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**Modeling and Control of Automatic Generation Control of Upper Trishuli 3A
Hydropower Plant.**

by

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SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING
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DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM ENGINEERING**

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Modeling and Control of Automatic Generation Control of Upper Trishuli 3A
Hydropower Plant.

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degree of Master of Science in Power System Engineering

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2 ABSTRACT

With rising load demand resulting in mismatches between load and generation, simply producing electrical power is insufficient, particularly with today's sophisticated power systems. These mismatches generate changes in the frequency of the power system, rendering it unstable. Restoring the frequency to its normal value quickly is a critical and difficult operation. This task is managed by Automatic Generation Control (AGC), which is critical to preserving the power system's stability and reliability.

This effort comprises modeling and control of AGC to reduce the frequency response settling time of the Upper Trishuli 3A (UT3A) hydropower plant, which is linked to the INPS in a double-area power system. Four scenarios are explored based on step load input to the system, using different controllers: PID, PSO-tuned SSSC, FLC, and ANFIS, with the goal of minimizing the Area Control Error (ACE) and stabilizing the frequency response of the UT3A hydropower plant under the AGC model. Among these controllers, ANFIS has been shown to be the most successful at reducing the frequency response settling time to its minimum value. This approach also addresses frequency instability, which can cause system breakdowns owing to synchronization failures in networked systems.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGC	:	Automatic Generation Control
PSO	:	Particle Swarm Optimization
SSSC	:	Static Synchronous Series Compensator
FLC	:	Fuzzy Logic Controller
ANFIS	:	Adaptive Neuro Fuzzy Inference System
ACE	:	Area Control Error
IEEE	:	Institute of Electrical and Electronics Engineers
INPS	:	Integrated Nepal Power System
IPP	:	Independent Power Producer
UT3A	:	Upper Trishuli 3A
MATLAB	:	Matrix Laboratory
MW	:	Mega Watts
MWh	:	Mega Watts Hour
NEA	:	Nepal Electricity Authority

CHAPTER 1. INTRODUCTION

1.1 Background

Nowadays power system across the world faces the leading challenges of frequency instability, voltage instability, poor voltage profile and high system losses. Due to different technical, economic, environmental and economical constraints, the extension of our power system is not possible causing power system to operate forcefully closer to their stability limits (maximum capacity). The rule in electricity is that, generated power must be equal to load consumptions. Unbalance between generation and load demand or consumption causes unbalance in frequency because change in rotor angle or change in frequency is directly associated with change in real power demand. Therefore, most of the power system planner are becoming more concern about change in real power demand or frequency stability. The deviation of real power and frequency is balanced by Load frequency control (LFC). Automatic Generation Control (AGC) is the process of maintaining frequency deviation negligible or zero, when power demand in power system changes. It is achieved with the introduction of secondary loop in LFC in which it contains integrator with constant [1].

Recent developments in the field of high-power electronics show the use of Flexible AC Transmission System (FACTS) controllers in power systems. Static Synchronous Series Compensator (SSSC), a series synchronous voltage source, is one of the FACTS devices that is very effective in control of the current in the line as well as control of the voltage profile and stability of the system. It can change the effective impedance of the transmission line by applying a voltage with an applicable phase angle with respect to the line current. It has the ability to exchange active and reactive power with the transmission system. For example, if the applied voltage is in phase with the current, the voltage will exchange real power. On the other hand, if a voltage is applied in quadrature to the current then reactive power, consumed or produced, will be exchanged. SSSC appears to be an advantageous controller over TCSC

due to its expertise in adjusting not only line reactance but also line resistance according to power fluctuations, thereby improving generator damping and contributing to generate fluctuating power. [2] [3] [4]

Upper Trishuli 3A(UT3A) hydropower plant is located in Rasuwa district of Nepal. It is run of river (ROR) type hydropower plant with capacity of 60MW. It has two unit of 30MW equipped Francis turbine. As the system load changes continuously, system frequency also tends to changes accordingly, but for proper operation and safety of electrical equipment frequency must remain constant or frequency must return to its standard value at very less time. Currently, UT3A settling time of frequency response is little high causing high impact in a power system. Therefore, objective of this project is to minimize settling time of frequency response of UT3A hydropower Plant as low as possible and it is motivation of this work.

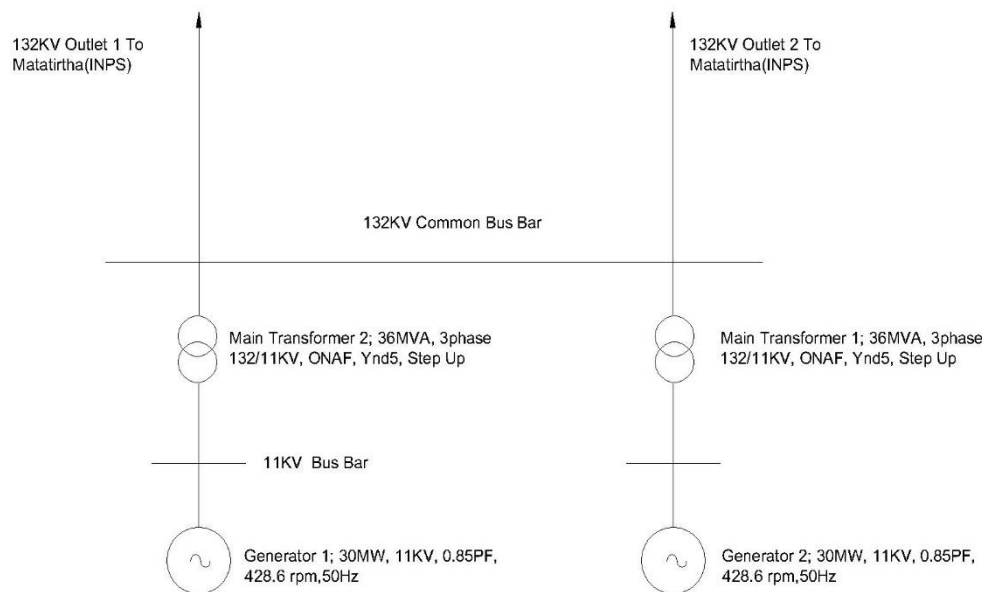


Figure 1: Single Line Diagram of UT3A Hydropower Plant

1.2 Problem Statement

Frequency and voltage are critical parameters in hydropower plants, and managing them may be a serious challenge. The frequency is determined by actual power generation and should be modified to be consistent throughout a wide range of operational conditions.

In an interconnected hydropower plant, there are a number of generating units that communicate with one another and share control with nearby plants via tie lines. A change in the dynamic control parameter of one control line affects the entire operational frequency.

The creation of a large generator was unable to bridge the gap between load consumption and power generation due to the dynamic nature of load demand, resulting in frequency instability. As a result, keeping consistent generating frequency and tie line flow within a desired range becomes more difficult, potentially leading to power system instability and blackouts if not addressed quickly. Finally, AGC comes into play to solve the aforementioned difficulties. The major tough task is to create AGC to preserve frequency stability in a very short period of time.

1.3 Objectives

Principle Objective:

The goal are as follows:

- To model and Control AGC of the UT3A hydropower plant
- To examine response of PID, PSO tuned SSSC, FLC and ANFIS controllers.
- To identify the suitable controller based of settling time of frequency response.

Validation of the system will take place using the Integrated Nepal Power System (INPS).

Other Objectives:

- To know the effectiveness of different controller in AGC.

- To know Automatic Generation Control at different loading conditions.
- To understand, how tripping of plant be reduced due to frequency instability at various step load input.

1.4 Scope

- Modeling of UT3A AGC in MATLAB/SIMULINK
- Impact of PID, PSO tuned AGC, FLC and ANFIS controller
- Calculation of settling time of various controller.

CHAPTER 2. LITERATURE REVIEW

In [5] the work involves an absolute analysis of a hydropower plant's AGC utilizing ANFIS. The primary purpose is to reduce frequency variations in the production system. The conventional PID, FLC, and ANFIS controllers were investigated using MATLAB. A study of the reaction of a hydropower plant's AGC (in single and double areas) to incremental load variations. The simulation results show that the ANFIS controller outperforms both PID and FLC. Further results show that the proposed ANFIS controller accelerates the functioning of the hydropower plant's AGC.

In [6] the paper focuses on LFC of a double-Area Power System considering Integrated Nepal Power System (INPS) in Area 1 and Indian Power System in Area 2. This article investigates three different scenarios in MATLAB/SIMULINK: the base scenario, 50% droop reduction, 50% inertia reduction, and load change scenarios. The findings reveal that if there is a quick load shift in one region, each area will adjust its own modifications; also, the transients found in examples I and II can be a major concern.

In [7] the paper addresses AGC of a hydropower system that connects several units in two regions. To correct for such load instability and stabilize zone frequency fluctuations, it is recommended to use dynamic current management of a TCPS or SSSC in conjunction with SMES. The integral controller and parameter gain of SMES, SSSC and TCPS are adjusted using crazy-based particle swarm optimization (CRPSO), which is better variant of PSO and is created by author.

In [8], A PSO-rooted PID controller was used to provide AGC in a double-zone power system. The PSO-rooted PID controller generates double control signals, one for every zone, to increase bandwidth response. The error among the preferred bandwidth response and the actual bandwidth response is calculated using mean square error (MSE) modeling, and the correlation results show that AGC of the double-zone power system using a PSO-rooted PID controller aids in achieving the expected bandwidth response.

In [9] FACTS devices are used in AGC to reduce frequency fluctuations on the zone and tie lines. This research compares the changing properties of a TCSC as an oscillation damper to a TCPS and a SSSC as FACTS series oscillation damper. The damping controller is designed using the Improved Particle Swarm Optimization (IPSO) algorithm and the integral time squared performance index (ITSE).

In [10] A fuzzy PID controller based on the Firefly Algorithm (FA) is suggested for AGC in multiple-zone, multiple-source power systems. Originally, a double-zone, hexad-unit power system is utilized, with the fuzzy PID controller's gains improved using the FA approach in accordance with ITAE criteria. The suggested FA-optimized fuzzy PID controller outperforms previously published approaches, for example Differential Evolution (DE) and optimum control-adjusted PID controllers, for similar networked power systems.

In [11] for AGC PI controller is compared with fuzzy controller. A two-zone system is considered with thermal plants. Different stepwise load changes were considered and the performance of both controllers was observed under different load conditions. The presented simulation results show that the fuzzy controller performs better than the PI controller.

In [12] a new fuzzy controller is applied to AGC of electrical grid system with alternative energy source is rooted on fuel cells, heat solar power and wind generated power. Controller's capabilities were first examined over a double-zone reheating thermal energy network and consequently on double-zone multiple-originated hydrothermal energy system. To avoid issues caused by incorrect regulator variable, the scaling coefficient and remaining variable of the FIPD-TI controller are methodically collected utilizing the Slap Swarm Algorithm (SSA) with the goal of reducing the ISE benchmark. Worthiness and participation of the SSA adjusted FIPD-TI regulator are demonstrated with evaluating the findings of various contemporary controllers. Examinations reveal that the proposed method beats serious competitors with respect to reduced overshoot and faster settling time.

In [13] an energy storage element based on capacitor energy storage (CES) is used to maintain balance of the generation load and suppress power frequency fluctuations. The impact of CES on AGC is also analyzed. Additionally, due to the superior performance of the fuzzy control strategy, the fuzzy PID controller with derivative filter (F-PIDF) has been shown to increase the system stability. The controllers are designed by optimization using a new biologically inspired Selfish Herd Optimization (SHOA) algorithm. The superiority of the recommended controller is demonstrated by comparing the transient response with a PID controller. It is observed that CES devices contribute to ACE mitigation by reducing system frequency and link power deviation.

In [14] it is explained that the DFIG wind turbine can actively participate in regional frequency control in the AGC and improve frequency regulation. The PSO-fuzzy algorithm is also used to optimize the parameters of AGC's fuzzy PI regulator. The output illustrate that the regulator adjusted with the PSO fuzzy algorithm is capable of improving the area frequency deviation, link power variation, stabilization time, frequency amplitude fluctuation, and magnetic field. That improves the stability of the power system.

In [15] FACTS devices have been utilized in AGC to increase efficiency by minimizing oscillations in power system transient response in uncontrolled conditions. When a fuzzy controller is used in place of an integrated controller with FACTS devices attached to the system, the response improves even further.

In [16] a new load frequency control (LFC) method for multi-zone power systems is developed based on the direct-indirect adaptive fuzzy control technique. The LFC for each region is designed based on the available frequency deviation of each region and the link power deviation between regions. The approximation capabilities of fuzzy logic systems are exploited to develop adaptive control laws and parameter updating algorithms suitable for unknown interconnected LFC regions. The tracking performance criterion H_{∞} is introduced to minimize the approximation error and the influence of external noise. The proposed controller ensures the stability of the entire closed-loop system. Realistic three-zone power system simulation results demonstrate the effectiveness of the proposed LFC and show its superiority over conventional

PID controllers and type 2 fuzzy controllers.

In [17] The parameters of the AGC's PID controller are determined using the chaotic optimization (COA) method. The suggested algorithm has been validated on several connection topologies, including double thermal plant, one thermal plant plus a solar photovoltaic array, and a multiple-plant with three units: gas, hydroelectric and reheat. Furthermore, the short-term effectiveness of the AGC system was examined to show that the suggested algorithm outperformed numerous techniques utilized in the literature. The research took into account a variety of transient characteristics, including the noticed parameters' stability time.

2.1 Automatic Generation Control

Because of the dynamic structure and unpredictable characteristics of energy demand, professional intelligent AGC is needed for consistent function and regulation of the power system. [1]

As a result, in this paper, a PSO regulation controller based on SSSC, FLC, and ANFIS is presented in the hydropower system's AGC to successfully reduce frequency and power deviation under rapid load demand conditions. Differences between power production and requirement triggers system frequency and connecting line current to diverge from normal levels.

AGC is an incredibly important regulation design in power systems used to support the current of interconnecting lines within specified tolerances and adjust the zone frequency within limits. The allowable range in the case of small, sudden load disturbances continuously attempted. to disrupt normality. operate an electrical system. [18]

2.2 STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

The SSSC is one among largest series FACTS regulators that functions as a VSC, providing a programmable leading or lagging offset voltage in perpendicular with respect to current that is free of circuit impedance. Unlike series capacitor-based compensators, SSSCs can increase the transmission power, independent of δ , within the critical operating range of $0 < \delta < \pi/2$.

