Comparative Studies on Load Frequency Control with Different Governors connected to Mini Hydro Power Plant via PSCAD Software

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ABSTRACT

Mini Hydropower Plants (MHPPs) are increasingly popular for rural electrification in developing nations due to their ecologically friendly operation. However, constant load fluctuation in these facilities poses a speed control issue. The mechanical, hydraulic governor, commonly used to face this challenge, cannot provide the best speed control due to its mechanical component system. Thus, an electrohydraulic PID-based governor is proposed to control the frequency and speed of MHPPs in a distribution network. This governor's suitability for regulating the system's frequency in response to significant load variations within the distribution network is going to be determined in this study. The small hydropower plant and distribution system are modeled using the PSCAD software. A comparison between the mechanical hydraulic governor and the electro-PID governor was conducted by analyzing load fluctuations between 5% and 20%. The electro-PID governor responded faster and more actively to load connections and disconnections than the mechanical hydraulic governor, as the latter reduces large overshoots and undershoots, which can be dangerous and damaging to equipment. The electro-PID governor also helps to maintain a stable frequency within acceptable limits, ensuring smooth operation and minimizing the risk of system failures or disruptions.

Keywords-control; energy; frequency; hydro governor; load; renewable energy sources

I. INTRODUCTION

Load frequency control is a crucial aspect of power systems as it ensures the stability and reliability of the grid. By continuously monitoring and adjusting the generation and load balance, the former helps maintain a steady frequency within acceptable limits. This is vital to prevent power outages, equipment damage, and disruptions in electricity supply, ultimately ensuring the smooth functioning of various industries and meeting consumers' energy demands [1]. Governors play a significant role in load frequency control as they help prevent frequency fluctuations and ensure the efficient operation of power systems [2]. In the context of comparative studies on load frequency control involving different governors, connected with mini hydro power, it is important to analyze the performance and effectiveness of various governor types in maintaining frequency stability. Understanding how different governors respond to load changes and their ability to prevent frequency fluctuations, will provide valuable insights for optimizing the operation of mini hydro power systems [3]. These systems are popular for generating renewable energy, especially in remote areas. Therefore, studying the performance of different governor types in mini hydro power systems is essential for maximizing their efficacy and minimizing frequency fluctuations [4]. Mini hydro power refers to the generation of electricity using small-scale hydroelectric systems, typically with a capacity of less than 10 MW. It provides a sustainable source of electricity, particularly in remote areas where grid connectivity is limited or non-existent [5]. Mini hydro power systems can also contribute to load frequency control in power generation. Load frequency control refers to the regulation of power output to match the varying demand for electricity [6]. These systems must be able to quickly detect changes in demand and adjust their output accordingly to maintain a stable frequency.

Proper coordination and communication between multiple Mini Hydro Power Plants (MHPPs) within a grid is essential to ensure balanced load sharing and prevent frequency deviations [2]. Governors play a crucial role in load frequency control for mini hydro power systems. Proper calibration and maintenance of governors is necessary to ensure accurate and reliable frequency control. Additionally, advanced control algorithms and technologies can be implemented to optimize governors' performance and enhance load frequency control in mini hydro power systems [7]. Governors are mechanical or electronic devices that regulate the speed and power output of turbines in power systems [8]. Two main types of governors are used in mini hydro power systems: mechanical and electronic. Mechanical governors use mechanical components such as flyweights and springs to control the water flow and maintain a stable frequency. Both types of governors play a crucial role in optimizing the performance of mini hydro power systems by ensuring efficient load frequency control [9]. Governors in load frequency control are responsible for maintaining a stable frequency by adjusting the water flow to the turbine. This is crucial because any deviation in frequency can lead to disruptions in the power supply and potentially damage electrical equipment. By continuously monitoring and adjusting the turbine speed and power output, governors help regulate the balance between power generation and load demand, ensuring system stability and preventing blackouts or brownouts [10]. By comparing the performance of governors in different systems, researchers can identify the most suitable approaches for load frequency control, leading to improved power system reliability and efficiency [11]. This review aims to provide a comprehensive understanding of the various governor types used in MHPPs and their impact on load frequency control. It will also aid in identifying possible areas for additional research and advancement in this sector [12]. Furthermore, the analysis of comparative studies will enable a comprehensive understanding of each governor type strengths and weaknesses, facilitating the implementation of informed choices in MHPPs [13].

