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An Optimization of Load Frequency Control Based on Hydraulic Power Plant Using Transfer Function Balanced PID Controller

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Abstract: Power generator often rely on the stability and efficiency. For both active power and reactive power stability, it is needed a device that could control the power. In active power control, the output frequency must be controlled. Load frequency control has become a common solution for frequency control in hydraulic power generating units. The design of the load frequency control is still far from good but has succeeded in controlling the frequency back to normal at each load source and input. In this study, the proposed model is to use a PID controller that has been set with the Transfer Function Balanced tuning method. From the source input simulation results, the proposed model could fix the overshoot frequency by 71.929%. and reached rise time by 4.426 s. From the load input simulation results, the proposed model could fix the undershoot frequency by 58.974%. and reached rise time by 1.076 s.

Keywords: Frequency, hydraulic power generating unit, load frequency control, transfer function balanced tuning

1. Introduction

The qualities of a power system that enable it to sustain a balanced state of operation under normal operating conditions and return to an appropriate balance state after being disrupted are referred to as power system stability. Depending on the system setup and operating mode, power system instability can show itself in a variety of ways. Traditionally, [1] Stability concerns have long been a source of contention when it comes to sustaining synchronous operation. Because the electric power system relies on synchronous motors to create energy, all synchronous motors must be synchronized or, in layman's terms, "synchronized" in order for the system to function properly. The dynamics of the connection between the generator rotor angle and the dynamic angle impact this element of stability. Instability can occur even if there is no breakdown of synchronization.

Transient voltage stability is influenced significantly by the induction motor. The induction motor may experience load and voltage instability as a result of system failure and operation. When the induction motor's slip exceeds the critical value of the slip, adaptive load shedding regulation is required to safeguard the induction motor from instability and voltage collapses [2] [3]. The obstructions may be tiny or huge. Minor unsettling influences within the frame of stack changes proceed, and the framework will alter itself, agreeing to the changing conditions. The framework must work palatably beneath these conditions and effectively give the most excellent stack. It must also be able to resist an assortment of genuine unsettling influences, such as short-circuits in transmission lines or misfortune of associations between two subsystems [4][5].

Many devices are involved in the system's reaction to interference. A short circuit of a key component, for example, isolated by a protective relay, will result in changes in power transmission, machine rotor speed, and bus voltage. The voltage change will drive the generator and the voltage regulator of the transmission system at the same

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time; the speed change will drive the prime mover governor; the change of the tie-line load may start the power generation control; the voltage and frequency changes will affect different degrees according to their characteristics the load of the system [6].

Furthermore, equipment designed to safeguard a single device may react to changes in system factors, affecting overall system performance. However, in other situations, only a small number of devices may be required to respond. As a result, various assumptions are often made in order to simplify the problem and focus on the elements that impact a certain sort of stability problem. The classification of stability dramatically facilitates the understanding of stability issues into various categories.

The purpose of this paper is to compare the automatic load frequency control based on PID controller with the automatic load frequency control of wild hydroelectric power plant based on integrator feedback. The proposed method is to use PID controller feedback and transfer function balance adjustment through MATLAB Simulink simulation.

From the previous work, the PID model used is the PID tuning method using Ziegler Nichols. However, Ziegler Nichols is using a manual computational method for PID determination. Meanwhile, the novelty in this research is by using the automatically computational method by finding the best performance within each method used by PID automatic tuner.

As a result, the stability and efficiency of frequency stability of hydroelectric power plants are obtained to achieve better active power control.

2. Basic Knowledge

This chapter contains the necessary knowledge about plant simulation, hydraulic power plant stability, load frequency control, and PID controller.

2.1 Hydraulic Power Plant Stability

Hydropower is electricity generated by moving water. In modern technology, hydroelectric power transfers the turbine's energy to the generator to generate electrical energy. Hydropower is a renewable energy source. The power plant will create practically no trash or none at all after it is completed [1]. Hydroelectric power plants create electricity by capturing the energy of falling water. The kinetic energy of falling water is converted into mechanical energy by the turbine. The generator then transforms the turbine's mechanical energy into electrical energy [7].