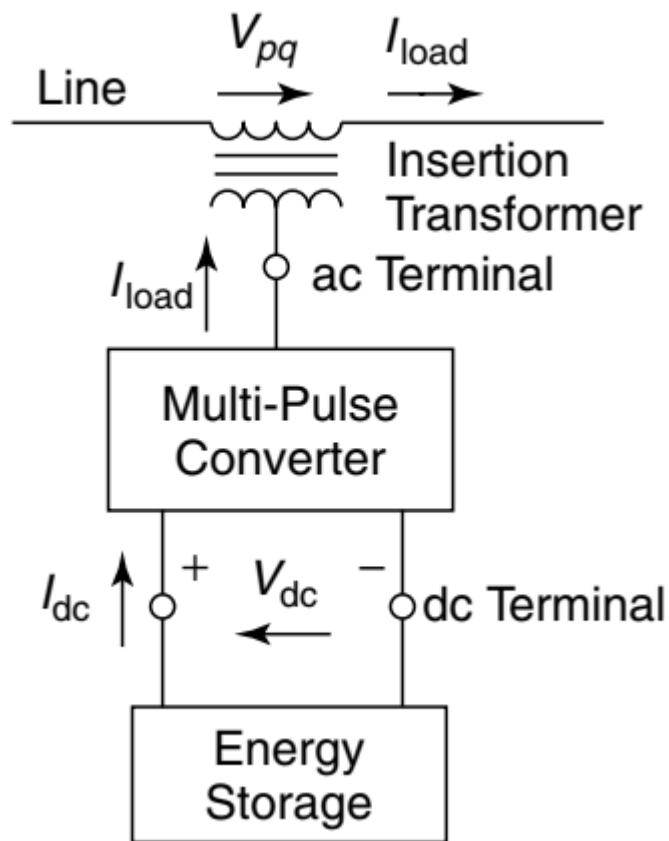


Figure 2: Generalized series connected synchronous voltage source [3]

In power flow control applications (steady state or dynamic), SSSC has a large regulated compensation range by design. In addition to bidirectional compensation, the SSSC has a remarkable response time and a precisely uninterrupted and sustained transition from high to low current. SSSC can provide simultaneous and separately controlled compensation for the active and reactive element of line impedance, allowing the reactance to resistance ratio upto feasible. Create an optimum reactive line to maximize power transmission. [3].

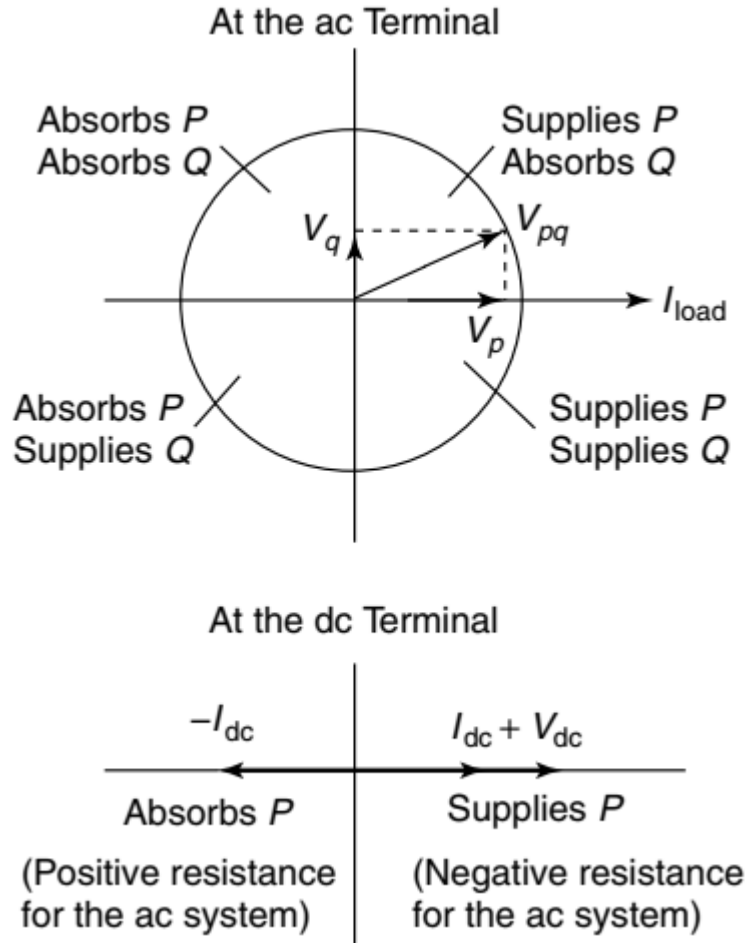


Figure 3: Real and reactive power exchanges at different mode [3]

Furthermore, SSSCs are free from sub-synchronous resonance (SSR) because unlike series capacitors and impedance-type series compensators, VSC-based SSSCs are fundamentally AC voltage sources that function only at frequencies of the preferred basic output [3].

2.1 Particle Swarm Optimization

Particle Swarm Optimization as a way to fathom computer issues. Particle Swarm Optimization reenacts the social behavior of creepy crawlies, fowls running and creatures grouping where these swarms explore for food in a collaborative way. Each particle in PSO encompasses a position and a speed. The position is upgraded concurring to the encounters of the prior best particle and the global best particle. The following equation 1 & 2 are used for updating of velocity and position of particle [8].

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

$$rand2() * (g_{best} - X_i(t)) \dots \dots \dots \text{Equation 1}$$

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

P_{best} is previous best particle of the i th 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 $[0,1]$. Defined as the population size, NE is the number of function evaluations, and MAX_{NE} is the maximum number of function evaluations. PSO is summarized as below [8].

Begin

While $NE < MAX_{NE}$ *do*

For each particle i *do*

Update the velocity according to equation (1);

Update the position according to equation (2);

Calculate the fitness value;

$NE + +;$

End for

Update the P_{best} and g_{best} in the population;

End while

End

2.2 Fuzzy Logic Controller

A Fuzzy Logic Controller (FLC) could be a control framework based on fuzzy logic—a scientific approach to managing with instability or imprecision. Not at all like conventional control frameworks that depend on exact scientific models, FLCs can handle unclear or vague inputs and yields [19].

Here's how an FLC ordinarily works:

- a) **Fuzzification:** Inputs from sensors or other sources are changed over into fuzzy sets. Rather than utilizing exact values, these sets speak to degrees of enrollment in etymological terms (e.g., "tall," "medium," "moo").
- b) **Rule Evaluation:** Fuzzy rules, regularly communicated within the frame of "if-then" articulations, are connected to the fuzzy input factors. These rules encode the master information's or heuristics approximately the system's behavior.
- c) **Inference:** The fuzzy rules are combined to decide the fuzzy yield sets. This step totals the impact of diverse rules on the input factors to create a fuzzy yield.
- d) **Defuzzification:** At last, the fuzzy yield sets are changed over back into fresh yield values. Different strategies, such as centroid defuzzification or weighted normal, can be used for this task.

FLCs have been effectively connected in different control applications, particularly in circumstances where exact scientific models are troublesome to get or when the framework flow are nonlinear or questionable. They are especially valuable in spaces such as car control frameworks, mechanical mechanization, and shopper gadgets. In any case, planning a viable FLC frequently requires space ability to characterize suitable fluffy rules and enrollment capacities [19].

2.3 Adaptive Neuro Fuzzy Inference System (ANFIS)

An Adaptive Neuro Fuzzy Inference System (ANFIS) could be a crossover shrewdly framework that combines the capabilities of Artificial Neural Networks (ANNs) and fuzzy logic. ANFIS was presented by Jang within the early 1990s and has since been broadly utilized in various fields, counting control frameworks, design acknowledgment, and forecast [20].

The most thought behind ANFIS is to use fuzzy logic to speak to human master information within the frame of etymological rules and after that to utilize neural systems to adaptively tune the parameters of these fuzzy rules based on information. This combination permits ANFIS to successfully demonstrate complex frameworks with dubious or uncertain data [19].

Here's a brief process of how ANFIS works:

- a) **Fuzzification:** The inputs to the ANFIS framework are fuzzified, meaning that fresh numerical values are changed over into fuzzy phonetic items. This step allots enrollment grades to each input variable concurring according to the fuzzy sets characterized for each phonetic item.
- b) **Rule Evaluation:** In this step, the fuzzy rules are connected to the fuzzified inputs. Each run the show comprises of a predecessor (input conditions) and a resulting (yielding activity). The terminating quality of each run the show is calculated based on the degree coordinate between the fuzzified inputs and the forerunners of the run the show.
- c) **Normalization:** The terminating quality obtained from the previous step are averaged to ensure that the final yield from all rules add up to 1.
- d) **Consequent Parameter Adjustment:** The resulting parameters of each rule are balanced based on both the input information and the normalized terminating qualities of the rules. This alteration is regularly performed employing a least squares method or a gradient descent optimization calculation.
- e) **Output Aggregation:** The ensuing parameters from all rules are totaled to get the ultimate yield of the ANFIS framework.
- f) **Defuzzification:** At last, the total yield is DE fuzzified to get a fresh numerical esteem.

ANFIS has the advantage of being able to memorize from information whereas consolidating human skill through fuzzy logic rules. This makes it reasonable for modeling complex frameworks where express numerical models may be troublesome to determine. ANFIS has been effectively connected in different real-world applications, counting budgetary determining, mechanical handle control, and therapeutic determination [19].

2.4 Step Response Characteristics

Step response characteristics are utilized to analyze and get it the behavior of dynamic systems in reaction to a step input. A step input may be a sudden alter

with in the input signal of a system, ordinarily from zero to a fixed value. The response of the system to this step input can uncover vital data almost its stability, transient behavior, and steady-state performance. Here are few key features of step responses [19]:

- a) **Rise Time:** It is the time taken by the response to rise from a indicated low value to a indicated high value. It's often measured between, for example, 10% and 90% of the ultimate steady-state value.
- b) **Settling Time:** Settling time is the time needed for the reaction to reach and stay within a certain tolerance band around the ultimate steady-state value. This tolerance band is typically defined as a percentage (e.g., 5%) of the ultimate value.
- c) **Settling Min:** It refers to the minimum value reached during the settling time of a step response.
- d) **Settling Max:** It refers to the maximum value reached during the settling time of a step response.
- e) **Undershoot:** Undershoot could be characteristic of the step response of a framework especially in framework that are underdamped. It alludes to the circumstances where the response quickly falls underneath the steady-state value before in the long run coming to and stabilizing at the ultimate steady-state value.
- f) **Peak:** Within the setting of step response characteristics, "peak" ordinarily alludes to the most noteworthy esteem come to by the reaction bend amid its temporal behavior some time recently settling down to the steady-state esteem.
- g) **Overshoot:** Overshoot is the greatest deviation of the reaction from its last steady-state esteem, more often than not communicated as a rate of the steady-state esteem.
- h) **Steady State Value:** The ultimate esteem that the reaction settles to after the temporal behavior has ceased. It's the esteem that the framework tends to preserve over time in reaction to the step input.

i) **Peak Time:** Peak time is the time required for the response to reach the first greatest value.

j) **Peak Overshoot:** Peak overshoot is the greatest peak value of the response relative to the ultimate steady-state value.

These characteristics provide information about the behavior and performance of a dynamic system and are essential for the analysis and design of control systems, such as those used in engineering applications. technology such as robotics, automotive systems and industrial processes.

CHAPTER 3. METHODOLOGY

3.1 Introduction

The various parameters of upper trishuli 3A hydropower plants, are obtained by studying its operating manuals [21], applying formula of rotational dynamics and data obtained during operation of plant. The various parameter for Integrated Nepal Power System (INPS) is obtained from [6] Since, the current peak demand of INPS is around 1900MW therefore base value is taken as 2000 MVA. Double area power system is considered, where INPS is established at area 1 and UT3A is established at area 2. Four cases are considered for analyzing the effectiveness of PID, PSO tuned SSSC, FLC and ANFIS controllers. Case I is the condition when step input of 750 MW is applied at area 1 and step input of 10.5 MW is applied at area 2. Case II is the condition when step input of 1200 MW is applied at area 1 and step input of 30MW is applied at area 2. Similarly, Case III is the condition when step input of 1800 MW is applied at area 1 and step input of 60 MW is applied at area 2 & Case IV is the condition when 1000 MW is decreased from INPS and 20MW is decreased from UT3A

3.2 Modeling of Hydropower Plant

Hydropower Plant is modelled as follows

3.2.1 Modeling of Speed Governor

A turbine speed governor detects fluctuations in the speed of a hydroelectric plant and controls the input of the turbine valve. The Governor is modelled as appeared in Figure 4: [5]

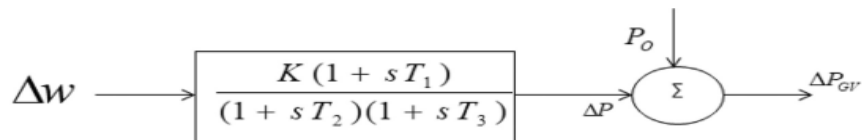


Figure 4:Block diagram of Speed Governor

3.2.2 Hydro Turbine Modeling

The tangent property of a hydro turbine is computed using the variations of water flowing through the penstock. The hydro turbine is modeled as

appeared in figure 5 [5]

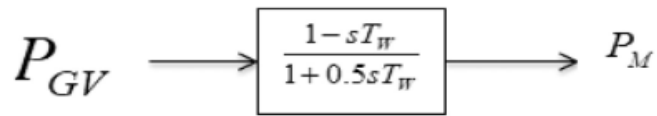


Figure 5: Block Diagram of Hydro Turbine

3.2.3 Synchronous Generator Modeling

In a hydropower facility, a generator assists the water-powered control unit in turning the turbine, so enabling energy generation. A mechanical torque is connected to extend turns, while an electrical drive is used to reduce revolution. When an electrical load increases a mechanical torque smaller than the electrical torque, the overall turn of the framework begins to decrease. In this way, it is essential to restore the mechanical torque to its balancing point [1].

