The Simulation of Synchronous Generator Dynamic in Third Order Model Using Simulink

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Abstract—This paper presents the simulation techniques of synchronous generator dynamic using Simulink. The synchronous generator including transformer, transmission line, and voltage sources are represented in RMS value. This method is called stability mode of simulation. The benefit of working in this mode is to faster generate the simulation results than commercial software. The implementation of mathematical model into Simulink is reported in this paper.

Keywords—Synchronous generator, third order model, stability, Simulink.

I. INTRODUCTION

The analysis of power system stability have been affected dramatically by the widespread use of personal computers. The power system stability is concerned with the behavior of the synchronous generator after a disturbance. Steady state stability refers to the ability of a synchronous generator subject to small and gradual changes in load. The mathematical model is represented by a simple constant voltage and impledance. This model is used for power flow analysis, power market, and economic dispatch [1-2]. Transient stability refers to the stability of synchronous generator refers to the stability of a synchronous generator subject to sudden and severe disturbance. If the second order differential equation is used, it will be accepted only the first swing stability analysis [3-4]. For the multi-swing stability so called dynamic stability the order model should be at least third order model [5-6].

There are two methods of power stability simulation. The first method is called momentary method. When working in this method, all components in power system are modelled in detailed of three-phase ac power. The electrical quantities such as voltage, current, etc. are in instantaneous value of time. The examples in this method are in DIgSILENT, PSCAD, EMTP, etc [7-10]. The main disadvantages are time consuming and in closed source code procedure. The second method is called stability method. When working in this method, all components in power system are modelled in simpler way. The electrical quantities such as voltage, current, etc. are in RMS

value. The numerical algorithm of solving nonlinear equation is carried out through the standard software such as Fortan, C, MATLAB/Simulink. The main advantage is in open source code method. The simulation time is much faster than the first method.

MATLAB is a matrix-based software package and widely used to obtain numerical solutions. Simulink provides a highly interactive environment for simulation in power system dynamic. Simulink has been widely used and accepted in power system analysis both steady state, transient, and dynamic stability.

This paper presents the simulation techniques of synchronous generator dynamic using Simulink. The presented method will be tested in sample system with various fault occurrences.

II. MATHEMATICAL MODEL

A. Second Order Model

Fig. 1 shows a synchronous generator in a simple system connected to the electrical grid. The second order differential equation or model of the generator is described by [11]

$$\dot{\delta} = \omega \tag{1}$$

$$\dot{\omega} = \frac{1}{M}[P_m - P_e] \tag{2}$$

Here

δ = synchronous generator rotor angle

ω = synchronous generator speed

M = moment of inertia

P_m = mechanical input power
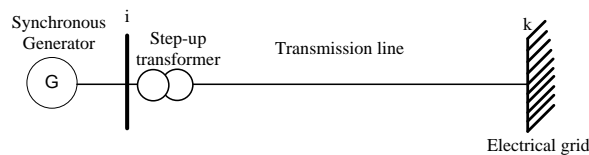
P_e = electrical output power

Fig. 1 A synchronous generator in a simple system

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B. Third Order Model

The third order model of the generator is given by [12]

$$\frac{dE'_q}{dt} = \frac{1}{T'_{do}}\left[E_f - E'_q + I_d\left(X_d - X'_d\right)\right] \quad (3)$$

Here

E'_q = quadrature axis transient voltage is given by

$$E'_q = V_s + R_s I_q + X'_d I_d \quad (4)$$

T'_{do} = direct axis open circuit transient voltage time
　　　Constant

E_f = field voltage constant

I_d = direct axis line current

X_d = direct axis synchronous reactance

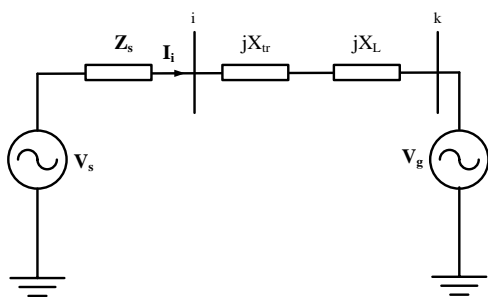X'_d = direct axis synchronous transient reactance

Fig. 2 Synchronous generator one axis equivalent circuit

The synchronous generator one axis equivalent circuit as shown in Fig. 2 assists to evaluate the P_e in (2). The voltage source $\mathbf{V_s}$ is given by

$$\mathbf{V_s} = \left[\left(X_q - X'_d\right)I_q + jE'_q\right]e^{j(\delta-\pi/2)} \quad (5)$$

