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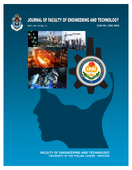

PID VS PI CONTROL OF SPEED GOVERNOR FOR SYNCHRONOUS GENERATOR BASED GRID CONNECTED MICRO HYDRO POWER PLANT

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Abstract

Most of the micro hydro power plants operating in isolated mode are based upon induction generator technology. However; in the recent years, there has been a growing interest in the use of synchronous generator based Micro Hydro Power Plants (MHPPs), for grid connected systems, because of the proven advantages over other renewable technologies where the extension of grid systems are economically viable for grid connection. Among various other components of micro hydro power plants, the speed governor mainly functions to control the hydraulic turbine. It constitutes not only the control mechanism but also the actuating equipment to regulate the flow of water, to start and stop the unit, and to regulate the speed and power output of the generator in case of any electrical disturbance. The proper control of actuating devices for these governors plays a significant role in stable and acceptable operation of the connected power system. The use of the Proportional-Integral-Derivative (PID) based control in speed governors is now gaining popularity because of the simplicity and flexibility. This research work makes an effort to analyze the behavior of the PID vs PI (Proportional-Integral) controllers; for speed governor operation of grid connected MHPP, deploying synchronous generator, under the influence of a electrical disturbance; to identify more suitable controller from the regulation point of view. The dynamic performance of the proposed controllers for speed governor function is fully validated through digital simulations carried out using MATLAB/Simulink software package.

Keywords: Speed Governor, Synchronous Generator, Micro Hydro Power Plant, Proportional-Integral (PI), Proportional-Integral-Derivative (PID)

1. Introduction

The electrical energy is one of the key factors for the socio-economic development of any country. Therefore, sufficient amount of energy generation in a sustainable fashion is of utmost importance. Rapid depletion of the fossils fuels and the associated environmental impacts are forcing to explore various renewable energy sources to aid the sustainable development of a country. Due to the very low adverse environmental and social impacts, the micro hydro power is coming to the forefront as a key resource of renewable energy [1].

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Furthermore; when the potential sites are available near to the local power grids, it is more economically feasible for grid connection in comparison to the other renewable resources specifically wind and solar [2, 3]. Moreover, the payback period for grid connected systems is reasonable, often 5-8 years or lesser [4]. Currently, Micro Hydro Power Plants (MHPPs) are based on synchronous or induction generators [5], but the plants deploying synchronous generators can be considered to be more consolidated and widely accepted [6].

Figure 1 shows the functional block diagram of a Micro Hydro Power Plant (MHPP) along with its various components interconnected with power system network. The performance of the power system is highly affected by the dynamic characteristics of these components not only during but also after any disturbance including a fault and a rapid change of load etc [7, 8]. In order to ensure power system stability, several levels of controls, including prime mover or turbine control and excitation control, are involved in a complex system to overcome and minimize the effects of the disturbances [9]. However, the primary control is the prime mover or turbine control achieved through a speed governor which regulates the active power along with the frequency by regulating the turbine-generator speed in order to respond to the load and water flow variations [10-13]. Numerous types of speed governors are available but the electro-hydraulic type is simple, flexible and gives better performance as far as the regulation of basic parameters is concerned [14-17], because it electrically performs the functions of computations, speed sensing and droop compensation [12, 15]. In electro-hydraulic speed governors, circuits providing compensation deploy Proportional-Integral (PI) or Proportional-Integral-Derivative (PID) controllers [12-17]. While supplying power to an isolated load, the stability of a hydro electric unit is ensured by adjusting the PID settings [12, 18]. Keeping in view, a grid connected system; this research work makes an effort, from the regulation viewpoint, to identify the better controller among PI and PID for speed governor to control the operation of a synchronous generator based MHPP in case of any electrical contingency. The study is conducted, deploying MATLAB/ Simulink, by analyzing the dynamic performance of the power system on the High Voltage (HV) side of the system considering constant load under transient and steady state conditions.