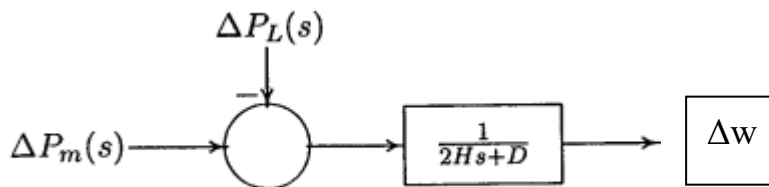


Figure 6: Synchronous Generator Modeling

3.2.4 Modeling of Tie-Line

The equation used to design the tie lines is provided below:

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

3.2.5 Modeling of SSSC based damping controller

Suitable dynamic modeling and regulations of the SSSC are essential for supporting tie-line power trading and successfully sogging oscillations in the power system. The damping controller based on SSSC is expressed in the equation below [22]

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

3.3 Block Diagram of AGC for hydropower plant [1] [6] [5]

The block diagram for AGC is as shown below:

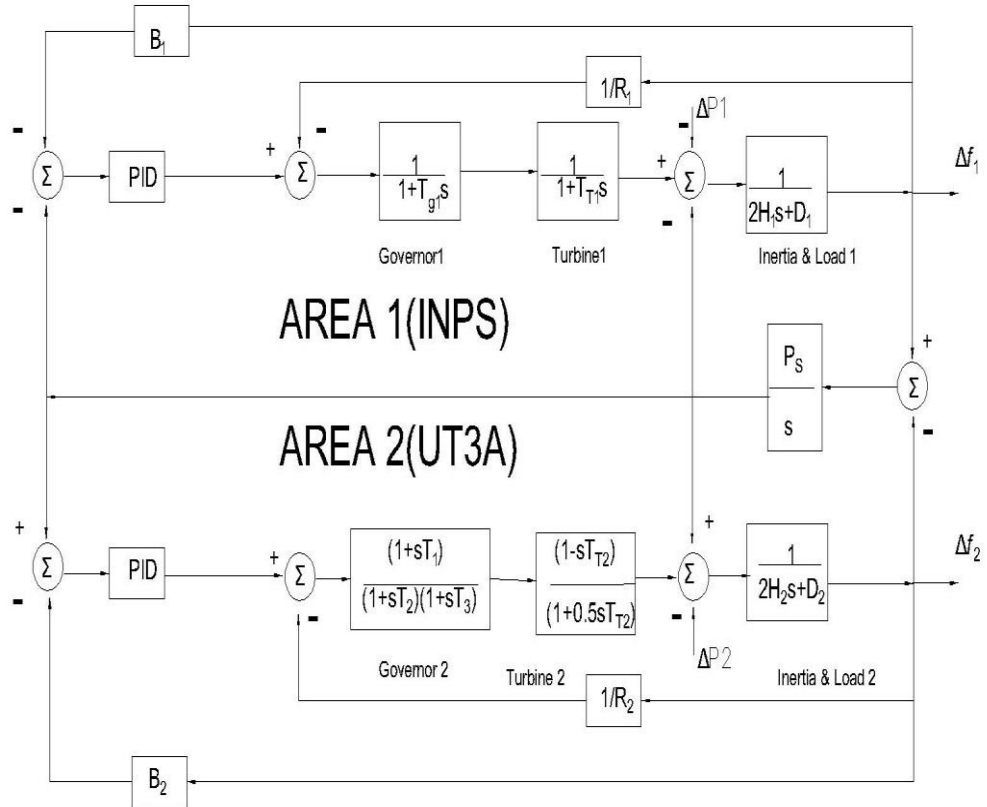


Figure 7: Block Diagram for AGC

The important data required for AGC of hydropower plant is as follows (Calculations are in Appendix).

Table 1: Parameter for Area 1 and Area 2 [1] [21] [6] [5] [23]

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

3.4 Algorithm of Project

STEP 1: Model AGC in MATLAB/Simulink with only PID Controller.

STEP 2: Obtain frequency deviation of the system.

STEP 3: Model AGC in MATLAB/Simulink incorporating SSSC/FLC/ANFIS for Case I ($P_1=750\text{MW}$ & $P_2=10.5\text{MW}$), Case II ($P_1=1200\text{MW}$ & $P_2=30\text{MW}$) Case III ($P_1=1800\text{MW}$ & $P_2=60\text{MW}$) & Case IV ($P_1=-1000\text{MW}$ & $P_2=-20\text{MW}$).

STEP 4: Make program in M file for tuning parameter of SSSC by using Particle Swarm Optimization (PSO) in MATLAB/Simulink.

STEP 5: Obtain value of parameter of SSSC at minimum value of Objective function.

STEP 6: Obtain frequency deviation of the system having SSSC/FLC/ANFIS in it for all four Cases.

STEP 7: Compare the result according to settling time of frequency response of UT3A hydropower plant of all four cases.

STEP 8: Obtain the conclusion

3.5 Flowchart of the Project

The flowchart of the project is as follows:

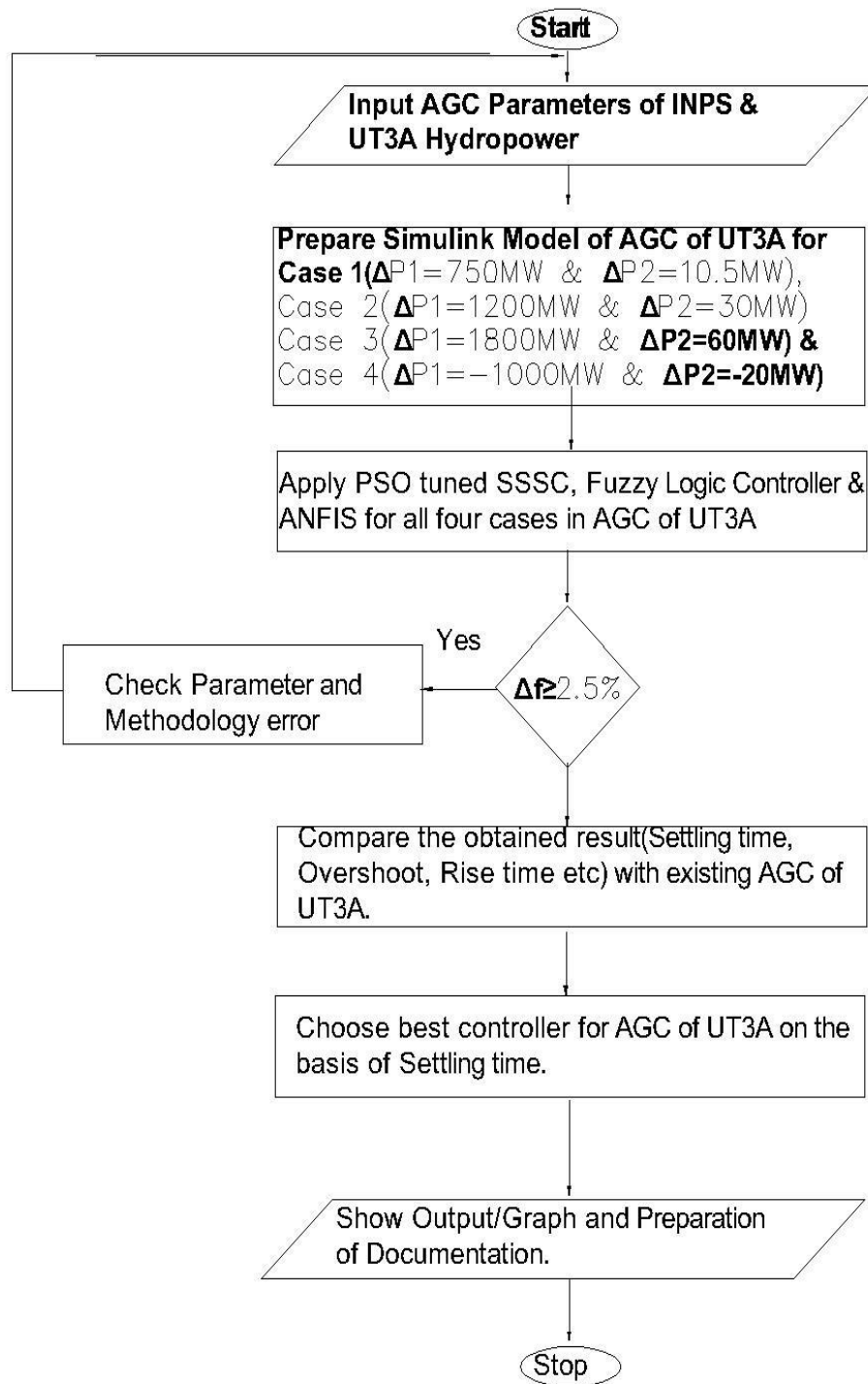


Figure 8: Flowchart of the Project

The first part involves to calculate the parameters required for Automatic Generation Control (AGC) such as inertia constant of rotating parts, damping constant of Generators, governor rest time, transient drop constant, main servomotor time constant, turbine time constants of UT3A Hydropower plant as well as for INPS.

The second work involves developing AGC model for two area power system of UT3A Hydropower Plant and INPS in Simulink/MATLAB for all four cases.

The third step involves use of PSO tuned SSSC in AGC model as well as use of Fuzzy Logic Controller and Adaptive Neuro Fuzzy Inference System (ANFIS) in AGC model.

The fourth step involves to check whether change in frequency(Δf) is greater than 2.5% (NEA frequency tolerance) of base frequency i.e. 50Hz or not. If Δf is greater than 2.5% of base value, design of AGC is not useful and we have to redesign the controller

The fifth step involves to compare result of all four cases by evaluating step response characteristics obtained from all controllers

The sixth step involves to select best method or controller for AGC at UT3A Hydropower Plant on the basis of step response characteristics (especially of settling time).

The seventh or final step involves documentation.

This way, each step may open the door to major research and finding for AGC at UT3A Hydropower Plant. But sticking to the scope of this work and the time frame for this thesis work, I intend to customize the steps a little bit.

3.6 Objective function of PSO tuned SSSC in AGC

Within control framework, the essential targets of AGC i.e., attenuation the zone oscillation and tie-line inaccuracy power frequency to null stay unaltered. To realize as much conceivable superior time domain attenuation features, choosing a fitting benchmark effectiveness measure is basic. The ITSE effectiveness measure is utilized to minimize proficiently the frequency [9]. Subsequently, the ideal plan of the recommended regulator is defined as a mitigation issue.

$$Min\{ITSE\} = \int_0^{T^{sim}} t[\Delta f_1^2 + \Delta f_2^2 + (\Delta P_{12}^{error})^2]dt \dots \dots \dots Equation 5$$

Subjected to the following constraints for the changeable parameters:

$$0 \leq K_{I1}, K_{I2}, K_{SSSC}, K_P, K_T, K_I, K_D \leq 5$$

$$0 \leq T_{SSSC}, T_1, T_3 \leq 1$$

$$0 \leq \lambda, \mu \leq 1$$

Tsim illustrates the simulation time. Compared to the ISE and IAE effectiveness metrics, the ITAE and ITSE prioritize minimizing long-term oscillations by incorporating a time factor, thereby reducing settling time effectively. One drawback of IAE and ISE metrics is their potential for prolonged settling periods due to their consistent weighting of errors over time. In contrast, ITAE and ITSE reduce longer-term oscillations compared to those at the onset, resulting in reduced settling time, which is not achievable with IAE or ISE-based adjustments.

However, ITAE is hindered by its tendency to favor responses characterized by generally larger oscillations. Due to its better handling of mismatch provisions, the ITSE metric mitigates divergence increased effectively compared to ITAE, thereby reducing the risk of significant oscillations. ITSE is therefore a suitable performance metric for effectively minimizing immense and prolonged-term fluctuations. For optimize the adjustable variables belonging to the regulators under consideration, ITSE metric is reduced using particle swarm optimization (PSO). The experimental enhancement algorithms are implemented in .m files as well as integrated alongside SIMULINK model for identify the best array of configurable variables through resolving the refinement issue, specifically reducing ITSE metric.

CHAPTER 4. SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE

4.1 System considered

4.1.1 Integrated Nepal Power System (INPS)

The Integrated Nepal Power System (INPS) is being proposed for Area 1 of AGC's double area power system. The different parameter values for AGC are taken from [6] and the peak demand is considered as the current peak demand. The developed algorithm is tested on the INPS to assess the applicability and validity of the proposed method.

4.1.2 Upper Trishuli 3A Hydropower Plant (UT3A)

Upper Trishuli 3A (UT3A) Hydropower Station, a run of river type hydropower with capacity of 60MW (2 unit, each capacity 30MW) having vertical Francis Turbine is considered as case study for AGC, a two-area system is considered, area one considers INPS and area two considers UT3A hydropower plant. Various parameter for AGC of UT3A is taken from [21]

4.2 Tools and software

To model and design AGC of UT3A hydropower station MATLAB2019/Simulink software is used in a PC having processor Intel(R) Core (TM) i5-7200U CPU @ 2.50GHz 2.70 GHz, 4GB RAM and 256 SSD. The modelled and designed AGC in MATLAB/Simulink is in Appendix of this report.

CHAPTER 5. RESULTS AND DISCUSSIONS

For the selection of best controller, four cases are considered i) Case I ($\Delta P_1=750$ MW & $\Delta P_2= 10.5$ MW), ii) Case II ($\Delta P_1=1200$ MW & $\Delta P_2=30$ MW), iii) Case III ($\Delta P_1=1800$ MW & $\Delta P_2=60$ MW) and iv) Case IV ($\Delta P_1=-1000$ MW & $\Delta P_2=-20$ MW). The result obtained from all four cases are explained as follows:

5.1 CASE I($\Delta P_1=750$ MW(INPS) & $\Delta P_2=10.5$ MW(UT3A))

First of all a condition is created where step input of 750MW is applied in Area 1(INPS) and step input of 10.5MW is applied in Area 2(UT3A). The per unit values are as follows:

$$\Delta P_1 = 0.375 \text{ p.u} \dots \dots \dots \text{Equation 6}$$

$$\Delta P_2 = 0.00525 \text{ p.u} \dots \dots \dots \text{Equation 7}$$

5.1.1 System with PID Controller

A system for AGC in two area system is considered having PID Controller (Area 1; P= 0, I=0.460194, D= 0 & Area 2; P= 0, I= 0.0362942, D= 0) as shown in Appendix. The frequency deviation is as follows:

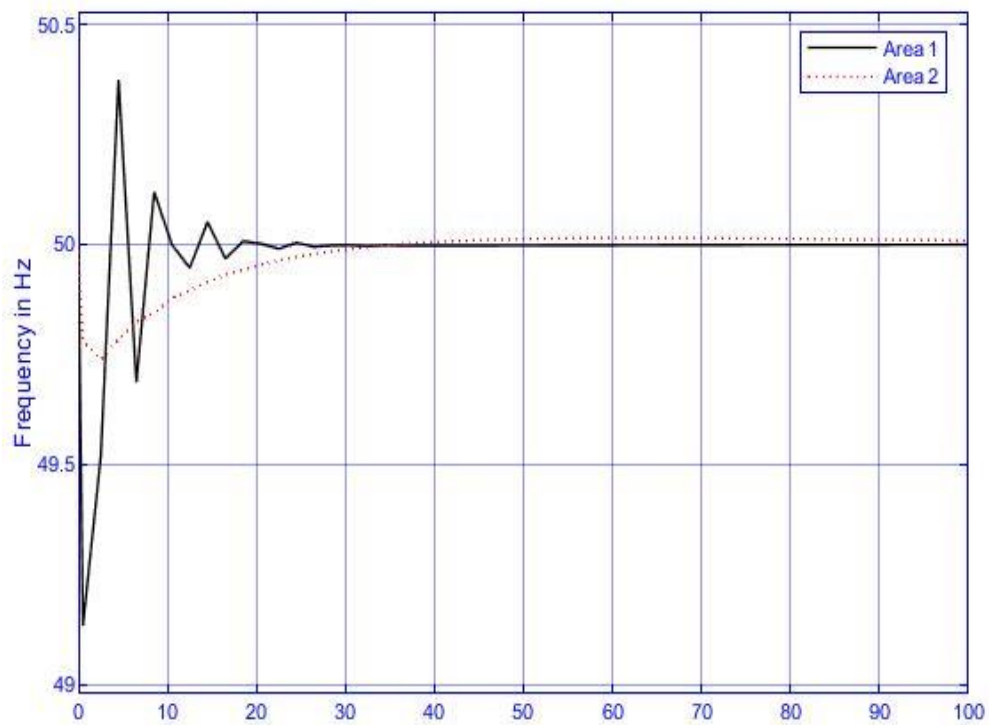


Figure 9: Frequency response of System with PID Controller

The table for step response characteristics is as follows:

Table 2: Step response Characteristics of UT3A with PID Controller

Rise Time(s)	5.9133
Settling time(s)	71.9528
Settling Min	$1.6891e^{-04}$
Settling Max	$2.9099e^{-04}$
Overshoot	72.28
Undershoot	$3.0978e^{+03}$
Peak	0.0052
Peak Time(s)	2.5103

5.1.2 System with SSSC

A system for AGC in a two-area system is believed to have an SSSC whose gain and time constants are set using the PSO algorithm to produce an optimum value with the lowest frequency deviation. The simulation diagram is mentioned in the appendix. After tuning the system with the PSO method, the following result is achieved.

