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A Matlab / Simulink Based Fault Analysis of Small Hydropower Plant

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Abstract: *Renewable Energy Sources (RES) are well-defined as energy sources, that are in abundance within the natural surroundings and are much inexhaustible. In addition, hydroelectricity (HE) is a vital part of world renewable energy supply and Hydropower remains a bulk source of electricity generation because of its environmental friendliness in nature. Modeling is the analysis of the non-linear models which represent the fundamental parts of the Hydropower plant (governor, turbine, servomotor). This paper studies accurate and elaborate hydraulic turbine and governor models and its implementation in MATLAB/Simulink combined with the Sims cape Power Systems (SPS). An effort has been created to develop a plant model and examine the suitableness of controllers during a governor model for fault incidence within the system by means Simulink based simulation. The Ziegler– Nichols tuning methodology was applied for specifying the gain coefficients of a governor (PID-PI) under 50% of load demand from the plant. Also, MATLAB/Simulink gave the chance to record and compare the figures of the plant with PID & PI controllers through simulation tests within the commonest cases (three-phase fault, load demand variation) with a view of finding out the potency and therefore, the stability of the system.*

Keywords: *Renewable energy, hydroelectricity, fault incidence, PID & PI controller*

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1. NTRODUCTION

The excessive usage of fossil fuels has led to world climatic changes and warming. It's believed that attention should be drawn towards the application of renewable energy sources that possess the potential to be the foremost appropriate future fuel. With the rise within the request for electrical energy, Hydropower plants have assumed importance [7]. Hydropower plants are known as an appropriate alternative to conventional electricity generation for many developing countries around the world. However, these are affected by numerous technical and economic challenges. Hydropower is rising as a great contributor to the planet's energy demand [9]. Hydropower is inexhaustible and clean in nature; it is the answers to the matters of environmental pollution [4]. On the contrary, it needs an oversized space and initial capital investment is incredibly high. The main supply provided by electrical power utilities is the kinetic energy of water that is regenerated into mechanical energy by the prime movers. The voltage to be equipped to the end-users is then transformed from energy by the synchronous generators. The speed governing system adjusts the generator speed deviations of each system frequency and interchanged power with reference to the reference settings. This is to confirm that the generator operates at or close to the nominal speed at the least bit times. A fault in the electrical system is defined as a defect within the electric circuit because current is diverted from the supposed path. The characteristic of fault merely implies any abnormal condition that causes a reduction within the basic insulation strength between phase conductors or between phase conductors and ground. The foremost common and dangerous fault, that happens in a very power system is short or shunt fault. This fault arises as a result of a breakdown of insulation of current-carrying phase conductors relative to earth or within the insulation between phases. [12],[13] The Line to ground, fault happens most typically in overhead line practice. The balanced three-phase faults are incredibly rare in incidence, accounting for less than 5% of the whole, but it is the severest of all sorts of faults and imposes the foremost harm on the circuit breakers. Faults sustained on the system and period of the faults can be decreased by improving the system design. The steady-state operation of a 3- phase ac power system is a balanced one. However, sudden external, or internal changes within the system disrupt this condition. Failure of insulation of the system at one or more points or the coming of life point in the contact with a conducting object results in a short circuit. Fault involve all the 3-phases are known as symmetrical(balanced) fault whereas one involving one or two phases is known as an unsymmetrical fault. In abnormal operation, the synchronous the generator could also be subjected to transient conditions which can occur as a result of switching, sudden load variation, and sudden short circuit. This short circuit could develop severe mechanical stresses on the generator coil which can damage it. Fault conditions, don't seem to be confined to 3-phase condition, and so the majority of fault that occurs in power system are unsymmetrical faults, like a single line to ground faults, line to line faults, Generally, in power system synchronous generator could also be subjected to different kinds of faults at its terminals. These faults are listed as follows within the increasing order of severity. [8],[12] Ø Single line -to- ground (L - G) fault. Ø Line - to line (L - L) fault Ø Double line -to ground (L -L- G) fault Symmetrical 3-phase (L- L - L or L - L – L - G) fault. Note in this paper the sort of fault simulated is L-L-L-G fault

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II. METHODOLOGY

In this section general methodologies models of key elements of the plant, such as the synchronous generator, the hydraulic turbine, and the governing system, excitation system, Hydraulic Servo System Modell, Modelling of Proportional Integral Derivative (PID) and simulation are described.