The system's frequency and voltage exhibit synchronous fluctuations in response to changes in load, which result from a delayed response in load demand balancing. These power plants employ diverse control systems to maintain the frequency and voltage within acceptable limits [14]. A new adaptive scheme to avoid miscoordination associated with recloser-fuse protection of distribution network under distributed generation insertion is explored in [15]. MHG control technique is older and comprises of both hydraulic and mechanical components. Since electric components perform better and are more flexible than mechanical components, modern hydraulic turbine governors use electro-hydraulic systems [16]. The PID controller that comes with these electro-hydraulic governors is called an electro-hydraulic based PID governor, and it regulates the system frequency during significant load fluctuations. It responds faster and performs better than a hydraulic governor with a mechanical foundation. The proportionate term (P) handles the current control. Error and integral term (I) address past control errors, while derivative term (D) addresses potential future control errors [17]. The goal of this effort is to identify an appropriate governor that will stabilize the system following a significant load variation. In order to do this, a distribution test network that is linked to a MHPP of the Distributed Generation (DG) type is taken into consideration. The primary goals of this endeavor are:

- To use the PSCAD/EMTDC software to model the mechanical hydraulic governor and the electro-hydraulic PID based governor for the micro hydro power plant's load frequency regulation.
- To demonstrate the efficacy of both governors and compare their responses for load frequency control under various load fluctuation scenarios.

II. LITERATURE REVIEW

A. Distributed Generation

DG refers to the generation of electricity from small-scale power sources that are located close to the point of use. These power sources can include renewable energy technologies, such as solar panels, wind turbines, and micro-hydro systems, as well as conventional fossil fuel-based generators. DG offers numerous benefits, including increased energy efficiency, reduced transmission losses, and improved grid reliability [18]. Additionally, DG promotes energy independence and empowers communities to generate their own clean energy, fostering sustainability and reducing reliance on fossil fuels [19].

B. Types of Distributed Generation

DGs include solar photovoltaic (PV) systems, wind turbines, biomass generators, fuel cells, and microturbines.

These technologies enable electricity production either at or near the consumption point, reducing transmission and distribution losses and increasing overall system efficiency. Each DG technology type has its own unique advantages and considerations, making it important for policymakers and stakeholders to understand their characteristics and potential applications in order to effectively incorporate them into the energy landscape [20]. DG systems can be expensive to install and maintain, requiring significant upfront investment. They may also face regulatory barriers and challenges during their integration with existing grid infrastructure [21]. Firstly, DG systems have the ability to operate independently from the main grid, providing a reliable power source during grid failures or emergencies. Additionally, DG systems can be more competent in terms of energy transmission as they are located closer to the end-users, reducing transmission losses that occur in centralized power generation [22]. The distributed generation technologies can be categorized as shown in Figure 1. Distributed generation refers to the production of electricity from multiple small-scale power sources located near the end-users. These sources can include renewable energy technologies, such as solar panels, wind turbines, and fuel cells, as well as conventional generators. The technical aspects of distributed generation involve various considerations, namely system integration, power quality, grid interconnection, and control strategies [23].

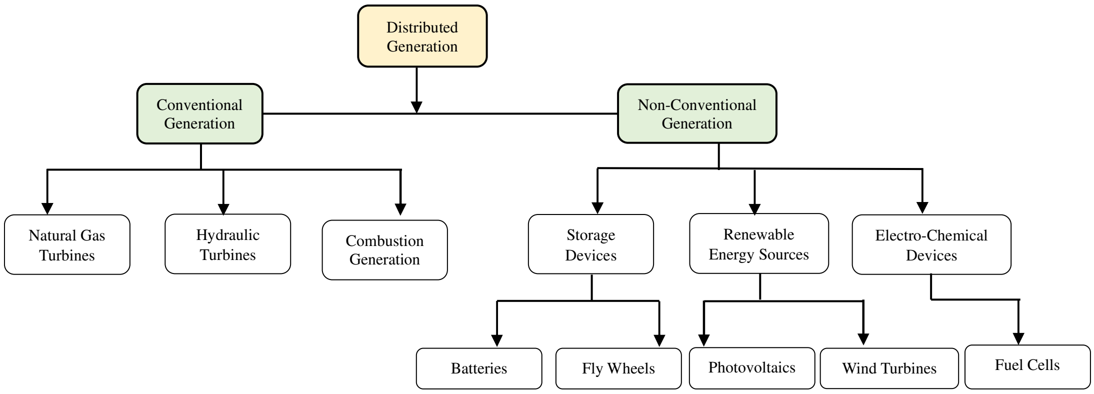

Fig. 1. Distributed generation and source classification.

1) DG Operation Mode

DG or premeditated islanded mode [24] operation refers to the process of generating electricity at various smaller-scale locations, like homes or businesses, rather than relying solely on centralized power plants. This decentralized approach allows for greater flexibility and reliability in the power grid, as well as increased energy efficiency.