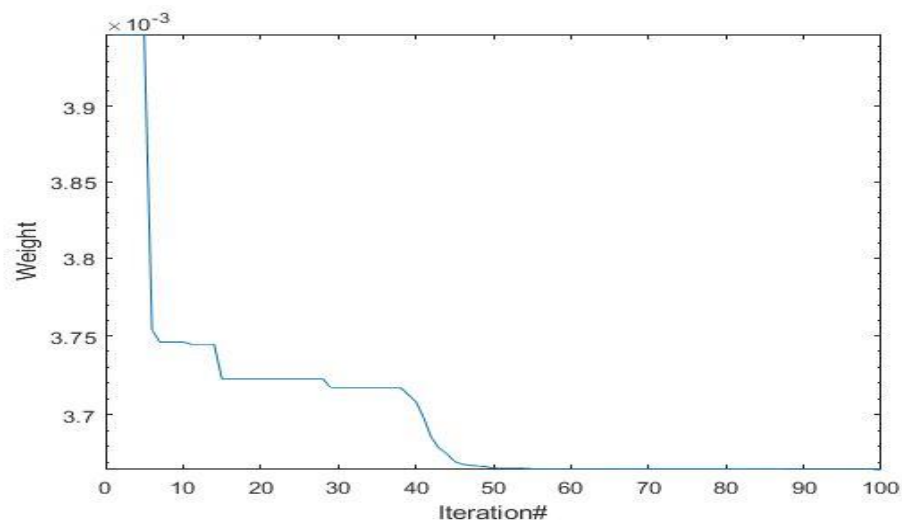


Figure 10: Iteration Vs Values

The gain and time constant after tuning by PSO algorithm are as follows:

$$K_{SSSC} = 0.1235$$

$$T_{SSC} = 1$$

$$T_1 = 0.5837$$

$$T_2 = 0.01$$

$$T_3 = 0.4274$$

$$T_4 = 0.3458$$

The frequency response of a system with SSSC is as follows:

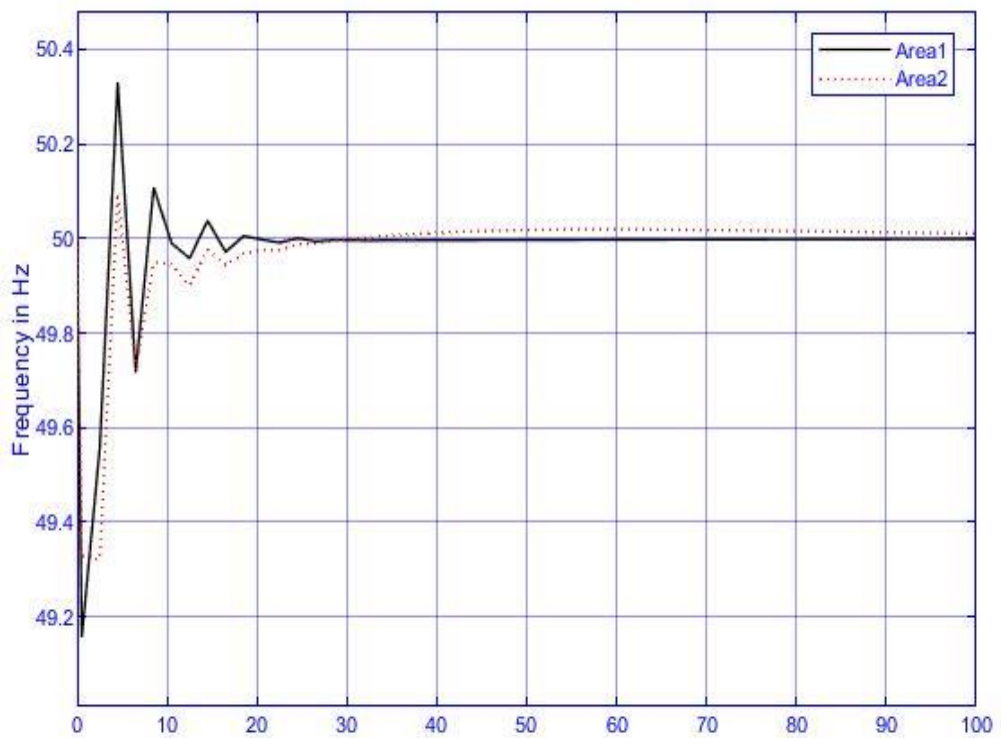


Figure 11: Frequency response of system with SSSC

The table for step response characteristics is as follows:

Figure 12: Step response characteristics of UT3A with SSSC controller

Rise Time(s)	0.0216
Settling time(s)	29.2317
Settling Min	-0.0055
Settling Max	0.0019
Overshoot	818.41
Undershoot	$6.5e^{+03}$

Peak	0.0136
Peak Time(s)	2.5103

From step response characteristics the settling time of a system with SSSC is improved than a system with PID Controller

5.1.3 System having controller as Fuzzy Logic Controller (FLC).

A system for AGC in two area system is considered having controller as Fuzzy Logic Controller which take single input as Area Control Error (ACE). For designing FLC controller array for input and output to controller are required. For those input and output array, a PID controller in auto tuned mode is kept for control of area control error and input and output of PID controller are transferred to workspace. From workspace input and output array for FLC controller are obtained. The simulation diagram is mentioned in Appendix.

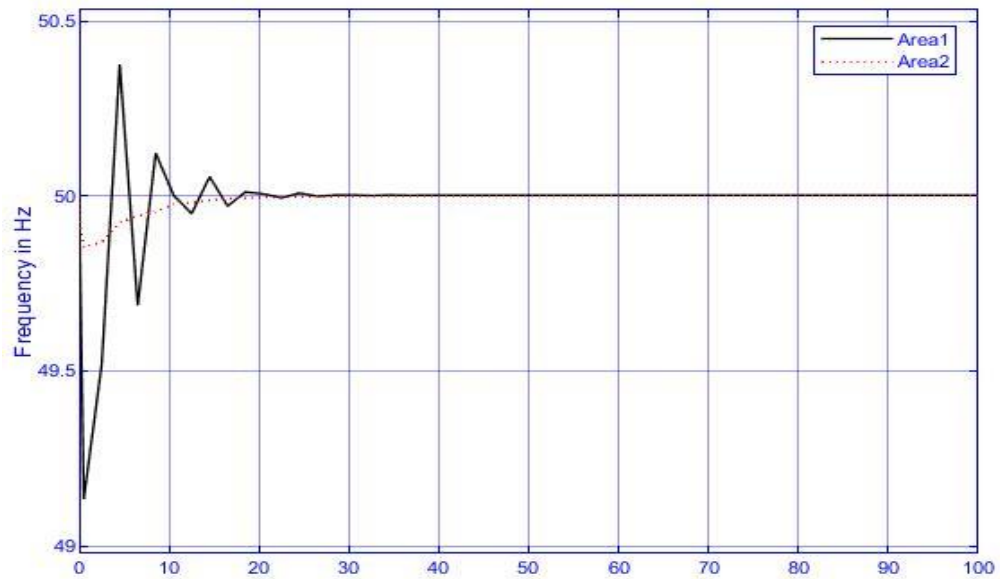


Figure 13: Frequency response of system with FLC

The table for step responses characteristics is as follows:

Table 3: Step response characteristics of UT3A using FLC

Rise time(s)	44.7909
Settling Time(s)	27.0558
Settling Min	$3.4904e^{-05}$

Settling Max	3.8284e ⁻⁰⁵
Overshoot	0
Undershoot	7.6281e ⁰³
Peak	0.0029
Peak Time(s)	0.5103

From step response characteristics and frequency deviation curve it is seen that the settling time for system with FLC controller is just 27.0558 seconds which is less than settling time of system with SSSC (29.2317s) and with PID (71.9528s)

5.1.4 System having controller as ANFIS Controller

A double-zone AGC network is regarded to have an ANFIS controller. To create an ANFIS controller, an array for input and output to the controller is needed. For such input and output arrays, a PID controller in auto tuned mode is kept at area control error, and its input and output data are retrieved and sent to the workspace. The workspace's input and output arrays for the ANFIS controller are obtained. The simulation diagram is mentioned in the appendix. The frequency deviation output of the ANFIS controller is displayed in Figure.

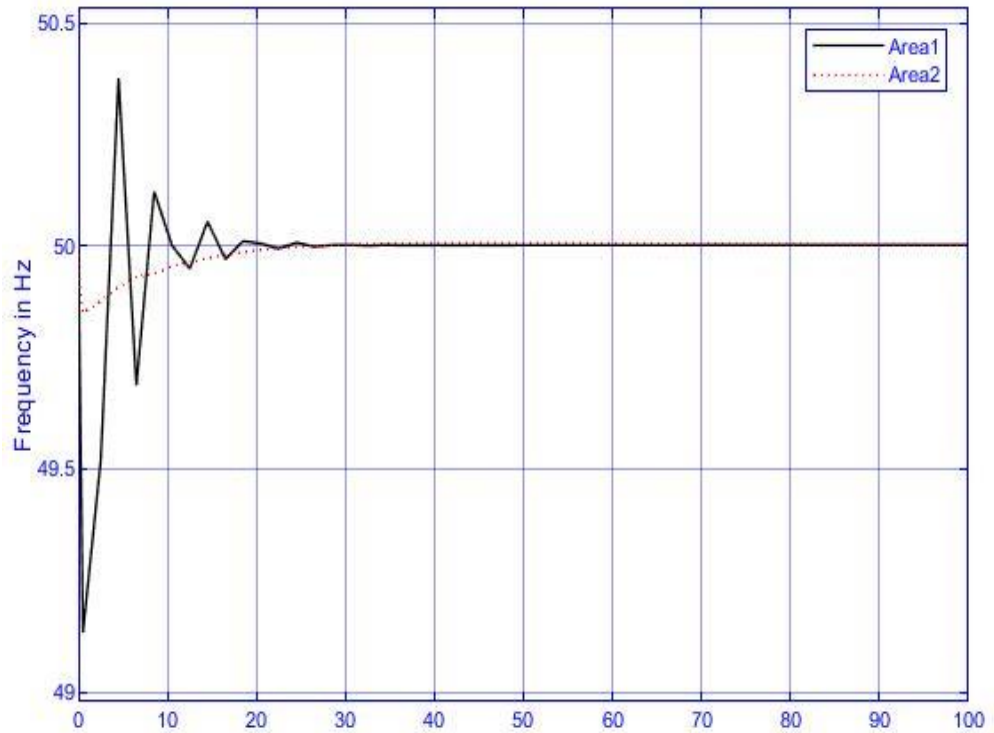


Figure 14: Frequency response characteristics of system with ANFIS Controller

The step response characteristics of system having ANFIS Controller is as follows:

Table 4: Step response characteristics of UT3A with ANFIS controller

Rise time(s)	3.6808
Settling Time(s)	26.4583
Settling Min	$7.1165e^{-05}$
Settling Max	$1.3109e^{-04}$
Overshoot	83.6733
Undershoot	$4.1913e^{+03}$
Peak	0.0030
Peak Time(s)	0.5103

The settling time of a system having ANFIS as controller has best settling time i.e. 26.4583s than previous all controller settling time.