1.MODELLING AND CONTROL OF SMALL HYDROPOWER PLANT (SHPP)

The modeling of SHPP elements, such as a synchronous generator, the hydraulic turbine, and the governing system is essential to study the electric power system behavior during any perturbation on the system. The power system exhibition is affected by the dynamic characteristic of a turbine and Its governing systems when the system perturbs influence Power system performance. Fig 1 below shows the block model

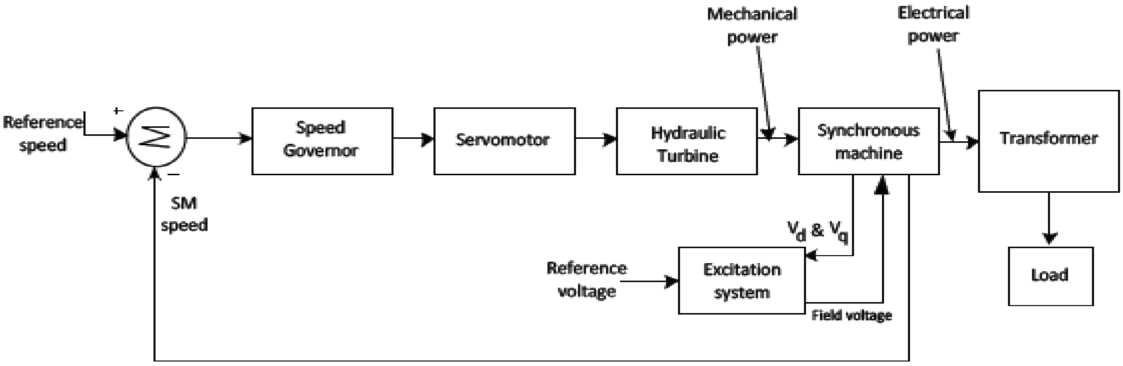

Fig:1 Block diagram of the Hydropower plant model [8]

of the turbine governor system.

The reference speed is fed into the governor, the servo motor control gate valve in accordance to signal of proportional integral derivative (PID) controller. The measured generator speed is fed backward to compare the reference setting of the speed signal. The speed deviation is gotten by comparing the speed of reference and generator speed is fed into the PID as input error. The control signal is initiated by PID which triggers an adjustment in gate position. The turbine creates a starting torque that drives the generator which produces the electrical energy as an output. The PID which is the speed governor constantly monitors the variation in the process. The governor produces the control signal that triggers an alteration in the gate opening. [10]

2 Modelling of Proportional Integral Derivative (PID) Controller

The PID is the speed governor, it reduces the error in speed which is fed into its input by amending its constants. It tries to reduce the deviation between the real speed and speed of reference. The PID can also be called three-term controllers. The P, I, and D terms donate proportional, integrator and derivative respectively. The P, I, and D terms depended on the current, past and future error respectively.

Equation 1 represents the PID output response.

$$\theta(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \qquad (1)$$

Equation 2 is gotten be applying Laplace scheme.

$$\theta(s) = k_p E(s) + k_i \frac{E(s)}{s} + k_d\, sE(s) \qquad (2)$$

The PID transfer function is given in equation as inequation 3

$$C(s) = \frac{Q(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \qquad (3)$$

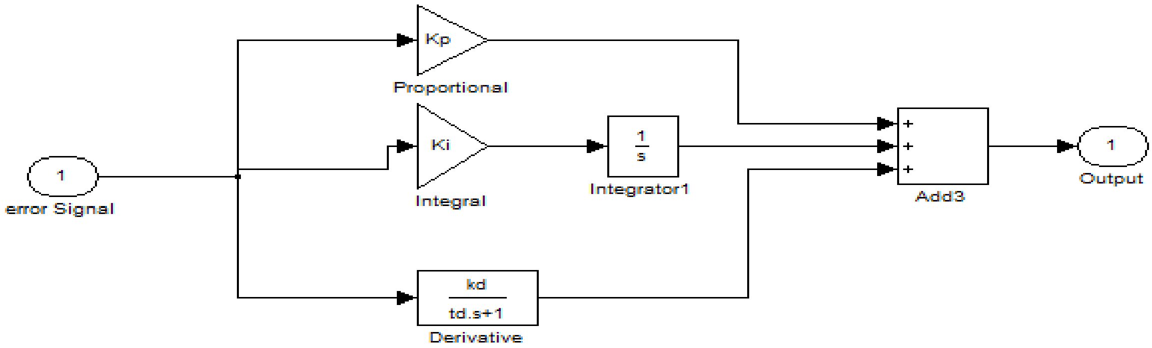

Fig.2: Block Model showing PID Controller in Simulink

3.MODELLING OF PI CONTROLLER

In the PI controller, the derivative action is absent. The controller Simulink model is shown below.

