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Innovation of control valve motorization method for regulating turbine rotation in micro hydro generators

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ABSTRACT

The method of transferring the main load to the dummy load is still used in micro hydropower plants. Because the turbine and generator are constantly operating at maximum capacity, the load transfer system, also known as the electronic load control (ELC) system, is ineffective and inefficient. The researcher devised a method for controlling the pressure/flow rate on the branch pipe by using a control valve motorized (CVM). Control valve motorized (CVM) is responsible for the opening and closing of branch pipelines using an electric motor. The goal is to achieve voltage and frequency stability by using CVM to adjust the flow/pressure of water in the branch pipe. The method involves designing and testing the CVM system via a Pelton turbine module connected to the generator. The results of testing the Pelton turbine module with a pressure of 4 kg/cm^2 on a 34-inch pipe show that the turbine rotates at 800 rpm. Brushless direct current (BLDC) generator with 12 poles and a Pelton turbine. The proportional integral derivative (PID) controller control parameters are calculated by the control system using the Nichols-Ziggler method, with tuning results of PB 130%, Ti 2.8 seconds, and Td 0.7 seconds. A frequency of 50 Hz and a voltage of 61 volts is produced by controlling the set point (SP) at 55% of the process variable (PV) and the manipulated variable (MV) to CVM at 38%, respectively. The conditions are implemented by varying the load on the system by connecting and disconnecting the load; the system remains stable for 5 seconds.

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1. INTRODUCTION

A micro hydro power plant is a small-scale power plant that employs the head and flow rate of water as the driving force, such as an irrigation canal, river, or natural waterfall. The phrase "micro hydro" is made up of the words "micro," which means "tiny," and "hydro," which means "water." Generator rotation irregularity brought on by changes in the linked load is a frequent issue in the micro hydro power plant. As a result, the system frequency fluctuated, which increased the risk of electrical equipment damage [1]-[3]. The generator's rotational speed has a significant impact on the electrical frequency and voltage that it produces. Any technologies that have been developed regarding micro hydropower plants can be seen through reference [4]-[9].

Electronic load controllers (ELCs) are now being developed for micro hydropower plants to ensure voltage and frequency stability [10]-[15]. The micro hydro power plant's ELC is used to change the load to a heater with a resistance of 1–5 Ohms as a dummy load. The ELC's basic operating principle is to transfer the primary load to a dummy load [16]-[20]. The generator and turbine operate at their highest capacity continually as a result of the ELC system. The ELC method is less effective and efficient, according to researchers. Researchers consider introducing a fresh idea to enhance the ELC system. The novel technique that will be investigated is controlling the turbine's spin using a control valve motorized (CVM). The novel technique that was investigated is controlling the rotation of the turbine using a control valve motorized (CVM). A turbine rotation control system that designed and tested by researchers with CVM controlled by a proportional integral derivative (PID) controller. The CVM system was developed as a voltage and frequency stabilizer for micro hydro generators. PID controller parameter values greatly affect the level of stability of the controller performed by CVM. The expected goal of the results of this study is to obtain voltage and frequency stability by adjusting the flow rate to the turbine with CVM.

Pelton type turbine is used, has input energy (Pin) in the form of water pressure on a turbine driving the turbine blade and producing kinetic energy (Pm) in the form of rotation. Turbine efficiency is defined as the ratio of input energy to generated kinetic energy. Turbine efficiency should be between 80% and 90%. Turbine blades, penstock pipes, nozzles, and water guides are some of the components that influence the value of low turbine efficiency [10], [21]-[27]. The turbine's mechanical energy then rotates the generator, converting mechanical energy to electrical energy.

The rotation control system in large-scale generators employs a hydraulic valve with governor control [13], [28]-[32]. The turbine is set to rotate at a constant rate, which requires controlling the control valve so that the flow to the turbine is always stable [1], [15], [33]. The synchronous generator, AVR excitation, and automatic governor control (AGC) are the three main components of the generation system [1], [6], [17]-[20], [29], [30]. The turbine system, generator system, and control system are the three main components of a hydroelectric energy generation system. The advantages and disadvantages of these types of turbines, particularly for a very specific design, can be used to determine the type of turbine to be used. In the early stages, the type of turbine can be considered by taking into account the special parameters that affect the turbine operating system, as in reference [30], [32]. As the load influences the generator's rotation speed. Consequently, frequency control is required in the working environment. Currently, ELCs are frequently used to develop various knowledge such as vehicle steer control also to ensure voltage and frequency stability. As a result, researchers were eager to experiment with PID controllers to optimize the AVR based on CVM. A CVM is used because it is simpler than a control valve, which needs pressurized air or a source of hydraulic pressure to operate. This study was carried out by designing and implementing the CVM method to control the rotation of the Pelton turbine which is coupled to the generator in a micro hydro generator. A control valve that may be opened to a different degree and is driven by an electric motor is known as a control valve motorization (CVM). The signal given at 0–10 volts determines the proportion of CVM valve opening.