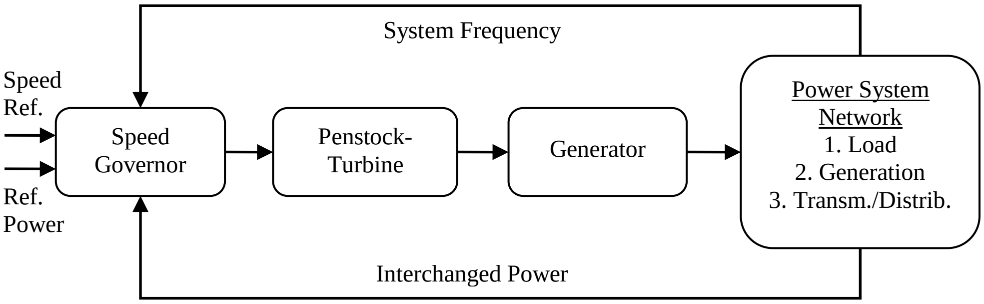


Figure 1. Functional block diagram of micro hydro power plant interconnected with power system network.

2. Theory of Speed Governor

The speed governor is an essential component of MHPP which regulates the flow of water through the penstock-turbine, by controlling the gate position, based upon the feedback error signal generated by analyzing the speed and load variations [12, 19]. This ensures not only the gird frequency stability but also balance of the active power considering variations in the load [19]. Principally, it is a combination of devices and mechanisms that detects the deviation in speed from the set point reference; the speed deviation is transformed into a signal and then amplified to trigger an actuator that controls and regulates the inlet water flow into the turbine [20]. The block diagram of a speed governor is given in Figure 2.

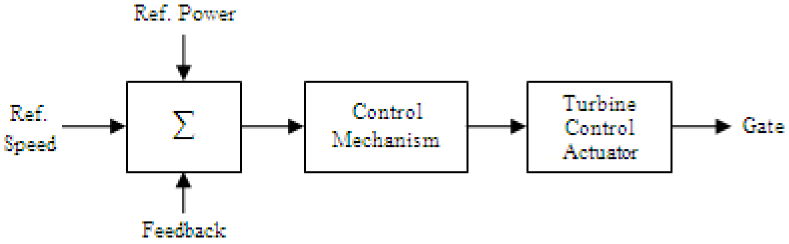


Figure 2. Block diagram of a speed governor.

2.1. PID Speed Governor

The name PID comes from the fact that it operates by utilizing the integral (the past control error), proportional (the present control error) and the derivative (the predicted control error). The PID speed governors have simple structure, stability, robustness and non steady state error [8]. PID speed governors function as an Automatic Voltage Regulator (AVR) for micro hydro power systems [21] by providing control mechanism using electronic circuits instead of mechanical components in the low power range [15]. To cope with the deviation in the speed, it generates a control signal to adjust the position of the gate of the prime mover achieved by the operation of various servos and hydraulic valves [19]. Rapid speed response is ensured by the PID controller facilitated by the provision of transient gain increment as well as the reduction [16]. The block diagram of a PID speed governor is given in Figure 3, where K_p, K_i, and K_d represent the gains, which are selected with the help of frequency response analysis and repeated time-domain simulations to provide the best response [15]. While, the parameters T_A, T_C, and T_D are the time constants of servos which depend upon the pressure and flow characteristics of the gate and associated servos.

2.2. PI Speed Governor

PI governor is simply a PID governor with gain $K_d = 0$ [10]; so it does not have a derivative action. In operation, it is effectively equivalent to a mechanical–hydraulic governor [12, 16].

3. Power System Under Consideration

Figure 4 shows the schematic diagram of the power system under consideration. A three phase 400 V, 85 kVA synchronous generator is connected to the 11 kV, 1000 kVA grid system. A micro hydro power turbine drives the DC excitation based synchronous generator. To connect the MHPP with the utility grid system, the AC voltage level of synchronous generator is stepped up to the grid voltage level using a 100 kVA transformer. The power generated by the synchronous generator based MHPP is fed to the grid system via 2.5 km transmission line.

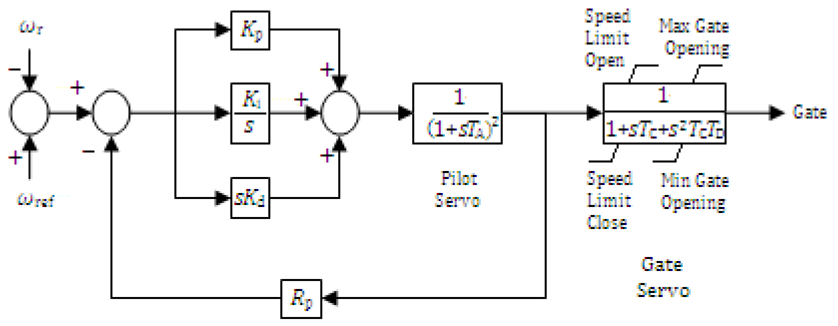


Figure 3. PID speed governor.

