A Solution to Load Frequency Control Problem in Small Hydro Power Plant

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Abstract

This paper presents a solution for the problem of load frequency control in small hydro power plant (SHPP) for its continuous operation during dynamic condition. Hydro electric power is an efficient and reliable form of renewable energy. The small hydro power plant is designed for a run of river type, because it requires very little or no reservoir in order to provide more power to the turbine. The water will run straight through the turbine and back into the river to use it for the other purposes. This has a minimal environmental impact on the local ecosystem. In this paper load frequency control (LFC) has done with Governor model, Turbine model, Exciter model and Generator-Load model. PID controller has used in this proposed system to control rotor speed, output power and stator current. The proposed system is modelled by Hydraulic Turbine Governor (HTG), Excitation system with Synchronous Generator. Modeling and Simulation of small hydro power plant has designed and tested with MATLAB Simulink software. The proposed system is tested without fault and with fault condition with load. The fault is generated and simultaneously load is applied, to check the dynamic condition, after starting of the synchronous generator to check load frequency control. The observed results show that the proposed system is operated efficiently under dynamic condition.

Keywords: *SHPP, Hydro Electric Power, LFC, PID controller, HTG, Synchronous Generator*

1.0 Introduction

Hydro power plants whose capacities range from 1 to 15 MW are classified as small hydro power plants [1]. Small hydro power plants are among the ideal renewable energy resources to electrify isolated rural communities in developing countries. Unfortunately, it is technically feasible and cost wise to extend the national grid to isolated rural communities. As the current international trend in rural electrification is to utilize renewable energy resources, small hydro power plants have become paramount. This renewable energy resource has not yet been exploited sufficiently for electric generation.

One of the challenges in developing small hydro power plants are associated with the frequency control system. The frequency control system is intended to be cost-effective so that isolated rural communities can afford to develop their own small hydro power plants [2]. Moreover, the frequency control system is expected to be less complex and more reliable. Frequency stability can be defined as, the ability of power system to maintain steady frequency within an acceptable range (0.5%). It depends on the ability to keep the balance between a generated power and load demand, with minimum loss of load. There are two systems of interest namely isolated system and interconnected system.

A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation. However, the users of the electric power change the loads randomly and momentarily. It is impossible to maintain the balances of both the active and reactive powers without control. As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values.

Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled. The frequency is highly dependent on the active power while the voltage is highly dependent on the reactive power. Thus the control issue in power systems can be decoupled into two independent problems. One is about the active power and frequency control while the other is about the reactive power and voltage control. The active power and frequency control is referred to as load frequency control (LFC). The foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also referred to as unknown external disturbance.

In this paper, a model of one power plant (isolated system) having one power generation units connected to a source and load is considered. The main objective is to keep supplying the load at rated frequency therefore, a controller is required to deal with any sudden increase or decrease in load demand which will affect the frequency. A new control structure with a tuning method to design a PID load frequency controller for power systems is presented. The controller parameters are obtained by expanding controller transfer function. The proposed scheme ensures that overall system remains asymptotically stable for all bounded uncertainties and for system oscillations. Simulation results show the feasibility of the approach and the proposed method improves the load disturbance rejection performance significantly even in the presence of the uncertainties in plant parameters. The frequency of a system is dependent on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected throughout the system.

2.0 Recent Research Works

Dianwei Qian, et.al.,[3] have addressed the scheme of sliding mode control by model order reduction for the LFC problem of micro hydro power plants. They explained the two operating modes, i.e., isolated mode and grid-connected mode. Under each operating mode, mathematical model and model reduction are investigated and according to the reduced-order model, a sliding mode control law is subsequently derived. Since the control law is applied to the original system, a sufficient condition about the system stability is proven in light of small gain theory.

Ebru Özbay, et.al.,[4] have proposed a novel model design for small hydro power plant (SHPP) using linear and nonlinear turbine model without surge tank effects. They created this model using adaptive fuzzy logic controller to improve their implementations by developing a SHPP model without using conventional control methods. The conventional control methods require choosing individual P and I parameters for each load value whereas in the developed model this process carried out by means of a single equations by using adaptive fuzzy logic controller.

Ravindra Kumar Yadav, et.al.,[5] have introduced a variable structure controller to show the significant improvement in the transient response with different step input change in load. They explained an isolated hydro power plant and the rating of dump load. They reduced the rating of dump load to 50 percent of its plant rating by having variable flow rate of water. They discussed the potential advantages of variable flow rate of water in isolated hydro electric generation, the advantage of using multi-pipe system and the reduction in dump load rating with its transient response.