Sections in this study are as follows: i) Section one introduces CVM and the method that can be used to regulate the rotation of the Pelton turbine due to generate voltage in the micro hydro power plant system; ii) Section two proposes and explains the innovative method in regulating the rotation of Pelton turbine due to generate voltage in the micro hydro power plant system; iii) Section three simulating and analyzing the proposed system to see the plant responds and also determining the PID parameters (stable and unstable conditions) and addressing it to the load changes circumstances; iv) and The final section is concluding the behavior of the proposed system.

2. METHOD

The generator system is the load that the turbine must drive in order to produce a voltage at a specific frequency [34]-[37]. According to (1), the need for generator rotation must be met based on the number of poles and the desired frequency. At the same point, the turbine rotates the rotor magnetic field, which induces a magnet to the stator coil and results in the induced voltage [30], [32]. The (2) describes how much voltage is produced.

$$N_s = \frac{(120.f)}{P} \quad (1)$$

Where N_s is synchronous rotation (rpm); f is frequency (Hz); and P is the number of poles.

$$E = 4.44 \times f \times N \times \phi \quad (2)$$

Where E is induced voltage (volts); f is frequency (Hz); N is the number of turns; and ϕ is flux magnetic field excitation (wb).

The rotation control system is used on the turbine to adjust the flow rate by adjusting the CVM opening. The turbine power is related to the flow rate Q in the penstock, as shown in (3).

$$P = 9.81 \times Q \times H \times \eta\_turbine \quad (3)$$

Where P is turbine power (kW); Q is water discharge (m3/s); and H is effective head height (m).

CVM can adjust the flow rate based on the generator power requirements. The flow rate control system is made up of three major components: sensors, controllers, and actuators. Electrical signal standards include current signals 0-20 mA and 4-20 mA, as well as voltage signals 0-5 volts and 0-10 volts. The industry standard signal ranges from 4-20 mA [38]-[40]. The shape of this signal must be understood so that no errors occur during the system control process. Signal standardization is very important, so the industry's instrumentation equipment must be recalibrated so that the signal matches the real-time in the field [17].

The design process involves creating a generating plant module with a Pelton turbine operating at a specific turbine rpm and water pressure [21]-[27]. The PID control parameters are then calculated and determined [20], [31], [41], [42]. PID control parameters are calculated and determined based on the Ziegler-Nichols in Table 1.

The test procedure involves measuring the outcomes of the power plant design and testing using the PID control settings that have been determined to see how the CVM control reacts to the Pelton turbine. Figure 1 illustrates the system design of Pelton turbine. The turbine rotation is carried out in accordance with Figure 2 to measure and record control response data using LabSoft [16], [18], [19], [42]-[44].

Table 1. PID control parameter of Ziegler-Nichols

Controller	Kp	Ti	Td
Proportional	$\frac{Tg}{Tu}$	∞	0
PI	$\frac{0.9\,Tg}{Tu}$	3.3 Tu	0
PID	$\frac{1.2\,Tg}{Tu}$	2 Tu	0.5 Tu