2) Mini Hydro Power Plant

An MHPP is a small-scale hydroelectric power station that harnesses the energy of flowing or falling water to generate electricity. These plants are typically designed to have a capacity of less than 10 MW and are often located in rural or remote areas where access to larger power grids may be limited. They provide a sustainable and renewable energy source, contributing to the reduction of greenhouse gas emissions and promoting local economic development [25].

a) Working Principle of a Mini Hydro Power Plant Type DG

MHPPs work by utilizing the water flow from a natural source, such as a river or stream, to generate electricity through the use of turbines and generators. Control systems ensure the effective operation and monitoring of these components, optimizing power generation from the available water flow [26]. The advantages of implementing MHPPs include their lower environmental impact, as they require smaller dams and reservoirs compared to larger-scale installations. Additionally, considering factors such as water flow rate, available land area, and environmental impact is crucial in assessing the viability of MHPPs [27]. Figure 2 displays the block diagram for the MHPP islanded mode of operation.

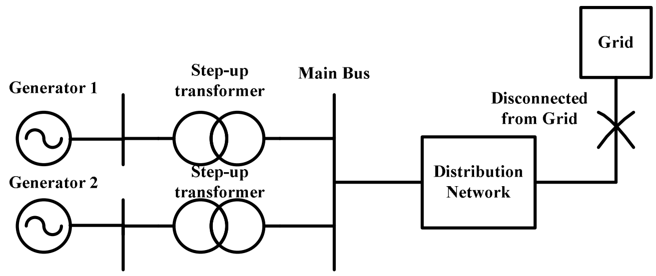

Fig. 2. MHHP islanded mode of operation.

Traditionally, mechanical hydraulic PI and PID governors as well as electro-hydraulic governors have been used to regulate speed. PID controllers are perfect for governor control since they have three different system management methods. Owing to its proportional, integral, and derivative functions—which, in turn, reduce rising time, zero steady state error, and reduced oscillation—the system may respond swiftly to load perturbations. PID and PI controls are excellent for second-order systems and operate well with linear models. One such instance in which he controlled a prototype micro hydropower plant's load frequency using the PI controller technique is described in [28]. Although PID controllers offer many advantages, they struggle to reach the optimal degree of parameter adjustment. PID controllers are unable to offer satisfactory control over non-linear systems that have a severe integrator wind-up problem [29]. The suggested technique is called the Maximum Peak Resonance Specifications (MPRS) methodology. A predefined bandwidth and phase margin provide system stability [30]. In comparison to conventional PI controllers, this controller's dynamics and stability have shown enhanced power system dampening and better performance [31].

b) Electro-Hydraulic PID Governor Functionality

Electro-Hydraulic PID governors use electric hydraulic systems. Functionally, their operation is very similar to that of mechanical-hydraulic governors, but:

- Electrical systems are employed in many computation and measurement activities, including speed detection and both permanent and temporary droop.
- Electric components provide greater flexibility and improved performance in terms of dead bands and time lags.
- The dynamic features of a PID governor are usually adjusted to mimic those of a mechanical hydraulic governor.

c) Alternative Control Techniques

Several alternative control strategies have been suggested, in addition to conventional techniques, to stabilize frequency fluctuations. One strategy to reduce frequency variation is to use ballast or dump loads [32]. To distribute the load and protect the generator, dump loads need high resistors. A dump load's operation can be controlled with an Electronic Load Governor (ELG). The ELG is composed of an electrical device that automatically adjusts the ratio between the real Load and the dump load in order to maintain a constant load on the generator. Figure 3 illustrates the dump load and ballast concept.

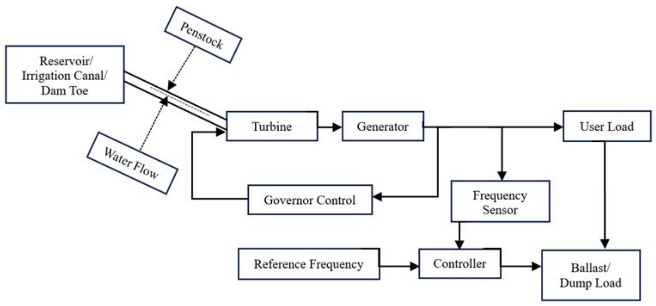

Fig. 3. Block diagram showing the dump load for a little HPP.

d) Frequency Balance and Control

A power system is made up of several linked generators that can supply massive loads much like a single generator, but all the generators and consumers add to the system when demand fluctuates. Practically speaking, the electricity system is never in a state of balance because consumer demand is constantly fluctuating.

III. RESEARCH METHODOLOGY

MHPPs commonly employ mechanical hydraulic governors, electro-hydraulic PI governors, and electro-hydraulic PID governors to regulate load frequency. This study examines the use of an electro-hydraulic PID governor in the load frequency control technique. To demonstrate its advantages, the response of the suggested governor is compared with that of the mechanical hydraulic governor under various load fluctuations. The test system and its different components are modeled in PSCAD/EMTDC software.

