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Modelling and Control of Automatic Generation Control of Upper Trishuli 3A Hydropower Plant

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Abstract

Only producing electricity is insufficient due to rising load demands and mismatches between generation and load, particularly in the contemporary power system of today. The power system's frequency becomes unstable due to a mismatch between the load and generation (active power). Automatic Generation Control (AGC) handles this crucial and difficult task, which involves quickly returning the power system's frequency to its normal value. In order to minimize the settling time of the frequency response of the UT3A hydropower plant connected to Integrated Nepal Power System(INPS) in a two area power system, this effort entails modeling and managing the AGC. In order to minimize ACE and stabilize the frequency response of the UT3A hydropower plant in the AGC model, three scenarios are taken into consideration based on the step load input to the system with PID, PSO tuned SSSC, FLC, and ANFIS controller. In the UT3A hydropower facility, ANFIS is proven to be the best controller for minimizing frequency response settling time. The issue of frequency instability, which results in system outages because synchronization breaks in an interconnected system, is also better addressed in this work.

Keywords*—Upper Trishuli 3A (UT3A), Automatic Generation Control(AGC), Particle Swarm Optimization(PSO), Static Synchronous Series Compensator(SSSC), Fuzzy Logic Controller(FLC), Adaptive Neuro Fuzzy Inference System(ANFIS), Area Control Error(ACE)*

1. INTRODUCTION

These days, poor voltage profiles, significant system losses, frequency instability, and voltage instability are the main problems facing power systems worldwide. Our electricity system cannot be extended due to many technological, financial, environmental, and economic limitations, which forces it to operate violently closer to its stability limits (maximum capacity). When it comes to electricity, the rule is that the power generated must match the power consumed by the load. Because changes in rotor angle or frequency are closely related to changes in real power demand, an imbalance between generation and load demand or consumption results in an imbalance in frequency. As a result, the majority of power system planners are growing increasingly concerned about frequency or rotor angle stability. Load frequency control (LFC) balances the real power and frequency variation. When power demand in the power system varies, Automatic Gen Control (AGC) maintains frequency deviation to be minimal or nil. It is accomplished by adding a secondary loop to LFC, which has an integrator with constant [1].

The application of FACTS (Flexible AC Transmission System) controllers in power systems is demonstrated by recent advancements in the field of high power electronics. One of the FACTS devices that is particularly good at regulating line current, voltage profile, and system stability is the series synchronous voltage source (SSSC). By delivering a voltage with the proper phase angle in relation to the line current, it can alter the transmission line's effective impedance. The transmission system can interchange active and reactive power with it. For instance, the applied voltage will exchange real power if it is in phase with the current. Conversely, reactive power that is generated or absorbed will be swapped if a voltage is provided in quadrature to the current. Because it can modify both line reactance and line resistance in response to power fluctuations, SSSC seems to be a better controller than TCSC. This enhances generator damping and helps to produce fluctuating power. [2] [3] [4].

The Upper Trishuli 3A (UT3A) hydroelectric facility is situated in Nepal's Rasuwa district. It is a 60MW hydroelectric project of the run-of-river (ROR) type. It comprises two Francis turbines with a combined capacity of 30 MW.

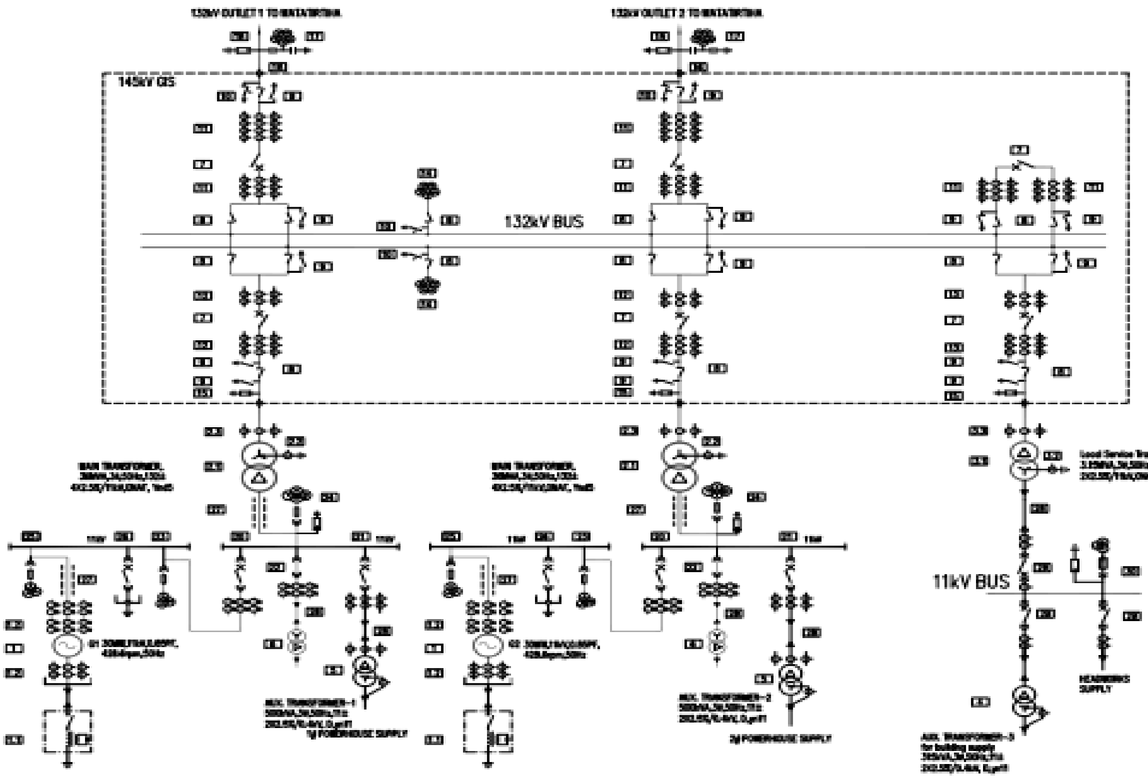


Figure 1: Single Line Diagram of UT3A Hydropower Plant [5]

1.1 Problem Statement

In hydropower plants, frequency and voltage are crucial parameters that can be quite problematic to control. The frequency should be regulated and remain constant under a variety of operating conditions, as it is dependent on the actual power generation.

In an interconnected hydropower plant, a group of utilities connect to one another and use tie lines to exchange control with nearby plants. A change in one control line's dynamic control parameter affects the frequency of the entire system.

The creation of a large generator cannot overcome the discrepancy between load consumption and power generation due to dynamic nature of load demand generating frequency instability. As a result, it becomes more difficult to maintain a steady generating frequency and tie line flow within a desired range, which, if left unattended, could result in power system instability and blackout. Lastly, AGC is used to solve the aforementioned issues. Making AGC to maintain frequency stability in a short amount of time is the primary difficult issue.

1.2 Scope

This work's scope involves modeling and managing the AGC of a UT3A hydropower plant connected to INPS utilizing MATLAB/SIMULINK's PSO-tuned SSSC, FLC, and ANFIS Controller in three distinct scenarios.