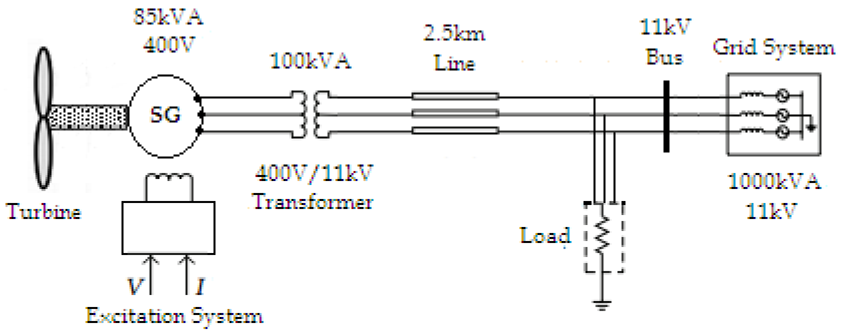


Figure 4. Schematic of power system.

4. System Simulation and Modeling

Generally, the mechanical power (P_m) available from a micro hydro power turbine is determined by the hydraulic power (P_{hyd}) which is proportional to the flow rate of the water (Q) and the effective hydraulic head (H). But in practice; this is reduced by an efficiency factor (η_{turb}) to account for the turbine power losses. In effect, mechanical power is equal to the product of turbine efficiency and hydraulic power. Mathematically:

$$P_m = \eta_{turb}\rho g Q H = \eta_{turb} P_{hyd} \tag{1}$$

However, for the modeling of an actual micro hydro power turbine, other factors must also be included to calculate the P_m. To take into account the inefficiency of the turbine the effective flow rate is given by taking the difference of the no load flow (q_{nl}) and the net rated flow (q_r). Its product with the effective rated head (h_r) gives the actual P_m. Furthermore, a speed deviation damping effect ($DG\Delta\omega$) must also be considered [10], which is a function of gate opening. Therefore, the mechanical power can also be expressed as:

$$P_m = A_t h_r (q_r - q_{nl}) - DG\Delta\omega \tag{2}$$

Where: D = the damping coefficient; G = the ideal gate opening based on the change from no load to full load; $\Delta\omega$ = the speed difference between the actual turbine-generator speed and the normal speed; A_t = the turbine gain, and it is calculated as:

$$A_t = \frac{\text{Turbine kW rating}}{\text{Generator kVA rating } h_r\left(q_r - q_{nl}\right)} \tag{3}$$

The mechanical power from the hydro turbine is used to drive the generator. The electrical power (P_e) produced by generator, is mathematically expressed in terms of mechanical power from turbine as:

$$P_e = \eta_{gen} P_m \tag{4}$$

This is the final output power from a MHPP in the form of electricity that is exported towards utility grid. Where: η_{gen} gives the generator efficiency to account for the generator power losses during conversion.

The simulation model of the power system under consideration is presented in detail in Figure 5. The simulations were performed by using 'SimPowerSystems' library in MATLAB/Simulink. For modeling the speed governor and turbine, the 'Hydraulic Turbine and Governor (HTG)' block-set is used from the 'Machines' sub-library. Excitation system and synchronous generator are modeled using 'Excitation System' and 'Synchronous Machine' block-sets respectively from the same sub-library. Three phase transformer, transmission line, load, and fault are modeled using 'Three-phase Transformer', 'Three-phase Pi Section Line', 'Three-phase Parallel RLC Load', and 'Three-phase Fault' block-sets respectively from the 'Elements' sub-library. Grid system