Pankaj Kapoor, et.al.,[6] have explained an electronic load controller which senses and regulates the generated frequency in a micro hydro power plant. They also explained an ELC is a solid-state electronic device designed to regulate output power of a micro-hydropower system and maintaining a near-constant load on the turbine generates stable voltage and frequency.

Marques.J.L,et.al.,[7] have discussed a full detailed modeling and new control scheme of three phase grid connected micro hydro electric power plant. They implemented a new control scheme which consists of multi-level hierarchical structure and incorporates maximum power point tracker for better use of hydro resource. They have also included the reactive power compensation and active power generation.

In this paper a new control structure with a tuning method to design a PID load frequency controller for power systems is presented. The controller parameters are obtained by expanding controller transfer function. The proposed scheme ensures that overall system remains stable during dynamic state conditions.

3.0 Modeling and Simulation of Small Hydro Power Plant

3.1 Modeling of Load Frequency Control:

Modeling of LFC can be obtained by combining the governor model, turbine model and generator load model and which is shown in the Figure 3.1. By assuming the single generator will supply power to the load and the generator is not connected to a network of very large size. In this system the incremental control input ΔP_C is due to the change in the speed changer setting while the incremental disturbance input ΔP_D is due to the change in load demand.

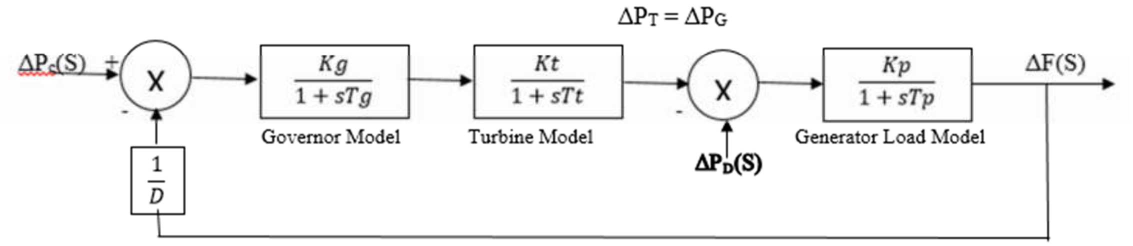

Figure 3.1 Modeling of Load Frequency Control

For steady state response uncontrolled case the speed changer has a fixed setting as $\Delta P_C = 0$.

$$\Delta f_{stat} = \frac{-K_P}{1+\frac{K_P}{D}} . \Delta P_D \qquad (3.1)$$

In controlled case the load demand remains fixed as $\Delta P_D = 0$.

$$\Delta f_{stat} = \frac{K_P}{1+\frac{K_P}{D}} . \Delta P_C \qquad (3.2)$$

For dynamic response the change in frequency as function of time for the uncontrolled case.

$$\Delta f(t) = \frac{-K_P}{1+\frac{K_P}{D}} . \Delta P_D \left[1 - e^{-t\left(\frac{K_P+D}{DT_P}\right)}\right] (3.3)$$

In controlled case,

$$\Delta f(t) = \frac{K_P}{1+\frac{K_P}{D}} \,.\Delta P_C \left[1 - e^{-t\left(\frac{K_P+D}{DT_P}\right)}\right] \quad (3.4)$$

3.2 Modeling of Hydraulic Turbine Governor:

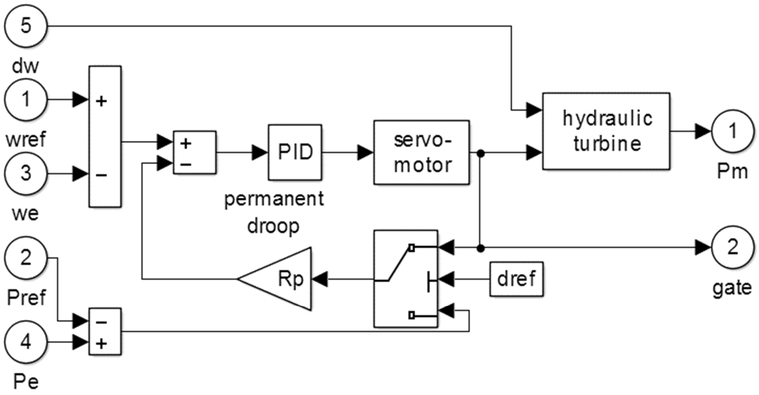

Figure 3.2 Modeling of Hydraulic Turbine Governor

The modeling of Hydraulic Turbine and Governor [8] implements a nonlinear hydraulic turbine model, a PID governor system, and a servomotor which is shown in Figure 3.2. The hydraulic turbine is modeled by the following nonlinear system which is shown in Figure 3.3.