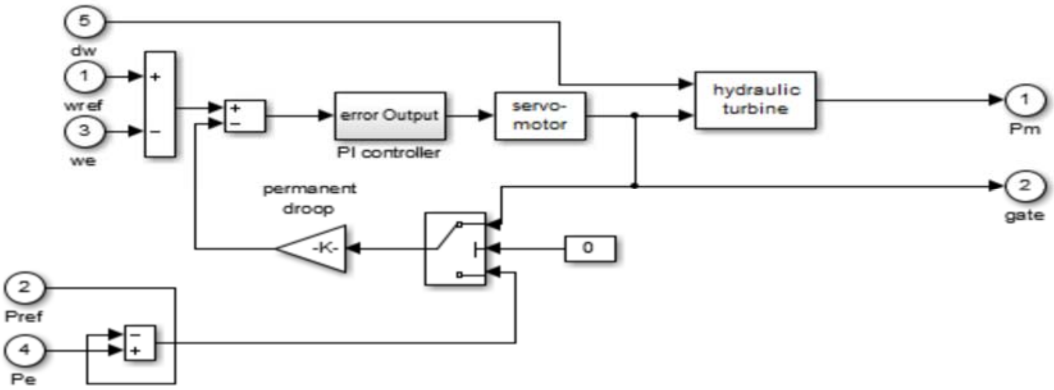

Fig.3: Simulink PI controller model [12]

4. Hydraulic Servo System Modell

The function of the servo motor is to control the gate position opening depending on the PID signal. The annulment of the speed deviation by the PID is achieved by initiating a response to the motor to regulate the gate opening position. The torque produced this motor depends on the signal error as well as the speed. T_m= f ($\dot{\theta}$, e) (5)

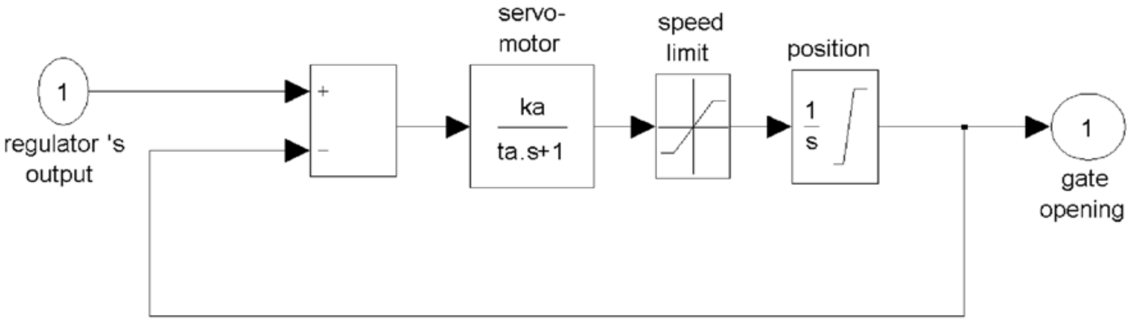

Fig.4: A block diagram showing of a Hydraulic servo system. [6]

5. Power System Stabilizer (PSS)

The main function of PSS is to provide the rotor speed deviation to an input of the excitation system, it also minimizes the instability of the system which is characterized by swinging response. The output of the generator is dependent on the mechanical torque created by the turbine this torque can be altered by changing the excitation value. A PSS senses the generator output power controls the excitation system value and reduces the rapid fluctuations. [11]. The distortion that occurs in a power system leads to the inducement of electromechanical oscillations of the electrical generators. These oscillations, also called power swings, should be efficiently damped to sustain the system stability. The PSS output functions as a supplementary input signal (Vstab) to the Exciter block. The power system stabilizer input could be either the generator's deviated speed (dw) or its power, Pa = Pm- Peo. Since the main function of the PSS is to regulate the rotor fluctuations, the input signal is typically rotor speed deviation. [1] The PSS model is made up of a general gain, low-pass filter, a phase-compensation system, a washout high-pass filter, and an output limiter. The gain (K) regulates the

amount of damping formed by the stabilizer. The washout high-pass filter has the responsibility of eradicating low frequencies that exist in the dw signal and permits the PSS to react only to speed variation. The phase-compensation system is embodied by two first-order lead-lag transfer functions applied to compensate the phase lag among the excitation voltage and the torque of the generator.