5.2 CASE II ($\Delta P_1=1200\text{MW}(\text{INPS})$ & $\Delta P_2=30\text{MW}(\text{UT3A})$)

A condition is created where step input of 1200MW is applied in Area 1(INPS) and step input of 30MW is applied in Area 2(UT3A). The per unit values are as follows:

$$\Delta P_1 = 0.6 \text{ p.u} \dots \dots \dots \text{Equation 8}$$

$$\Delta P_2 = 0.015 \text{ p.u} \dots \dots \dots \text{Equation 9}$$

5.2.1 System with PID Controller

A system for AGC in two area system is considered having PID Controller (Area 1; P= 0, I=0.460194, D= 0 & Area 2; P= 0, I= 0.0362942, D= 0) as shown in Appendix. The frequency deviation is as follows:

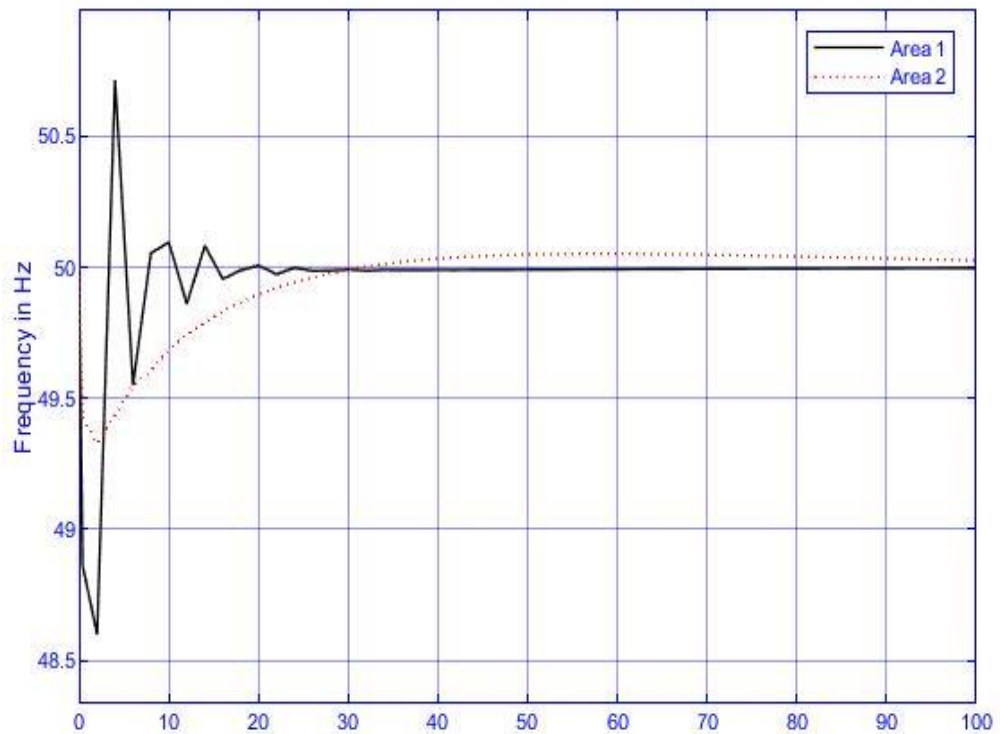


Figure 15: Frequency response of system with PID controller

The step response characteristics of system having PID Controller is as follows

Table 5: Step response characteristics of UT3A with PID Controller:

Rise Time(s)	5.06
Settling time(s)	80.7166

Settling Min	5.4060e ⁻⁰⁴
Settling Max	0.0010
Overshoot	93.5431
Undershoot	2.4846e ⁺⁰³
Peak	0.0134
Peak Time(s)	2.0172

5.2.2 System with SSSC

A system for AGC in a two-area system is believed to have an SSSC whose gain and time constants are set using the PSO algorithm to produce an optimum value with the lowest frequency deviation. The simulation diagram is mentioned in the appendix. After tuning the system with the PSO method, the following result is achieved.

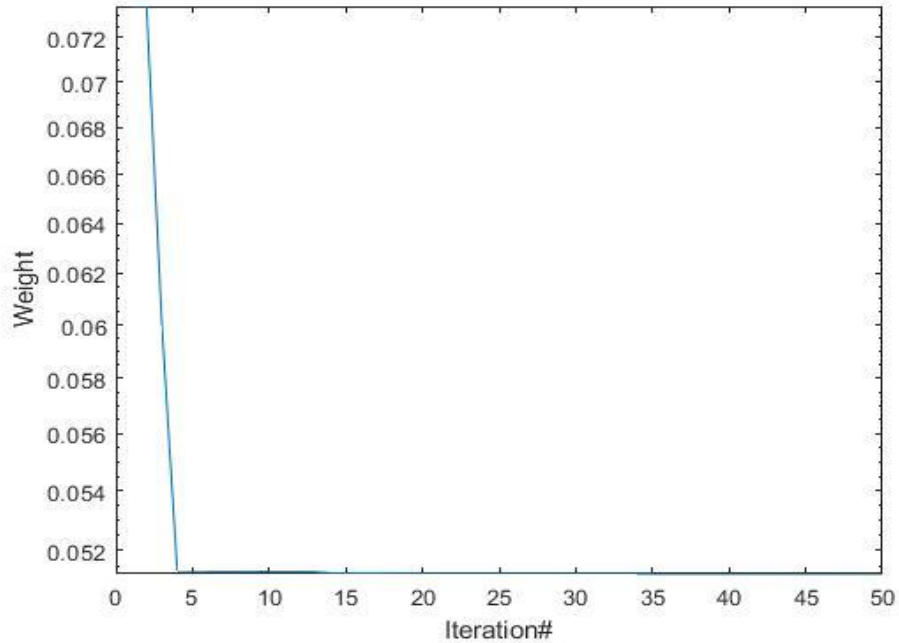


Figure 16: Iteration vs Values

The gain and time constant after tuning by PSO algorithm are as follows:

$$K_{SSSC} = 0.4311$$

$$T_{SSSC} = 1$$

$$T_1=0.4711$$

$$T_2 = 1$$

$$T_3=0.4704$$

$$T_4=1$$

The frequency deviation of a system with SSSC is as follows:

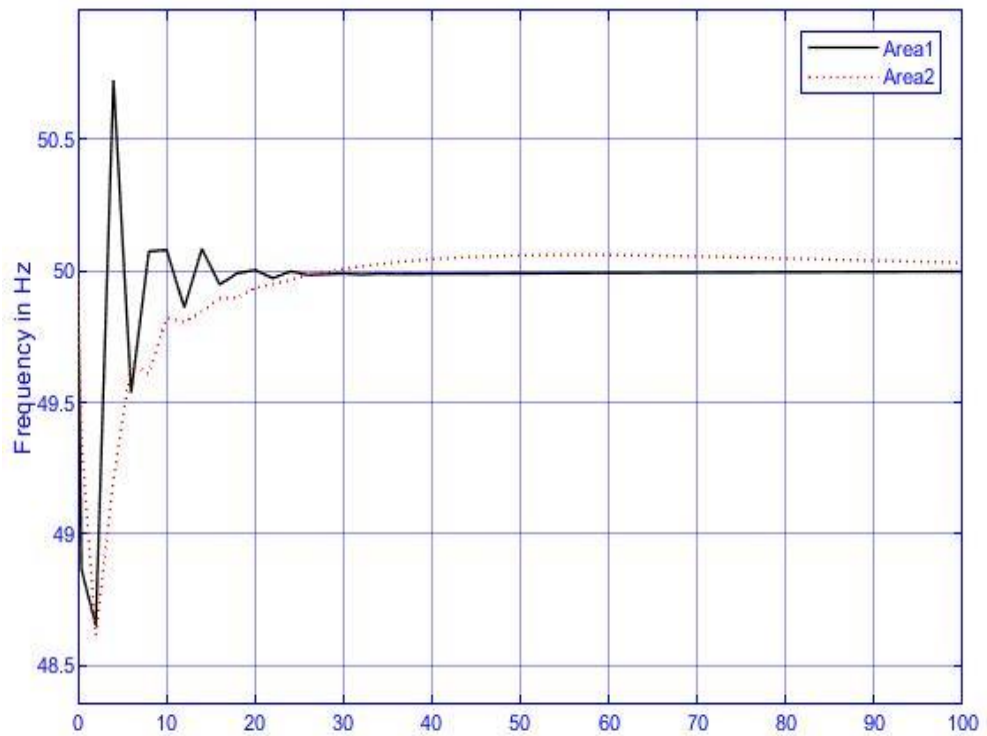


Figure 17: Frequency response of system with SSSC

The table for step response characteristics for SSSC as controller is as follows

Table 6: Step response characteristics of UT3A with SSSC

Rise Time(s)	5.3352
Settling time(s)	62.4004
Settling Min	$6.2207e^{-04}$
Settling Max	0.0012
Overshoot	95.0132

Undershoot	4.4502e ⁺⁰³
Peak	0.0277
Peak Time(s)	2.0172

From step response characteristics the settling time of a system with SSSC is improved than a system without SSSC.

5.2.3 System having controller as Fuzzy Logic Controller (FLC)

A system for AGC in two area system is considered having controller as Fuzzy Logic Controller which take single input as Area Control Error (ACE). For designing FLC controller array for input and output to controller are required. For those input and output array, a PID controller in auto tuned mode is kept for control of area control error and input and output of PID controller are transferred to workspace. From workspace input and output array for FLC controller are obtained. The simulation diagram is mentioned in Appendix.

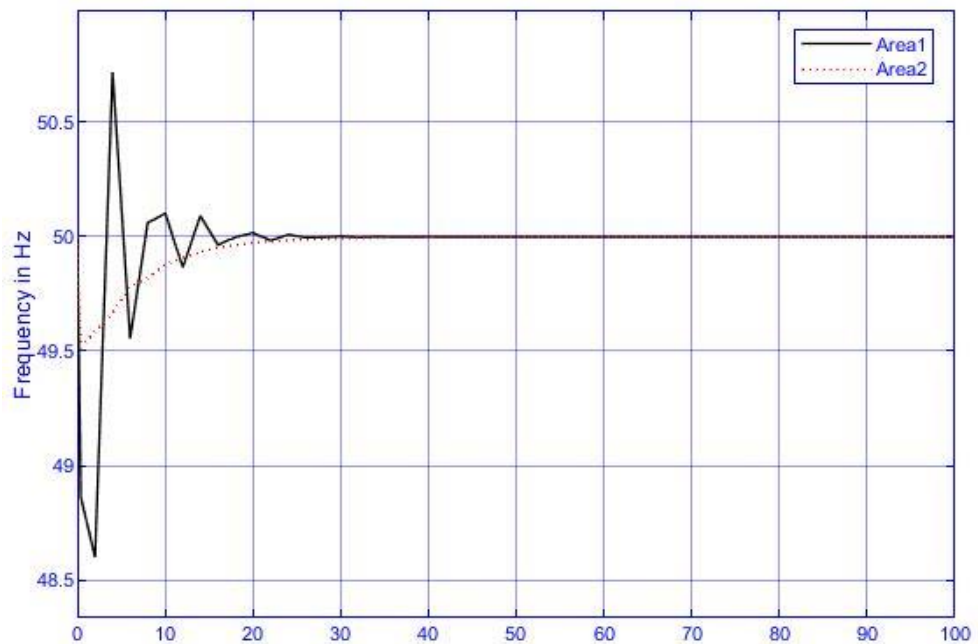


Figure 18: Frequency response of system with FLC

The table for step response characteristics is as follows

Table 7: Step response characteristics of UT3A with FLC

Rise time(s)	5.5161e ⁻⁰⁴
Settling Time(s)	26.7197

Settling Min	-0.0097
Settling Max	-3.7382e ⁻⁰⁵
Overshoot	2.5913e ⁺⁰⁴
Undershoot	0
Peak	0.0097
Peak Time(s)	0.4034

From step response characteristics and frequency deviation curve it is seen that the settling time for system with FLC controller is just 26.7197 seconds which is less than settling time of system with SSSC (62.4004s) and with PID (80.7166s)

5.2.4 System having controller as ANFIS Controller

A double-zone AGC network is regarded to have an ANFIS controller. To create an ANFIS controller, an array for input and output to the controller is needed. For such input and output arrays, a PID controller in auto tuned mode is kept at area control error, and its input and output data are retrieved and sent to the workspace. The workspace's input and output arrays for the ANFIS controller are obtained. The simulation diagram is mentioned in the appendix. The frequency deviation output of the ANFIS controller is displayed in Figure.

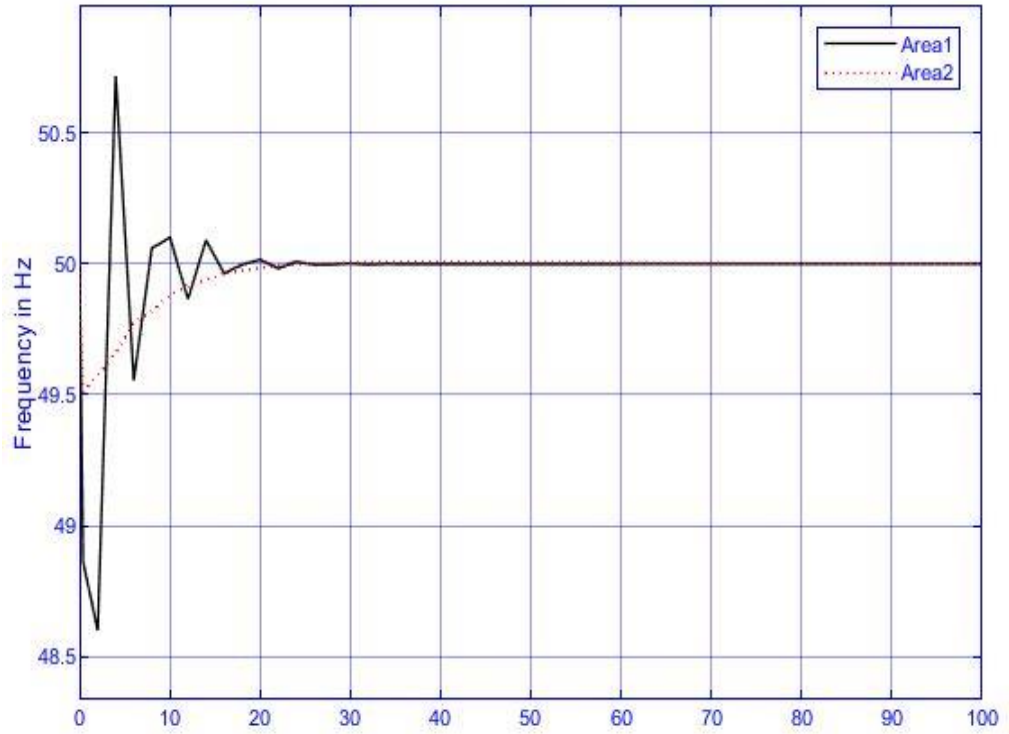


Figure 19: Frequency response of system with ANFIS Controller

The step response characteristics with ANFIS controller is as follows

Table 8: Step response characteristics of UT3A with ANFIS controller

Rise time(s)	0.4471
Settling Time(s)	21.6742
Settling Min	$2.0632e^{-05}$
Settling Max	$1.3450e^{-04}$
Overshoot	515.035
Undershoot	$4.4535e^{+04}$
Peak	0.0097
Peak Time(s)	0.4034

The settling time of a system having ANFIS as controller has best settling time i.e. 21.6742s than previous all controller settling time.

