DYNAMIC MODELLING OF EXCITATION AND GOVERNOR EFFECT ON STABILITY OF ELECTRICAL MACHINES

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1.0 ABSTRACT

The performance of an electric system is characterized by the stability of the frequency and voltage. To sustain electric performance, a governor is used to maintain the speed (and hence frequency) of the generator at its nominal value. Another important factor in stability is the excitation control. In this paper, a study of the effect of excitation and governor on the stability of electric machines is presented. In particular, a model of a synchronous machine (in generator mode) connected to a hydraulic turbine Proportional-Integral-Derivative (PID) governor with excitation system is analyzed. A three phase fault is used to represent system disturbance. All simulations were performed in simulink. Simulation results obtained shows that excitation and governor control stabilizes the output terminal voltage of the synchronous electrical machine within three seconds in the presence of a fault. This shows that excitation and governor control play a vital role in the dynamic stability of electric machines.

KEYWORDS: Electric system, Governor, Excitation, Synchronous machine, Stability, Generator.

1. INTRODUCTION

An electric governor is a control device that controls the speed of a generator. Its task is to keep the speed of the engine constant - to keep the speed of the engine at a predetermined speed without being affected by changes in the load (Theraja and Theraja, 1983). In a machine that uses field coils – for example, in most large generators, a field has to be established by a current, for electricity to be produced by the generator. To generate the field, a current has to flow in the coil; or else there is no power transfer to or from the rotor. Excitation is the process of generating a magnetic field by means of an electric current. It is important to be able to control this field because this will in turn sustain the system voltage at a nominal value.

There have been several studies on power system stability. Many of the important contributions made, have been in the area of analyzing the dynamics of stability. These contributions are also concerned with improvements in the transmission systems stability (Sharma *et. al.*, 2007; Hiyama *et. al.*, 1997; Ukoima and Ekwe, 2019). Among the techniques utilized, generator control is the most extensively applied (Hiyama, 1997). Typically, this includes excitation and governing control. The majority of the attention is mostly towards excitation control. Many of which are the single input single output – proportional differential integral based control, multiple input multiple output linear control, non-linear control, optimal linear and intelligent control. Examples of such applications are the fuzzy logic, neural network and a combination of both (hybrid) that is to say neuro-fuzzy systems (Dash *et. al.*, 1998).

Caused by large disturbances, transient instability still remains one of the major issues of power systems stability. Power oscillations that small in value and low in frequency usually continue for a lengthy duration. This in turn, limits the capability of the system to transfer power. This problem is usually curbed using power system stabilizers. The PSS adds damping to the rotor of the generator. The voltage modes however, cannot be stabilized by the use of a PSS (Hossain *et. al.*, 2013; Hossain *et. al.*, 2010). An automatic voltage regulator (AVR) together with a PSS can be used to enhance power systems voltage and transient stability.

The stability of electrical machines can be attained by either the inclusion of flexible alternating current devices that control the flow of power and regulate the level of voltage or by controlling the excitation of synchronous generators (Hossain *et. al.*, 2013; Leona *et. al.*, 2011). The use of excitation controller is proven to be more economical than governor. However, to improve overall performances of electrical machines, the coordination between the governor and excitation controllers is essential. Extensive studies of excitation control have been reported in (Bevrani and Hiyama, 2006; Bevrani and Hiyama, 2007; Lawt *et. al.*, 1994; Saidy, 1997). Many of the methods are based on linearizing the power system model while others are based on simulation of complex nonlinear models. The design of excitation controllers that are based on linearizing non-linear models have a major limitation. This is because such models depend on sets of operating conditions. Hence, they are not likely to work properly if and when the operating conditions vary (Cao *et. al.*, 1994).

In this paper, we aim to complement the various studies in the literature by studying the effects of governor and excitation on electrical machines. In particular, we focus on the generator in conjunction with a hydraulic turbine governor. Faults (three phase) were introduced into the system and the stabilizing effects of the governor and excitation control is shown. This rest of this paper is arranged in the following order. Section 2 describes models of the governor, exciter and turbines. The methodology used in this work is presented in section 3. Section 4 presents the results of the simulation. Section 5 discusses the results and finally section 6 draws conclusions.

2. POWER SYSTEM MODELS

In this section, we present the models of the synchronous generator, exciter and governor.

2.1 SYNCHRONOUS MACHINE

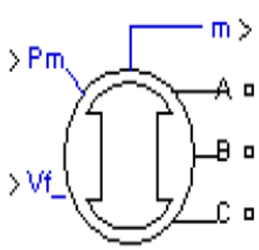

Figure 1: Simulink synchronous machine block
Source: (Matlab, 2019)

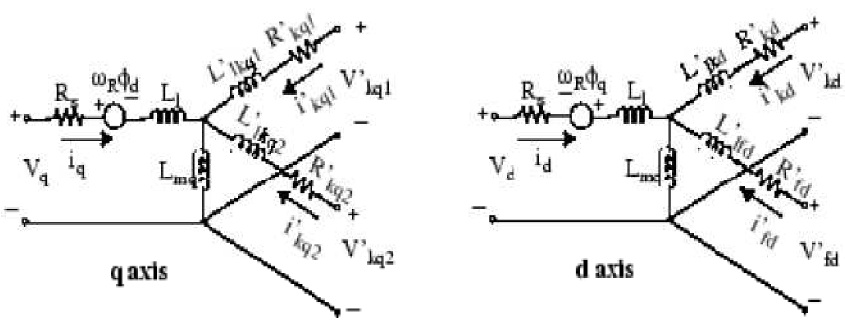

Figure 2: Electric model of synchronous machine
Source: (Matlab, 2019)