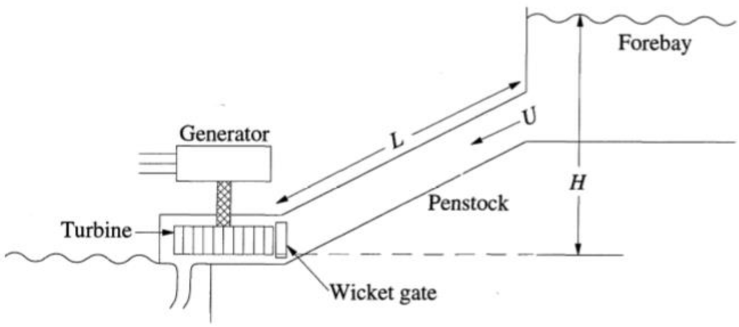

Fig. 1 - Hydropower plant

Stability is defined as a state of equilibrium between conflicting forces [8].The restoring force, which works when the force seeks to induce one or more machines to accelerate or decelerate other machines, is the process by which interconnected synchronous motors maintain synchronization. Each machine's input mechanical torque and output electrical torque are balanced under steady-state circumstances, and the speed remains constant. If the system is disrupted, it will lose its equilibrium, forcing the rotor of the motor to accelerate or decelerate in accordance with the spinning body's law of motion. When one generator runs quicker than another over a short period of time, its rotor position relative to the slower motor's rotor advances [9]. The angle difference that results is determined by the power angle relationship, which transfers the load from the slow to the fast machine. The speed difference and, as a result, the angular separation tend to be reduced as a result of this.

The power angle connection is very nonlinear, as previously stated. An rise in the angular interval is followed with a decrease in power transmission beyond a certain point, which increases the angular interval and produces instability. The system's stability is determined by whether the rotor's angular position variation produces adequate restoring torque in any given circumstance. When a synchronous motor loses synchronization with the rest of the system, its rotor will operate at a faster or slower speed than is necessary to create voltage at the system frequency. When a synchronous motor loses synchronization with the rest of the system, its rotor will operate at a faster or slower speed than is necessary to create voltage at the system frequency. One machine may lose synchronization with the rest of the system, or multiple machines may lose synchronization.

It is feasible to preserve synchronization when each group is isolated from the others in the latter situation. In some ways, the synchronous functioning of interconnected synchronous motors is like to many vehicles speeding around a circular track connected by elastic connections or rubber bands. The vehicle depicts the rotor of a synchronous motor, while the rubber band represents a transmission line. The rubber band remains unbroken while all automobiles are traveling side by side. If a force is supplied to one car to momentarily accelerate it, the rubber band connecting it to the other car will stretch, slowing the quicker cars and speeding up the others. A chain reaction occurs until all cars are driving at the same speed again. If the pulling force of one of the rubber bands exceeds its strength, it will break, and one or more cars will pull away from the other car.

The existence of two components of each synchronous motor's torque is required for the system's stability. Due to a lack of synchronization torque, the rotor angle will wander aperiodically, resulting in instability. Insufficient damping torque, on the other hand, causes unstable oscillation [6].

2.2 Load Frequency Control

So far, the most significant aspect of power system control is load frequency control [7]. Consider a little increase in load to better understand how frequency management works. The initial distribution of load increases is determined by the system impedance. And the immediate generator's relative rotor position [10]. The primary aim of load frequency control (LFC) is to maintain the basic frequency and needed power output in an interconnected power system while also controlling tie-line power changes across control regions [11]. Essentially, the frequency of the power system is managed by ensuring that the injected power (from the linked generator) meets the system demand after all losses are taken into consideration.

Load frequency control is used to ensure that a given area meets its load demand first and to assist in restoring the system's steady-state frequency f to zero. To maintain the system frequency constant, the load frequency control operates with a reaction time of several seconds. The governor is modeled, and the integrator is the major load frequency control model [8].

2.3 PID Controller

PID (proportional integral derivative) control is the most widely used control algorithm in the world and is well recognized in industrial control [12]. PID controllers are popular because of their outstanding performance under a variety of operating situations. The other is a straightforward function that allows engineers to work directly. The PID algorithm has three primary coefficients, as the name implies. To achieve the optimum reaction, you may adjust the ratio, integration level, and different levels.

The PID controller's fundamental concept is to read the sensor and then compute the needed actuator output by combining the proportional, integral, and derivative responses. The definition of performance criteria is the first step in the control design process. The performance of a control system is often assessed by measuring the response of the process variable using a step function as a setpoint command variable [13]. In most cases, the reaction is measured using established waveform characteristics. The rise time is defined as the time it takes for the system to go from 10% to 90% of its steady-state or ultimate value. The amount by which the process variable overshoots the final value, given as a percentage of the final value, is the overshoot percentage. Stabilization time is required for process variables to stabilize within a specified percentage (typically 5%) of the final value. The absolute difference between the process variable and the specified value is the steady-state error.