1.3 Objective

This work's primary goal is to model and regulate the UT3A's AGC in order to determine the optimal controller based on the frequency response's shortest settling time.

2. LITERATURE REVIEW

In [6] stated AGC modelling, design, and experimental evaluation for hydropower facilities utilising ANFIS. Reducing frequency variations in the manufacturing system is its primary objective. MATLAB was used to study conventional PID, FLC, and ANFIS controllers. investigation of how a hydropower plant's AGC reacts to gradual load fluctuations in both single and double areas. According to simulation data, the ANFIS controller outperforms both PID and FLC. Additional findings show that the suggested ANFIS controller improves the hydropower plant's AGC performance.

In [7] suggests load frequency control for two area power systems, taking into account the Indian Power System in Area 2 and the Integrated Nepal Power System (INPS) in Area 1. This study examines three distinct situations using MATLAB/SIMULINK: the base scenario, 50% droop reduction, 50% inertia reduction, and load change scenarios. According to the results, if there is a quick shift in the load in an area, each region will adjust its own adjustments. In addition, the transients seen in cases I and II can pose a significant issue.

In [8] AGC proposal for a hydropower system connecting two areas and several units. It is suggested to use superconducting magnetic energy storage (SMES) in combination with dynamic management of the current of a static synchronous series compensator (SSSC) or thyristor-controlled phase shifter (TCPS) to compensate for such load disturbances and stabilize zone frequency oscillations. Because of the author's development, crazy-based particle swarm optimization (CRPSO), an enhanced kind of particle swarm optimization, is used to optimize the integral controller and parameter gain of SSSC, TCPS, and SMES.

In [9] A PSO-based PID controller was used to create automatic generation control (AGC) for a two-zone power system. In order to increase the frequency responsiveness, the PSO-based PID controller creates two control signals, one of which is given to each zone. Mean square error (MSE) simulation is used to determine the difference between the desired and actual frequency response. The comparison results demonstrate that automatic generation control of the two-zone power system using a PSO-based PID controller helps to achieve the expected frequency response value with load change.

In [10] Area and tie line frequency fluctuations are lessened in AGC by using FACTS devices. The dynamic properties of a static synchronous series compensator (SSSC) as a FACTS series damping controller and a Thyristor-Controlled Series Capacitor (TCSC) as a damping controller are compared in this work with a Thyristor-Controlled phase shifter (TCPS). The damping controller is designed using the integral time squared performance (ITSE) index and the enhanced particle swarm optimization (IPSO) algorithm.

2.1 Particle Swarm Optimization [9]

Using Particle Swarm Optimisation to understand computer problems. The social behaviour of creepy crawlies, birds scurrying, and creatures assembling is replicated by particle swarm optimisation, in which these swarms cooperatively search for food. In PSO, every particle has a position and a speed. In accordance with the experiences of the previous best particle and the global best particle, the position is improved. The particle's position and velocity are updated using equations 1 and 2.

$$V_i(t+1) = w * V_i(t) + C_1 * rand1(\ ) * \left(P_{best\,i} - X_i(t)\right) + C_2 * rand2(\ ) * \left(g_{best} - X_i(t)\right)$$

Equation 1

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad \text{……………………………………………………Equation 2}$$

P_{best} is the previous best particle of the ith particle, q_{best} is the global best particle, c1 and c2 are two learning factors, w is weight factor, rand1(), rand2() are two random numbers independently generated within the range of [0,1]. Achieving good performance with Particle Swarm Optimisation (PSO) requires careful consideration of parameters such as swarm size and iteration count. Usually, empirical tuning and previous research are combined to choose these factors.For Swarm size, it is chosen,

- **Empirically**: Try small, medium, and large swarm sizes (e.g., 10, 30, 50, 100) and evaluate performance.
- **Based on literature**: Often chosen based on values that worked well for similar problems.

For Number of Iteration, it is chosen,

- **Convergence testing**: Run the algorithm and check when fitness values plateau.
- **Budget-based**: Sometimes set based on time or computational limits.
- **Stopping criteria** can also include:(Maximum iterations, No improvement over a fixed number of steps, Threshold fitness value reached)

2.2 Fuzzy Logic Controller [11]

A control system built on fuzzy logic, a scientific method of handling instability or imprecision, may be known as a fuzzy logic controller (FLC). FLCs are capable of handling ambiguous or imprecise inputs and yields, in contrast to traditional control frameworks that rely on precise scientific models.

2.3 Adaptive Neuro Fuzzy Inference System(ANFIS) [11]

The characteristics of fuzzy logic and artificial neural networks (ANNs) may be cleverly combined in an adaptive neuro fuzzy inference system (ANFIS). Since its introduction by Jang in the early 1990s, ANFIS has been widely used in a number of domains, including forecasting, design acknowledgement, and control frameworks. [12] Within the framework of etymological rules, fuzzy logic is used to communicate with human master information. Neural systems are then used to adaptively adjust the parameters of these fuzzy rules in response to input. This is the main idea behind ANFIS. Because of this combination, ANFIS is able to effectively illustrate intricate frameworks using questionable or ambiguous data. ANFIS deployment in real-time environments necessitates meticulous preparation to satisfy computational limitations without sacrificing performance. Factors affecting computational requirements are written below.

- **Number of Inputs and Membership functions(MFs):**

If each input has M , MFs, and have n inputs: Number of rules= M^n

- **Rule base complexity:**

Each rule must be evaluated in real time, involving: Fuzzy Membership Computation(e.g. Gaussian, Triangular etc)

- **Type of ANFIS Output Function:**

Sugeno-type ANFIS uses weighted linear outputs: Lower computation than Mamdani-type fuzzy systems and Complexity is linear with the number of rules.