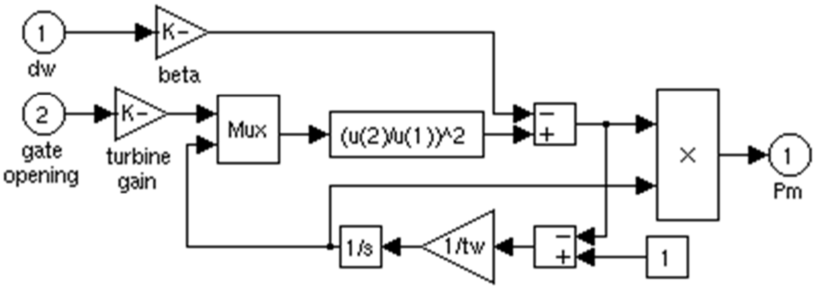

Figure 3.3 Modeling of Hydraulic Turbine

The gate servomotor [9] is modeled by a second-order system which is shown in Figure 3.4.

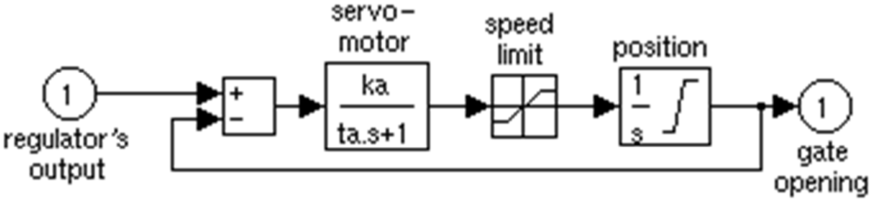

Figure 3.4 Modeling of Gate Servomotor

The servomotor gain K_a is 3.33 and time constant T_a is 0.07 seconds of the first-order system of the servomotor. The gate opening limits g_{min} and g_{max} (pu) are selected as 0.01 and 0.9753 imposed on the gate opening, and v_{gmin} and v_{gmax} (pu/s) are selected as -1.0 and 1.0 imposed on gate speed. The static gain of the governor is equal to the inverse of the permanent droop R_p of 0.05 in the feedback loop.

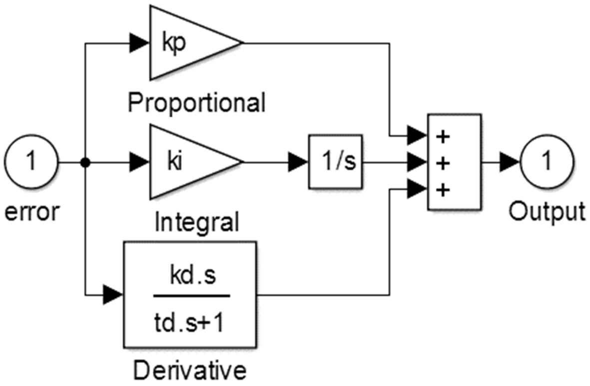

Figure 3.5 PID Controller

Figure 3.5 shows the PID controller. The PID regulator[10-11] has a proportional gain K_p of 1.163, an integral gain K_i of 0.105, and a derivative gain K_d of 0. The high-frequency gain of the PID is limited by a first-order low-pass filter with time constant T_d of 0.01 s. In Hydraulic turbine the speed deviation damping coefficient β is selected as 0 and water starting time T_w is selected as 2.67 s. Droop reference is specified as the input of the feedback loop in which gate position is set to 1 or electrical power deviation is set to 0. The initial mechanical power P_{m0} is selected as 0.7516 p.u. at the machine's shaft.

3.3 Modeling of Excitation System:

Modeling of an excitation system is shown in Figure 3.6. The basic elements of this system are the voltage regulator and excitor.

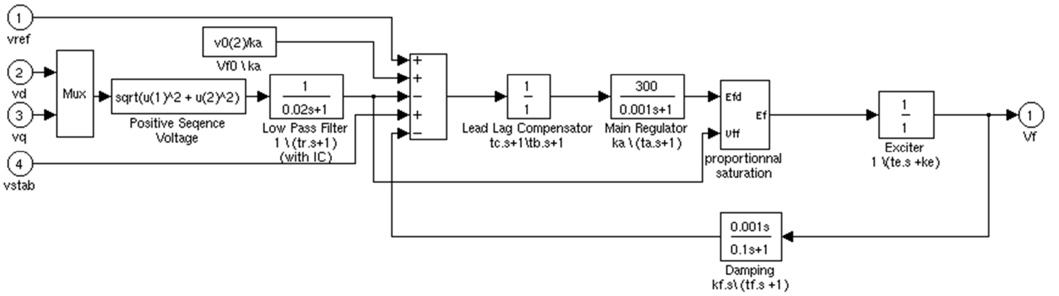

Figure 3.6 Modeling of Excitation System

The regulator gain K_a and time constant T_a are selected as 300 and 0.001 s. In the exciter the constants K_e and T_e are selected as 1 and 0.