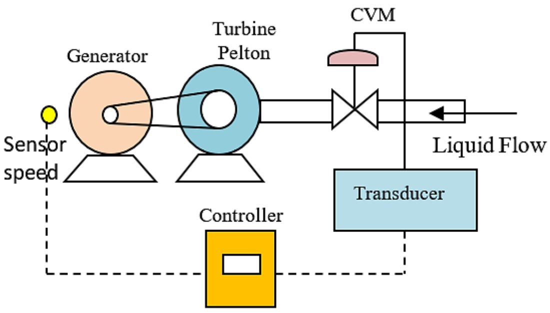

Figure 1. Pelton turbine generator system design

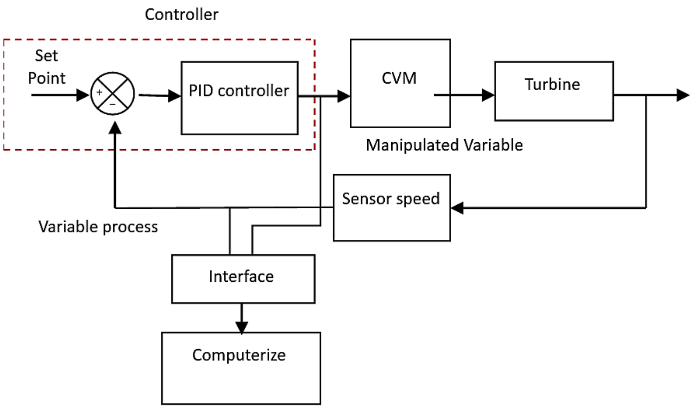

Figure 2. Rotation control block diagram

Figure 2 shows that the turbine rotation sensor by the tacho generator provides a linear signal of 0-10 volts through a cable conductor from the field to the panel. Then the signal from the controller is sent again to the servo motor actuator with a signal of 0-10 volts. Before the actuator in the form of a servo valve, the 0-10 volts electrical signal is changed by a converter with a 24 volts DC source voltage to rotate the valve. The responses to be recorded are the setpoint, variable process (VP), and the control response manipulated variable (MV) through the interface to the computer.

A technique for managing the load involves using CVM and a PID controller to direct water flow or pressure in the penstock toward the Pelton turbine. Construction is needed, and the associated expenses are higher because a larger valve size is employed to directly set the pressure or flow in the quick pipe. Only 50% of the primary penstock's size is used in the procedure for rerouting pressure or flow from it. Figure 3 illustrates the Pelton turbine which is coupled to the generator in a micro hydro generator.

Figure 3. Micro hydro generator

3. RESULTS AND DISCUSSION

The experiment was carried out on a tiny Pelton turbine plant that was pumped with 4 BAR compressed water. Pelton turbine paired with a 2 kW, 12 pole, 500 rpm, 50 volts, and 50 Hz permanent magnet generator. At a turbine speed of 0-1000 rpm, the turbine speed is measured using a 0-10 volts signal. used as a controller MEP-SD multi channels digital instrument is the model name. For intelligent style, use a control valve with a 24-volt DC source, a run time of 55-100 seconds, and an input signal of 0-10 volts. The recorder system connects the plant to the computer via the Labsoft interface, which measures and records control response data on process variable (PV) and manipulated variable (MV). A technique for controlling loads involves using a CVM and PID controller to direct the flow or pressure of water in the penstock towards the Pelton turbine. Construction is required, and the associated costs are higher because larger valve sizes are used to directly regulate pressure or flow in the rapid pipe. Only 50% of the main penstock size is used in the procedure to divert pressure or flow from it. Figure 3 illustrates a Pelton turbine coupled to a generator in a micro hydro power plant.

3.1. Proposed system's general description

The water pressure coming out of the turbine is 1 ATM = 10322 kg/m^2. The density of water is 1 g/cm^3, which is 1000 kg/m^3, so the weight of water is 1000 kg/m^3 × 9.8 m/s^2 = 9800 Kg/m^{2}s^2. The results of the measurements carried out are the water pressure in the penstock measuring the pressure gauge leading to the turbine Pelton of 4 kg/cm^2 with a height of 3.03 m. We got the plant response as shown in Figure 4. The responses that can be analyzed are the delay time (td), rise time (tr), top time (tp), set time (ts), and overshoot (mp) values that occurred. The Td value = 1 s, Tr = 2.5 s, Tp = 3.5 s, ts = 7 s, mp = (35-30)/30 ×100% = 16.67% (can be seen in Figure 5).

Figure 6 shows that the turbine rotation sensor by the tacho generator provides a linear signal of 0-10 volts through the cable conductor from the field to the panel. Then the signal from the controller is sent again to the servo motor actuator with a 0-10 volts signal. Before reaching the actuator in the form of a servo valve, the 0-10 volts electrical signal is converted by a converter with a 24-volt DC source voltage to rotate the valve. The responses to be recorded are setpoint, variable process (VP), and control response (MV) via the interface to the computer.