3. METHODOLOGY

3.1 Flowchart of the Project

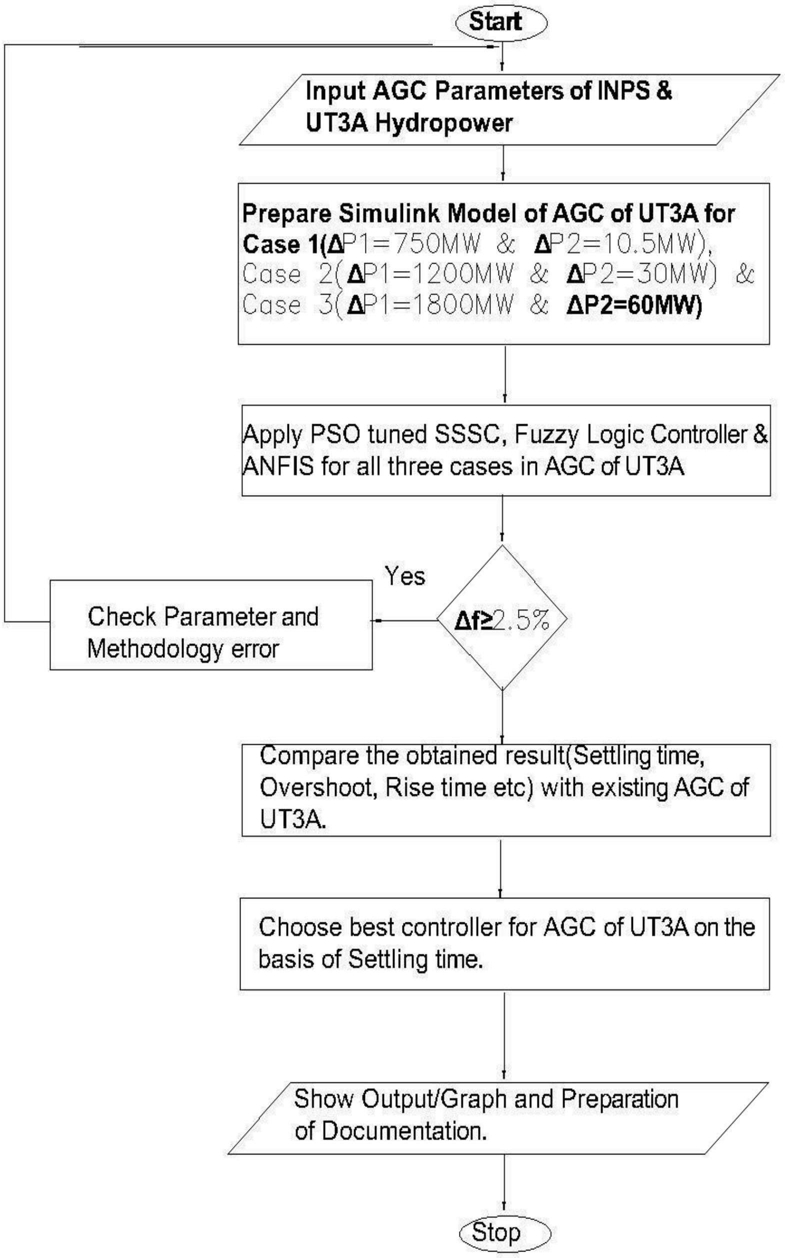


Figure 2: Flowchart of the Project

3.2 Modelling of Hydropower Plant

3.2.1 Modelling of Speed Governor

A turbine speed governor, which is used to regulate the turbine's valve input, detects variations in the hydroelectric plant's speed. Figure 3 shows the model of the governor [6].

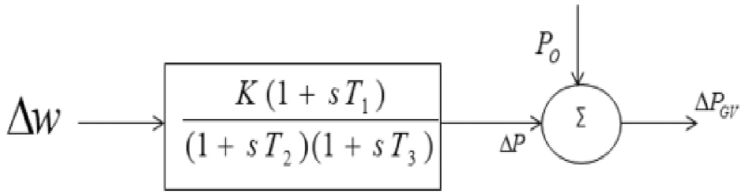


Figure 3: Block diagram of Speed Governor

3.2.2 Hydro Turbine Modelling

The dynamics of the water passing through the penstock of a hydro turbine is used to compute its tangent property. Figure 4 shows the model of the hydro turbine. [6]

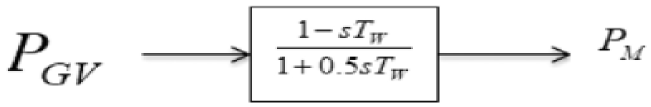


Figure 4: Block diagram of Hydro Turbine

3.2.3 Synchronous Generator Modelling.

In a hydroelectric plant, a generator is used to assist the water-powered control unit in rotating the turbine, enabling the vitality era. While an electrical drive is used to reduce revolution, a mechanical torque is linked to increase turns. The entire turn of the framework starts to decrease when an electrical load increases a mechanical torque that is smaller than the electrical torque. Restoring the mechanical torque to its balancing point in this way is essential [1].

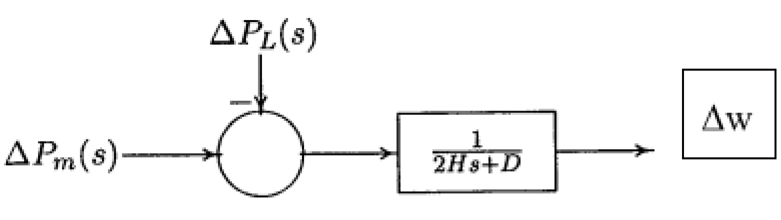


Figure 5: Synchronous Generator Modelling [1]

3.2.4 Modelling of Tie-Line

The tie lines were modelled using the following equation.

$$\Delta P_{12}(s) = \frac{2\pi T}{s}\left[\Delta f_1(s) - \Delta f_2(s)\right] \text{...} \textit{Equation 3}$$

3.2.5 Modelling of SSSC based damping controller

To support the tie-line power trade and effectively dampen the oscillations in the power system, appropriate dynamic modelling and control of the SSSC are essential. The following equation represents the SSSC-based damping controller. [13]

$$\Delta P_{SSSC}(s) = \frac{K_{SSSC}}{1+sT_{SSSC}}\frac{1+sT_1}{1+sT_2}\frac{1+sT_3}{1+sT_4}\Delta F_1(s) \text{.......................................} \textit{Equation 4}$$

3.2.6 Block Diagram of AGC for hydropower plant [1] [7] [6]

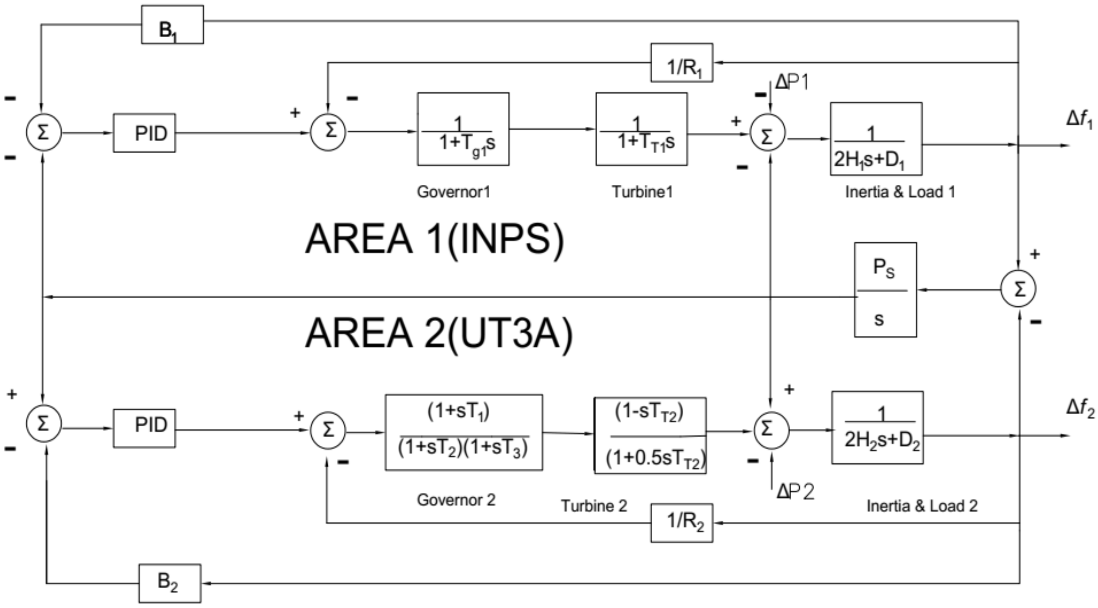


Figure 6: Block diagram for AGC

The various parameters of upper trishuli 3A hydropower plants, are obtained by studying it’s operating manuals [5], applying formula of rotational dynamics and data obtained during operation of plant. The various parameter for Integrated Nepal Power System(INPS) is obtained from [7]. The base number is 2000 MVA as the INPS's current peak demand is approximately 1900MW. The following crucial information is needed for the hydropower plant's AGC:

Table 1:Parameter for Area 1 and Area 2 [5] [7] [1] [14]

S.No	**Parameters**	**Units**	**Area 1(INPS)**	**Area 2(UT3A)**
1	**Inertia Constant(H)**	S	5	4.61
2	**Droop(R)**	%	5	5
3	**Frequency Sensitive Load(D)**	%	1	1
4	**Governor Time Constant(T_g)**		0.2	0.2

5	**Turbine Time Constant(T_T)**		0.5	0.5
6	**Synchronizing Coefficient(P_S)**		0.053	0.053
7	**Governor Rest Time(T_1)**	S		3
8	**Transient Drop time Constant(T_2)**			0.2
9	**Main Servomotor Time Constant(T_3)**			10
10	**Base MVA**		2000	60

3.3 Objective function of PSO tuned SSSC in AGC

The primary goals of AGC, which are to dampen area frequency and tie-line error power oscillations to zero, remain unchanged inside the control framework. Choosing a suitable standard performance index is essential to achieving the maximum possible improved time domain damping characteristics. To effectively reduce the oscillations, the integral of time multiplied squared error (ITSE) performance index is used[10]. The optimal strategy for the suggested controllers is then described as a minimization problem.

$$Min\{ITSE\} = \int_{0}^{Tsim} t[\Delta f_1^2 + \Delta f_2^2 + \left(\Delta P_{12}^{error}\right)^2]dt \text{.......................................Equation 5}$$

Subject to the following constraints pertaining to the parameters that can be adjusted:

$$0 \leqslant K_{I1},\ K_{I2}, K_{SSSC}, K_P, K_T, K_I, K_D \leqslant 5$$
$$0 \leqslant T_{SSSC},\ T_1, T_3 \leqslant 1$$
$$0 \leqslant \lambda,\ \mu \leqslant 1$$

where the simulation time is shown by Tsim. The integral of time multiplied absolute error (ITAE) and ITSE effectively reduces the settling time by imposing a cost on the long-lasting oscillations due to the use of the time factor, in contrast to the integral of squared error (ISE) and integral of absolute error (IAE) performance indices. Since the IAE and ISE indices consistently weigh all errors across time, one of their weaknesses is that they may produce an estimated reaction with a long settling time. The ITAE and ITSE indices lessen the oscillations which proceed for a long time than those at commencing. Therefore, the settling time is reduced by the ITAE and ITSE indices, which is not possible with IAE or ISE-based modifying. However, the fact that the ITAE occurs in reactions with usually expanding oscillations is a hindrance. The ITSE index successfully reduces the possibility of expansive oscillations by reducing deviations more than the ITAE index because of the higher control of the error terms. Here, the ITSE index is used appropriately as a suitable objective function to effectively reduce the wide and persistent oscillations. Particle swarm optimization (PSO) is used to reduce the ITSE index in order to change the tunable parameters of the controllers under consideration. By addressing the optimization problem—that is, minimizing the ITSE index—the heuristic optimization algorithms, which are implemented as.m files, are linked to the SIMULINK model to determine the ideal set of movable parameters.

3.4 System Considered, Tools and Software to be used

A case study is the Upper Trishuli 3A (UT3A) hydroelectric Station, a run-of-river hydroelectric facility with a 60MW capacity (two units, each with a 30MW capacity) with a vertical Francis turbine. A two-area system is taken into consideration for AGC; INPS is taken into account in area one, while the UT3A hydropower plant is considered in area two. MATLAB2019/Simulink software is used on a PC with an Intel(R) Core(TM) i5-7200U CPU running at 2.50 GHz to 2.70 GHz, 4GB RAM, and 256 SSD to model and develop the AGC of the UT3A hydropower facility.

4. RESULTS AND DISCUSSIONS

Three scenarios are taken into consideration for choosing the appropriate controller: i) Case I (ΔP1 = 750 MW & ΔP2 = 10.5 MW), ii) Case II (ΔP1 = 1200 MW & ΔP2 = 30 MW), and iii) Case III (ΔP1 = 1800 MW & ΔP2 = 60 MW). The following is an explanation of the results from all three cases:

4.1 CASE I (ΔP_1=750MW & ΔP_2=10.5MW)

Initially, a condition is established in which 750 MW of step input is applied in Area 1 (INPS) and 10.5 MW of step input is applied in Area 2 (UT3A).