3.4 Simulation of Small Hydro Power Plant:

The following Figure 3.7 shows the simulation of small hydro power plant by using MATLAB/Simulink.

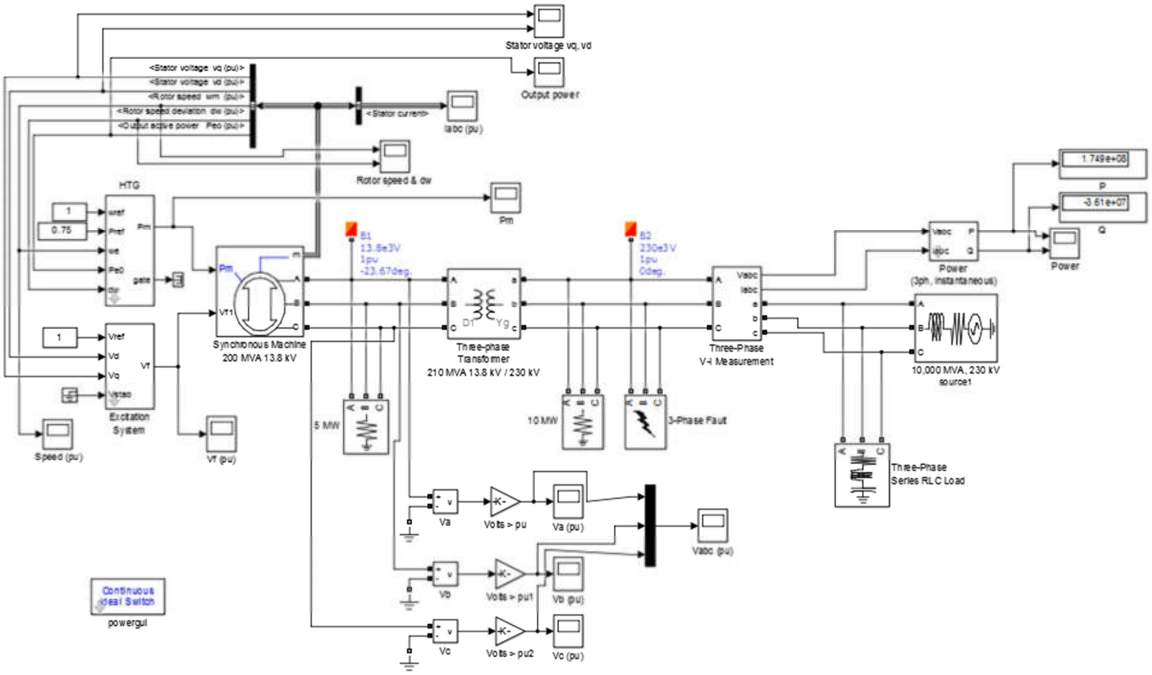

Figure 3.7 Simulation of Small Hydro Power Plant

A three-phase synchronous generator rated 200 MVA, 13.8 kV is connected to a 230 KV, 10,000 MVA network through a 210 MVA transformer. The series RLC load is connected to check the load frequency control before the source. At t = 0.1 s, a three-phase to ground fault occurs on the 230 kV bus. The fault is cleared t = 0.2 s. The system will be initialized in order to start in steady-state with the generator supplying 150 MW of active power and the dynamic response of the machine and of its voltage and speed regulators will be observed. In this simulation circuit, load flow will be initialized by providing terminal voltage as 13.8KV and active power as 150MW to start with steady state.

In order to start the simulation in steady state with the HTG and excitation system connected, these two Simulink blocks must also be initialized according to the values calculated by the load flow. This initialization is automatically performed when the load flow will be executed as long as the P_m and V_f inputs of the machine either constant blocks or regulation blocks from the machine library (HTG, STG, or Excitation System) will be connected.

The initial mechanical power has been automatically set to 0.7516 p.u (150.32 MW) by the Load Flow. Then, the initial terminal voltage and field voltage have been set respectively to 1.0 and 1.1291 p.u in Excitation system.