A. Test System for Load Frequency Control

To analyze the proposed Load Frequency Control (LFC) system, which includes a DG system with two MHPPs operating in parallel, the test system is simulated using PSCAD software. Each DG unit has the capability to transmit a maximum power of 1.8 MW when operating at its full capacity of 2 MVA. The distribution system consists of 20 lumped loads and 26 buses and it is completely separate from the main grid. Figure 4 illustrates the distribution network, while Figure 5 showcases the distribution system model developed with the PSCAD/EMTDC software. The distribution line is modelled as a theoretical PI circuit with a maximum length of 6 km.

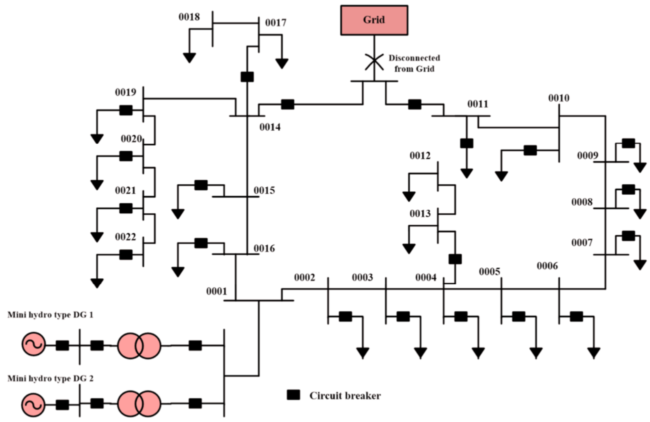

Fig. 4. MHPP connected with the distribution network.

B. Synchronous Generator Parameters

The two synchronous generator units in this research have nominal terminal voltages of 3.3 kV. Every generator has a transformer connected to it that steps up the voltage to 11 kV for the distribution network. The generators are linked to two circuit breakers. The synchronous generator model, equipped with a mechanical hydraulic governor and an electro-hydraulic PID-based governor, is designed with the PSCAD/EMTDC software. A hydraulic turbine that has every valve required to regulate the mechanical torque the water flow produces powers the generators. Another essential characteristic of the generators is excitement control, which is necessary because the device needs to maintain the voltage level within a specific range. The different synchronous generator parameters are shown in Table I. The transformer parameters corresponding to each generator are presented in Table II. Transformers are employed to convert the voltage level created by the generator from 3.3 KV to the distribution voltage level, which is 11 KV.

TABLE I. PARAMETERS OF A SYNCHRONOUS GENERATOR

Parameter	Value
Rated RMS line to line voltage	3.3 KV
Rated RMS line current	350 A
Inertia constant (H)	2.5 s
Iron loss resistance	300 p.u.
Base angular frequency	314.159 rad/s
Armature resistance [Ra]	0.01 p.u.
Potier reactance [Xp]	0.104 p.u.
Unsaturated reactance [XD]	0.838 p.u.
Unsaturated transient reactance [XD']	0.239 p.u.
Unsaturated transient time [TDo']	8.0 s
Unsaturated sub Transient time [TDo"]	0.05 s
Unsaturated reactance [Xq]	0.534 p.u.
Unsaturated sub transient reactance [Xq"]	0.12 p.u.
Unsaturated sub transient time [Tqo"]	1.0 p.u.
Air gap factor	1.0

TABLE II. TRANSFORMER PARAMETERS

Parameter	Value
3 phase transformer MVA	2 MVA
Primary winding type	Delta
Secondary winding type	Star
Positive sequence leakage reactance	0.08 p.u.
Air core reactance	0.2 p.u.
Inrush decay time constant	1 s
Knee voltage	1.15 p.u.
Magnetizing current	0.001%

C. Exciter System Model

Giving the synchronous machine field winding direct current is the excitation system's primary job. Furthermore, the excitation system carries out control tasks that are necessary for the power system to operate satisfactorily. Voltage and reactive power flow control are examples of control functions. The excitation system autonomously regulates the field current of the synchronous generator in order to uphold the terminal voltage. The excitation system model chosen for this study is based on the IEEE type AC1A standard model shown in Figure 5. This model can be used with brushless excitation systems and offers a field-controlled alternator excitation system with uncontrolled rectifiers. The voltage regulator draws power from a source that is unaffected by transients in the outside world and the exciter does not use self-excitation. Table III lists the typical parameters used in the simulation.