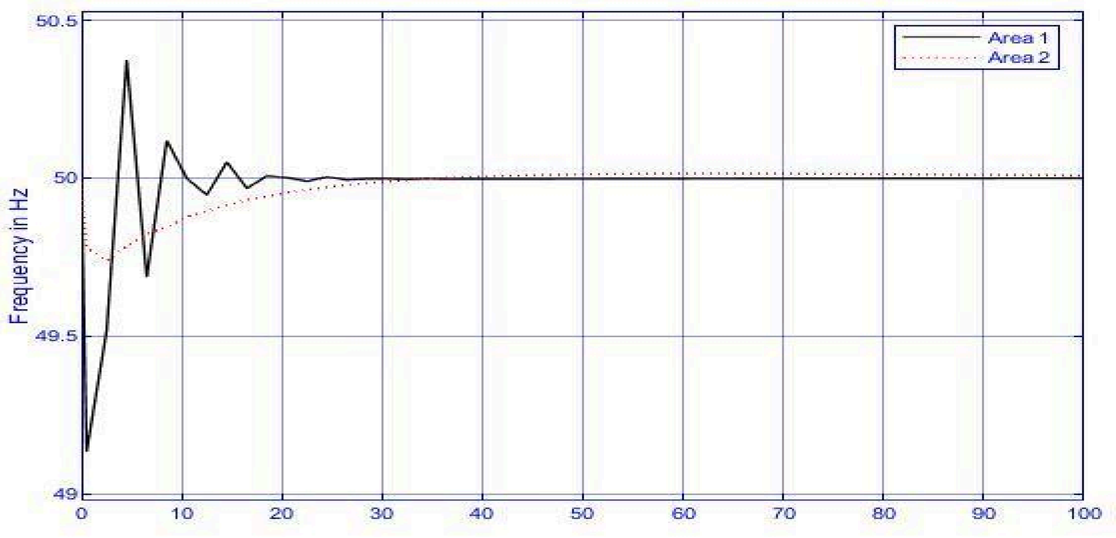


Figure 7: Frequency deviation of system with PID controller

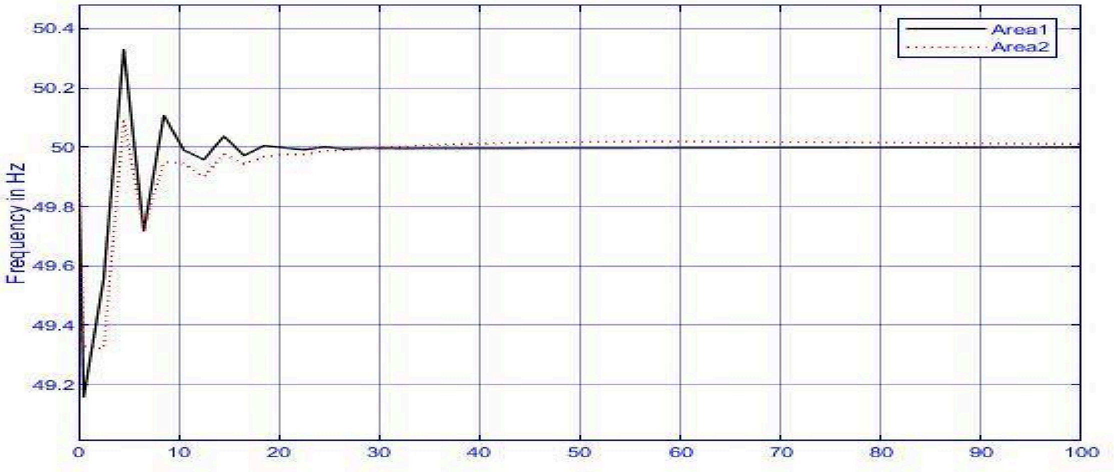


Figure 8: Frequency deviation of system with SSSC

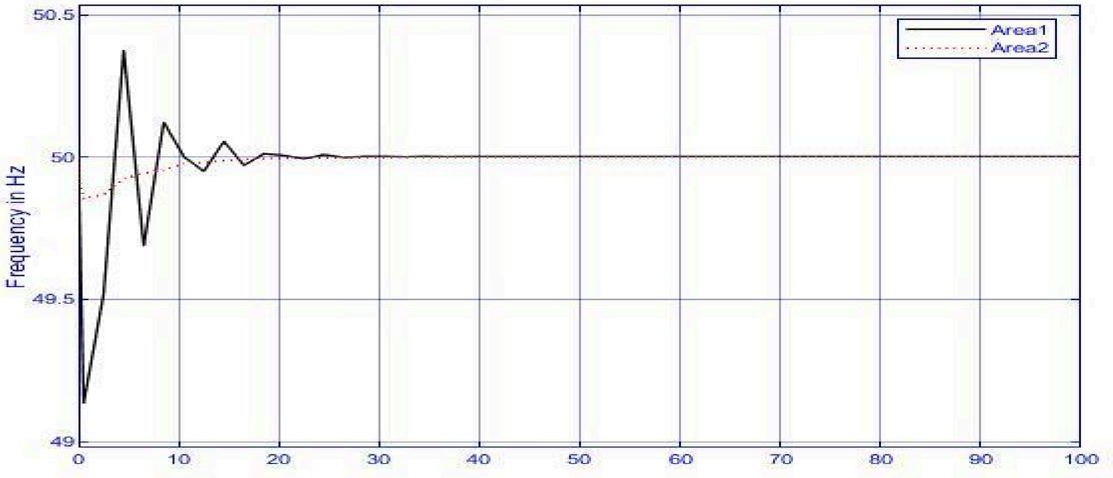


Figure 9: Frequency deviation of system with FLC

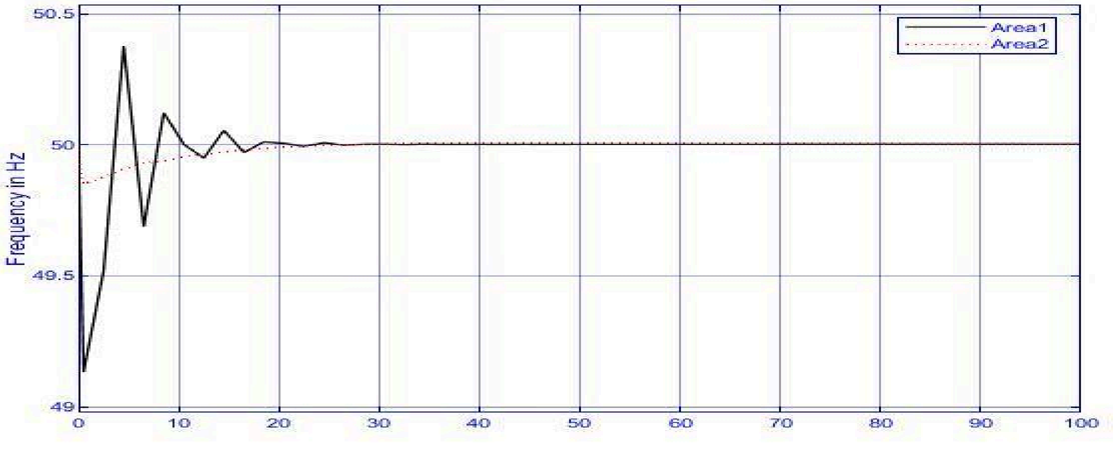


Figure 10: Frequency deviation of system with ANFIS.

The system with ANFIS as the controller has the best settling time, which is 26.4583 seconds, compared to the previous all-controller settling time.

4.2 CASE II (ΔP_1=1200MW & ΔP_2=30MW)

A scenario is established in which Area 1 (INPS) receives a step input of 1200MW, whereas Area 2 (UT3A) receives a step input of 30MW.