The synchronous machine in simulink can operate in the generator or motor modes. The mode of operation is determined by the mechanical power sign. When the sign is positive, it operates in the generator mode. A negative sign implies motor mode of operation. The mathematical model of the machine is represented by the following equations (Matlab, 2019):

$$V_d = R_s i_d + \frac{d}{dt}\varphi_d - \omega_R \varphi_q \qquad \varphi_d = L_d i_d + L_{md}(i'_{fd} + i'_{kd}) \tag{1}$$

$$V_q = R_s i_q + \frac{d}{dt}\varphi_q + \omega_R \varphi_d \qquad \varphi_q = L_q i_q + L_{mq} i'_{kq} \tag{2}$$

$$V'_{fd} = R'_{fd} i'_{fd} + \frac{d}{dt}\varphi'_{fd} \qquad \varphi'_{fd} = L'_{fd} i'_{fd} + L_{md}(i_d + i'_{kd}) \tag{3}$$

$$V'_{kd} = R'_{kd} i'_{kd} + \frac{d}{dt}\varphi'_{kd} \qquad \varphi'_{kd} = L'_{kd} i'_{kd} + L_{md}(i_d + i'_{fd}) \tag{4}$$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\varphi'_{kq1} \qquad \varphi'_{kq1} = L'_{kq1} i'_{kq1} + L_{mq} i_q \tag{5}$$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\varphi'_{kq2} \qquad \varphi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q \tag{6}$$

The subscripts d and q are used to represent the d and q axis quantity. R and s represents the rotor and stator quantity. l and m represents leakage and magnetizing inductance. f and k represents field and damper winding quantity.

2.2 GOVERNOR

The implementation of a combination of governor and hydraulic turbine in simulink is represented by the block in fig. 2.

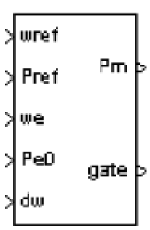

Figure 2: Simulink hydraulic turbine and governor
Source: (Matlab, 2019)

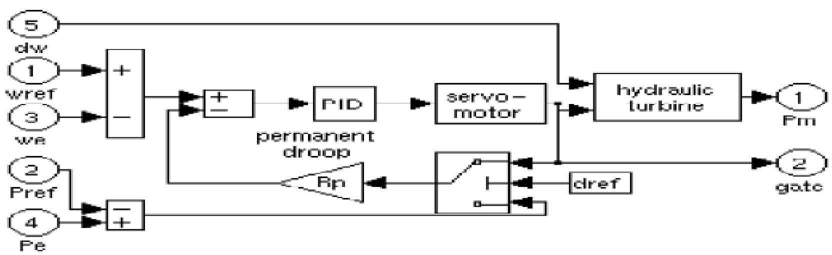

Figure 3: A hydraulic turbine and PID governor model
Source: (Hydraulic turbine dynamics, 1992)

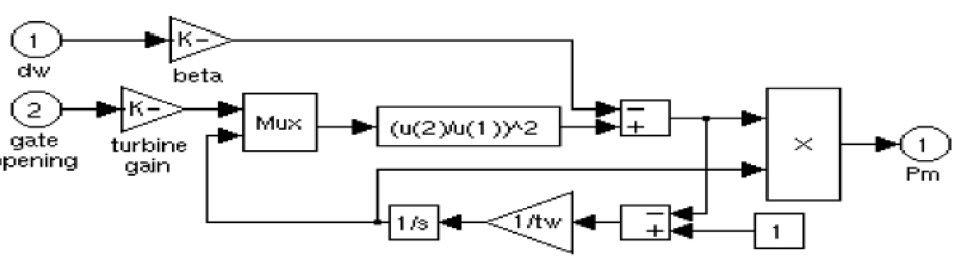

Figure 4: Nonlinear model of a hydraulic turbine. Source: (Hydraulic turbine dynamics, 1992)

2.3 EXCITER

Fig. 5 shows the synchronous machine excitation block. The excitation system regulates the terminal voltage of the synchronous machine in the generator mode.

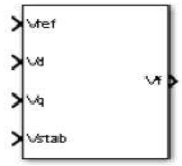

Figure 5: Simulink excitation system. Source: (Matlab, 2019)