5.3 CASE III ($\Delta P_1=1800\text{MW}(\text{INPS})$ & $\Delta P_2=60\text{MW}(\text{UT3A})$)

A condition is created where step input of 1800MW is applied in Area 1(INPS) and step input of 60MW is applied in Area 2(UT3A). The per unit values are as

follows:

$$\Delta P_1 = 0.9 \text{ p.u} \dots \dots \dots \text{Equation 10}$$

$$\Delta P_2 = 0.03 \text{ p.u} \dots \dots \dots \text{Equation 11}$$

5.3.1 System with PID Controller

A system for AGC in two area system is considered having PID Controller (Area 1; P= 0, I=0.460194, D= 0 & Area 2; P= 0, I= 0.0362942, D= 0) as shown in Appendix. The frequency deviation is as follows:

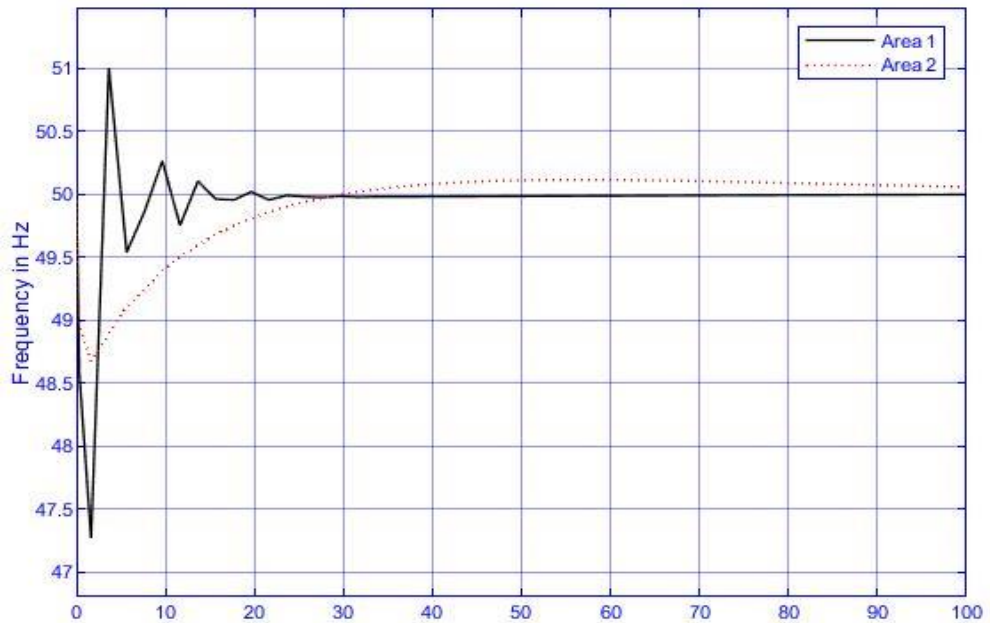


Figure 20: Frequency response of system with PID controller

The table for step response characteristics is as follows

Table 9: Step response characteristics of UT3A with PID Controller

Rise Time(s)	4.7565
Settling time(s)	81.9746
Settling Min	0.0010
Settling Max	0.0022
Overshoot	100.4246
Undershoot	$2.7366e^{+03}$
Peak	0.0266

Peak Time(s)	1.6470
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5.3.2 System with SSSC

A system for AGC in a two-area system is believed to have an SSSC whose gain and time constants are set using the PSO algorithm to produce an optimum value with the lowest frequency deviation. The simulation diagram is mentioned in the appendix. After tuning the system with the PSO method, the following result is achieved.

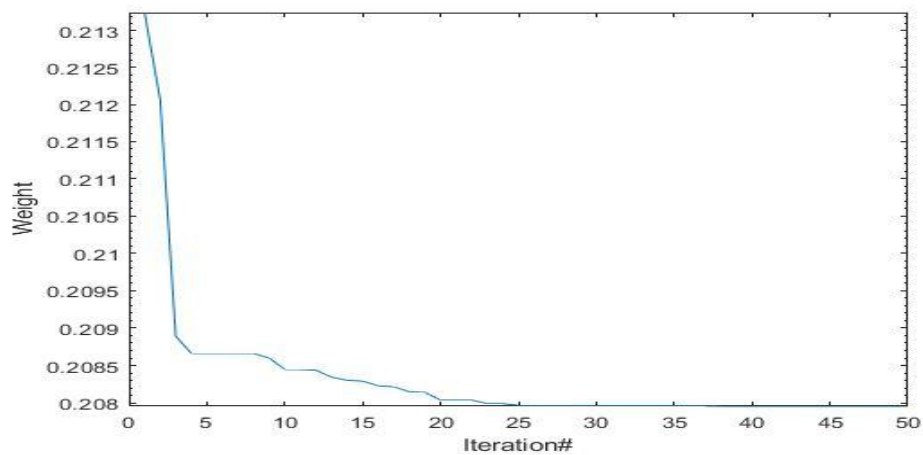


Figure 21: Iteration vs Values

The gain and time constant after tuning by PSO algorithm are as follows:

$$K_{SSSC} = 0.2305$$

$$T_{SSSC} = 1$$

$$T_1 = 0.2871$$

$$T_2 = 1$$

$$T_3 = 0.3476$$

$$T_4 = 0.01$$

The frequency deviation of a system with SSSC is as follows:

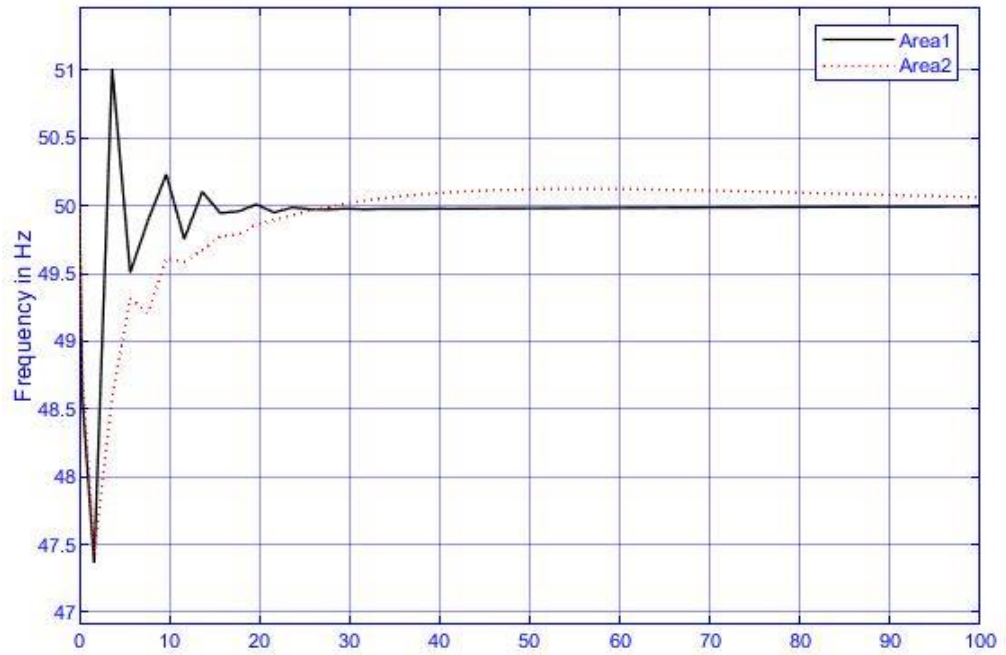


Figure 22: Frequency response of system with SSSC as controller

The table for step response characteristics is as follows

Table 10: Step response characteristics of UT3A with SSSC controller

Rise Time(s)	5.1012
Settling time(s)	67.9045
Settling Min	0.0013
Settling Max	0.0025
Overshoot	98.8578
Undershoot	$4.0936e^{+03}$
Peak	0.0514
Peak Time(s)	1.6470

From step response characteristics the settling time of a system with SSSC is improved than a system without SSSC.

5.3.3 System having controller as Fuzzy Logic Controller (FLC)

A system for AGC in two area system is considered having controller as Fuzzy Logic Controller which take single input as Area Control Error (ACE). For designing FLC controller array for input and output to controller are required. For those input and output array, a PID controller in auto tuned mode is kept for

control of area control error and input and output of PID controller are transferred to workspace. From workspace input and output array for FLC controller are obtained. The simulation diagram is mentioned in Appendix.

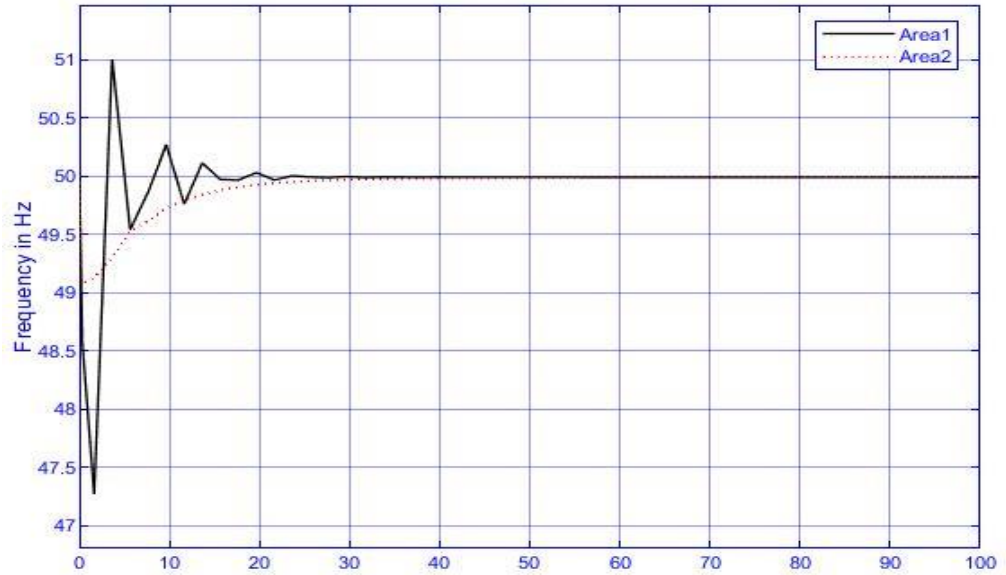


Figure 23:Frequency response of system with FLC

The table of Step response characteristics is as follows

Table 11: Step response characteristics of UT3A with FLC

Rise time(s)	0.0014
Settling Time(s)	30.8159
Settling Min	-0.0186
Settling Max	-1.9290e ⁻⁰⁴
Overshoot	9.5518e ⁺⁰³
Undershoot	0
Peak	0.0186
Peak Time(s)	0.3294

From step response characteristics and frequency deviation curve it is seen that the settling time for system with FLC controller is just 30.8159 seconds which is less than settling time of system with SSSC (67.9045s) and with PID (81.9746s)

5.3.4 System having Controller as ANFIS controller

A double-area AGC network is regarded to have an ANFIS controller. To create an ANFIS controller, an array for input and output to the controller is needed. For such input and output arrays, a PID controller in auto tuned mode is kept at area control error, and its input and output data are retrieved and sent to the workspace. The workspace's input and output arrays for the ANFIS controller are obtained. The simulation diagram is mentioned in the appendix. The frequency deviation output of the ANFIS controller is displayed in Figure.



Figure 24: Frequency response of system with ANFIS controller

The table for step response characteristics is as follows

Table 12: Step response characteristics of UT3A with ANFIS controller

Rise time(s)	0.0017
Settling Time(s)	27.6870
Settling Min	-0.0196
Settling Max	$2.3218e^{-04}$
Overshoot	$8.3288e^{+03}$

Undershoot	0
Peak	0.0196
Peak Time(s)	0.3294

The settling time of a system having ANFIS as controller has best settling time i.e. 27.6870s than previous all controller settling time.

5.4 CASE IV ($\Delta P_1 = -1000\text{MW}(\text{INPS})$ & $\Delta P_2 = -20\text{MW}(\text{UT3A})$)

First of all a condition is created where step input of 1000MW is decreased in Area 1(INPS) and step input of 20MW is decreased in Area 2(UT3A). The per unit values are as follows:

$$\Delta P_1 = -0.5 \text{ p.u} \dots \dots \dots \text{Equation 12}$$

$$\Delta P_2 = -0.01 \text{ p.u} \dots \dots \dots \text{Equation 13}$$

5.4.1 System with PID Controller

A system for AGC in two area system is considered having PID Controller(Area 1; P= 0, I=0.460194, D= 0 & Area 2; P= 0, I= 0.0362942, D= 0) as shown in Appendix. The frequency deviation is as follows:

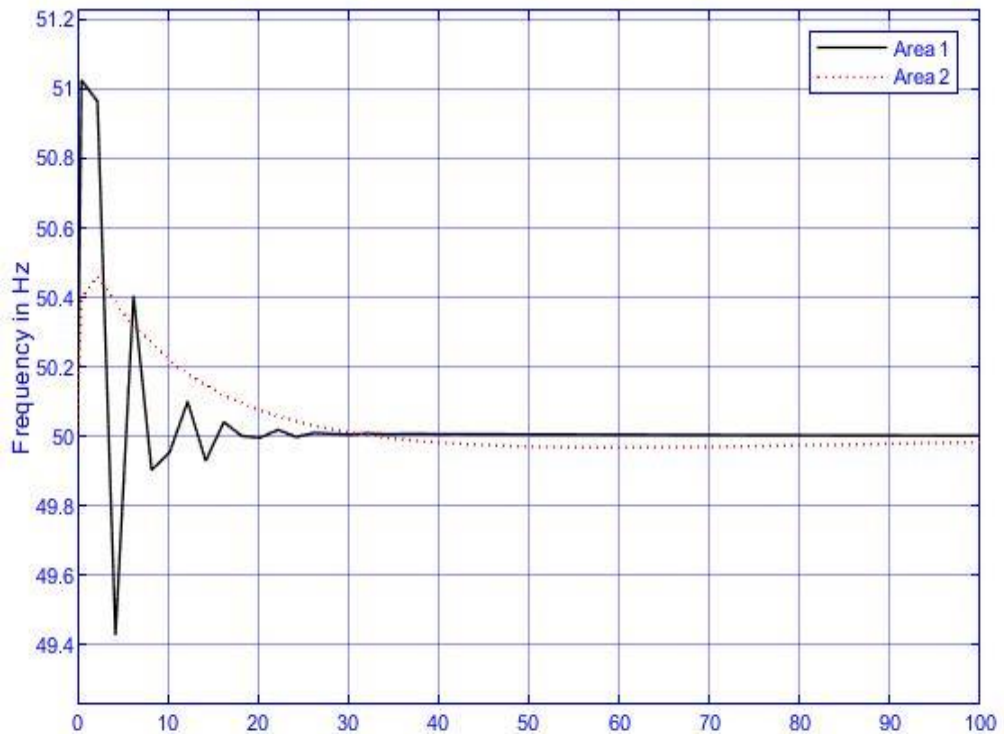


Figure 25: Frequency response of System with PID Controller

The table for step response characteristics is as follows:

Table 13: Step response Characteristics of UT3A with PID Controller

Rise Time(s)	5.2686
Settling time(s)	78.8232
Settling Min	-6.4944e ⁻⁰⁴
Settling Max	3.4809e ⁻⁰⁴
Overshoot	86.5712
Undershoot	2.6510e ⁺⁰³
Peak	0.0092
Peak Time(s)	2.2097

5.4.2 System with SSSC

A system for AGC in a two-area system is believed to have an SSSC whose gain and time constants are set using the PSO algorithm to produce an optimum value with the lowest frequency deviation. The simulation diagram is mentioned in the appendix. After tuning the system with the PSO method, the following result is achieved.