TABLE III. SAMPLE DATA OF IEEE AC1A EXCITATION MODEL PARAMETERS

Parameter	Value	Parameter	Value
T_C	0	K_F	0.03
T_B	0	T_F	1
K_A	400	T_E	0.8
T_A	0.02	K_E	1
V_{AMAX}	14.5	K_C	0.2
V_{AMIN}	-14.5	K_D	0.38
V_{RMAX}	6.03	V_{RMIN}	-5.43
$SE_{(VE1)}$	0.1	$SE_{(VE2)}$	0.03
V_{E1}	4.18	V_{E2}	3.14

D. Model of Governor and Hydraulic Turbine

The major role of the governor is to regulate the generator speed in order to ensure a consistent frequency. The mechanical torque and power delivered to the generator are determined by the governor in order to control the water flow by detecting variations in velocity and adjusting the turbine gate accordingly. The main block diagram, which incorporates the governor and hydraulic turbine is seen in Figure 6. The turbine governor has to act fast to shut the hydraulic valve and divert water flow right away to prevent the hydro turbine from over-speeding when load is removed from the system and demand drops.

E. Electro-hydraulic PID Governor Transfer Function

The transfer function of the hydro governor model, also known as a PID controller, with proportional, integral, and derivative gain is shown in Figure 7. By offering both a transient gain increase and a transient gain reduction, it produces a higher response. Particularly when islanded mode is engaged, the significant derivative gain could lead to increased oscillations and instability. The proportionate and integral gains are responsible for producing the intended transient droop and reset time. In Figure 7, TA represents the time constant of both the pilot valve and servomotor. TC refers to the gain of the gate servo while TD represents the time constant of the gate servomotor. RP exhibits a persistent sagging. The governor model consists of two crucial parameters: the maximum rate at which the gate may open and close. These data demonstrate the pace at which the gate opens or closes, with the hydraulic turbine having a slower response compared to the steam or gas turbine. The PID parameters are shown in Table IV.

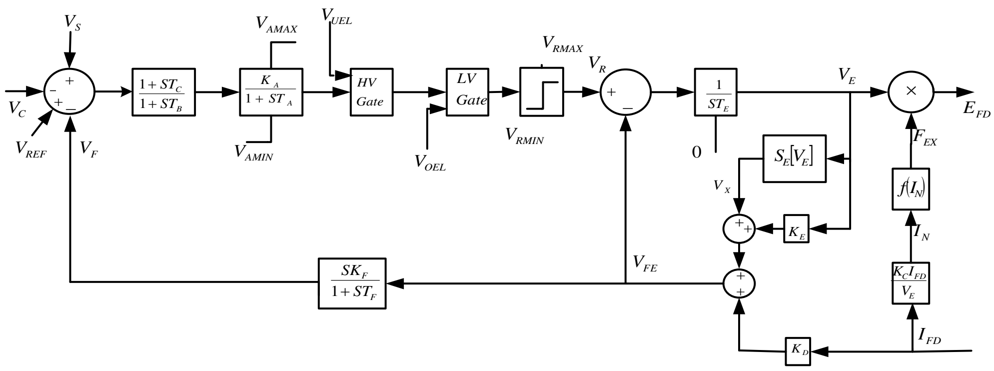

Fig. 5. IEEE type AC1A excitation transfer function.

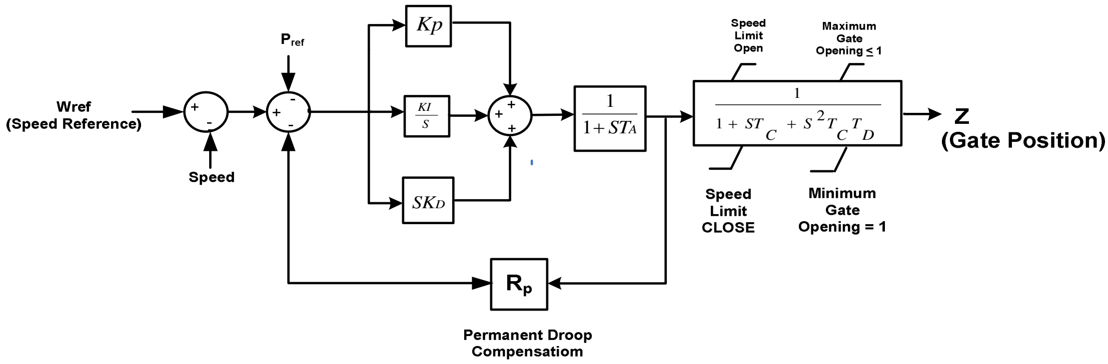

Fig. 6. Speed control with turbine and governor.

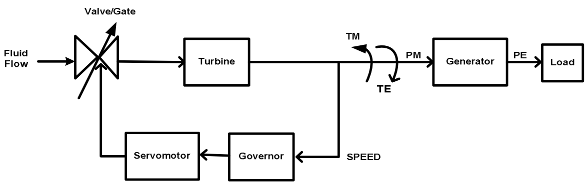

Fig. 7. Electro-hydraulic PID governor transfer function.