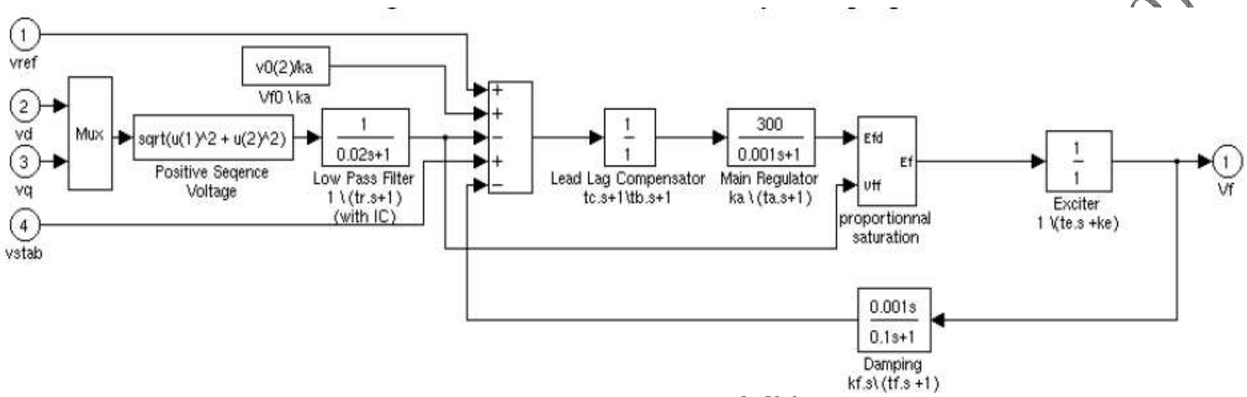

Figure 6: Internal configuration of the excitation system. Source: (Matlab, 2019)

3. METHODOLOGY

In this section, we present the model used in studying the effects of the governor and excitation system. This is shown in Fig. 7. The model was developed in simulink. The model shows a synchronous machine connected in generator mode and used in conjunction with a hydraulic turbine governor and an excitation system. The synchronous machine is connected to a 210kV network through a 210MVAtransformer. The results of the simulation is presented in section IV.

Table 1: Generator parameters

S/No	Description	Values
1.	Nominal power	200KVA
2.	Rated phase voltage	440V
3.	Initial mechanical power	48.9kW
4.	Nominal frequency	50Hz
5.	Rotor type	Salient pole
6.	Stator parameters	Rs(0.26Ω), L1(1.14mH) Lmd(13.7mH), Lmq(11mH)
7.	Field parameters	Rf(0.13Ω), Lf(2.1mH)
8.	Friction factor	0
9.	Inertia	24.9
10.	Pole pairs	2
11.	Preset model	No preset model

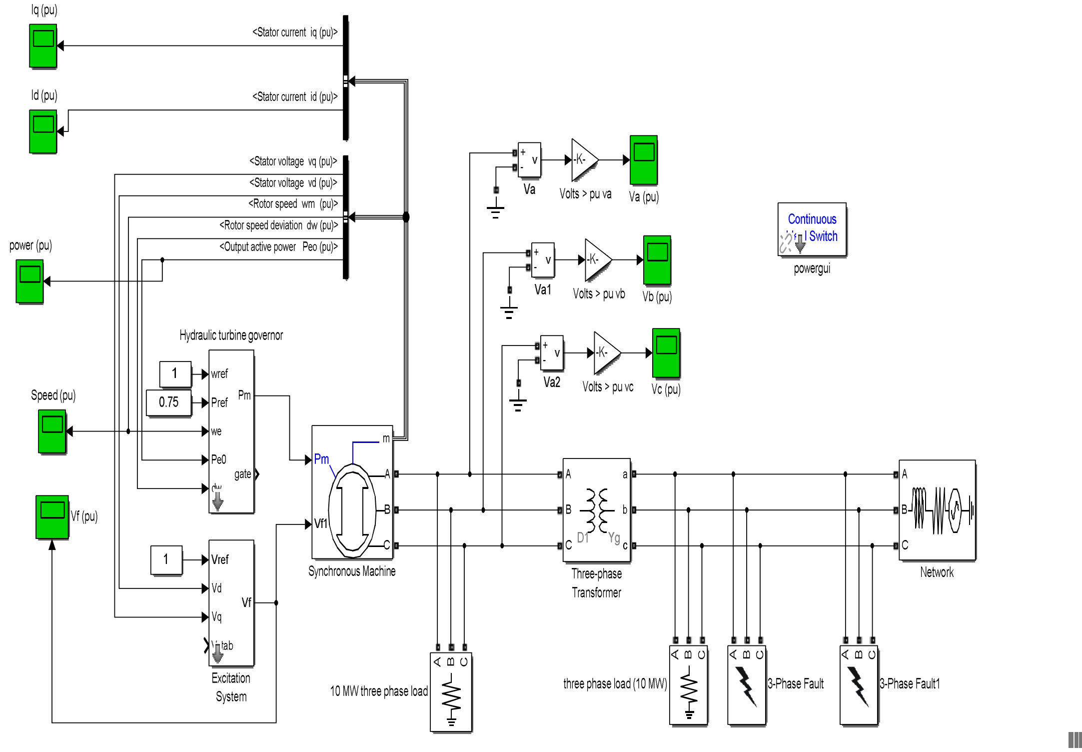

Figure 7: Simulation model to study effects of governor and excitation control

4. RESULTS

Case 1: Single fault for duration t = 0.1s (starts at 0.2s and ends 0.3s)