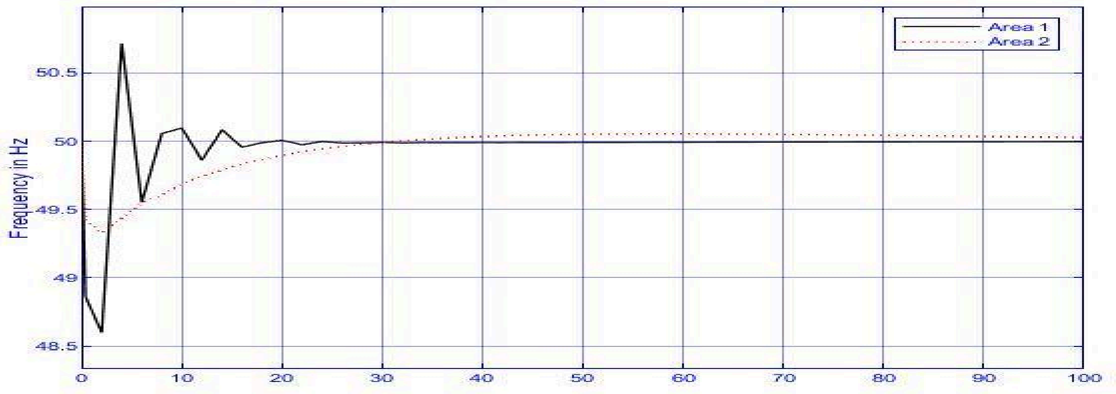


Figure 11: Frequency deviation with PID Controller

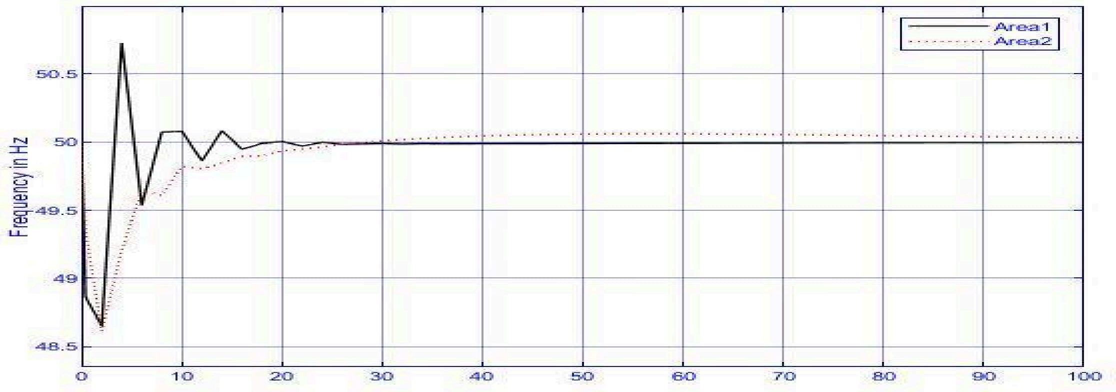


Figure 12: Frequency deviation with SSSC

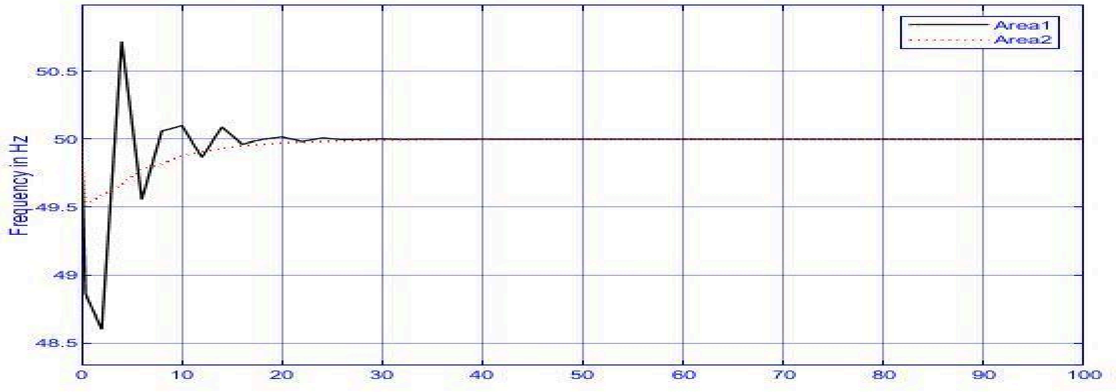


Figure 13: Frequency deviation with FLC

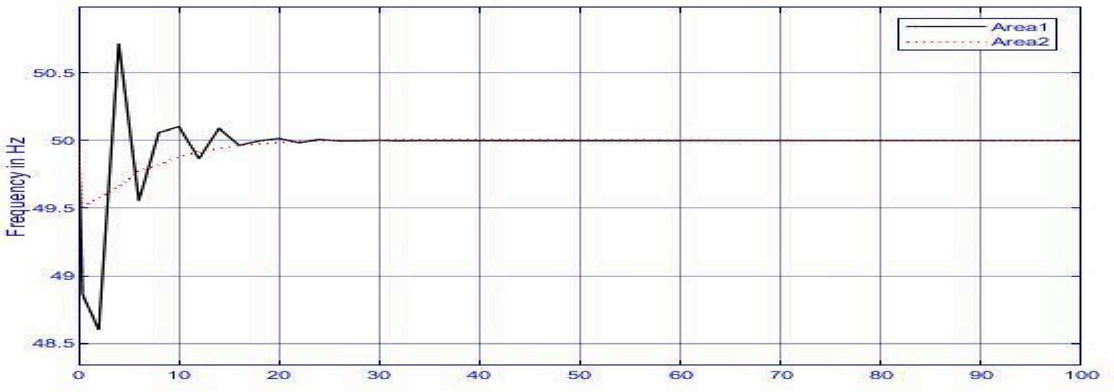


Figure 14: Frequency deviation with ANFIS

The system with ANFIS as the controller has the best settling time, 21.6742 seconds, compared to the prior all-controller settling time.

4.3 CASE III (ΔP_1=1800MW & ΔP_2=60MW)

Step inputs of 1800 MW are applied in Area 1 (INPS) and 60 MW are applied in Area 2 (UT3A) to generate a situation.