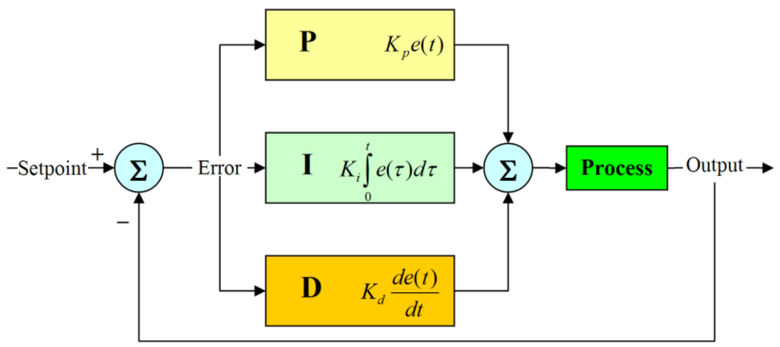

Fig. 2 - Typical PID controller

It's useful to specify the worst-case scenario in which the control system is anticipated to fulfill these design criteria after utilizing one or all of these values to establish the control system's performance needs. It's critical to create a control system that works well even in the worst-case scenario. The process variable or the measurement of the process variable is usually affected by the disturbance in the system. The interference suppression of the control system is a measure of how well the control system can resist interference.

The most frequent type of feedback in hydro-generator speed control systems is the proportional integral derivative (PID) controller. It is a necessary component of governors and a common process control tool. PID control is an important component of a distributed control system, and these controllers come in a variety of shapes and sizes. The usage of proportional integral derivative (PID) controllers in industries is unaffected. Until the previous decade, Proportional Integral Derivatives (PID) accounted for more than 90% of all control loops in the process industries [14]. They are utilized because of their simplicity, efficacy, and improved comprehension of control action and digital PID realization [15].

3. Method and Methodology

Two phases will be examined when the water flows into the plant and when the load is into the plant. This section will be carried out using the transfer function PID tuning and system modeling for the simulation. The simulation results are obtained by running the MATLAB Simulink results and running in 200 seconds simulation due to computational load.

3.1 Transfer Function Balanced PID Tuning

To prioritize in the design, a closed-loop performance goal. For a given goal phase margin, the PID Tuner selects a controller design that balances the two performance metrics of reference tracking and disturbance rejection. The tuning algorithm tries to modify the PID gains to favor either reference tracking or disturbance rejection while maintaining the same target phase margin when the Focus option is changed [6]. With more adjustable parameters in the system, the PID algorithm is more likely to achieve the intended design emphasis without compromising resilience [16]. Setting the design emphasis, for example, is more beneficial for PID controllers than for P or PI controllers [17].

Table 1 - Control parameters

	Tuned	Block
P	42.4204	1
I	27.8204	0
D	15.2779	0
N	174.4419	100

Table 2 - Performance and robustness

	Tuned	Block
Settling time	0.94 seconds	1.97 seconds
Rise time	6.4 seconds	7.76 seconds
Peak	3.97%	18.1 %
Gain margin	1.04	0.0537
Phase margin	41.9 dB	47 dB
Overshoot	64.5 deg	Inf deg
Closed-loop stability	Stable	Stable

To prioritize in the design, a closed-loop performance goal. For a given goal phase margin, PID Tuner selects a controller design that balances the two performance metrics of reference tracking and disturbance rejection.While maintaining the same goal phase margin, the tuning algorithm seeks to modify the PID gains to favor either reference tracking or disturbance rejection

The basics formula:

$$P + I\frac{1}{s} + D\,\frac{N}{1+N\frac{1}{s}} \tag{1}$$

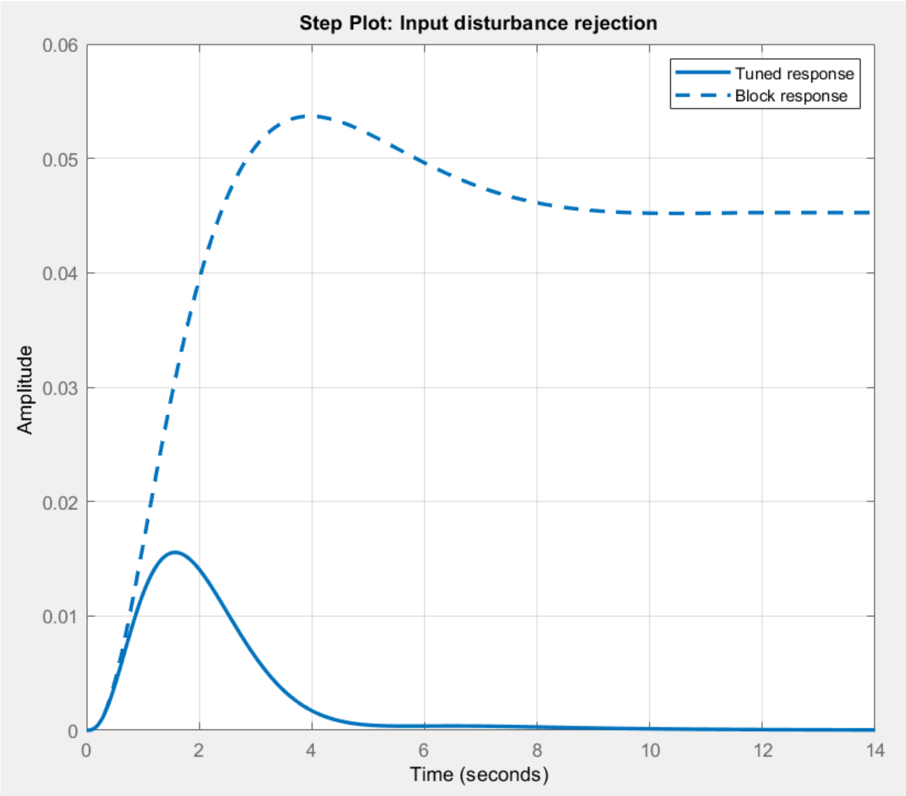

Fig. 3 - Input disturbance rejection

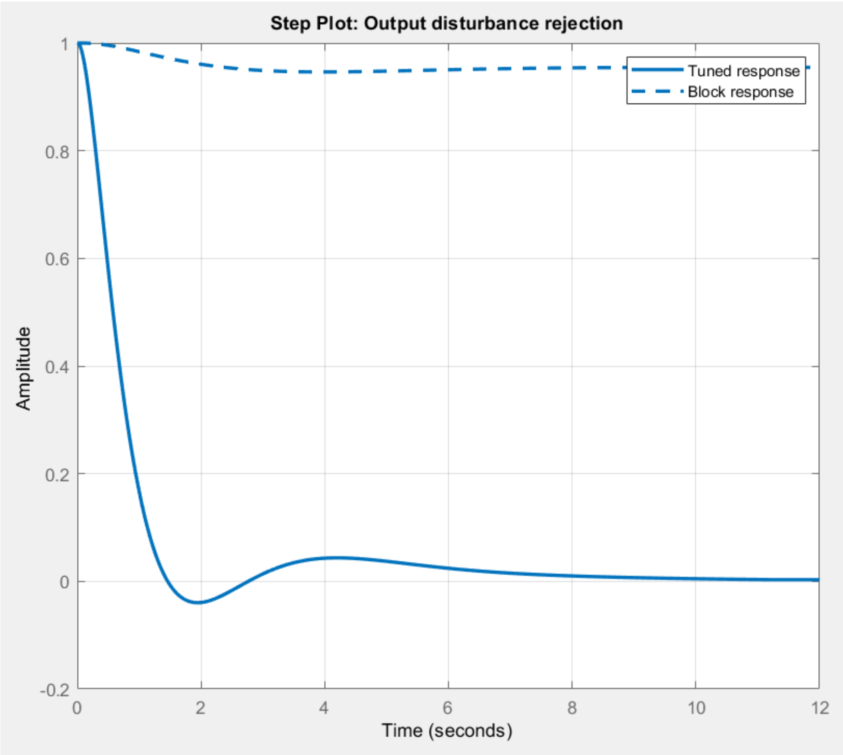

Fig. 4 - Input disturbance rejection

Chooses a controller form where the output is the sum of proportional, integral, and derivative actions, weighted by the independent gain parameters P, I and D. The pole of the derivative filter is determined by the filter coefficient N. The transfer function for a continuous-time parallel PID controller is:

$$C_{par}(s) = \left[P + I\left(\frac{1}{s}\right) + D\left(\frac{N_s}{s+N}\right)\right] \quad (2)$$

The transfer function for a discrete-time parallel PID controller is as follows:

$$C_{par}(z) = P_{Ia(z)} + D\left[\frac{N}{1+N_b(z)}\right] \quad (3)$$

When a(z) is determined by the Integrator technique and b(z) is determined by the Filter method (for sampling time Ts):

Table 3 - Performance and robustness

	Forward Euler Method	Forward Euler Method	Trapezod Euler Method
$a(z)$ (Ascertained using the integrator technique)	$\frac{T_s}{z-1}$	$\frac{T_s z}{z-1}$	$\frac{T_s z+1}{2z-1}$
$b(z)$ Filter technique determines	$\frac{T_s}{z-1}$	$\frac{T_s z}{z-1}$	$\frac{T_s z+1}{2z-1}$

Method for PID Tuning, but in the research, the tuning method automatically uses the best method for better performance.