TABLE IV. VALUE OF GOVERNOR MODEL PARAMETERS

Parameter	Value	Parameter	Value
K_P	2	T_C	0.2
K_I	0.35	T_D	0.2
K_D	0.9	Max gate opening	0.16
T_A	0.05	Max gate opening	0.16
R_P	0.004	Dead band value	0
Max gate position	1.0	Min gate position	0

F. Hydro Turbine

Water is commonly regarded as an incompressible fluid and a rigid conduit. The turbine flow is initially quantified as (q) before being diminished by a deflector and relief valves. Penstock head loss coefficient F_p is defined as follows: G is the gate position. The water beginning time is T_W, and the turbine gain factor flow is A_T. T_W shows how long it takes a head to speed up the water in the penstock. With load, this time varies from 0.5 to 4.0 s. The hydraulic turbine's transfer function is depicted in Figure 8. The hydraulic turbine's block diagram specifications are displayed in Table V. Lastly, the turbine model regulates the necessary mechanical power for the generator.

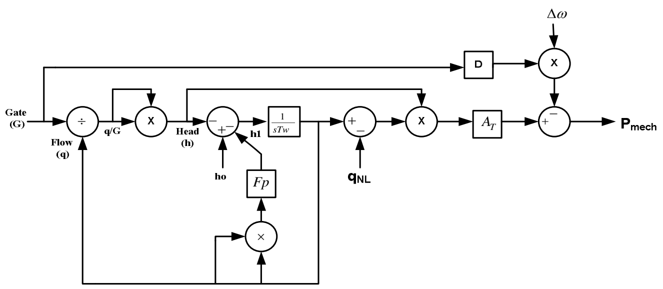

Fig. 8. Hydro turbine transfer function.

TABLE V. VALUE OF HYDRO TURBINE PARAMETERS

Parameter	Value	Parameter	Value
T_W	1.0	Initial output power	0.7
f_p	0.02	Initial operating head	1.0
0	0.5	Rated output power	1.0

G. Mechanical Hydraulic Governor

The traditional mechanical hydraulic governor is made up of both hydraulic and mechanical parts. For stable functioning, this governor makes use of persistent droop features. Permanent droop characteristics are employed to provide equitable load sharing between generating units. The water inertia causes hydroelectric turbines to react nonlinearly. A servomotor is an intricately engineered electric motor that rotates in direct response to an electronic command signal. As stated in [33], the transfer function of the relay valve and gate servomotor is:

$$\frac{g}{b} = \frac{Ks}{s(1+sTp)} \tag{1}$$

where K_S is the servo gain and T_P is the pilot valve /servomotor time constants. A dashpot transfer function is given by [17]:

$$\frac{d}{g} = Rt\frac{sT_R}{(1+sT_R)} \tag{2}$$

where R_t represents the temporary decrease in value, while T_R represents the duration it takes for the temporary decrease to return to its original value. Figure 9 illustrates the diagrammatic portrayal of a mechanical hydraulic governor.

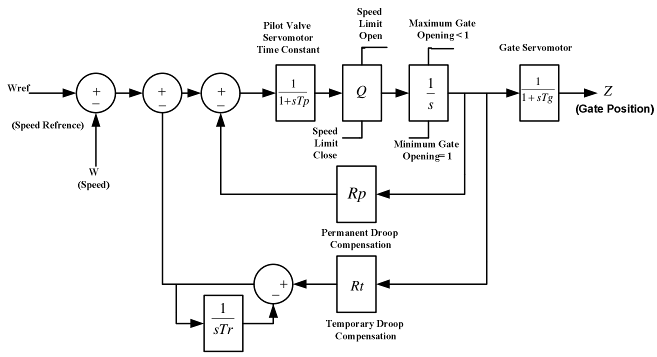

Fig. 9. Mechanical hydraulic governor.

IV. SIMULATION RESULTS AND DISCUSSION

The test system is designed to measure an electrohydraulic PID governor's reaction and a mechanical hydraulic governor that supplies power to a distribution network at both peak load and base load capacity. The test system is modelled and simulated using PSCAD software. The MHPP concept, along with its distribution network, can be seen in Figure 10.

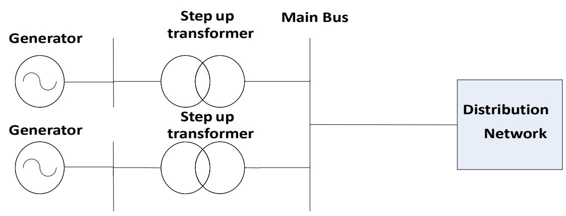

Fig. 10. MHPP model with distribution network.