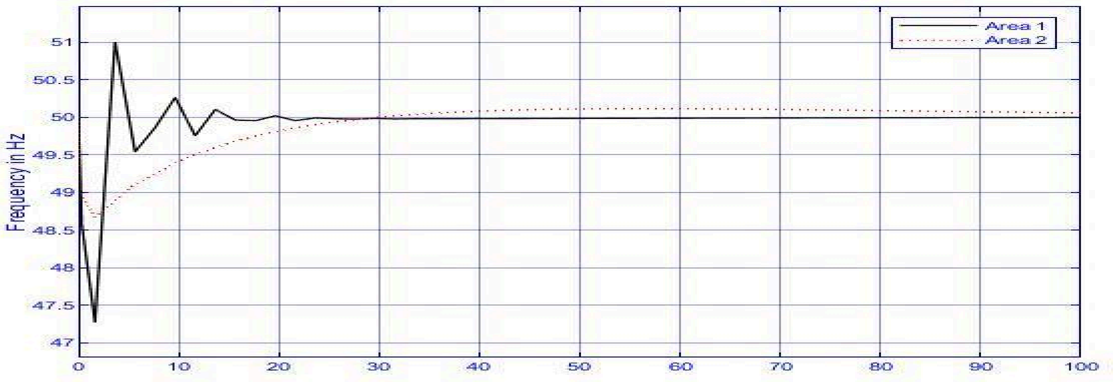


Figure 15: Frequency deviation with PID Controller

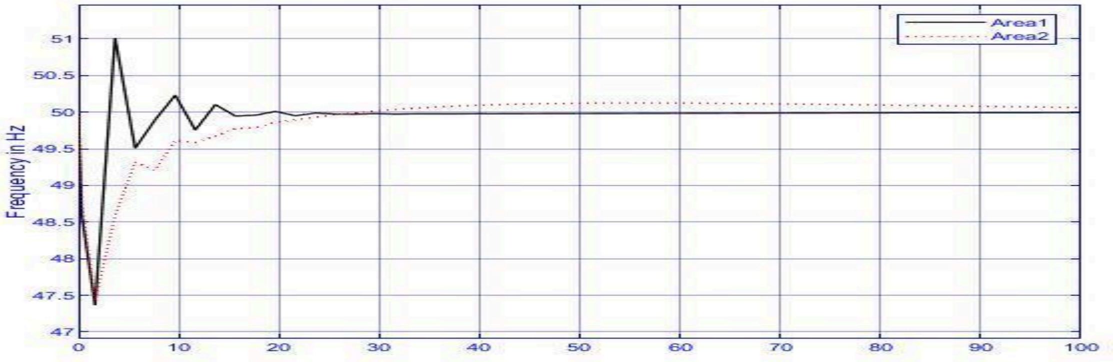


Figure 16: Frequency deviation with SSSC

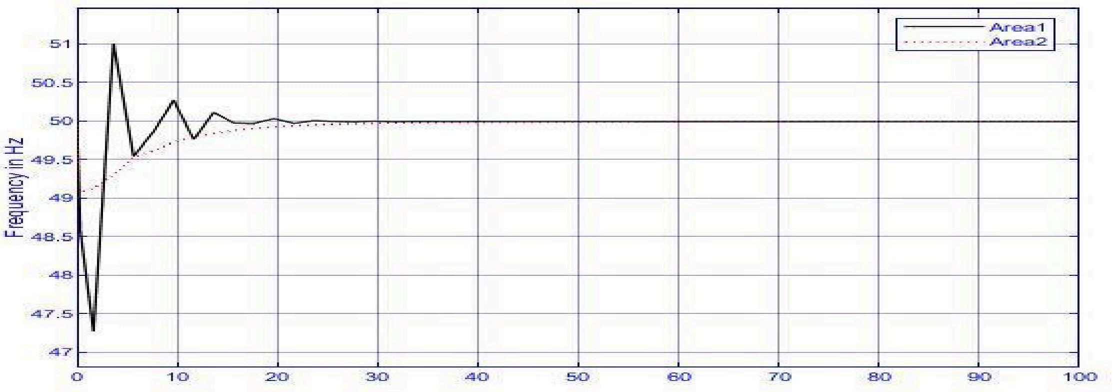


Figure 17: Frequency deviation with FLC

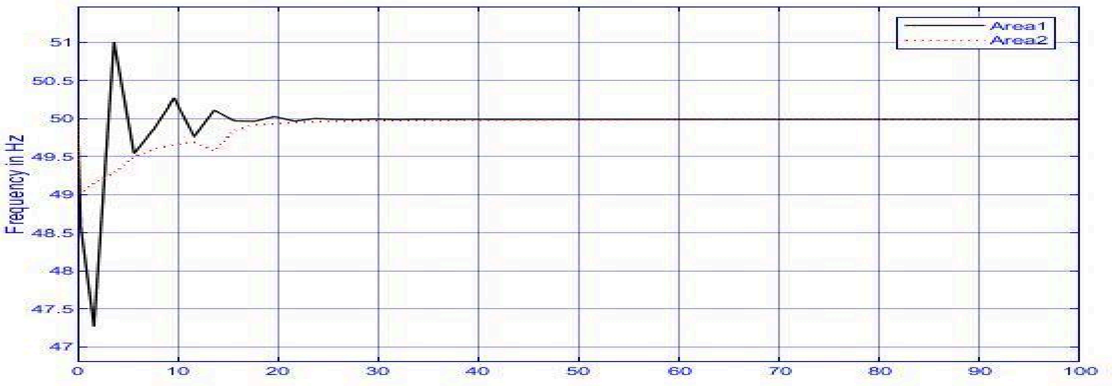


Figure 18: Frequency deviation with ANFIS

The system with ANFIS as the controller has the best settling time, which is 27.6870s, compared to the prior all-controller settling time.

4.4 Result Comparison

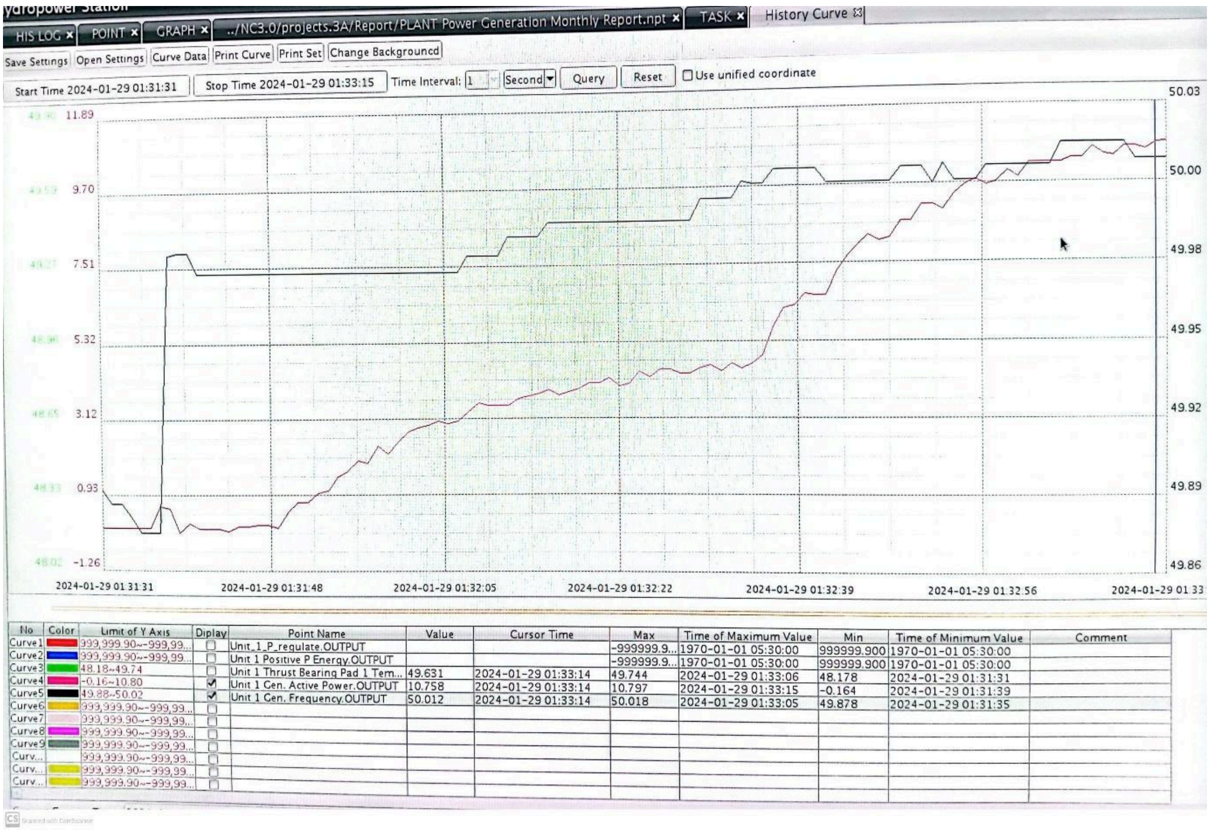
To assess a controller's superior performance, the step response characteristics of each case and controller are compared. The following table displays the comparative result.