The simulation will be started with normal steady state condition. The voltage V_{abc} and current I_{abc} and other parameters as rotor speed and mechanical output power are observed. After that the simulation is started with dynamic state condition. During dynamic state condition the fault was generated and cleared from 0.1 to 0.2 seconds. The terminal voltage V_a is 1.0 p.u. at the beginning of the simulation. It falls to about 0.4 p.u during the fault and returns to nominal quickly after the fault is cleared. This quick response in terminal voltage is due to the fact that the Excitation System output V_f can go as high as 11.5 p.u which it does during the fault. The speed of the machine increases to 1.01 p.u during the fault then it oscillates around 1 p.u. as the governor system regulates it. The speed takes much longer than the terminal voltage to stabilize mainly because the rate of valve opening/closing in the governor system is limited to 0.1 pu/s.

The voltage V_{abc} and current I_{abc} and other parameters as rotor speed and mechanical output power are observed. Now the voltage, current and other parameters are observed and compared before and after dynamic state condition and also shown graphically.

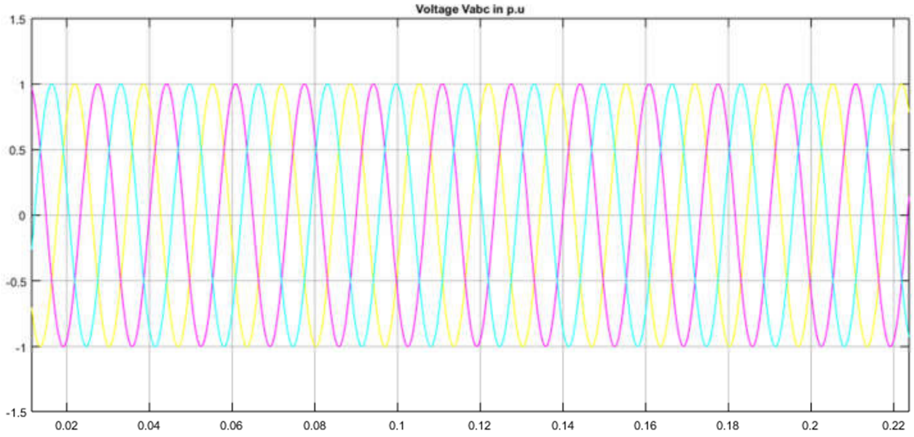

Figure 3.8 Voltage V_{abc} in p.u. Before Dynamic Condition

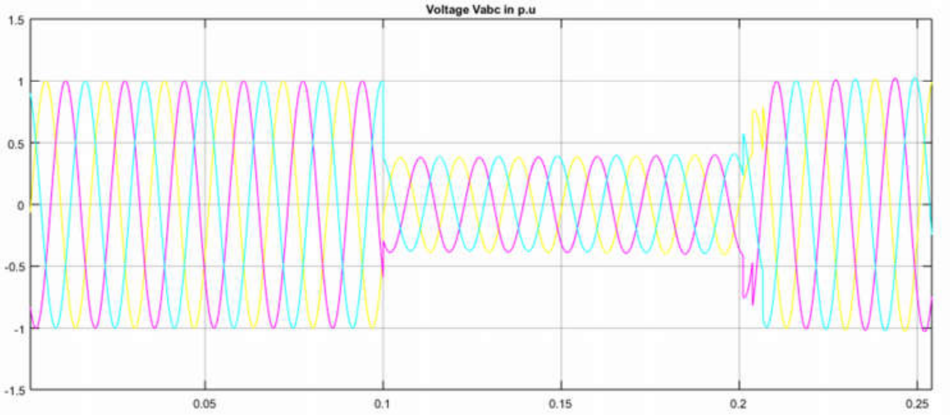

Figure 3.9 Voltage V_{abc} in p.u. During Dynamic Condition

Figure 3.8 and 3.9 show clearly that the voltage Vabc in p.u. before and during dynamic state condition. During the fault the voltage is disturbed and it will be normal after the fault is cleared.