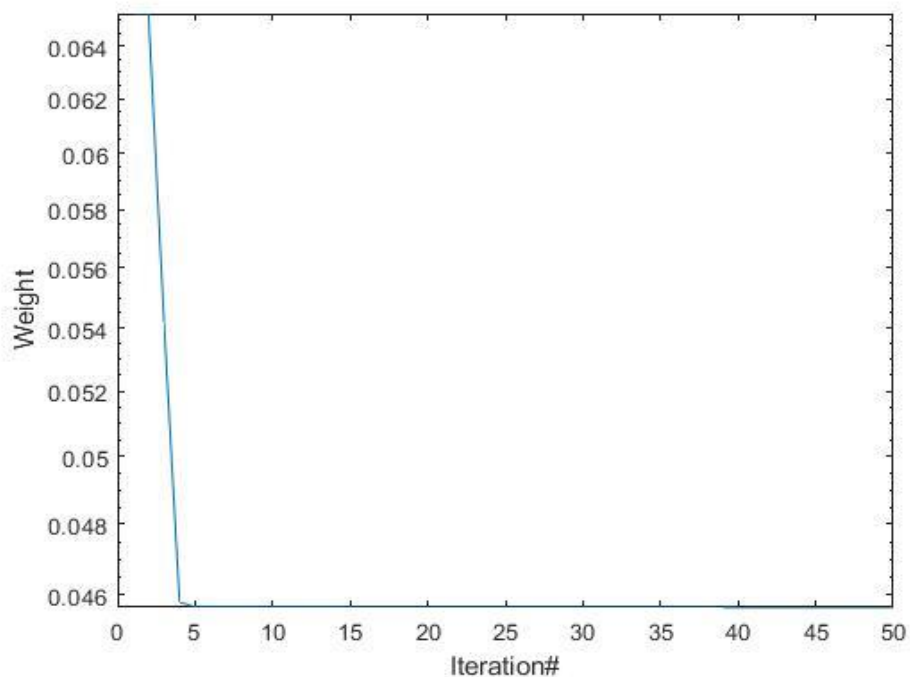


Figure 26: Iteration Vs Values

The gain and time constant after tuning by PSO algorithm are as follows:

$$K_{SSSC} = 0.0446$$

$$T_{SSSC} = 0.1103$$

$$T_1 = 0.5714$$

$$T_2 = 0.1130$$

$$T_3 = 0.0100$$

$$T_4 = 0.7899$$

The frequency response of a system with SSSC is as follows:

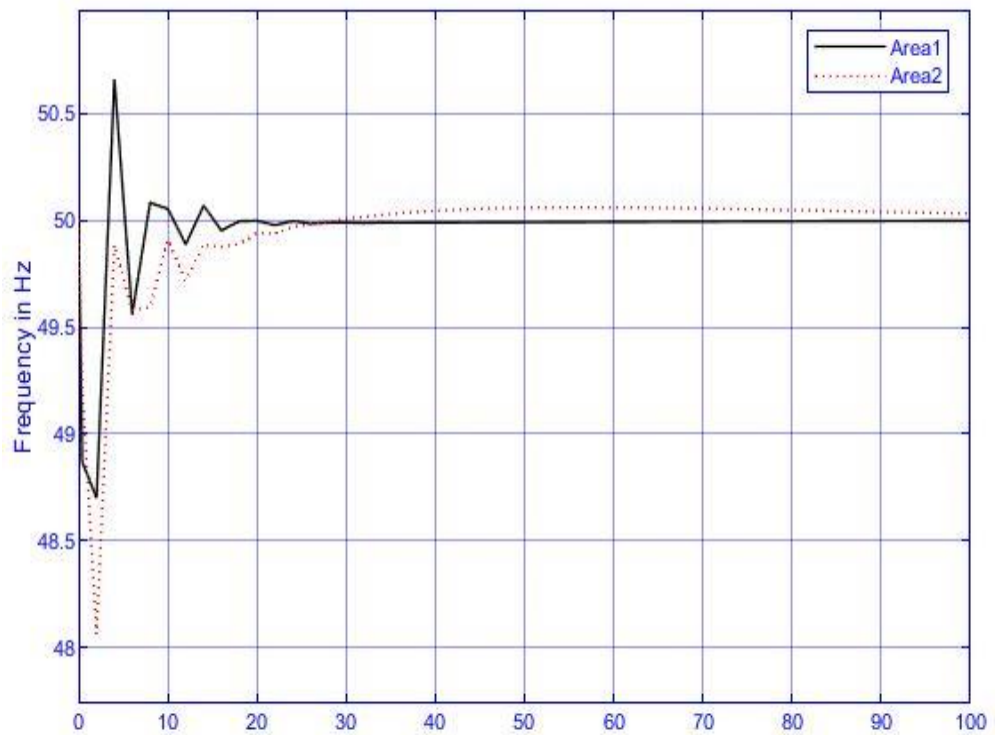


Figure 27: Frequency response of system with SSSC

The table for step response characteristics is as follows:

Figure 28: Step response characteristics of UT3A with SSSC controller

Rise Time(s)	5.3117
Settling time(s)	27.8519

Settling Min	-6.2008e ⁻⁰⁴
Settling Max	0.0012
Overshoot	95.2231
Undershoot	6.2464e ⁺⁰³
Peak	0.0387
Peak Time(s)	2.0172

From step response characteristics the settling time of a system with SSSC is improved than a system with PID Controller

5.4.3 System having controller as Fuzzy Logic Controller (FLC).

A system for AGC in two area system is considered having controller as Fuzzy Logic Controller which take single input as Area Control Error (ACE). For designing FLC controller array for input and output to controller are required. For those input and output array, a PID controller in auto tuned mode is kept for control of area control error and input and output of PID controller are transferred to workspace. From workspace input and output array for FLC controller are obtained. The simulation diagram is mentioned in Appendix.

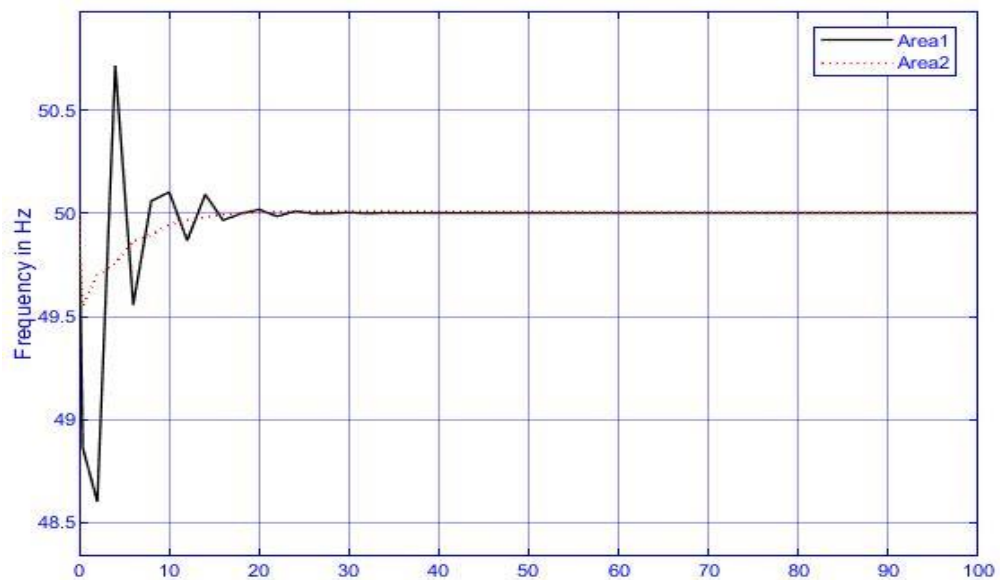


Figure 29: Frequency response of system with FLC

The table for step responses characteristics is as follows:

Table 14: Step response characteristics of UT3A using FLC

Rise time(s)	1.1732
Settling Time(s)	15.9538
Settling Min	$8.4306e^{-05}$
Settling Max	$2.3086e^{-04}$
Overshoot	173.8346
Undershoot	$1.0645e^{04}$
Peak	0.0090
Peak Time(s)	0.4034

From step response characteristics and frequency deviation curve it is seen that the settling time for system with FLC controller is just 15.9538 seconds which is less than settling time of system with SSSC (27.8519s) and with PID (78.8232s)

5.4.4 System having controller as ANFIS Controller

A double-zone AGC network is regarded to have an ANFIS controller. To create an ANFIS controller, an array for input and output to the controller is needed. For such input and output arrays, a PID controller in auto tuned mode is kept at area control error, and its input and output data are retrieved and sent to the workspace. The workspace's input and output arrays for the ANFIS controller are obtained. The simulation diagram is mentioned in the appendix. The frequency deviation output of the ANFIS controller is displayed in Figure.

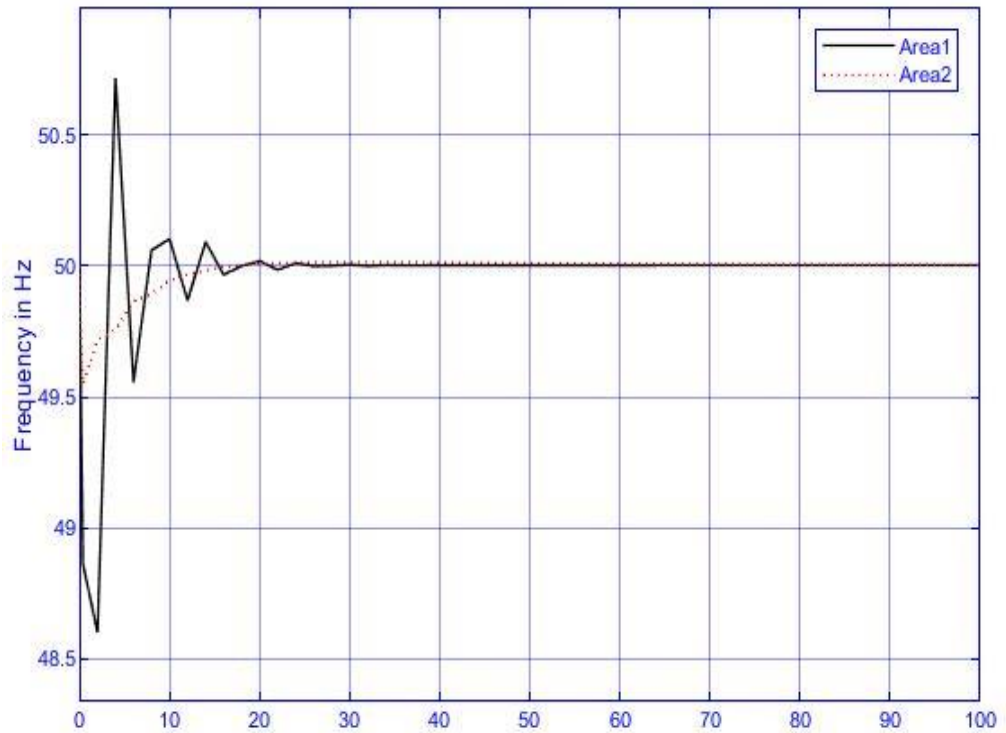


Figure 30: Frequency response characteristics of system with ANFIS Controller

The step response characteristics of system having ANFIS Controller is as follows:

Table 15: Step response characteristics of UT3A with ANFIS controller

Rise time(s)	1.5078
Settling Time(s)	14.6705
Settling Min	$1.0513e^{-04}$
Settling Max	$2.9551e^{-04}$
Overshoot	181.1016
Undershoot	$8.5436e^{+03}$
Peak	0.0090
Peak Time(s)	0.4034

The settling time of a system having ANFIS as controller has best settling time i.e. 14.6705s than previous all controller settling time.

5.5 RESULT COMPARISON

The step response characteristics of all the Cases and controller are compared to evaluate better performance of a controller. The comparison result is as shown in following table.

Table 16: Result Comparison of various controller on the basis of step response characteristics

Different Methods	CASE I				CASE II				CASE III			
	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	5.51e ⁻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	1.69e ⁻⁰⁴	-0.01	3.49e ⁻⁰⁵	7.12e ⁻⁰⁵	5.40e ⁻⁰⁴	6.22e ⁻⁰⁴	-0.0097	2.06e ⁻⁰⁵	0.001	0.001	-0.02	-0.02
Settling Max	2.91e ⁻⁰⁴	0.002	3.82e ⁻⁰⁵	1.31e ⁻⁰⁴	0.001	0.001	-3.73e ⁻⁰⁵	1.34e ⁻⁰⁴	0.002	0.003	-1.92e ⁻⁰⁴	2.32e ⁻⁰⁴
Overshoot	72.28	818.4	0	83.67	93.54	95.01	2.59e ⁺⁰⁴	515.03	100.42	98.85	9.55e ⁺⁰³	8.32e ⁺⁰³
Undershoot	3.09e ⁻⁰³	6.5e ⁺⁰³	7.62e ⁻⁰³	4.19e ⁺⁰³	2.48e ⁻⁰³	4.45e ⁺⁰³	0	4.45e ⁺⁰⁴	2.73e ⁻⁰³	4.09e ⁺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

Different Methods	CASE IV			
	With PID	With SSSC	FLC	ANFIS
Rise Time(s)	5.2686	5.3117	1.1732	1.5078
Settling Time(s)	78.8232	27.8519	15.9538	14.6705
Settling Min	-6.4944e ⁻⁰⁴	-6.2008e ⁻⁰⁴	8.4306e ⁻⁰⁵	1.0513e ⁻⁰⁴
Settling Max	3.4809e ⁻⁰⁴	0.0012	2.3086e ⁻⁰⁴	2.9551e ⁻⁰⁴
Overshoot	86.5712	95.2231	173.8346	181.1016
Undershoot	2.6510e ⁺⁰³	6.2464e ⁺⁰³	1.0645e ⁺⁰⁴	8.5436e ⁺⁰³
Peak	0.0092	0.0387	0.0090	0.0090
Peak Time(s)	2.2097	2.0172	0.4034	0.4034

From above table, it is seen that ANFIS controller has lowest settling time, than other controller in all four cases. Therefore, ANFIS controller is recommended for AGC in Upper Trishuli 3A Hydropower Plant.