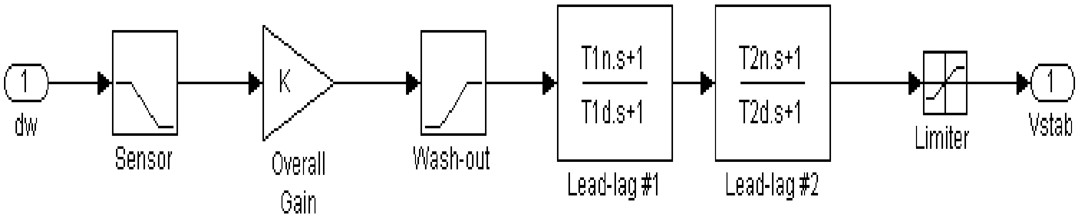

Fig.5: Simulink block model of a generic PSS

6. Synchronous Generator Model

The generator is made of three different winding; they are the field winding which is one in number, the damper windings which are two in numbers and Stator winnings which are three in numbers. The winding of the damper is magnetically fixed together. The Synchronous generator model uses the park's equations to model the electrical dynamics. [2],[5].

$$Td0'' \frac{dE''q}{dt} = Eq' \ - \ Eq'' \ (Xd' \ - Xd'' \ )I_d \qquad (6)$$

$$Tq0'' \frac{dE''d}{dt} = \ Ed' \text{ - } Ed'' \text{ +(} X_{q'} - \ Xq'') \ I_q \qquad (7)$$

$$Td0' \frac{dE'q}{dt} = \ Ef' \text{ - } Eq'' \text{ +(} X_d \text{ - } X'\mathrm{d}) \ I_d \qquad (8)$$

$$Tq0' \frac{dE'd}{dt} = \ - Ed' \text{ - } Eq'' \text{ +(} X_q \text{ - } X'\mathrm{q}) \ I_q \qquad (9)$$

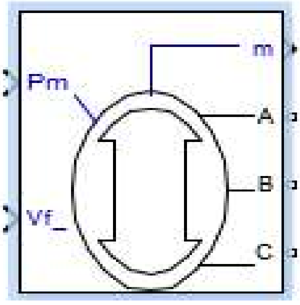

Fig. 6: Simulink block model of a synchronous generator

7. Excitation System Model

Excitation scheme model is described as a DC type excitation system without the exciter's saturation, which uses a commutator powered DC generator. The application excitation model creates exciter's voltage which feeds the generator. The application of a feedback scheme is achieved by the PID controller which monitors the mechanical power created by the turbine alongside the exciter's voltage. The transfer function of the DC excitation scheme is stated in equation (10) below.

V_{ef} And e_f Denote exciter voltage and the regulator's output respectively.

$$\frac{V_{ef}}{e_f} = \frac{1}{K_{e\,+sT_e}} \qquad (10)$$

Fig. 7: Excitation block in MATLAB/ Simulink.

8. Penstock (Pipe) Model

The penstock is modeled on the notion that the water cannot be compressed and the phenomenon of water hammer is not experienced in the pipeline. Again, the flowing water through the penstock acts as a solid mass. The deviation at the rate by water flows in a pipe is likened to pressure of water by the application of second law of motion postulated by Newton. This law states that" An acceleration of an entity is proportionate to the net force. The force that exacts on a mass of water can be stated as follows. [3].

The force that exacts on a mass of water can be stated as follows. [3].

$$(h_g - h - h_l)\mathrm{PgA{=}LA} \qquad (11)$$

Therefore, the deviation in a flow rate of the pipe can be determined as follows

$$\frac{d}{id} = \left(h_0 - h - h_f\right)\frac{g_a A}{L} \qquad (12)$$

9. Hydraulic Turbine Governor System

The hydro turbine governor system has the greatest significance in Hydropower plant. It has two key functions, the main function is to create mechanical power, and this mechanical power is inputted into the generating set for electric power generation. Again, another function is to monitor the deviated speed produced by the generator so that the system can run at synchronizes speed and thereby maintaining a constant frequency. The turbine and its governor system are made of PID, servo motor system, and the turbine. Its blocks diagram shown fig 8 below.