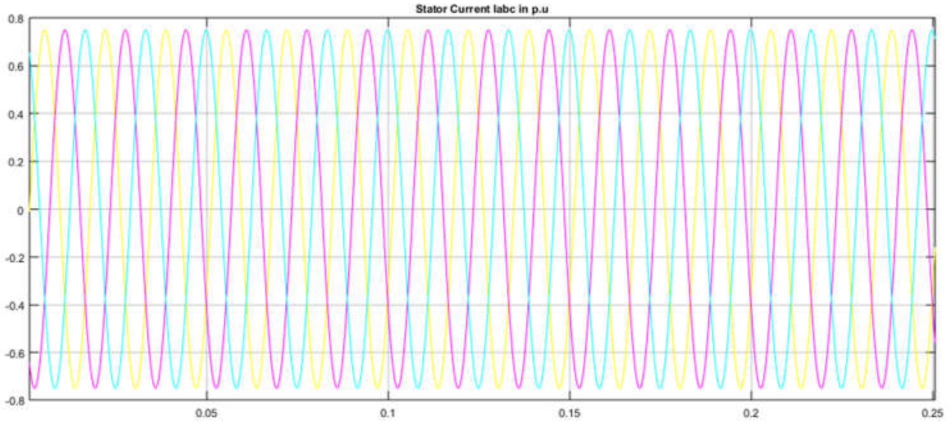

Figure 3.10 Stator Current I_{abc} in p.u. Before Dynamic Condition

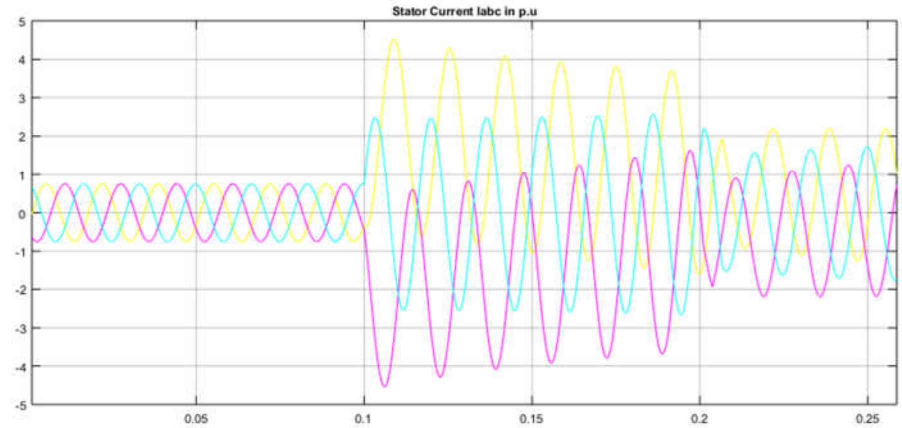

Figure 3.11 Stator Current I_{abc} in p.u. During Dynamic Condition

Figure 3.10 and 3.11 show clearly that the Stator current I_{abc} in p.u. before and during dynamic state condition. During the fault the current is disturbed and it will be normal after the fault is cleared.

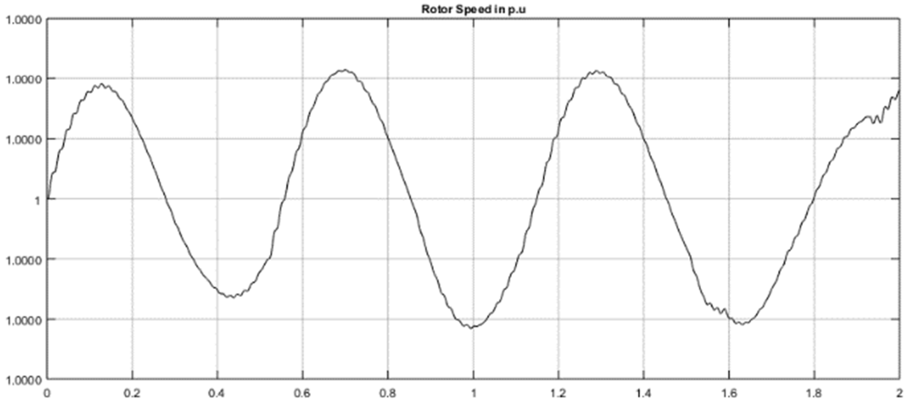

Figure 3.12 Rotor Speed in p.u. Before Dynamic Condition

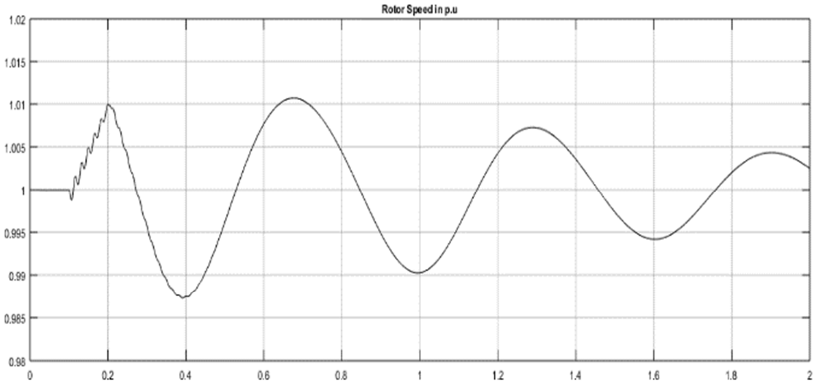

Figure 3.13 Rotor Speed in p.u. During Dynamic Condition

Figure 3.12 and 3.13 show clearly that the Rotor speed in p.u. before and during dynamic state condition. During the fault the speed is disturbed and it will be normal after the fault is cleared.

