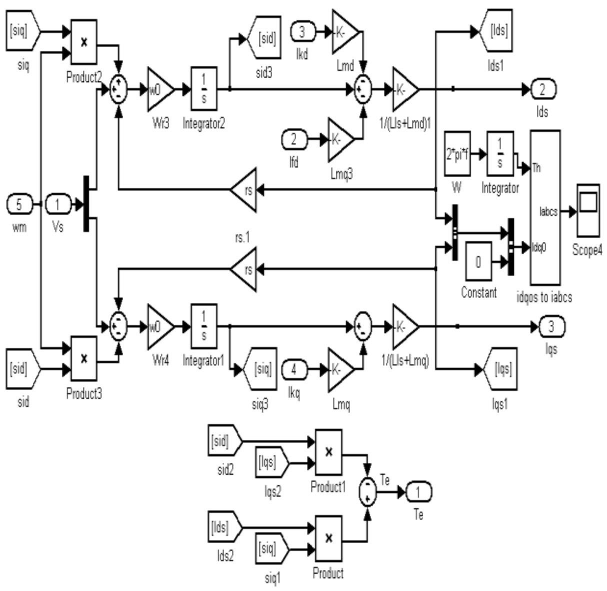
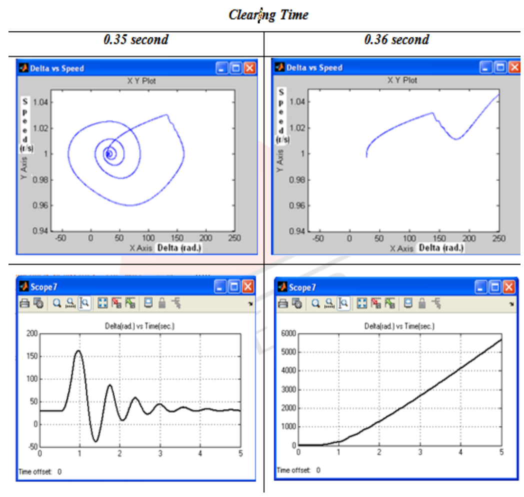


Figure-4: Armature Circuits model of 2.1 Synchronous generator

- *Data used in transient stability analysis for synchronous generator*

Sr.No.	***Generator Parameters***	***Value (pu)***
1	***Stator Resistance (rs)***	***0.02***
2	***d-axis inductance (Ld)***	***1***
3	***q-axis inductance (Lq)***	***1***
4	***Stator leakage inductance (Lal)***	***0.15***
5	***Field circuit resistance (rfd)***	***0.001***
6	***Field circuit inductance (Lfd)***	***0.2***
7	***d-axis damper circuit resistance (rkd)***	***0.02***
8	***d-axis damper circuit inductance (Lkdl)***	***0.11***
9	***q-axis damper circuit resistance (rkq)***	***0.04***
10	***q-axis damper circuit inductance (Lkql)***	***0.15***
11	***Inertia constant (H)***	***4 sec***
12	***Damper coefficient (D)***	***1e-6***
13	***Frequency (f)***	***60***
14	***Terminal voltage (v)***	***1***
15	***Delivering current (Ia)***	***1.25***
16	***Power factor (pf)***	***0.8***
17	***Clearing time (tc)***	***0.35, 0.36 sec***
18	***Field Circuit voltage (vf)***	***0.00218***

Results of transient stability analysis



2.3 Time Domain Method

Classical Model (0.0 Model) with swing equation in MATLAB

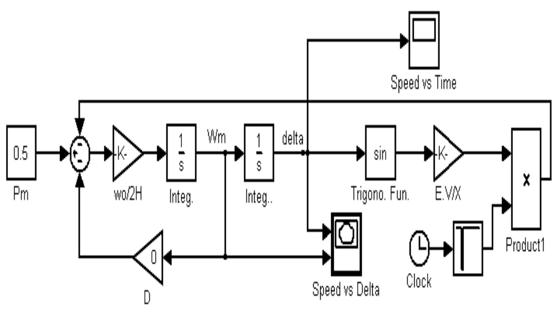
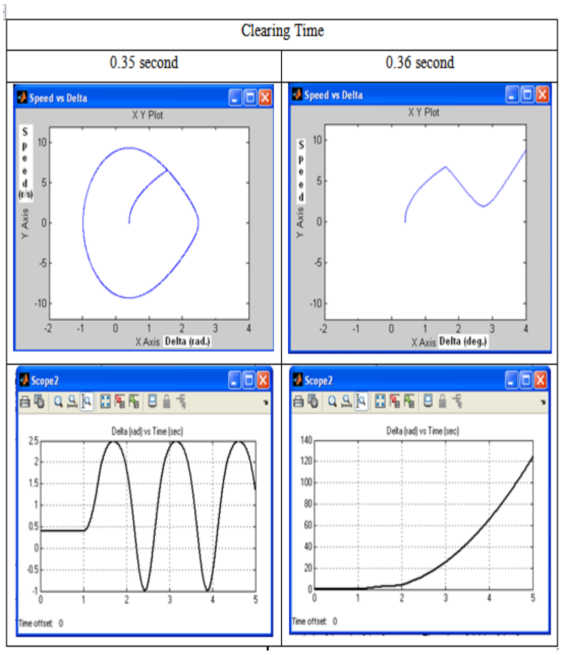


Figure-5: Classical Synchronous generator model

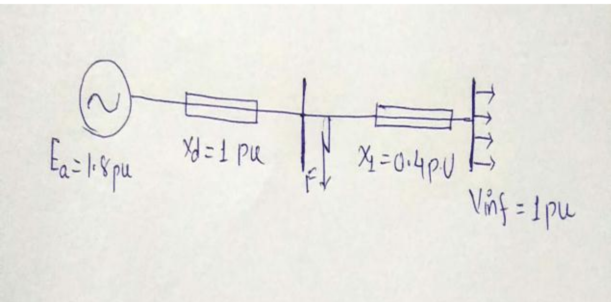
Result



3. *Comparison of Direct Method and Time Domain Method (For SMIB System)*

Problem:

A round rotor generator is delivering power in the steady state to an infinite bus through a transmission line with reactance Xl=0.4 pu Assume that Ea = 1.8 pu Vinf = 1 pu , H = 5 sec and Xd = Xq = 1 pu, P°g = 0.5 pu. Due to disturbance circuit breakers open and close. Neglecting damping and find critical clearing time.



Solution

3.1 Direct Method

Pre fault: System in steady state

$$P_m = P_e$$

$$P_m = \frac{E_a.V}{X}\sin\delta_\circ \Rightarrow 0.5 = 1.283\sin\delta_\circ$$

$$\delta_\circ = 0.4\ rad$$

Using Equal area criteria

$$0.5(\pi = 2\delta_\circ) = \int_{\delta_{tc}}^{\pi-\delta_\circ} (1.283\sin\delta).d\delta$$

$$\delta_{tc} = 90.61^\circ = 1.581\ rad$$

Fault on Condition

$$\textbf{delta}_{tc}=1.581=\frac{\pi*60*0.5}{10}t^2{}_{criti}+0.4$$

$$t_{criti}=0.354\ sec$$

4. *Conclusion*

We can conclude for time domain method critical clearing time in between 0.35 to 0.36 second using Model 2.1 and Model 0.0 in MATLAB Modelling and solving problem using Direct method critical clearing time is 0.354. 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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