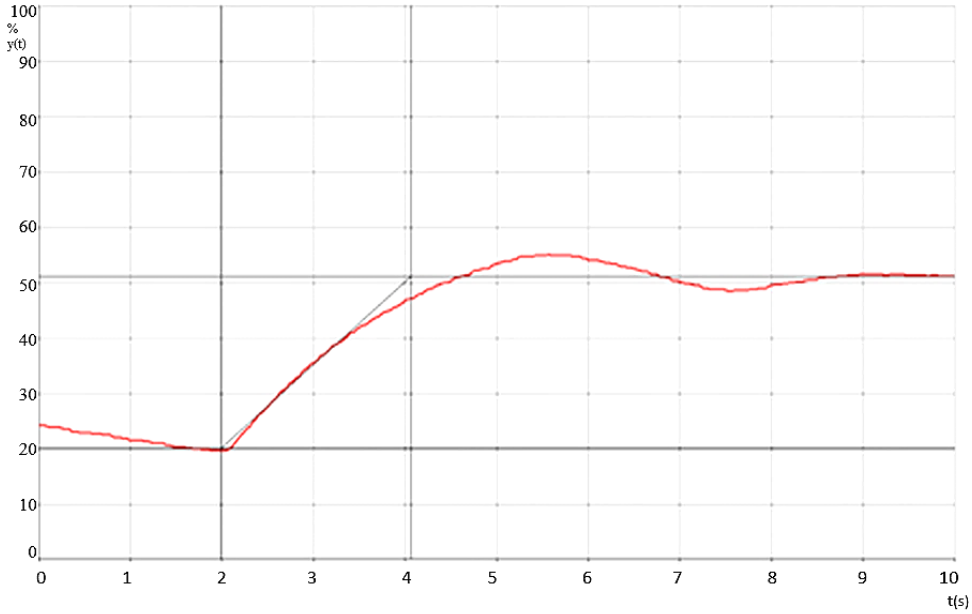

Figure 4. Plant responds

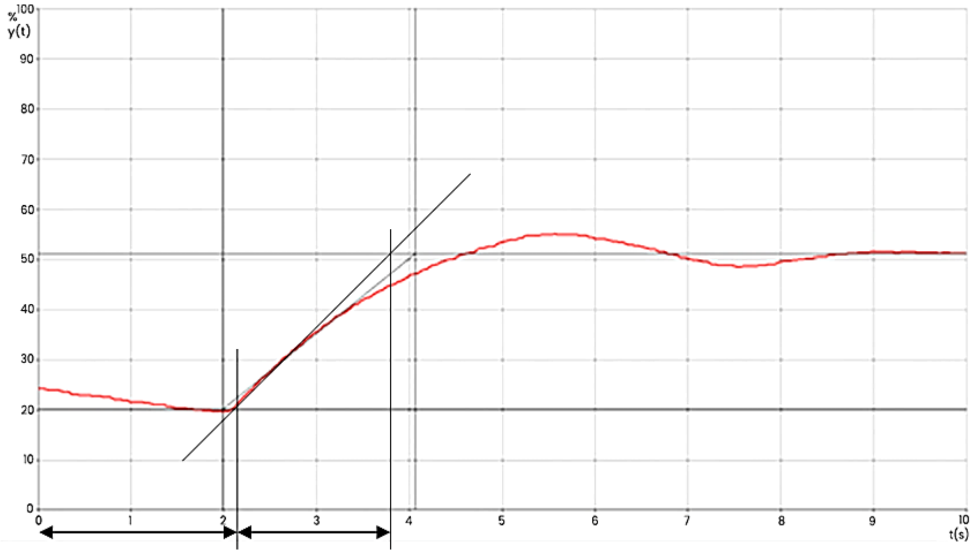

Figure 5. Determined of Tu and Tg

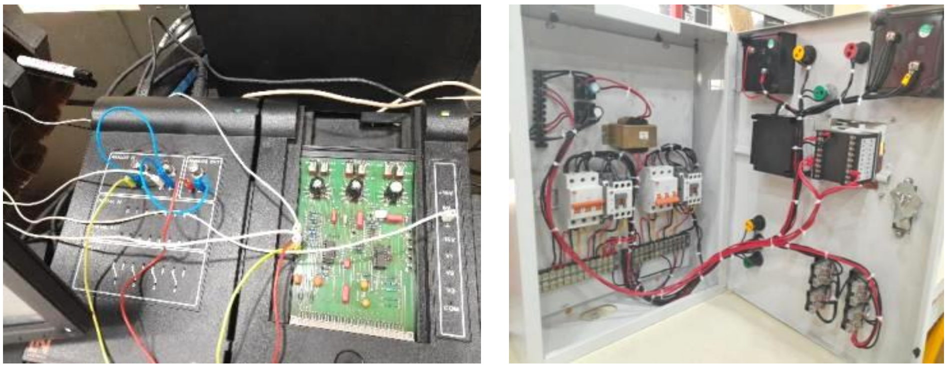

Figure 6. Simulation via Luecas Nuelle module and the wiring in panel

3.2. PID control parameters determination and applications

The parameters that must be calculated for PID control are the values of Kp, Ti, and Td. Following the Nichols-Ziggler method using the reaction curve in Figure 5, where Tu = 1.4 and Tg = 2.2. The magnitude of the PID control parameters is Kp = 1.2×1.4/2.2=0.764 or proportional band (PB)=1/0.764×100%=130.89%, Ti = 2×1.4=2.8 s, and Td = 0.5×1.4=0.7 s. Applying PID control parameter values by setting parameter values that have been calculated on the controller tool [21]-[25]. The steps are: i) running the turbine until it reaches a stable condition, ii) analyzing control response, iii) providing turbine and generator loads, iv) analyzing changes in response that occur, v) changing the PB values to 100% and 200%, vi) perform analysis from points 2 to 4, and vii) make another load changes.

The experiment initially takes the turbine and generator worked under zero load conditions with a set point at 51% or at a frequency of 51 Hz or a rotation of 510 rpm, with a voltage of 61 volts. Control parameter settings according to the calculation PB = 130%, Ti = 2.8 s, and Td = 0.7 s. Figure 7 shows the MV response, which is the output from the controller where the observed values td = 1 s, tr = 2.5 s, tp = 5.5 s, ts = 17.5 s, and mp = (61-51)/51×100%=19.6%. At 43 seconds, the load is carried out in the form of a 3×5-watt lamp. In this condition, the frequency and voltage drop to 50 Hz and 60 volts, respectively. The normal voltage and frequency then return to the setpoint values of 51 Hz and 61 volts automatically after 20 seconds.

As the experiment continues, 2 sets of PB (100% and 50%, respectively) have been simulated to see the response of the plant as other control parameter settings are still the same. Figures 8 and 9 illustrate the responses as the PB value on the PID control changes. Whereas at Kp 1 (PB 100%) the steady state time reaches 35 seconds, it is only 28 seconds with Kp 2 (PB 50%). The overshoot for Kp 1 is negligible, however for Kp 2 (50%) it is 19.6%. The static state time is only 5 seconds when loading and unloading is being done.