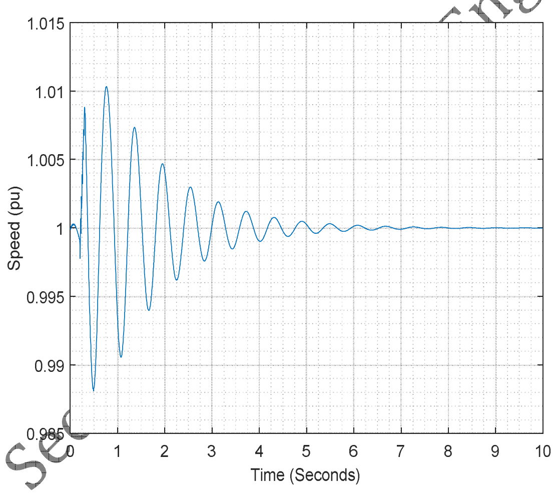

Figure 8: Rotor speed for case 1

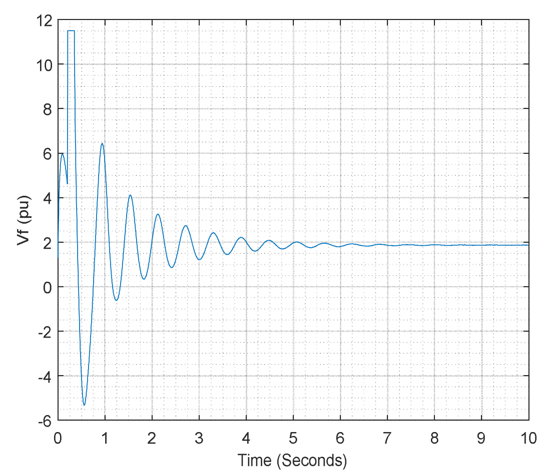

Figure 9: Field voltage for case 1

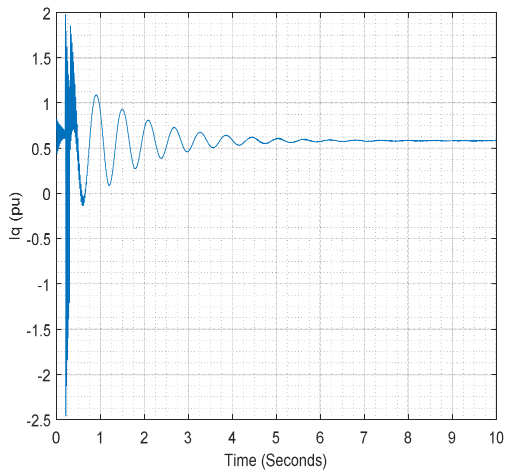

Figure 10: Stator current, Iq for case 1

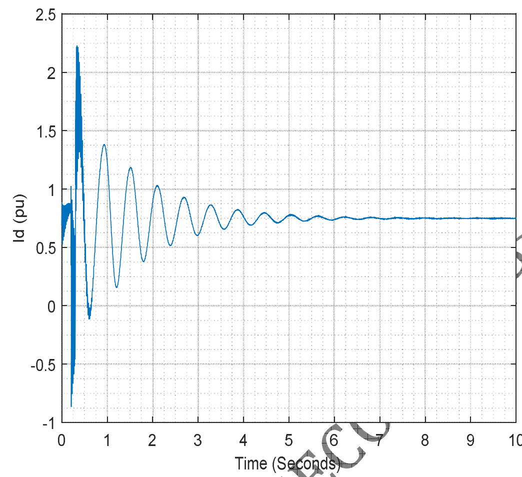

Figure 11: Stator current, Id for case 1

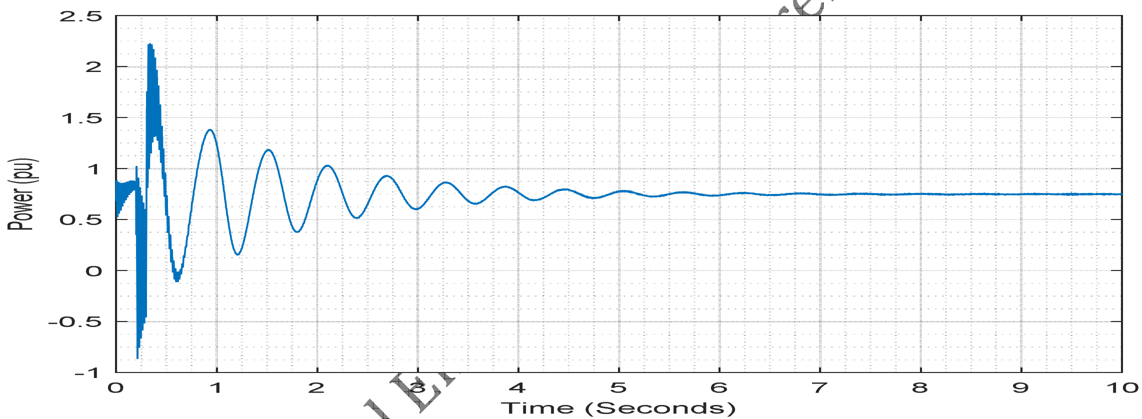

Figure 12: Mechanical power for case 1

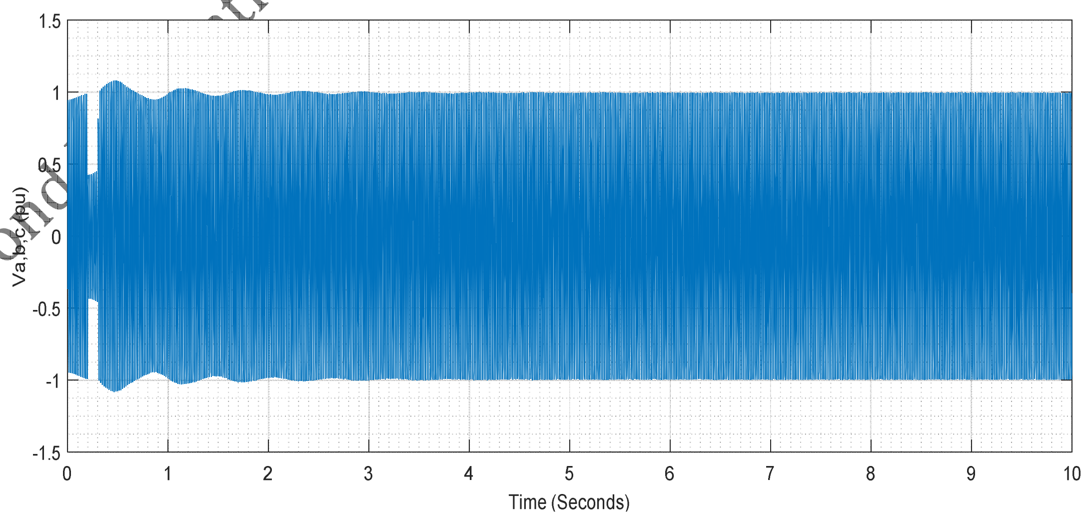

Figure 13: Terminal voltages, Va,b,c for case 1

Case 2: Single fault for duration t = 0.3s

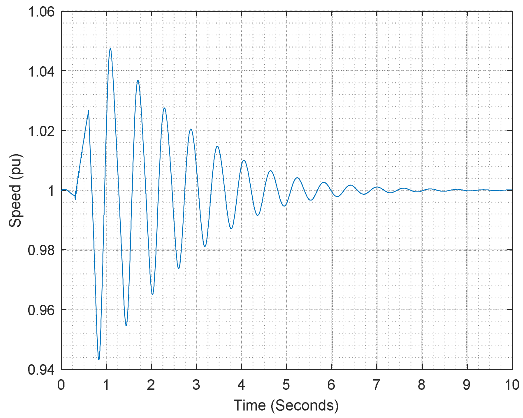

Figure 14: Rotor speed for case 2

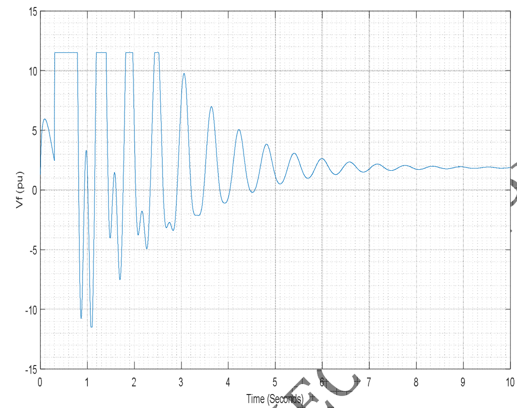

Figure 15: Field voltage for case 2