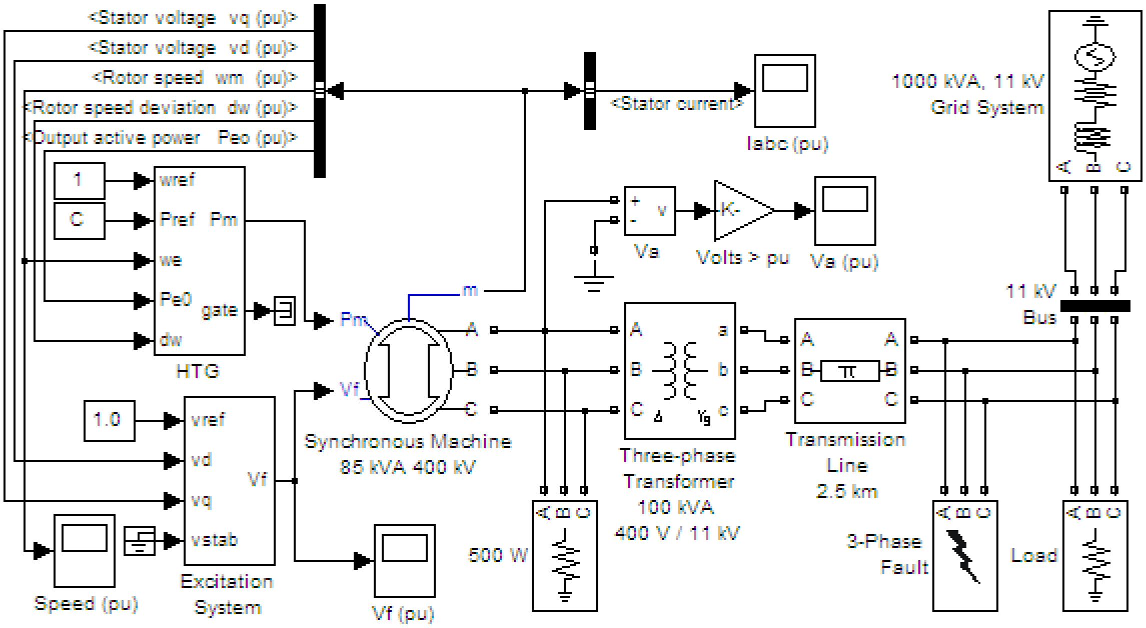


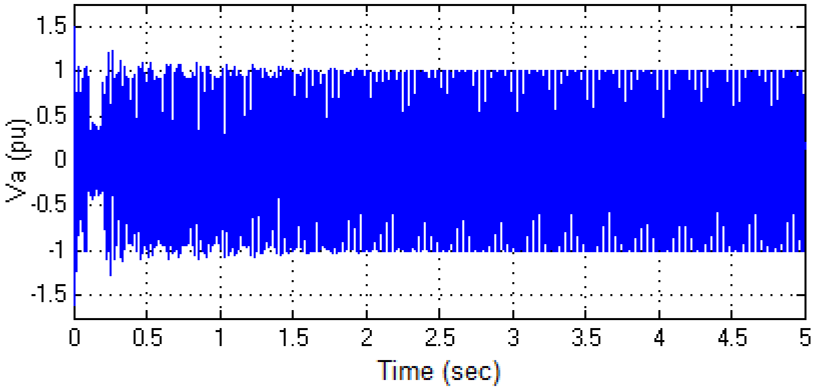
Figure 5. System simulation model.

is modeled using ‘Three-phase Source’ from ‘Electrical Sources’ sub-library, while the bus is modeled using the ‘Three-phase V-I Measurement’ block-set from ‘Measurements’ sub-library.

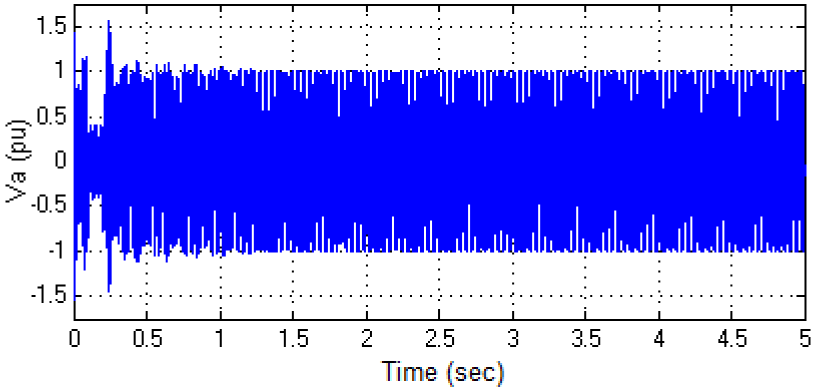
5. Results and Discussions

This section presents the simulation results of MHPP for both PID and PI controller based speed governors. The models are simulated for both PID and PI controllers to assess the regulation performance of the synchronous generator based MHPP against a three-phase to ground fault at full load, in the grid connected mode. The results consist of variation in synchronous generator terminal voltage, three phase stator current, field voltage and rotor speed under transient and steady state conditions. The simulation time for both the controllers is 5 sec with a three phase to ground fault, on 11 kV bus, occurring at 0.1 sec for a duration of 0.1 sec.