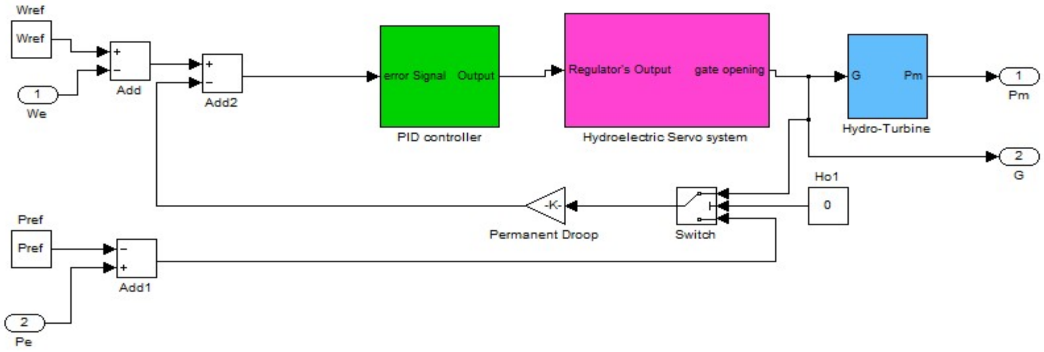

Fig.8: Block diagram showing of hydraulic turbine governor system

10. Simulation

The simulation was carried out under the following operating conditions such as 3φ to ground fault with PID controller, 3φ to ground fault with PI controller, under 50% load increment with PID controller, under 50% load increment with PI controller and under 50% load decrement with PID controller, under 50% load decrement with PI controller. In all this operating condition PSS is incorporated and its function is to act as a complementary controller. The three-phase fault block in Simulink represents a disturbance which is possible to occur in the three-phase line in the station. This fault is introduced at t=8s. The simulation time in the models in the simulation test for different values of RLC load demand in power is 20s. At t=6.0s the restive load is increased by 50% and later decreased by 50% This change is achieved with the use of a breaker line block in Simulink. In the start of the simulation, the breaker is an open circuit and when the time is at 6s closes and then opens again at 6.5s. The effect of this RLC load variation. The simulation consists of evaluating the terminal voltage, rotor speed, active power. Doing this enables the response of the SHPP to be perceived during different operating conditions. The simulation time of 20 seconds was adopted.

III. RESULTS AND DISCUSSION

The model outcomes are graphically shown as the waveform of the different measured output parameters. The outcome is shown in different cases from case 1 to case 3 which represents different operating conditions when a PID was used as the speed controller. The result of the simulation, when a PI controller was as the speed controller is not shown because it followed the pattern as the PID counterpart. The difference in the response was the starting oscillation and transient time which was summarized in table 1 below