A. Case Studies

In various scenarios, the power plant's base and peak load are used to test the governors' responsiveness. Table VI presents scenarios of increasing and decreasing load to see how the governors react significantly.

TABLE VI. CASE STUDIES

Case Study	Details
Case No. 1 (a)	5% load is suddenly added to the base load.
Case No. 1 (b)	5% load is suddenly subtracted from the base load.
Case No. 2 (a)	5% load is suddenly added to the peak load.
Case No. 2 (b)	5% load is suddenly subtracted from the peak load.
Case No. 3 (a)	10% load is suddenly added to the base load.
Case No. 3 (b)	10% load is suddenly subtracted from the base load.

1) Case No 1 (a)

The generators are running at their base load, or minimum load, when a 5% load is added. The frequency will decrease as the load increases. The perturbation was introduced at t = 20 s. The combined reaction of the mechanical hydraulic governor and the electro-hydraulic PID governor are shown in Figure 11.

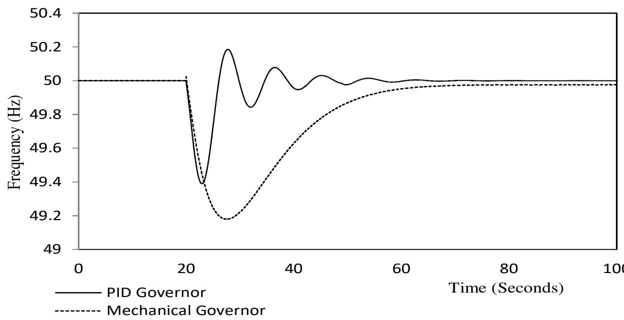

Fig. 11. Governors response for 5% addition of load.

According to Figure 11, it takes 31 s for the frequency to restore to its original value. Additionally, the electro-hydraulic PID governor exhibits reduced undershoot compared to the mechanical hydraulic governor. The mechanical hydraulic governor requires 40 s to return to its initial position. Therefore, in comparison to the mechanical hydraulic governor, the electro-hydraulic PID-based governor exhibits reduced undershot and necessitates a shorter duration.

2) Case No 1 (b)

Figure 12 illustrates how frequency increases in response to the drop in load and eventually returns to its initial value, contingent on the performance of both governors. The governors require 38.92 and 20 s, respectively, to reach 50 Hz values. Thus, in comparison to an electrohydraulic PID governor, a mechanical hydraulic governor has once again exhibited a delayed reaction and a greater degree of overshooting.

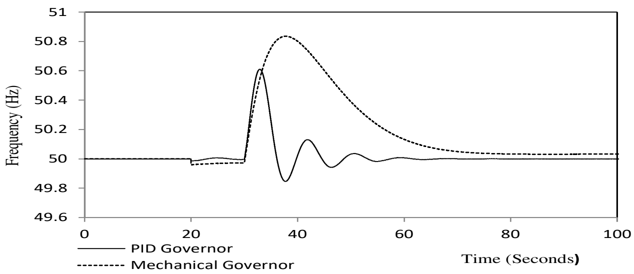

Fig. 12. Governors response for 5% reduction of load.

3) Case No 2 (a)

Suddenly, a 5% load is added to the generators, which are already running at maximum capacity. This load applied the disturbance at t = 20 s. The frequency drops as the load increases. Figure 13 displays the combined reaction of the hydraulic mechanical governor and the electrical PID governor. The electro-hydraulic PID governor clearly demonstrates a reduced amount of undershoot compared to the mechanical hydraulic governor. It takes 20.68 s for the frequency to return to its initial 50 Hz value, whereas the mechanical hydraulic governor requires 57.76 s to reach its operating frequency at 49.80 Hz during peak load.

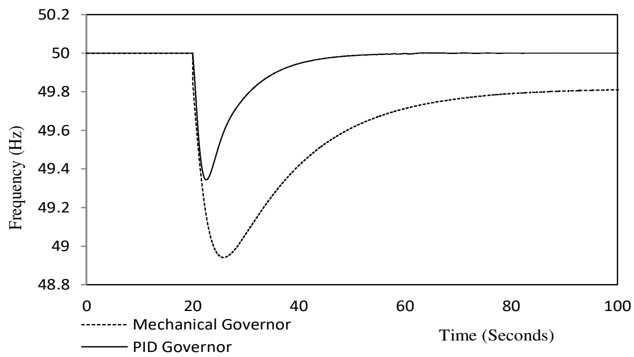

Fig. 13. Governors response for 5% addition of load.