The impledance $\mathbf{Z_s}$ is written by

$$\mathbf{Z_s} = R_s + jX'_d \quad (6)$$

The line current is given by

$$I_i = I_i\angle\theta_i = (I_d + jI_q)e^{j(\delta-\pi/2)} \quad (7)$$

The synchronous generator rotor angle (δ) in (1) and (7), is given by

$$\delta = angle\ of\ (V_i e^{j\theta_g} + (R_s + jX'_d))I_i e^{j\vartheta_i} \quad (8)$$

Thus, the required electrical output power is given by

$$P_e = E'_q I_q + (X_q - X'_d)I_d I_q \quad (9)$$

C. Simulink block diagram

The derived mathematical model of the synchronous generator equipped in a power system can be implemented in Simulink as shown in Fig 3. The initial condition of Integration 1, Integration 2, and Integration 3 can be obtained by setting the (1), (2), and (3) to be zero, respectively. The P_e, I_d, and I_q is performed at during and after disturbance for each step of numerical solutions.
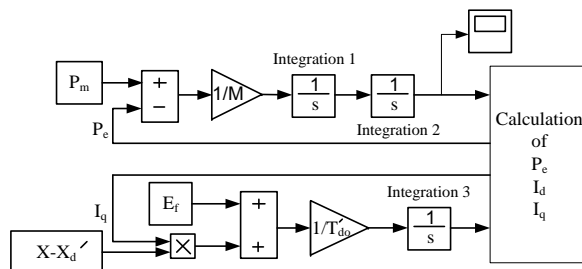

Fig. 3 Simulink block diagram of synchronous generator

III. SIMULATION RESULTS

The presented method is validated on the sample system as shown in Fig. 4. A 50 Hz synchronous generator is connected to electric grid through two parallel lines and a transformer. The generator is delivering electrical output power P_e=0.75 *pu* to the infinite bus at a voltage V_g= 1 *pu*. A temporary three-phase fault occurs near bus *m*. The sample system is tested with clearing fault time (t_{cl}) 100 *msec* and 200 *msec*. The swing curves of synchronous generator speed, electrical output power, direct, and quadrature axis line current are shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8, respectively. It can be observed from the swing curves that the presented method provide a reliable result. The t_{cl} is proportional to the amplitude of the swing curves.
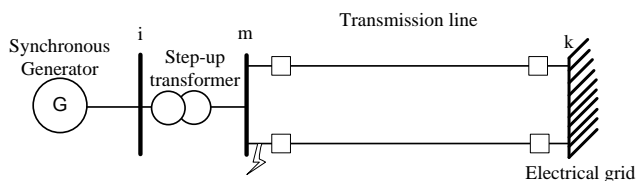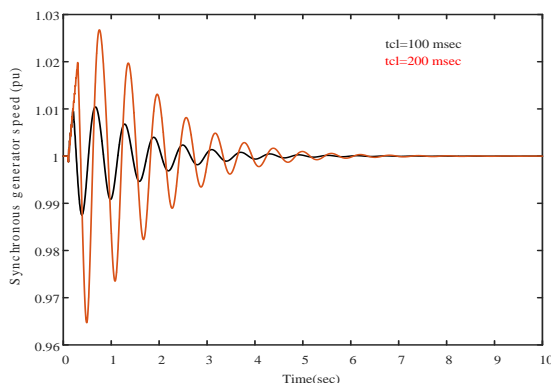

Fig. 4 Simulink block diagram of synchronous generator
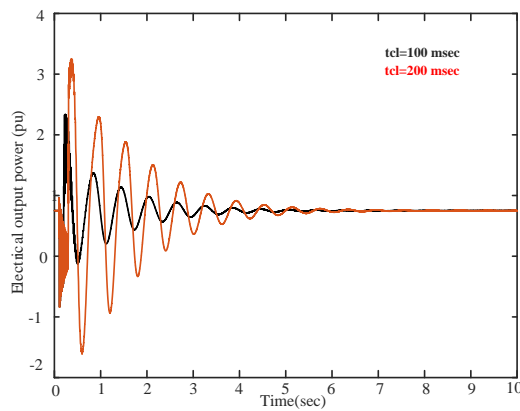