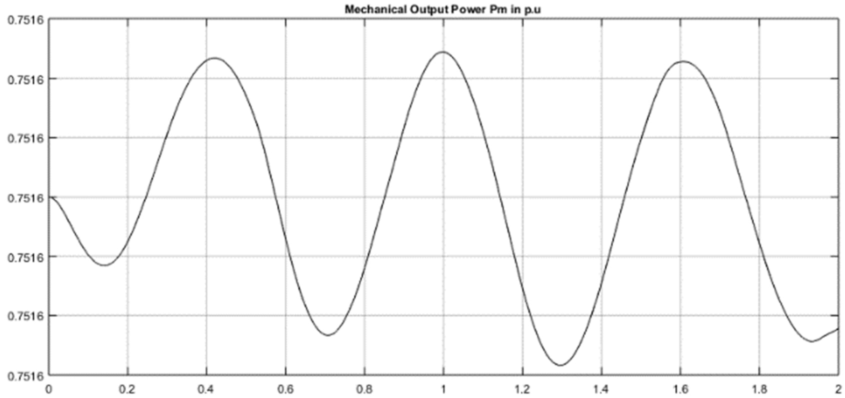

Figure 3.14 Mechanical Power Output in p.u. Before Dynamic Condition

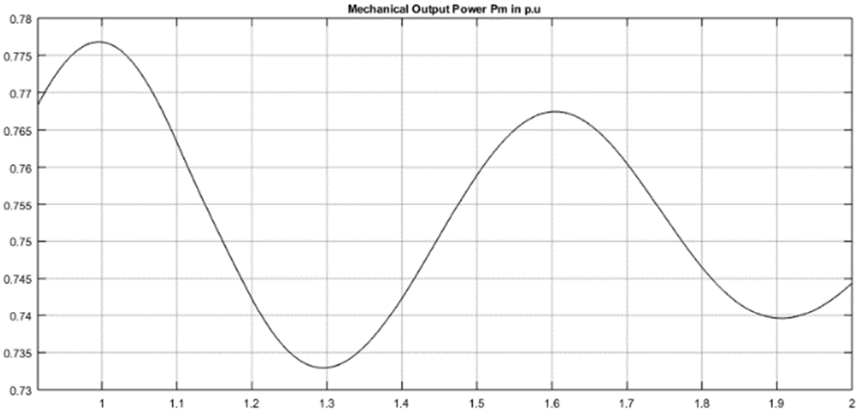

Figure 3.15 Mechanical Output Power in p.u. During Dynamic Condition

Figure 3.14 and 3.15 show clearly that the Mechanical Power Output in p.u. before and during dynamic state condition. Figure 3.16 shows the output power during the dynamic condition and it clearly states that the output power is disturbed from 0.1 to 0.2 seconds and came to normal after the fault is cleared.