4) Case No 2 (b)

The generators are running at their maximum load (peak load) when a 5% reduction in load occurs. The frequency rises as the load decreases. The perturbation was introduced at t = 20 s. Figure 17 displays the combined reaction of the electro-hydraulic PID governor and the mechanical hydraulic governor. Figure 14 shows that the electro-hydraulic PID governor has less overshoot than the mechanical hydraulic governor and that it takes 20.34 s for the frequency to return to its initial value of 50 Hz. The system will run at 49.90 Hz after the mechanical hydraulic governor takes 58.70 s to attain a frequency lower than 50 Hz.

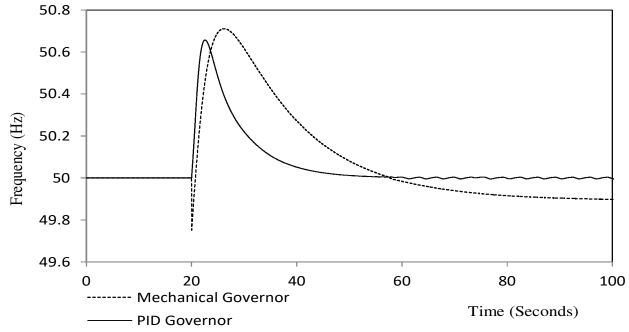

Fig. 14. Governors response for 5% reduction of load.

5) Case No 3 (a)

A 10% load is added to the generators while they are running at base load capacity. Frequency reduces as load increases. At t = 20 s, the disturbance was administered. Figure 15 illustrates the collective response of the electro-hydraulic PID governor and the mechanical hydraulic governor. According to Figure 15, the electro-hydraulic PID governor exhibits lower undershoot compared to the mechanical hydraulic governor. It takes 33.14 s for the frequency to revert back to its original value of 50 Hz, while it takes 54.83 s for the mechanical hydraulic governor to attain a frequency of 49.92 Hz.

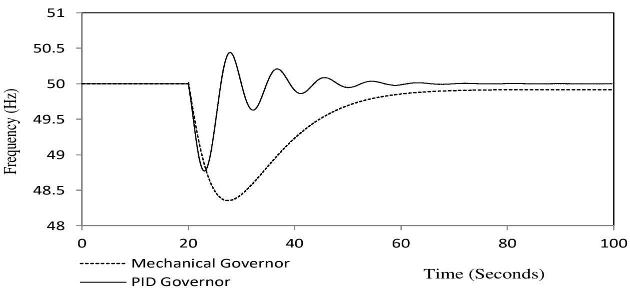

Fig. 15. Governor's response for 10% addition of load.

6) Case No 3 (b)

Figure 16 displays the response of both electro-hydraulic and mechanical hydraulic PID governors at the base load for a 10% load reduction. The frequency rises with decreasing load and returns to its initial value after a certain amount of time, contingent on the performance of both governors. The mechanical hydraulic governor in Figure 16 has a slower response and a bigger overshoot compared to the electro-hydraulic PID governor. Both electrohydraulic and mechanical hydraulic PID governors require 42 and 28.51 s, respectively, to obtain 50 Hz values.

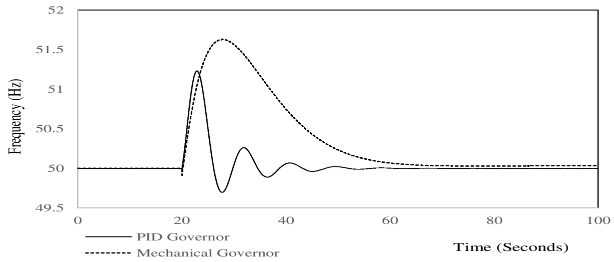

Fig. 16. Governor's response for 10% reduction of load.

V. CONCLUSIONS

This research introduces an electro-hydraulic PID-based governor for regulating frequency and speed in a Micro-Hydro Power Plant (MHPP) in a distribution network. The governor implementation is conducted using the PSCAD/EMTDC software. The efficacy of load frequency management when employing an electro-hydraulic PID-based governor has been verified on a 26-bus test system under several load fluctuation scenarios at both peak and base capacities. The efficacy and resilience of the suggested electro-hydraulic PID-based governor have been examined in relation to load increments and decrements ranging from 5% to 10% at both minimum and maximum capacities. The performance of the electro-hydraulic PID-based governor was compared to that of the mechanical hydraulic governor. The simulation findings indicate that the mechanical hydraulic governor exhibits significant frequency overshoot and undershoot and requires a longer time to settle the frequency compared to the suggested electro-hydraulic PID-based governor. It has been confirmed that the suggested electro-hydraulic PID-based governor is effective and dependable in ensuring the safe and stable functioning of power systems, surpassing the current UFLS schemes. In future work, a more complex and hybrid-renewable energy system along with batterers can be integrated into the power system to enhance its flexibility and stability.

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