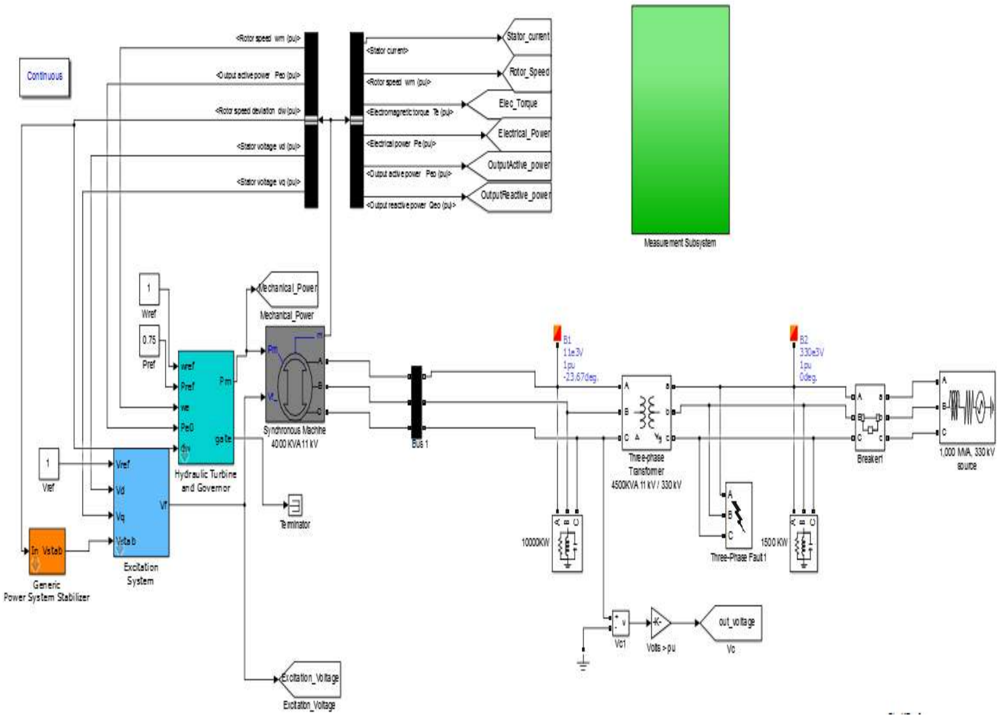

Fig. 9: Simulink model of the Hydropower plant.

Case 1: Running under three-phase fault condition with PID and PSS controllers

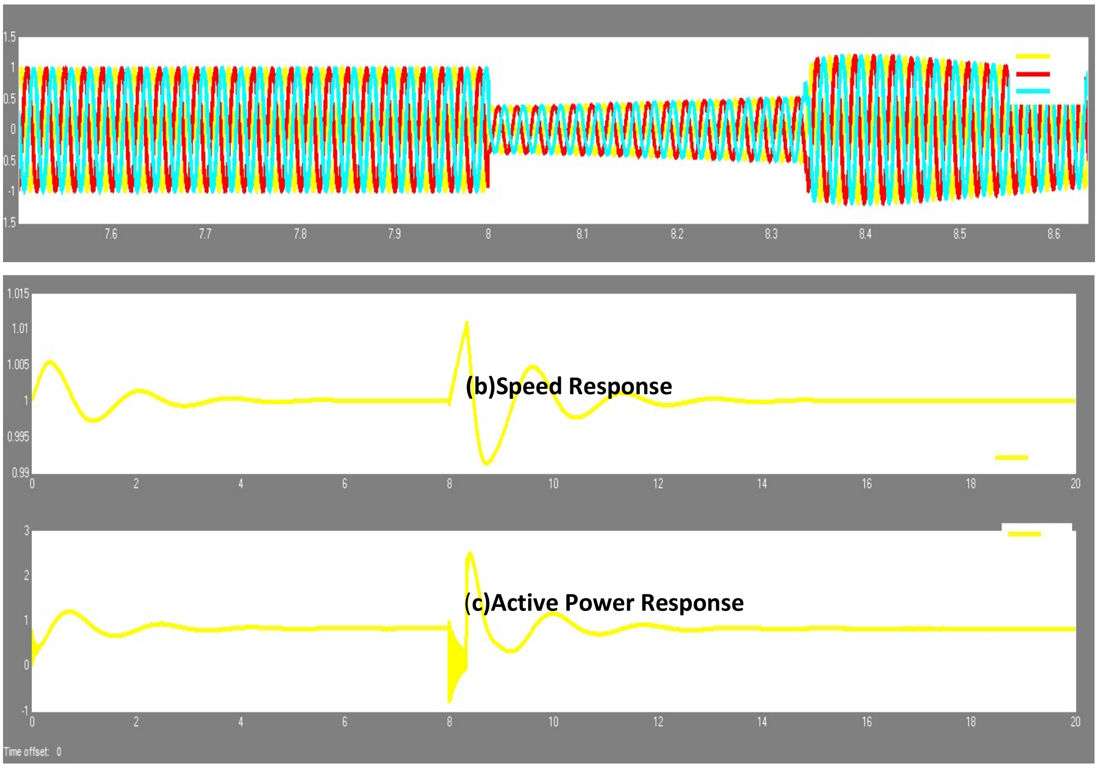

Fig.10: Response of Hydropower plant with PID and PSS controllers 3ɸ fault condition

The fig.10 above represents the waveform of the three-phase voltage, speed, and output power respectively during a three-phase fault condition. In the voltage waveform, it was observed that starting oscillation occurred for a period of 0 to 2s. After 2s the system was running at steady state until the introduction of a three-phase fault at 8s, at the point of integration of fault, the voltage output drastically reduced. The fault was cleared in 0. 3s, immediately the system was stabilized from 10s and maintained stability throughout the period of operation. Similarly, the speed of the system followed the same trend in the case of the voltage but when the fault occurred at 8s the speed spiked up and stabilizes after a few seconds. Also at the occurrence of a three-phase fault, the output power dropped to zero, then later spiked up, and stabilizes after 2s when the fault was cleared.