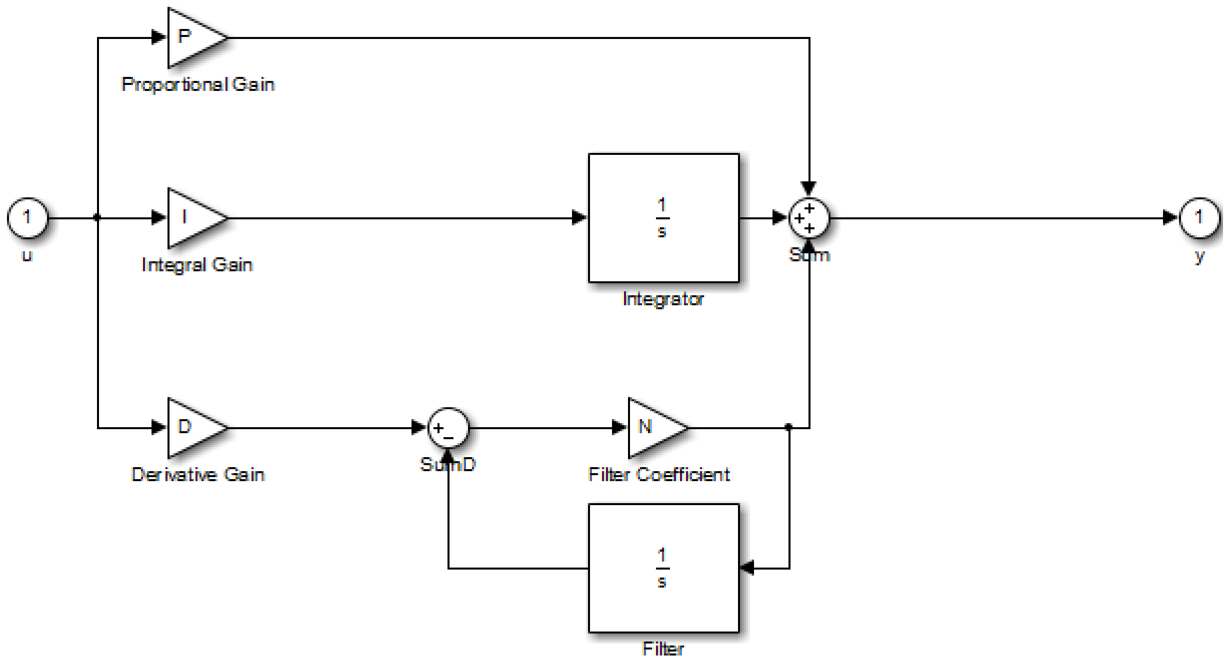

Fig. 5 - Scheme for parallel PID block diagram results

3.2 System Modelling

The hydropower plant's fundamental model (governor, turbine, and generator) is modelled in the MATLAB Simulink block diagram below [12].

R = 0.05
T_{CH} = 0.3 s
F_{LP} = 0.7
F_{HP} = 0.7
M =10.0 s
T_{RH} = 7.0 s
D = 0.05

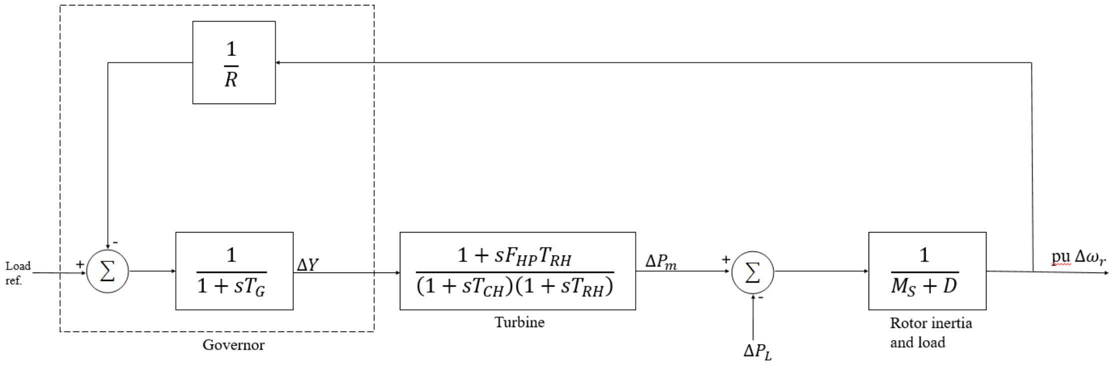

Fig. 6 - Typical model of hydraulic power plant unit for frequency examining

From the model, it is obtained the model for uncontrolled hydraulic power plant unit as shown below,