Figure 6 illustrates the terminal voltage variations for PID and PI controllers. For PID controller, the terminal voltage varies when the simulation starts. During the fault (transient state), it goes to approximately 0.4 pu and returns to nominal (steady state) value approximately at t = 1.9 sec, after the fault is cleared. For PI controller, the terminal voltage also drops down to approximately 0.4 pu during the fault; however, it returns to nominal value rapidly i.e. approximately at t = 1.1 sec after the fault clearance.



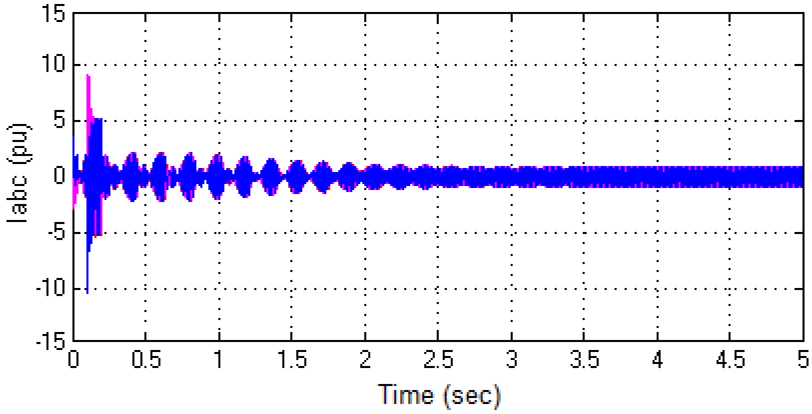
(a) PID based speed governor case



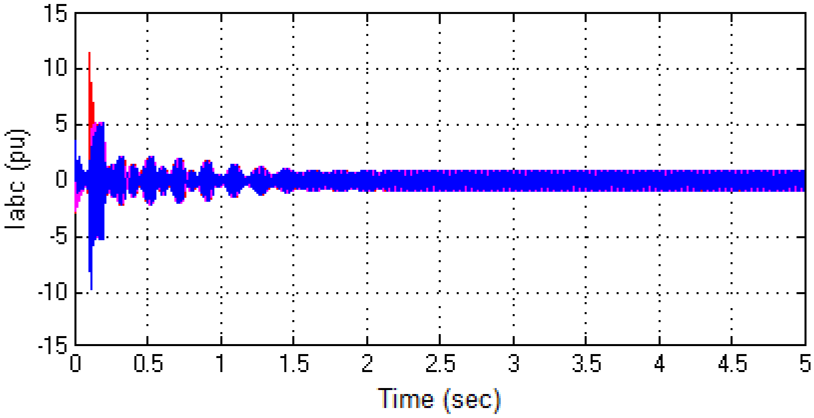
(b) PI based speed governor case

Figure 6. Terminal voltage variations vs time.

Figure 7 shows the stator current variations for both the controllers. For PID controller, the stator current increases significantly at the time of fault and reaches about 9 pu during the transient state returning to steady state, approximately at t = 3.4 sec, after the fault is cleared. For PI controller also, the stator current reaches a very high value of about 11.5 pu during the fault and returns to the nominal value, approximately at t = 2.1 sec, after the clearance of the fault.