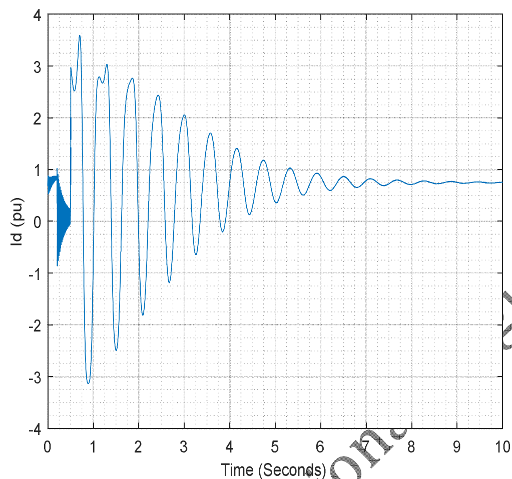

Figure 16: Stator current, Id for case 2

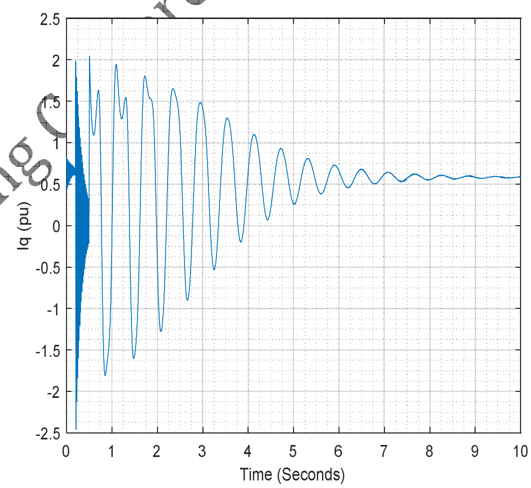

Figure 17: Stator current, Iq for case 2

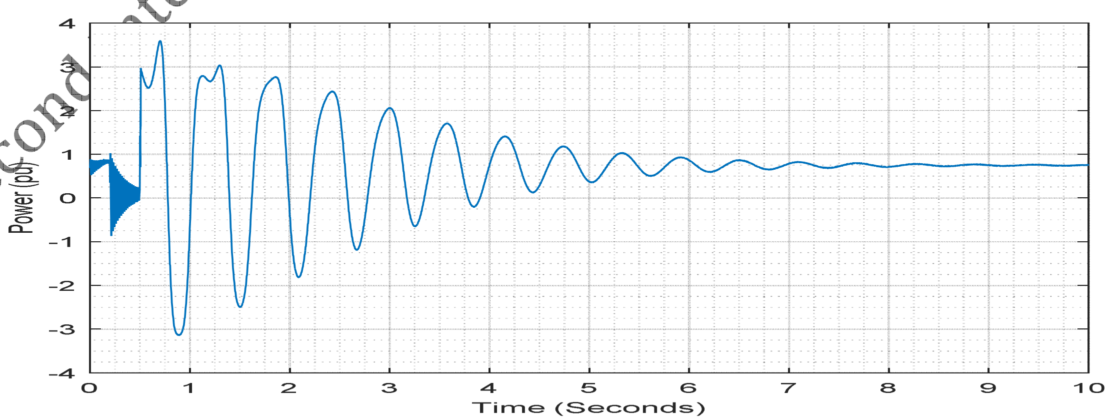

Figure 18: Mechanical power for case 2

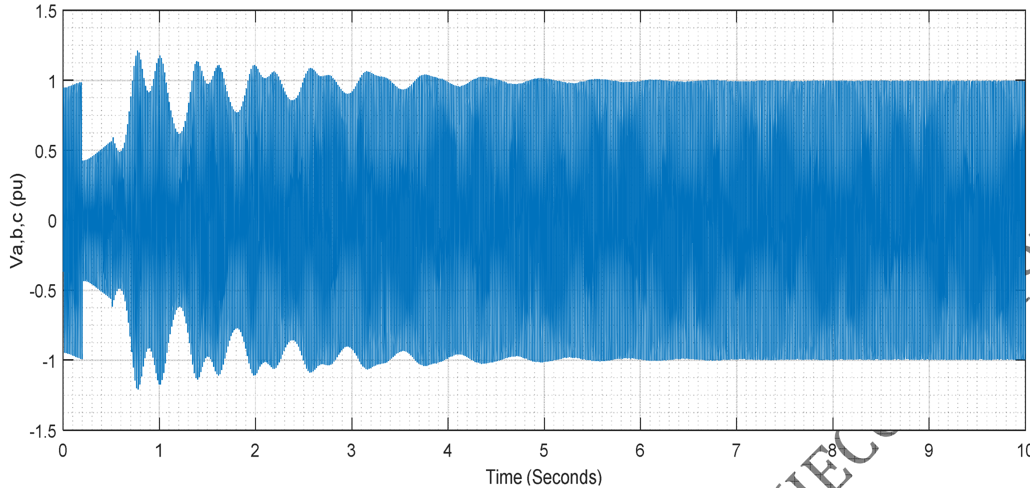

Figure 19: Terminal voltages, Va,b,c for case 2

Case 3: Multiple faults at time t = 0.2s and 1.2s – Each has a 0.1s duration

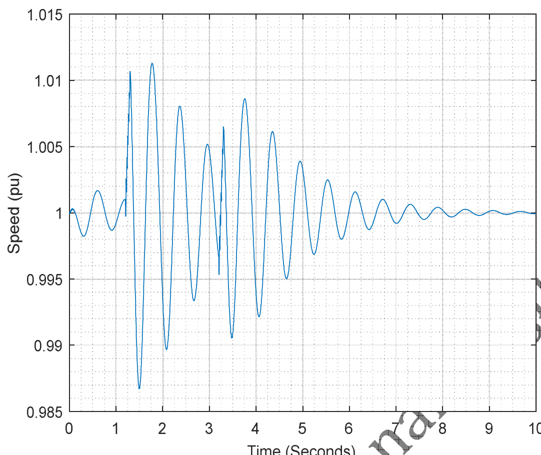

Figure 20: Rotor speed for case 3

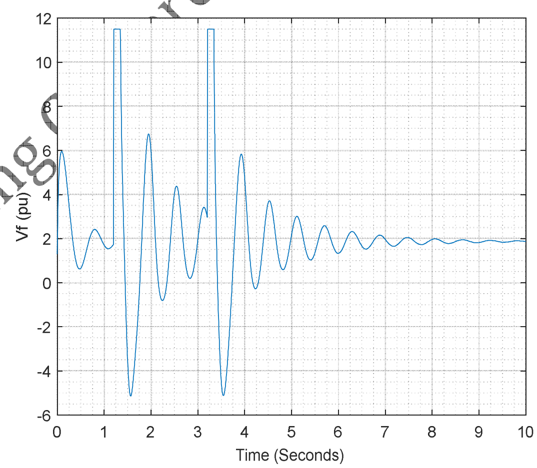

Figure 21: Field voltage for case 3

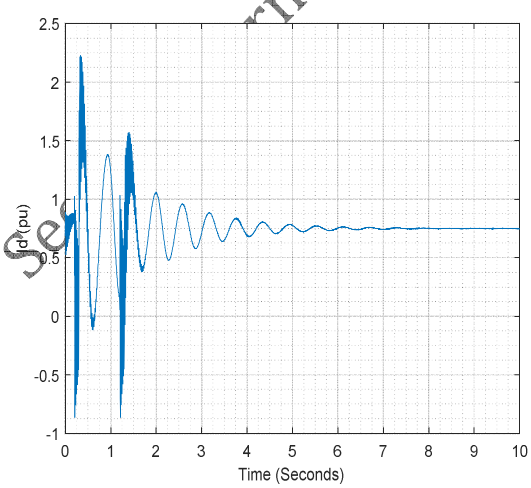

Figure 22: Stator current, Id for case 3