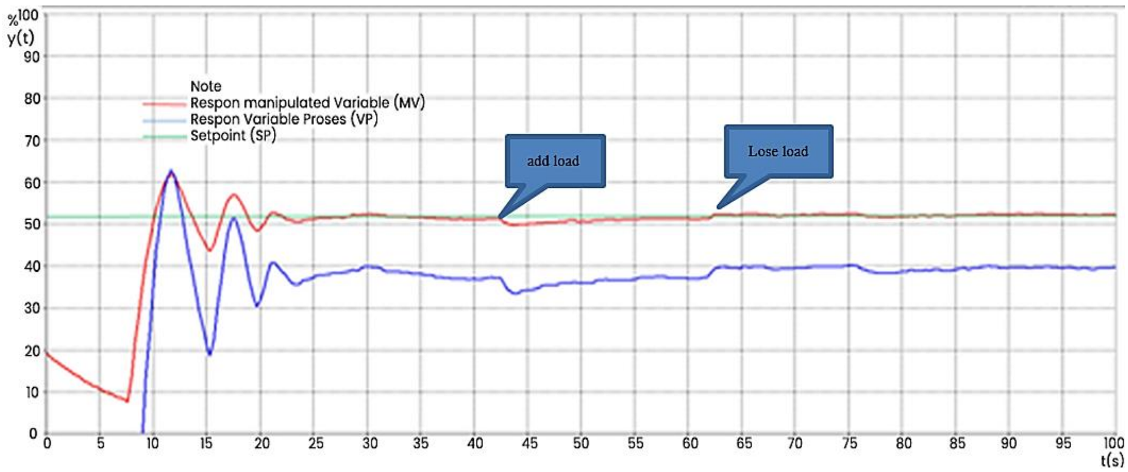

Figure 7. Plant responds as loaded condition

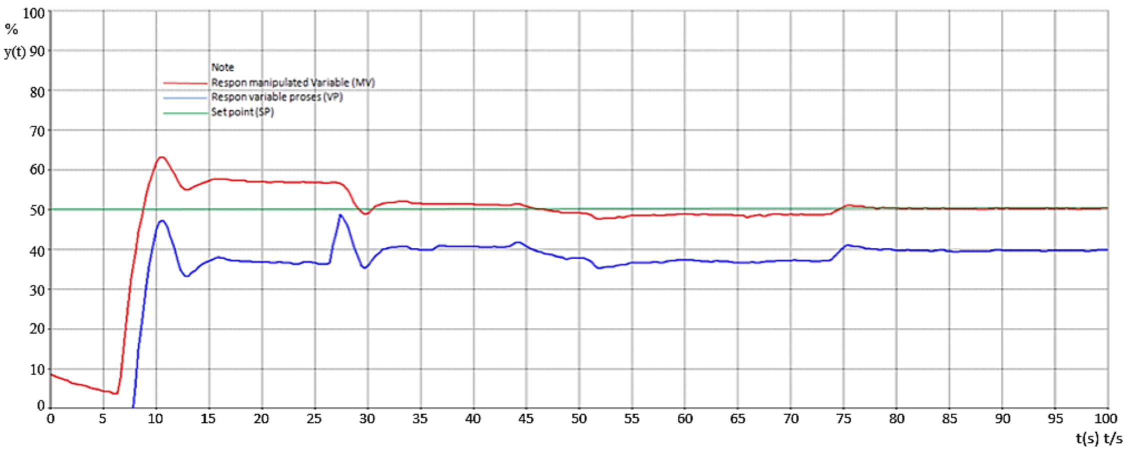

Figure 8. Plant responds at PB 100%

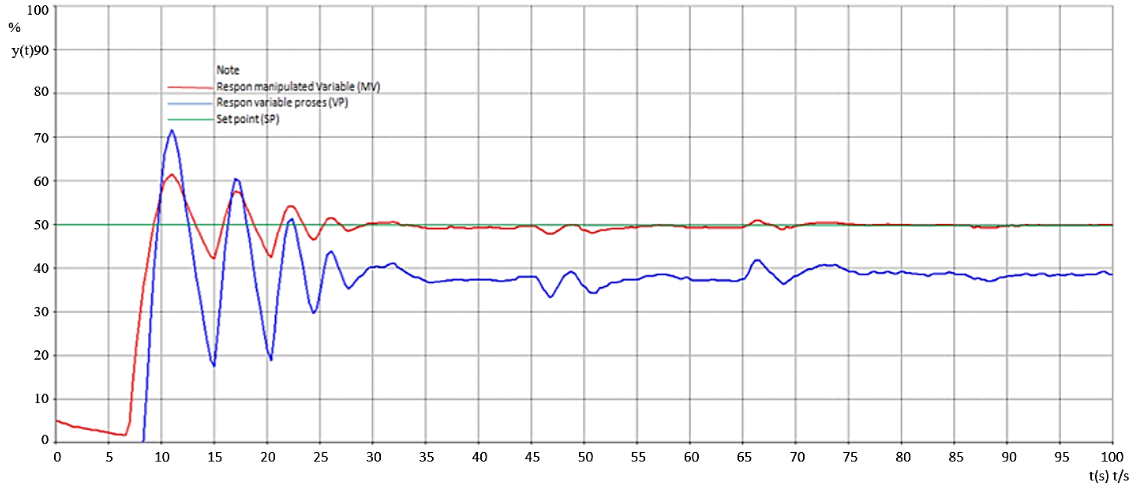

Figure 9. Plant responds at PB 50%

3.3. Load changes

In terms of speed, when a load change of 3×10 watts and 3×25 watts, respectively is made, it reaches a steady state, and the overshoot response that occurs is shown in Figures 10 and 11, respectively. In both Figures 10 and 11, it can be seen in the load changes of 3×10 watts and 3×25 watts, the zero load condition reaches a steady state for 12 seconds and 13 seconds, respectively, with an overshoot of 19.6%. The condition is carried out by loading a steady state time of about 5 seconds with an overshoot almost equal to zero. Then the load was released again during a steady state for 9 seconds with an overshoot of 4% and 16%, for a 3×10 watts and a 3×25 watts load, respectively.