	CASE I				**CASE II**				**CASE III**			
Different Methods	**With PID**	**With SSSC**	**FLC**	**ANFIS**	**With PID**	**With SSSC**	**FLC**	**ANFIS**	**With PID**	**With SSSC**	**FLC**	**ANFIS**
Rise Time(s)	**5.91**	**0.02**	**44.79**	**3.68**	**5.06**	**5.33**	**5.5x10^{-04}**	**0.45**	**4.75**	**5.10**	**0.001**	**0.002**
Settling Time(s)	**71.95**	**29.23**	**27.05**	**26.46**	**80.71**	**62.40**	**26.72**	**21.67**	**81.97**	**67.90**	**30.82**	**27.69**
Settling Min	**1.69x10^{-04}**	**-0.01**	**3.5x10^{-05}**	**7.12x10^{-05}**	**5.40x10^{-04}**	**6.22x10^{-04}**	**-0.0097**	**2.06x10^{-05}**	**0.001**	**0.001**	**-0.02**	**-0.02**
Settling Max	**2.91x10^{-04}**	**0.002**	**3.8x10^{-05}**	**1.31x10^{-04}**	**0.001**	**0.001**	**-3.7x10^{-05}**	**1.34x10^{-04}**	**0.002**	**0.003**	**-1.9x10^{-04}**	**2.32x10^{-04}**
Overshoot	**72.28**	**818.4**	**0**	**83.67**	**93.54**	**95.01**	**2.59x10^{+04}**	**515.03**	**100.42**	**98.85**	**9.55x10^{+03}**	**8.32x10^{+03}**
Undershoot	**3.09x10^{+03}**	**6.5x10^{+03}**	**7.62x10^{03}**	**4.19x10^{+03}**	**2.48x10^{+03}**	**4.45x10^{+03}**	**0**	**4.45x10^{+04}**	**2.73x10^{+03}**	**4.09x10^{+03}**	**0**	**0**
Peak	**0.01**	**0.014**	**0.003**	**0.003**	**0.013**	**0.028**	**0.01**	**0.01**	**0.03**	**0.05**	**0.02**	**0.02**
Peak Time(s)	**2.51**	**2.51**	**0.51**	**0.51**	**2.02**	**2.02**	**0.40**	**0.40**	**1.65**	**1.65**	**0.33**	**0.33**

Table 2: Result Comparison of various controller on the basis of step response characteristics

As can be observed from the above table, in all three scenarios, the ANFIS controller has the quickest settling time. Consequently, the Upper Trishuli 3A Hydropower Plant's AGC is advised to use an ANFIS controller.

4.5 Existing output response of Upper Trishuli 3A Hydropower Plant at step input of ΔP_1=750 MW in INPS & ΔP_2=10.5 MW in UT3A



Start Time 2024-01-29 01:31:31 | Stop Time 2024-01-29 01:33:15 | Time Interval: 1 | Second | ☐ Use unified coordinate

No	Color	Limit of Y Axis	Diplay	Point Name	Value	Cursor Time	Max	Time of Maximum Value	Min	Time of Minimum Value	Comment
Curve1	🟥	999,999.90~-999,99...	☐	Unit_1_P_regulate.OUTPUT			-999999.9...	1970-01-01 05:30:00	999999.900	1970-01-01 05:30:00	
Curve2	🟦	999,999.90~-999,99...	☐	Unit 1 Positive P Energy.OUTPUT			-999999.9...	1970-01-01 05:30:00	999999.900	1970-01-01 05:30:00	
Curve3	🟩	48.18~49.74	☐	Unit 1 Thrust Bearing Pad 1 Tem...	49.631	2024-01-29 01:33:14	49.744	2024-01-29 01:33:06	48.178	2024-01-29 01:31:31	
Curve4	🟪	-0.16~10.80	☑	Unit 1 Gen. Active Power.OUTPUT	10.758	2024-01-29 01:33:14	10.797	2024-01-29 01:33:15	-0.164	2024-01-29 01:31:39	
Curve5	⬛	49.88~50.02	☑	Unit 1 Gen. Frequency.OUTPUT	50.012	2024-01-29 01:33:14	50.018	2024-01-29 01:33:05	49.878	2024-01-29 01:31:35	
Curve6	🟧	999,999.90~-999,99...	☐								
Curve7	⬜	999,999.90~-999,99...	☐								
Curve8	🟪	999,999.90~-999,99...	☐								
Curve9	⬛	999,999.90~-999,99...	☐								
Curv...		999,999.90~-999,99...	☐								
Curv...	🟨	999,999.90~-999,99...	☐								
Curv...	🟨	999,999.90~-999,99...	☐								

Figure 19: Existing frequency response of UT3A at step input of 10.5MW & system load of 750MW

The SCADA of the Upper Trishuli 3A Hydropower Plant provided the frequency and power curve at step input of ΔP1=750MW and ΔP2=60MW, which is displayed above. The UT3A PID Controller for AGC calculates its PID parameter based on the load and stabilises the frequency.

According to the preceding figure, it took roughly 82 seconds for the frequency to settle from 49.86 Hz to 50 Hz when a step input of 10.5 MW was provided to the generator of Area 2 (UT3A) at a system load of about 750 MW, or INPS. Applying the same condition and simulating it in MATLAB/SIMULINK yielded a settling time of 72 seconds (see Table 2, Case I, With PID), which is extremely close to the actual time and validates the model with the real system.

There was a little discrepancy in the settling time between the Simulink model and the real system, which might have been caused by different PID values between the two. With the usage of the ANFIS controller, we now have even greater AGC. The aforementioned result also shows that the ANFIS controller has the shortest settling time of any controller discussed in this study, and that employing SSSC, FLC, or ANFIS produces results that are nearly superior to the current system at UT3A HPS for AGC.

5. CONCLUSION

This study applies a number of techniques and controllers, including PSO-tuned SSSC, FLC, and ANFIS controllers, to the current system model of UT3A hydropower plant AGC in three distinct scenarios (based on load demand), which produces better results than the current AGC at UT3A HPS.

The damping of frequency instability is also enhanced with the aid of SSSC. The ANFIS settlement time is the least of all, at 26.45 seconds (Case I), and the FLC settlement time is likewise shorter. In order to improve performance above the current response, either ANFIS or FLC is advised in UT3A HPS to achieve better results in AGC.

In order to lessen power system outages caused by frequency instability in an interconnected power system, this thesis study examines the practicality of enhancing the AGC of hydropower plants in Nepal.

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