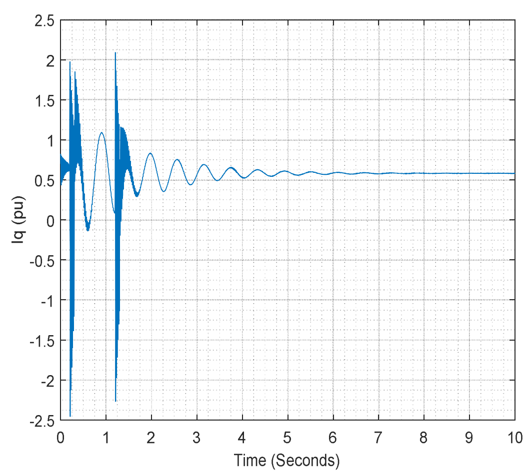

Figure 23: Stator current, Iq for case 3

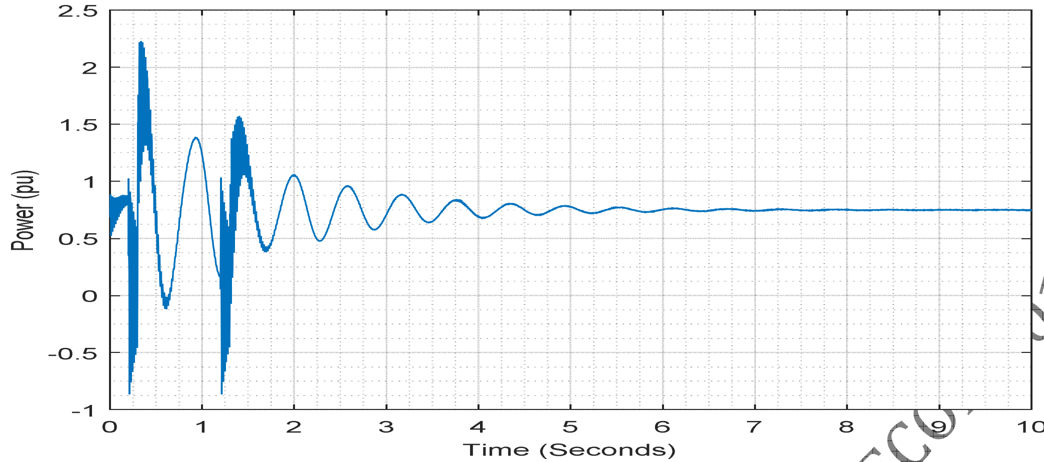

Figure 24: Mechanical power for case 3

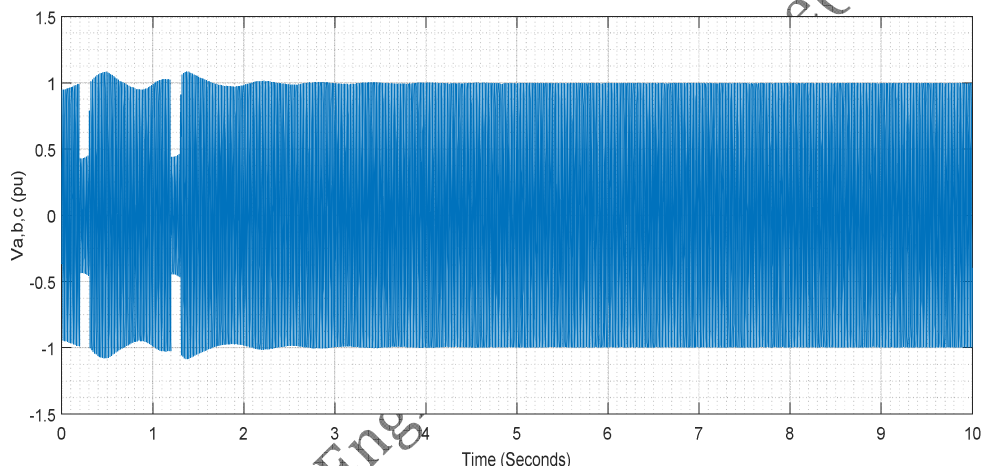

Figure 25: Terminal voltages, Va,b,c for case 3

5. DISCUSSION

The effects of faults on electric machines can be seen in figures 8 – 25. The stabilizing effects of the governor and excitation systems are also shown. In case one, a three phase fault was introduced into the system at 0.2 seconds after the machine starts. The fault lasts for 0.1 seconds. In figure 8, the system starts at a speed of 1 p.u. The introduction of the fault at 0.2 seconds causes oscillations in the speed. The oscillations are cleared and finally stabilized back to the nominal value. Figures 9-13 shows the oscillations caused by the faults to the field voltage, stator currents, mechanical power and output terminal voltage of the generator. Similarly, the governor and excitation dampens these oscillations to a steady state in 8 seconds. In particular, we focused on the generator output terminal voltages (Va, Vb and Vc) in figure 13. As can be seen in the plot, the oscillations caused by the fault caused a drop in the voltage. This is however cleared immediately by the governor and excitation control in 2 seconds after the fault was introduced and restores stability to the terminal voltages.