3.4. Unstable PID control parameter values

Unstable control systems are unavoidably the result of inappropriate control parameter settings. It is possible to see unstable system conditions when the response oscillates constantly and causes unstable voltage and frequency. Figure 12 illustrates this situation, which happens with a Kp = 3, Ti = 4, Td = 1, and a load of 3×10 watts.

3.5. System performance analysis

An intriguing finding emerged from all the tests run, in which the controller itself may adjust the PID control parameters. The turbine is first operated normally, and then the self-tuning setting is activated. After that, the controller performs its own calculations for roughly 60 seconds until the system is steady. According to the results of the controller's self-tuning, the PID control parameters were set to PB = 127.8%, Ti = 25 s, and Td = 6 s, as shown in Figure 13.

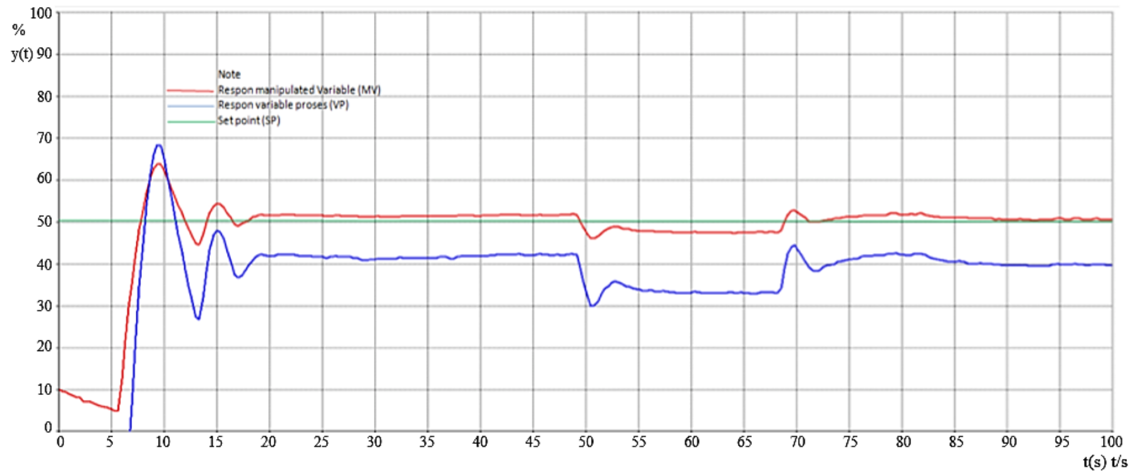

Figure 10. 3×10 watts load condition responds

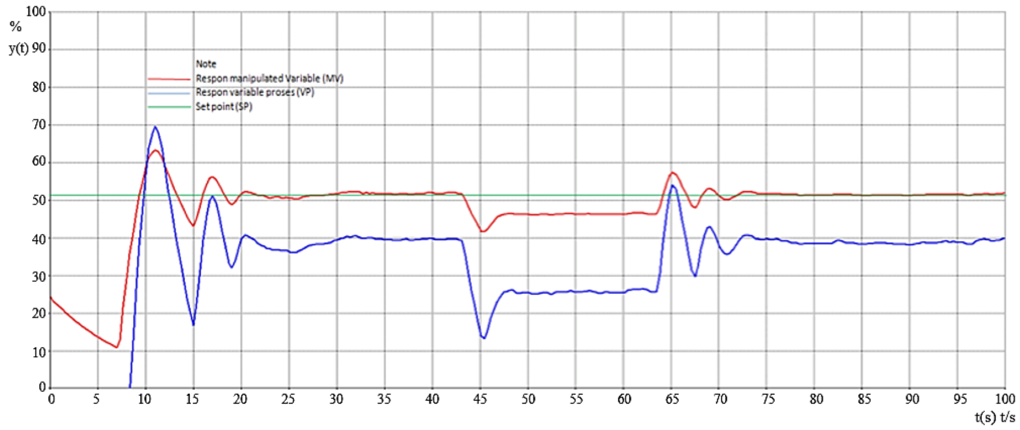

Figure 11. 3×25 watts load condition responds

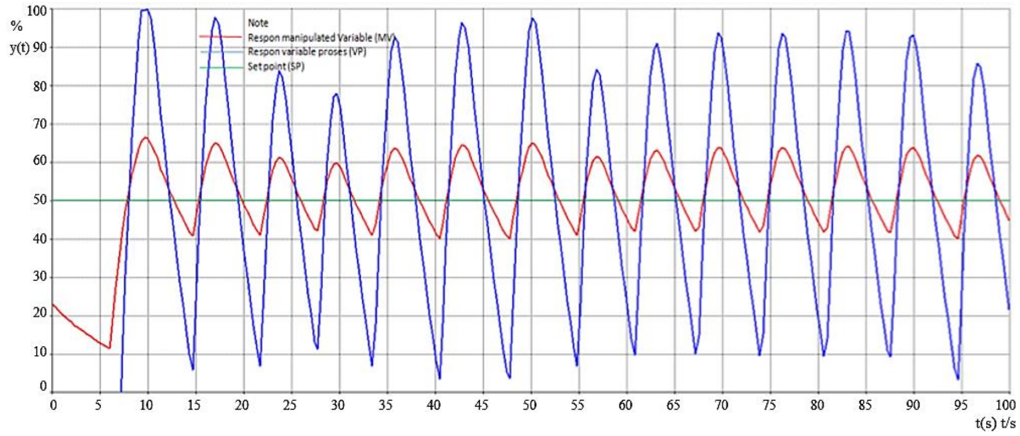

Figure 12. Unstable plant responds

Figure 13. PID parameter setting

In order to avoid huge input values to the controller using a potentiometer, restrictions on sensor settings are implemented. Since the voltage sensor can generate signals greater than 10 volts, this is done. A controller whose maximum sensor signal is 10 volts should not experience this. By changing the potentiometer, the sensor signal limit is restricted to a value of 6 volts. The set point value of 55% VP is at 55% and the MV value to the CVM setting is at position 38% in the response, resulting in a frequency of 50 Hz and a voltage of 61 volts. The issue is that when the load is connected, it disturbs the system, and releasing the load, the system remains stable, with a duration of about 5 seconds. The parameter calculated values manually compared to self-tuning have slight differences, particularly the PB value of 127.8%, with 130%, as well as the calculated Ti and Td values, which are 1/10 multiplication of the self-tuning values. Table 2 lists the changes that occurred during the tuning point when Ti is 2.8 seconds and Td is 0.7 seconds.