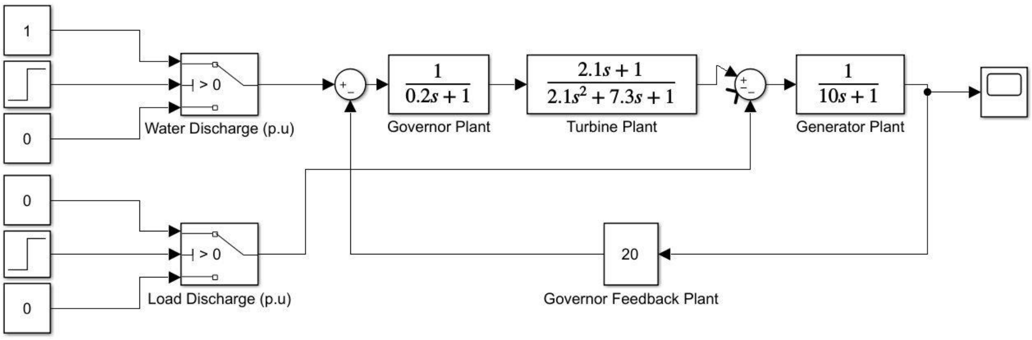

Fig. 7 - Hydraulic power plant uncontrolled frequency model

By applying the load frequency control for the model, it is obtained that the system could be modeled as below,