Fig. 5 Synchronous generator speed
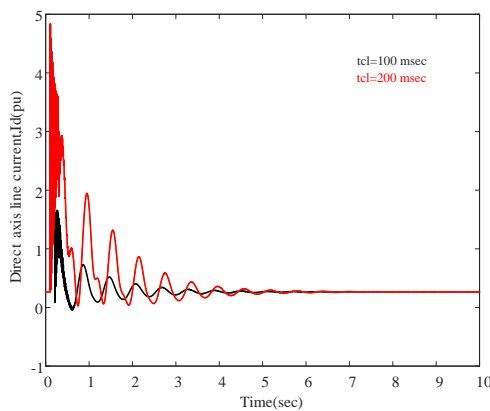
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Fig. 6 Electrical output power
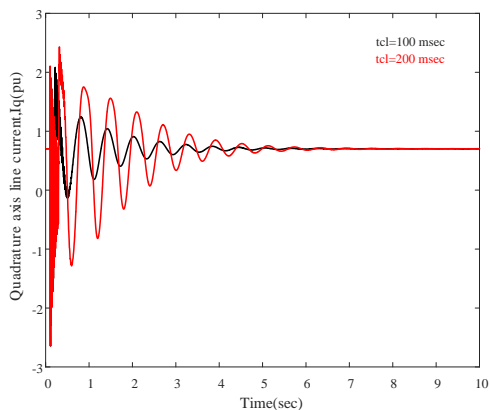

Fig. 7 Direct axis line current

Fig. 8 Quardrature axis line current

IV. CONCLUSION

This paper presented the method of power system dynamic simulation. Three differential equations are used to determine the dynamic behavior of the system. The electrical equivalent circuit of synchronous generator is in one axis equivalent circuit that helps us to evaluate the electrical output power at during and after fault of the system. This paper provided the method of construct the Simulink block diagram. The simulation results indicated the prefect agreement of the fault occurrence in the system.

REFERENCES

[1] Y. Yaozu and W. Mingdong, "Full-Characteristic power flow of wind power system with consideration of generator set frequency variation," *in Proc. Electrical and Energy Conference Conf.*, Nangjing, 2022, pp. 766–769.
https://doi.org/10.1109/CIEEC54735.2022.9845830

[2] N. Liu, Y. H. Yin, S. Y. Ma, T. Liu, and Z. Y. Gu, "Consideration of generator excitation current limitation for the improved continuation power flow," *in Proc. Power System Technology Conf.*, Hangzhou, 2010, pp. 1–6.
https://doi.org/10.1109/POWERCON.2010.5666145

[3] B. Sebastian, and R. Garg, "Transient stability analysis of multi-machine power system and first swing stability analysis using SVC," *in Proc. Advances in Electrical Engineering Conf.*, Vellore, 2014, pp. 1–3.
https://doi.org/10.1109/ICAEE.2014.6838511

[4] J. Ying, X. Yuan, and J. Hu, "Inertia Characteristic of DFIG-Based WT under transient control and its impact on the first-swing stability of SGs," *IEEE Trans. Energy Convers.*, vol. 32, pp. 1502 - 1511, Dec. 2017.
https://doi.org/10.1109/TEC.2017.2698521

[5] H. Amano and A. Yokoyama, "Rotor angle stability analysis using normal form method with high penetrations of renewable energy sources-energy index for multi-swing stability," *in Proc. Power systems computation Conf.*, Dublin, 2018, pp. 1–6.
https://doi.org/10.23919/PSCC.2018.8442791

[6] L.F.C. Alberto and N.G. Bretas, "Damping estimation for multi-swing transient stability analysis: the OMIB case," *in Proc. Power System Technology Conf.*, Beijing, 1998, pp. 1383–1387.

[7] R. Hiremath and T. Moger, "Transient analysis of LCC based HVDC offshore wind farms using DIgSILENT power factory," *in Proc. Iran wind energy conference Conf.*, Shahrood, 2021, pp. 1–5.
https://doi.org/10.1109/IWEC52400.2021.9467031

[8] S. Fan and H. Ding, "Time domain transformation method for accelerating EMTP simulation of power system dynamics," *IEEE Trans. Power Syst.*, vol. 27, pp. 1778 - 1787, Apr. 2012.
https://doi.org/10.1109/TPWRS.2012.2188913

[9] A. G. Rusina, D. A. Serohvostov, D. I. Kolesnikov, and A. Arestova, "PSCAD as a tool for development of a simulation model for a power system with renewable energy sources," *in Proc. Ural smart energy Conf.*, Ekaterinburg, 2020, pp. 39–42.
https://doi.org/10.1109/USEC50097.2020.9281187

[10] X. Han and H. Zhang, "Power system electromagnetic transient and electromechanical transient hybrid simulation based on PSCAD," *in Proc. Electric utility deregulation and restructuring and power technologies Conf.*, Changsha, 2015, pp. 210–215.
https://doi.org/10.1109/DRPT.2015.7432275

[11] P. W. Sauer and M. A. Pai, "Power system dynamics and stability," New Jersey: Prentice Hall, 1998, pp. 89–120.

[12] M. Erena and M. Shahidehpour, "Handbook of electrical power system dynamics," New Jersey: IEEE Press, 2013, pp. 9–134.

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