Case 2: Running under 50% of load demand increment with PID and PSS Controllers

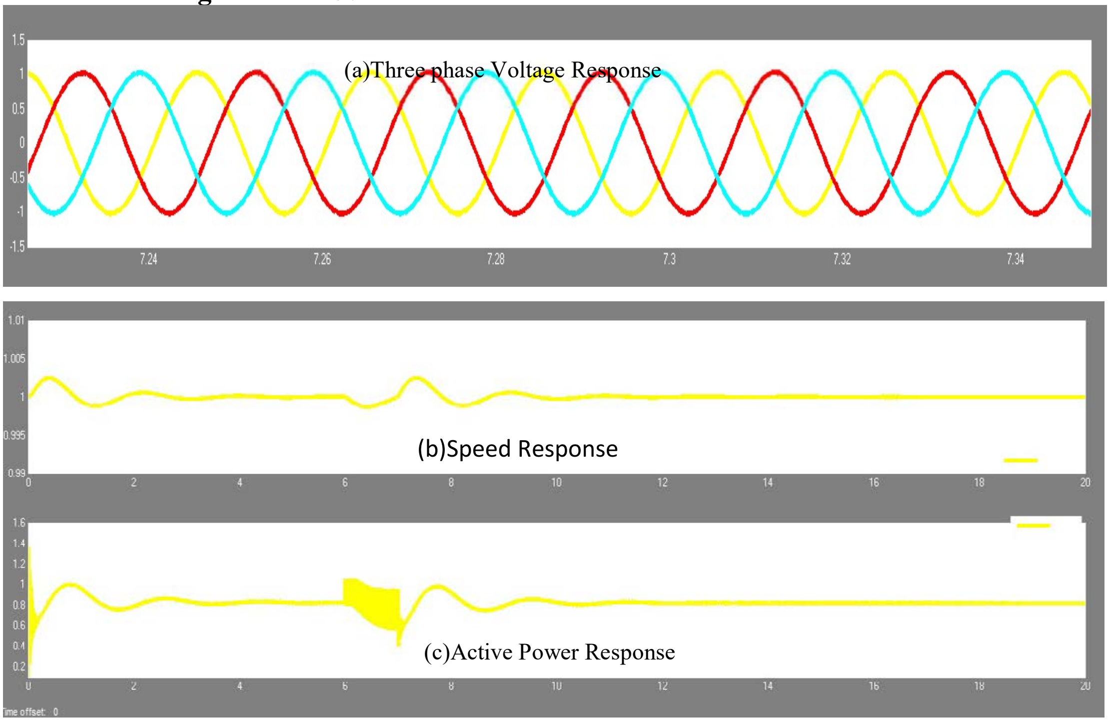

Fig. 11: The response of the proposed Hydropower plant during load increment of 50% with PID and PSS controllers.

In fig. 11a above it is noticed that the three-phase voltage is fairly constant and no noticeable oscillation at the period of 6s when the load increment occurred. In the fig.11b which represents the speed, a noticeable starting oscillation was observed at the period of 0s to 2s and became stable from 2s to 6s when the system was perturbed by load increment. At the period of 6s, the speed of the plant was reduced due to load increment. The system oscillated for 2s and immediately regains stability, it was observed as a stable for the entire period of operation. In the fig.11c active power of the system, it was observed that it followed the same pattern to that of the speed, at 6s the output power drastically declined and after a few second of oscillation, it regains stability and remains in the steady-state for the whole period of operation.