Table 2. Changes of PID control parameters at fix turning point initial time

Controller parameter (PB) %	Time delay (Td) (s)	Time rise (Tr) (s)	Time peak (Tp) (s)	Time setting (Ts) (s)	Overshoot percentage (mp) %
130	1	2.5	5.5	17.5	19.6
100	1.2	4	7.2	35	12.3
50	1.5	2.7	7.5	28	20

4. CONCLUSION

The proposed system is designed using the CVM method to control the rotation of the Pelton turbine which is coupled to the generator in a micro hydro generator. A rotation of 750 rpm is produced by the measurement of a pressure of 4 kg/cm^2, a potential energy of 4 kg, and a height of 3 meters. A 2 kW BLDC generator is linked with this rotation. Tacho generator sensor input 0-10 volts linearly, a 24-volt DC voltage source as a CVM voltage source, and a 0-10 volts analog input and output controller are all included in the control panel installation. The tuning results of the PID controller control parameters are determined at Ti 2.8 seconds, and applied for PB 130%, 100%, and 50%, respectively. However, the unstable system has occurred at PB 33%. As the two sets of PB were simulated, 100% and 50%, respectively, the results show that the steady-state time reaches 35 seconds with Kp 2 (PB 50%), but only 28 seconds with Kp 1. When loading and unloading occurred, at a static state time is only 5 seconds, the system reached a steady state condition, and the overshoot response occurred. Controlling the set point values at 55%, causes the CVM to be set at 38%, resulting in a frequency of 50 Hz and a voltage of 61 volts. The condition is that the system is disturbed by connecting and disconnecting the load; however, the system remains stable for approximately 5 seconds.

The CVM is used to regulate water pressure in the Pelton turbine in this latest design. This system is more effective and efficient if the electrical energy produced is stable under varying load situations. As a result, with ready-to-use modules, this system may be deployed in the field. The control response shows that the control system is stable.

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