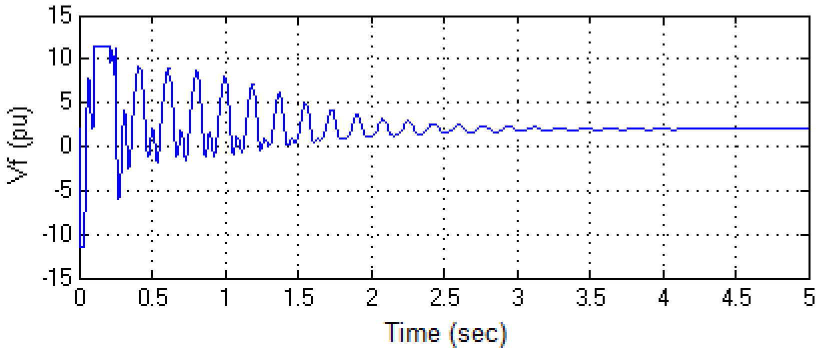
(a) PID based speed governor case



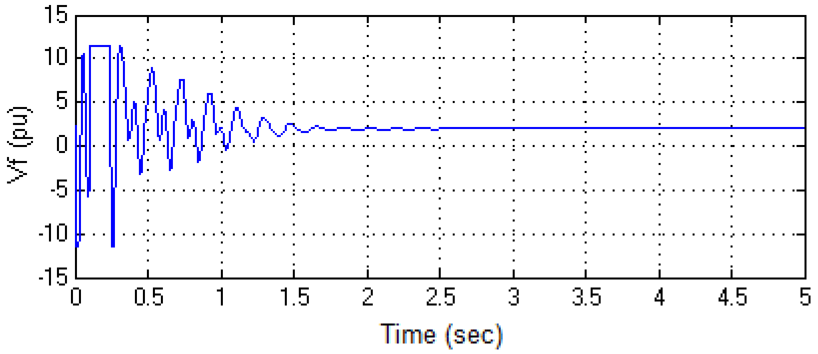
(b) PI based speed governor case

Figure 7. Stator current variations vs time.

Figure 8 reveals the field voltage variations. For PID controller, the field voltage rises severely to the value of 11 pu during fault and returns to nominal value, approximately at t = 4.1 sec, after the fault clearing. For PI controller, the field voltage also rises to the value of 11 pu during fault and returns to nominal value, approximately at t = 2.5 sec, after the fault is cleared. Figure 9 demonstrates the rotor speed variations. For both PID and PI controllers the rotor speed is near to 1 pu during the fault and oscillates around it. To regulate it, PID speed governor takes approximately 4.2 sec, while PI based speed governor takes 2.2 sec approximately. Hence, it is evident from the aforementioned results that the response time of PI controller is lesser than that of PID controller while the severity of the fault in either of the cases is comparable.

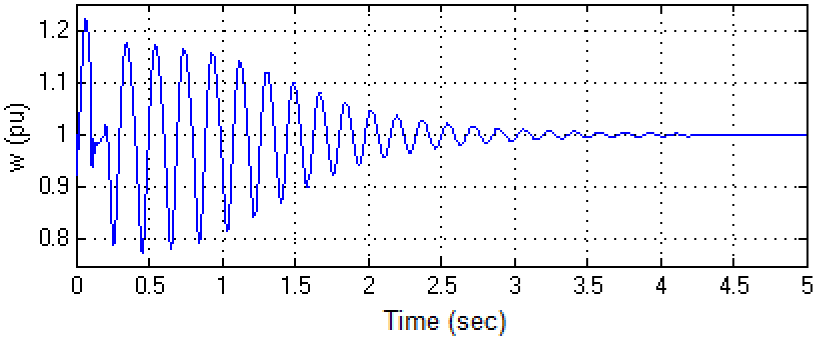


(a) PID based speed governor case

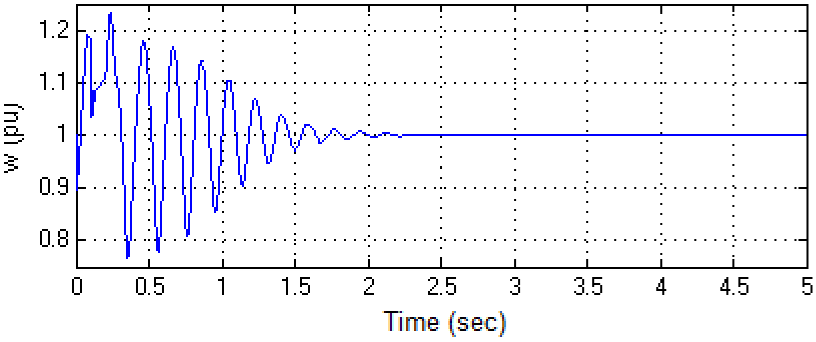


(b) PI based speed governor case

Figure 8. Field voltage variations vs time.



(a) PID based speed governor case



(b) PI based speed governor case

Figure 9. Rotor speed variations vs time.

6. Conclusions

The models of a grid connected synchronous generator based MHPP deploying both PID and PI controller based speed governors are built using the MATLAB/Simulink. To perform the comparative analysis of PID and PI controller based speed governors for grid connected MHPP under transient and steady state conditions, simulations were carried out to analyze the variation of synchronous generator terminal voltage, three phase stator current, field voltage and rotor speed under transient and steady states for constant load considering three phase to ground fault. From the simulation results, it can be concluded that the PI controller is the better suited option for the control mechanism of speed governors for grid connected MHPPs owing to its better regulation performance as compared to the PID controller. It requires lesser times to ensure the return of the system, to the steady state after the fault clearance. However the values of proportional and integral gains must be optimized because these parameters play a significant role in determining the time required by the system, to become steady.

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