Case 3: Running under 50% of load demand decrement with PID and PSS controllers

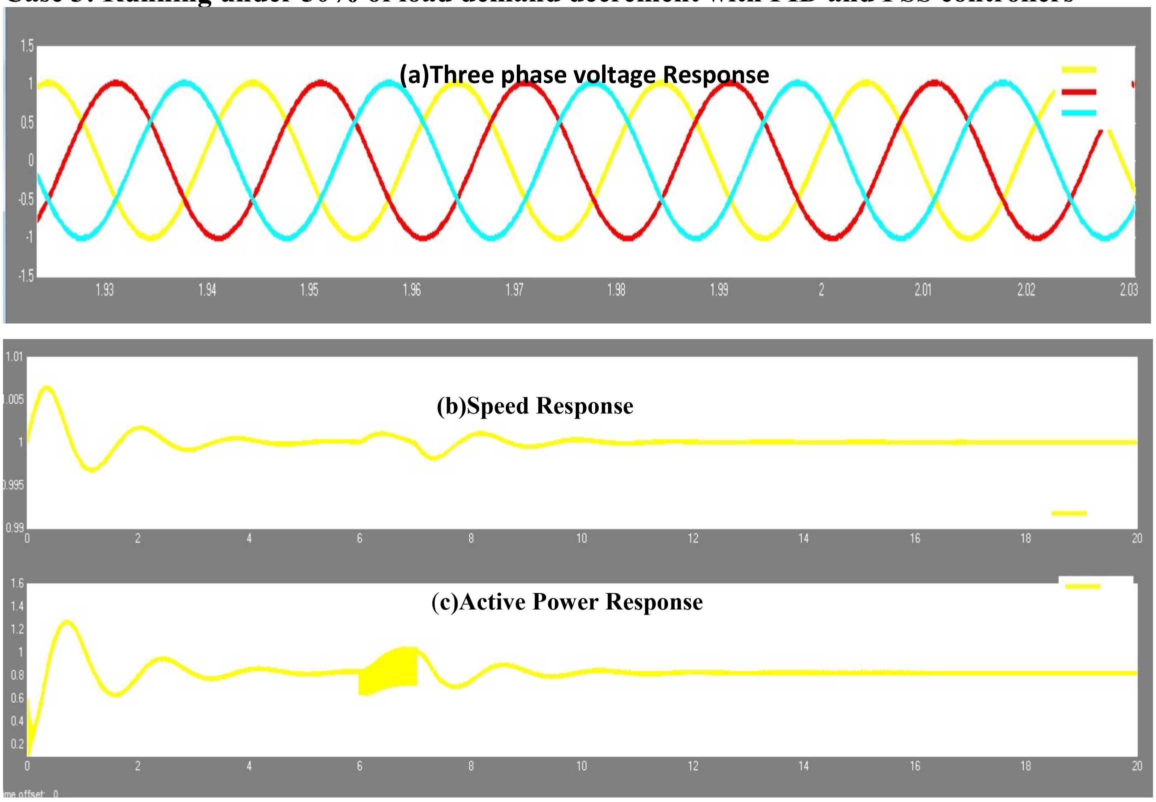

Fig. 11: The response of the proposed Hydropower plant during load increment of 50% with PID and PSS controllers

Table. 1: Comparison between PI and PID in Three phase fault simulation test

Active output power	Staring oscillations	Transient time
PI	0 -3	8 -10.8
PID	0 -2.8	8 - 12
ROTOR SPEED	Staring oscillations	Transient time
PI	0 -3	8 – 10.9
PID	0 -2.6	8 - 12
3Ø VOLTAGE	Staring oscillations	Transient time
PI	0 -1.8	8 -10
PID	0 – 1.4	8 -10.2

In fig. 11a above it is noticed that the three-phase voltage is fairly constant and no noticeable oscillation at the period of 6s when the load decrement occurred. The only noticeable oscillation was at 0 to 1s which is known as stating oscillation. In fig. 11b, which represents the speed, a noticeable starting oscillation was observed at the period of 0s to 2s and became stable from 2s to 6s when the system was perturbed by load decrement. At the period of 6s, the speed of the plant was increased due to load decrement. The system oscillated for 2s and immediately regains stability, it was observed as a stable for the entire period of operation. In the last waveform which represents the active power of the system, it was observed that it followed the same pattern to that of the speed, at 6s the output power was increased and after few seconds of oscillation, it regains stability and remains in the steady-state for the whole period of operation.

IV. CONCLUSION

In this paper, the transient time of a three-phase fault to the ground, and load variation of different operating conditions were investigated. A close look of table 1 above reveals there was smaller transient time which is the time of clearance of fault or perturbation before the system gets to the steady-state in the case of the PI controller. So, the choice of a PI controller seems to be a wiser option to address the three-phase fault problems and other disturbance in the system, hence PI controller has been proved as the most suitable controller for hydro turbine governing mechanism. The turned values of Proportional gain and Integral gain performs a significant part in defining the stabilizing time. The results proved that PI-based turbine governor has better performances. Moreover, good transient and steady-state responses for different operating points conditions.

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