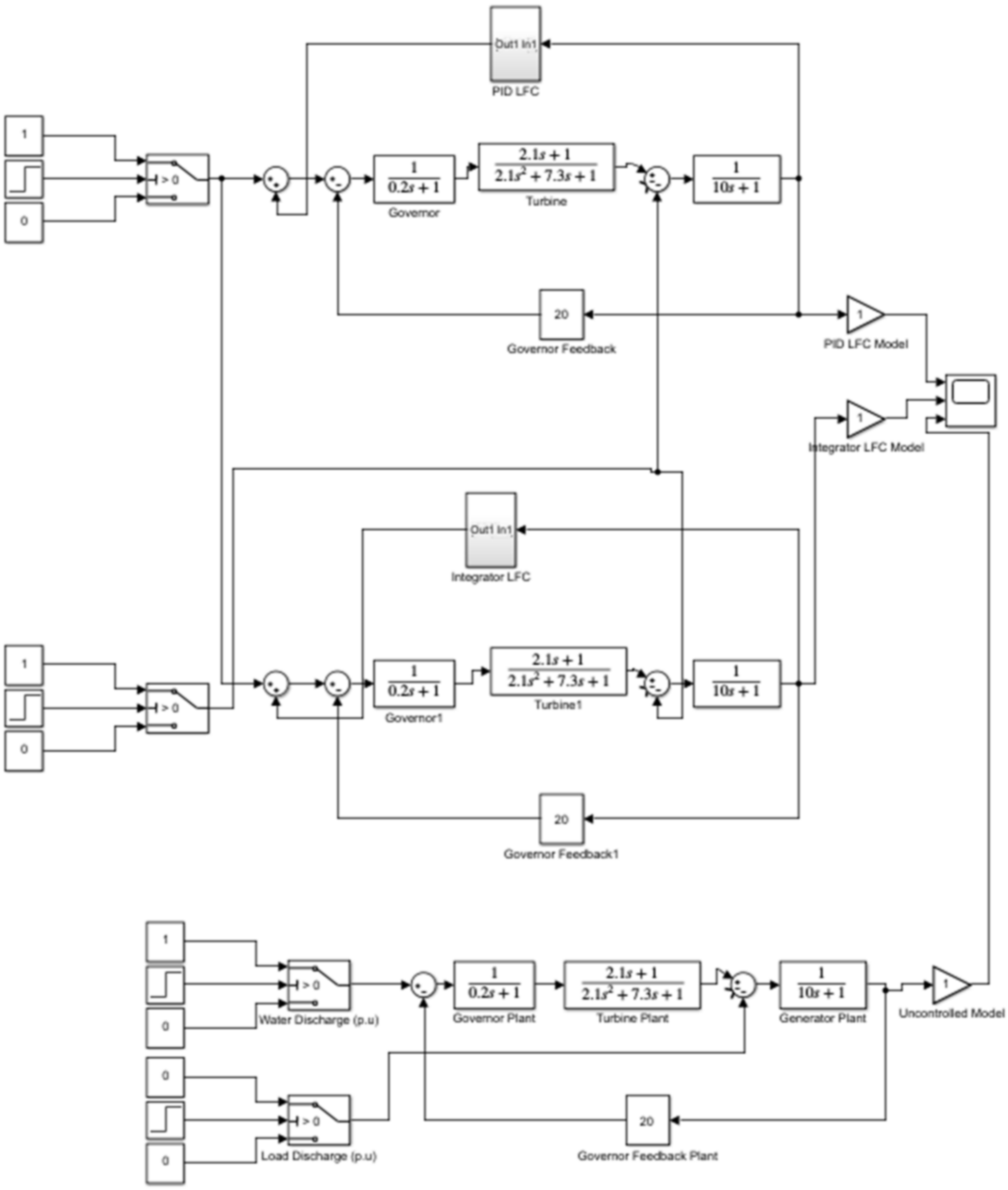

Fig. 8 - Hydraulic power plant with load frequency control PID and integrator model

4. Simulation Results

The comparison will be carried out from the beginning when the water input into the plant. After the load input into the plant after 100 seconds in the simulation, the second simulation will be carried out.

4.1 Source Input Simulation

The simulation scenarios are by giving a source of 1 p.u. Input in the time of 0 s. From the simulation, it is obtained that overshoot frequency is at 0.057 p.u., steady-state frequency is at 0.048 p.u., and steady-state time is at 10.132 s (Uncontrolled model). From the simulation, it is obtained that overshoot frequency is at 0.054 p.u., steady-state frequency is at 0 p.u., and steady-state time is at 90.146 s. (integrator LFC Model). From the simulation, it is obtained that overshoot frequency is at 0.016 p.u., steady-state frequency is at 0 p.u., and steady-state time is at 5.886 s. (PID LFC Model)

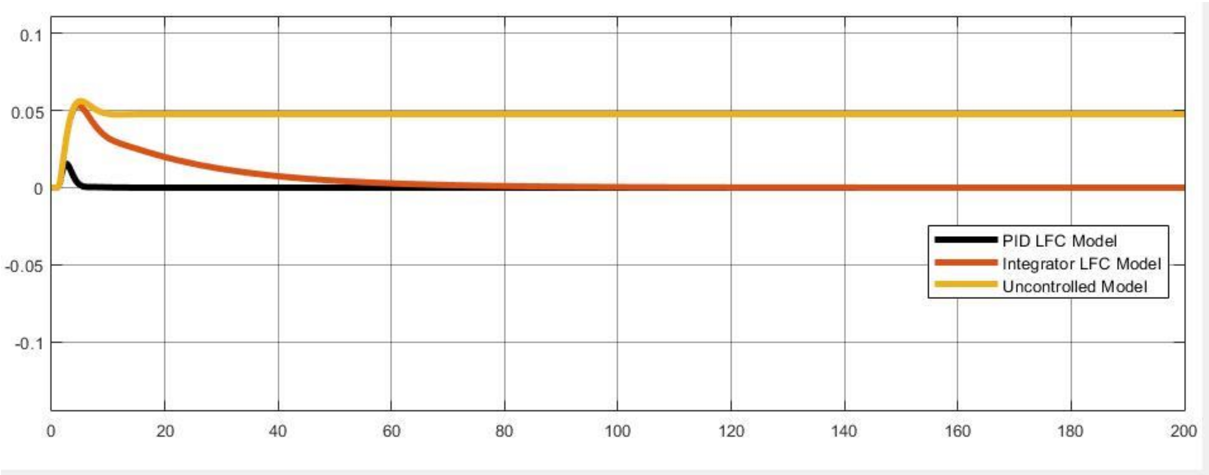

Fig. 9 - Comparison source input simulation result

The simulation results show that the Integrator LFC model could fix the overshoot frequency by 5.262%, and the Transfer Function Balanced PID LFC model could fix the overshoot frequency by 71.929%. Thus, integrator LFC is slower by 80.014 s from the uncontrolled model for a steady-state time, but the Transfer Function Balanced PID LFC model is faster by 4.426 s. In addition, the LFC model could control the frequency back to normal (in the simulation, the standard frequency position is 0).