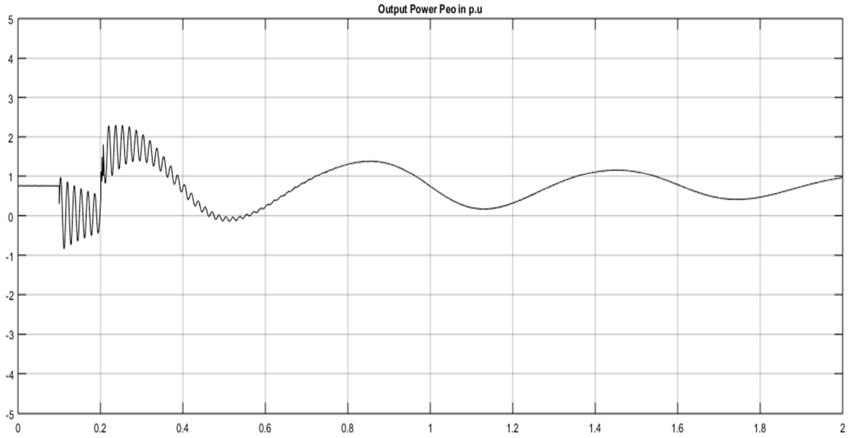

Figure 3.16 Output Power in p.u. During Dynamic Condition

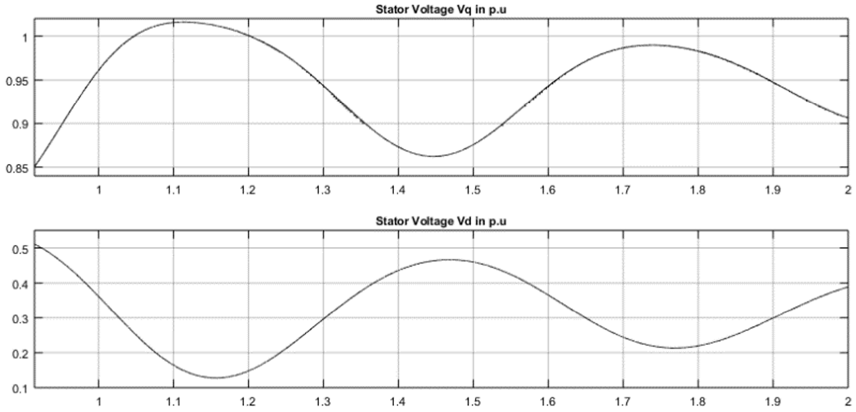

Figure 3.17 Stator Voltage V_q and V_d in p.u. During Dynamic Condition

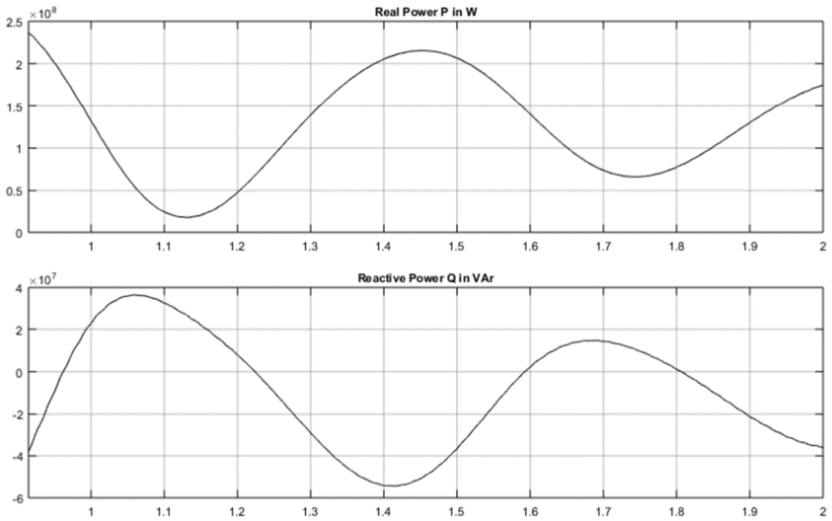

Figure 3.18 Real and Reactive Power During Dynamic Condition

Figure 3.17 and 3.18 show the stator voltage V_q & V_d and real and reactive power during dynamic state condition. From the graphs it is observed that the small hydro power plant is running efficiently during dynamic state conditions with load frequency control.

3.5 Summary

This paper presented a solution for the problem of load frequency control in small hydro power plant (SHPP) for its continuous operation during dynamic condition. Load frequency control (LFC) has done with Governor model, Turbine model, Exciter model and Generator-Load model. PID controller has used in this proposed system to control rotor speed, output power and stator current. The proposed system of SHPP was modelled by Hydraulic Turbine Governor (HTG), Excitation system with Synchronous Generator. The proposed system was tested without fault and with fault condition. The fault was generated at 0.1 second and simultaneously the load was also applied. During this condition stator voltage, stator current, output power, rotor speed and mechanical output power were observed. Fault was cleared at 0.2 seconds. All the parameters were observed after the clearance of fault. The observed values were drawn graphically before and during dynamic state conditions. Simulation of small hydro power plant was tested with MATLAB Simulink software. The observed results show that the proposed system was operated efficiently under dynamic conditions.

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Mr.Wondimu Dawit received M.Sc. Degree in Industrial Automation and Control Application Technology, from Adama Science And Technology Univ., on July 03, 2014 G.C., B.Ed. in Electrical and Electronics Technology Engineering, from BAHIR DAR University Faculty of Engineering on 23 SEP 2008 and DIPLOMA in Electrical and Electronics Technology from Adama Science and Technology Univ., on 8, July 2000. Currently he is working as an Associate dean for academic affairs in the college of engineering and as a lecturer, in the Department of Electrical and Computer Engineering, College of Engineering, Wolaita Sodo University, Sodo, Ethiopia. He has more than **14+** years of work experience in different Technology collages and Institutes with best performance and **3+** years of work experience in wolaita soddo university(from 2007-2009 E.C till now).