In case two, the duration of the faults was extended. These are shown in figures 14 – 19. A three phase fault was introduced at 0.2 seconds after the system starts. The fault lasts for 0.3 seconds.

As observed, the longer the duration of the fault, the higher the amplitude of the oscillation caused. The duration of the fault however, did not affect the damping and settling time caused by the stabilizing effect of the governor and excitation system. The settling time in case one for figures 9 – 13 was identical to that of case two for figures 14 – 18. Again in particular, special attention is given to the generator terminal voltages. As seen in figure 19, the duration of the fault first causes a drop in the output terminal voltage and then followed by extended oscillations when compared to that of case one (figure 13). This is however cleared and restored to steady state by the governor and excitation system in 5 seconds after the fault was introduced. The extended settling time is caused by the extended duration of the fault.

In case three, multiple faults were introduced at two different times. Each of the faults was for duration of 0.1 seconds. The first fault was introduced at 0.2 seconds after the system starts and the second fault was introduced at 1.2 seconds. Similar to case one and two, the oscillations in the field voltage, stator currents, mechanical power and output terminal voltage of the generator caused by the fault is damped and cleared. These are shown in figures 20 – 25. Also in focus in this case is the generator terminal voltage as shown in figure 25. Two drops in voltages can be seen in the plot. This is caused by the two faults introduced at 0.2 seconds and 1.2 seconds. This is however cleared immediately by the stabilizing effect of the governor and excitation control system in 1 second after the second fault.

6. CONCLUSION

This paper studied the effect of excitation and governor on the stability of electric machines. The generator terminal voltage was restored back to its nominal value within 2 seconds after a fault which lasts for 0.1seconds occurs. For extended fault duration of 0.3 seconds, the terminal voltage was stabilized within 5 seconds. Other system parameters such as the rotor speed, field voltages, stator currents and the mechanical input power were all restored back to their steady state values within 8 seconds after the fault occurs. These results show that the use of governors and excitation control can improve significantly the electromechanical oscillations, damping and the voltage stability of electric machines.

REFERENCES

Bevrani, H., Hiyama, T. (2006). Stability and voltage regulation enhancement using an optimal gain vector. *IEEE Power Engineering Society General Meeting, Canada*, pp. 1-6.

Bevrani, H., Hiyama, T. (2007). Robust coordinated AVR-PSS design using H_∞ static output feedback control. *IEEJ Trans Power Energy*. vol. 127, pp. 70-76.

Cao,Y., Jiang, L., Cheng, S., Chen, D., Malik, O., Hope, G. (1994). A non linear variable structure stabilizer for power system stability. *IEEE Trans Energgy Conversion*. Vol. 9, pp. 489-495.

Dash, P. K., Liew, A. C., Mishra, B. R. (1998). An adaptive PID stabilizer for power system usin fuzzy logic. *Electric Power Systems research*. Vol. 44, no. 3, pp. 213-222.

Hiyama, T., Ueki, Y., Andou, H. (1997). Integrated fuzzy logic generator controller for stability enhancement, *IEEE Transactions on Energy Conversion*. 12 (4). pp. 400 – 406.

Hiyama, T. (1997). Damping of multi-mode oscillations using integrated fuzzy logic generator controller. *APSCOM-97*. Vol. 1. pp. 77-82.

Hossain, J., Apel, M., Naruttam, K., Pota, H. (2013). Enhancement of transient stability limit and voltage regulation with dynamic loads using robust excitation control. *IJEEPS.* Vol. 14, no. 6, pp. 561-570. doi 10.1515/ijeeps-2013-0037

Hossain, J., Porta, H., Ugrinovskii, V., Ramos, A. (2010). Voltage mode stabilization in power systems with dynamic loads. *IJEPES.* Vol. 3, no. 2, pp. 911-920.

IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, Hydraulic Turbine and Turbine Control Models for Dynamic Studies. IEEE Transactions on Power Systems. (1992). Vol. 7, No. 1, pp. 167-179.

Lawt, K., Hill, D., Godferey, N. (1994), Robust coordinated AVR-PSS design. *IEEE Trans Power Syst*. Vol. 9, pp. 1218-1225.

Leona, A., Solsonaa, J., Figueroaa, J., Valla, M. (2011). Optimization with constraints for excitation control in sysnchronous generators. *Energy*. vol. 36, pp. 5366-5377.

Matlab/Simulink tutorials. (2019). Accessed 6th July, 2019. https://www.mathworks.com/help/physmod/sps/powersys/ref/synchronousmachine.html

Saidy, M. (1997). A unified approach to voltage regulator and power system stabilizer design based on predictive control in analogue form. *Int J Electrical Power Energy Syst.* Vol. 19, pp. 103-109.

Sharma, A., Jha, M., Qureshi, M. (2007). Governing control and excitation for stability of power systems based on ANIF. *IJIRSET*. 3 (1). pp, 13847 – 13855.

Theraja, A. K, Theraja, B. L. (2005).*A textbook of electrical technology*. 24th edition S. Chand

Ukoima, K. N. and Ekwe, O. (2019). A Review of the Impact of Electricity Supply on Economic Growth: A Nigerian Case Study. *IOSR-JEEE*. 14(1): pp. 28-34.