4.2 Load Input Simulation

The simulation scenarios are by giving a load of 1 p.u. Input in the time of 100 s. The main reason is that the maximum computational limit from our software and computers has several errors above 100s. It is also fit that, within 100 seconds (or less), the response should be given as usual due to several instabilities in more extensive power systems also contribute to each other.

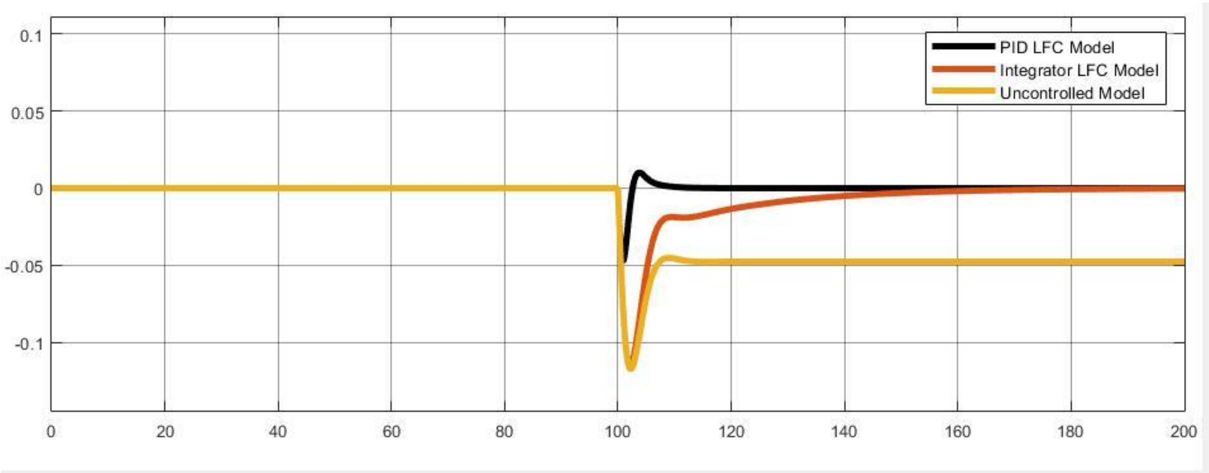

Fig. 10 - Comparison of load input simulation result

The simulation shows that the undershoot frequency is at -0.117 p.u., steady-state frequency is at -0.048 p.u., and steady-state time is at 13.311 s (Uncontrolled Model), the simulation shows that the undershoot frequency is at -0.115 p.u., steady-state frequency is at 0 p.u., and steady-state time is at 78.638 s (Integrator LFC model) and the undershoot frequency is at -0.048 p.u., steady-state frequency is at 0 p.u., and steady-state time is at 12.235 s (PID LFC Model).

The simulation results show that the Integrator LFC model could fix the undershoot frequency by 1.709%, and the Transfer Function Balanced PID LFC model could fix the undershoot frequency by 58.974%. Thus, integrator LFC is slower by 65.327 s from the uncontrolled model for a steady-state time, but the Transfer Function Balanced PID LFC model is faster by 1.076 s. In addition, the LFC model could control the frequency back to normal (in the simulation, the regular frequency position is 0).

Table 4 - Table of stability comparison

Stability Aspect	Uncontrolled	Integrator LFC	TFB PID LFC
Source Input Overshoot	0.057 p.u.	0.054 p.u.	0.016 p.u.
Source Input Steady State Time	10.132 s	90.146 s	5.886 s
Load Input Undershoot	-0.117 p.u.	-0.115 p.u.	-0.048 p.u.
Load Input Steady State Time	13.311 s	78.638 s	12.235 s
Back to Normal Frequency	No	Yes	Yes

5. Conclusion

The source input simulation results obtained that the Integrator LFC model could fix the overshoot frequency by 5.262%. The Transfer Function Balanced PID LFC model could fix the overshoot frequency by 71.929%. Integrator LFC is slower by 80.014 s from the uncontrolled model for a steady-state time, but the Transfer Function Balanced PID LFC model is faster by 4.426 s.

From the load input simulation results, it is obtained that the Integrator LFC model could fix the undershoot frequency by 1.709%, and the Transfer Function Balanced PID LFC model could fix the undershoot frequency by 58.974%. Thus, integrator LFC is slower by 65.327 s from the uncontrolled model for a steady-state time, but the Transfer Function Balanced PID LFC model is faster by 1.076 s.

Both models are proven that could control the frequency back to normal. Transfer Function Balanced PID LFC is also able to compensate for the overshoot and undershoot significantly. The following research could be about Transfer Function based on reference tracking PID tuning.

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