5.6 Existing output response of Upper Trishuli 3A Hydropower Plant at step input of $\Delta P_1=0.375$ p.u.(750 MW in INPS) & $\Delta P_2=0.00525$ p.u. (10.5 MW in UT3A)

The frequency and power curve at step input of $\Delta P_1=0.375$ p.u and $\Delta P_2=0.00525$

p.u is obtained from SCADA of Upper Trishuli 3A Hydropower Plant and is as shown below. The PID parameter of UT3A PID Controller for AGC is calculated according to load and frequency is stabilized.



Figure 31: Existing Output response of UT3A at output of 10.5MW

From above figure, when step input of 10.5MW is applied to generator of Area2(UT3A) at load of the system i.e. INPS was around 750MW, it took about 82 sec to settle frequency from 49.86Hz to 50 Hz. The same condition is applied and simulated in MATLAB/SIMULINK, where the settling time obtained was 72 seconds which is very close to actual value, which validates model with actual system. Now we got even better AGC with the use of ANFIS controller. And it is also seen from above result that, with the use of SSSC or FLC or ANFIS gives almost better result than existing system at UT3A HPS for AGC.

CHAPTER 6. CONCLUSION

In this work various methods and controllers are applied such as PSO tuned SSSC, FLC & ANFIS controller to the existing system model of UT3A hydropower plant AGC at four different cases (according to load demand) which gives better result than existing result of AGC at UT3A HPS

With the help of SSSC, damping of frequency instability is also improved. Settling time by using ANFIS is smallest among all 26.45sec (Case I) and settling time by using FLC is also less. Therefore, either ANFIS or FLC is recommended in UT3A HPS to obtain better result in AGC to give better performance than existing response.

Thus, this thesis work finds the applicability of the improving AGC of hydropower plant in Nepal which could reduce the power system outage due to frequency instability in an interconnected power system.

CHAPTER 7 RECOMMENDATION

This work is done for Run of River (ROR) and plant having Francis unit but the methodology can be applied to Peaking Run of River (PROR) type hydropower plant having Pelton or Francis Turbine for effective operation of Automatic Generation Control (AGC) in INPS.

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APPENDIX

a. Simulink Model with PID Controller

A simple model for AGC is designed with PID Controller (Area 1; P= 0, I=0.460194, D= 0 & Area 2; P= 0, I= 0.0362942, D= 0)

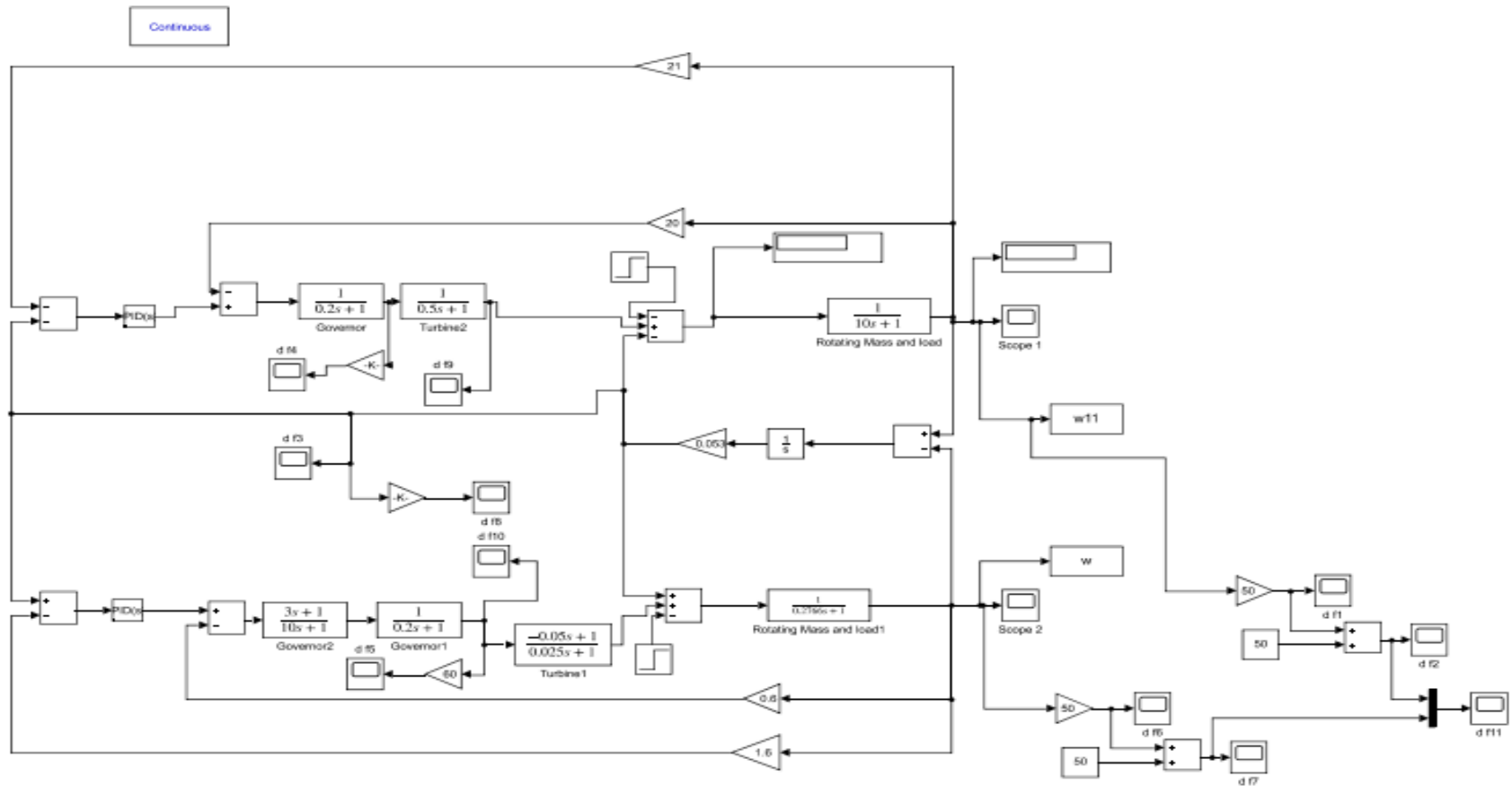


Figure 32: Simulink Model with PID Controller

b. Simulink model of PSO Tunning in AGC

A model for AGC with SSSC is created as shown in the figure below, and the SSSC parameters are modified using the Particle Swarm Optimization (PSO) algorithm.

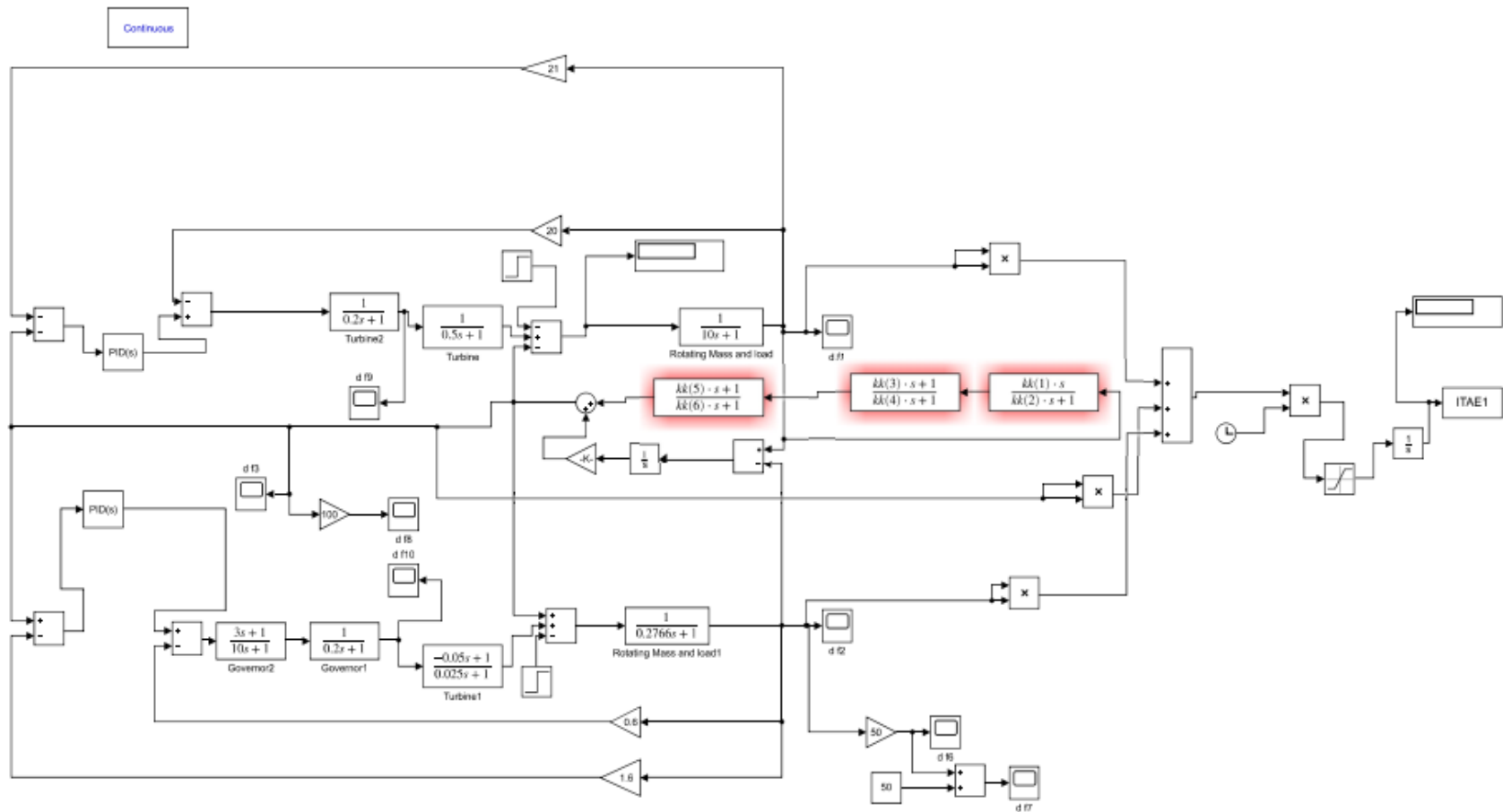


Figure 33: Simulink model for tuning SSSC in AGC

c. Simulink model of AGC with Fuzzy Logic Controller (FLC)

A Simulink model is designed having Fuzzy Logic Controller feeding with single input (area control error). The input array and output array for FLC are formed by placing PID controller at self-tuned and transferring it to workspace.

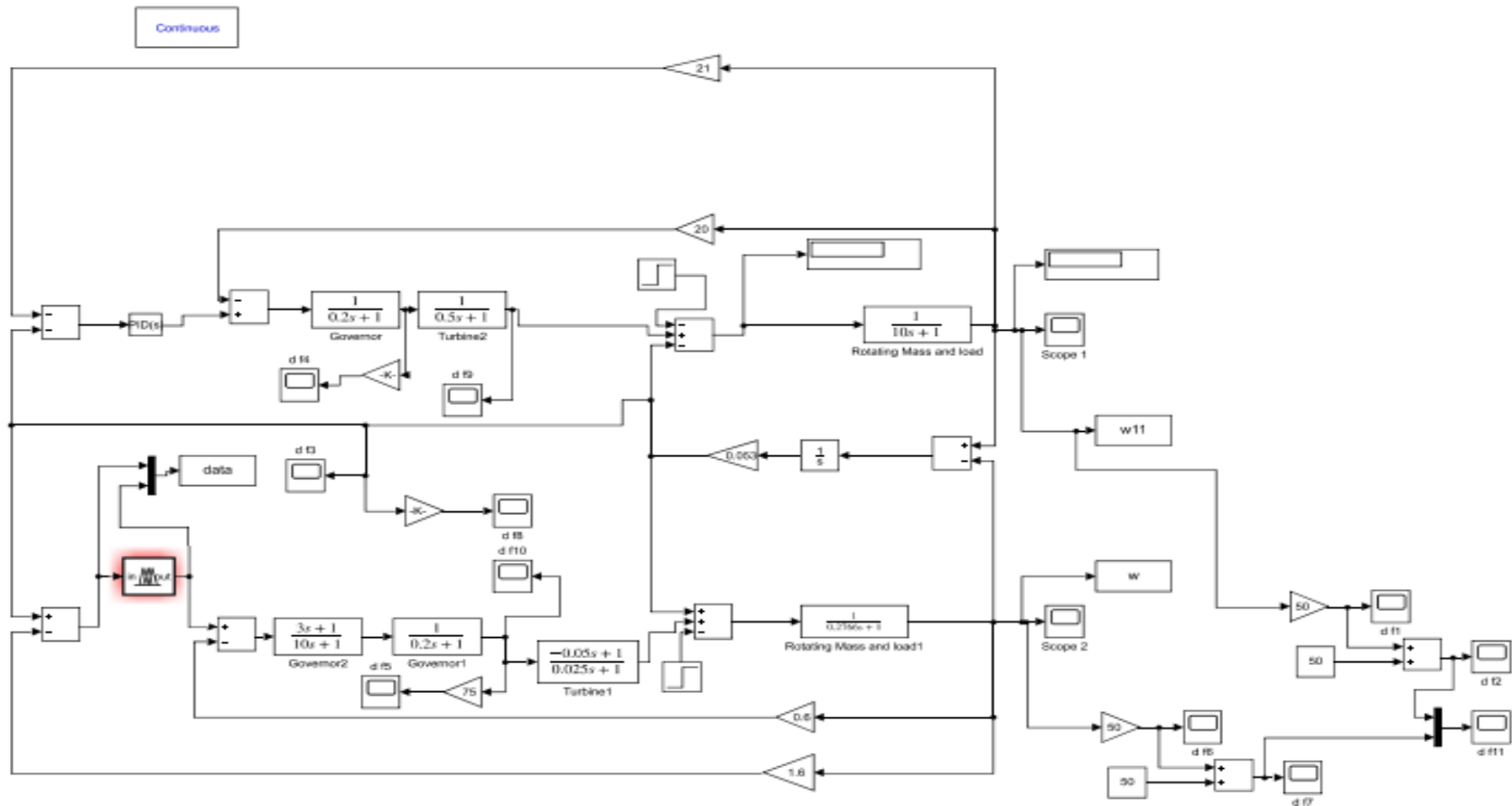


Figure 35: Simulink model for AGC with FLC controller

d. Simulink model of AGC with Adaptive Neuro Fuzzy Inference System (ANFIS)

A Simulink model is designed having ANFIS controller. The input array and output array for ANFIS are formed by placing PID controller at self-tuned and transferring it to workspace.

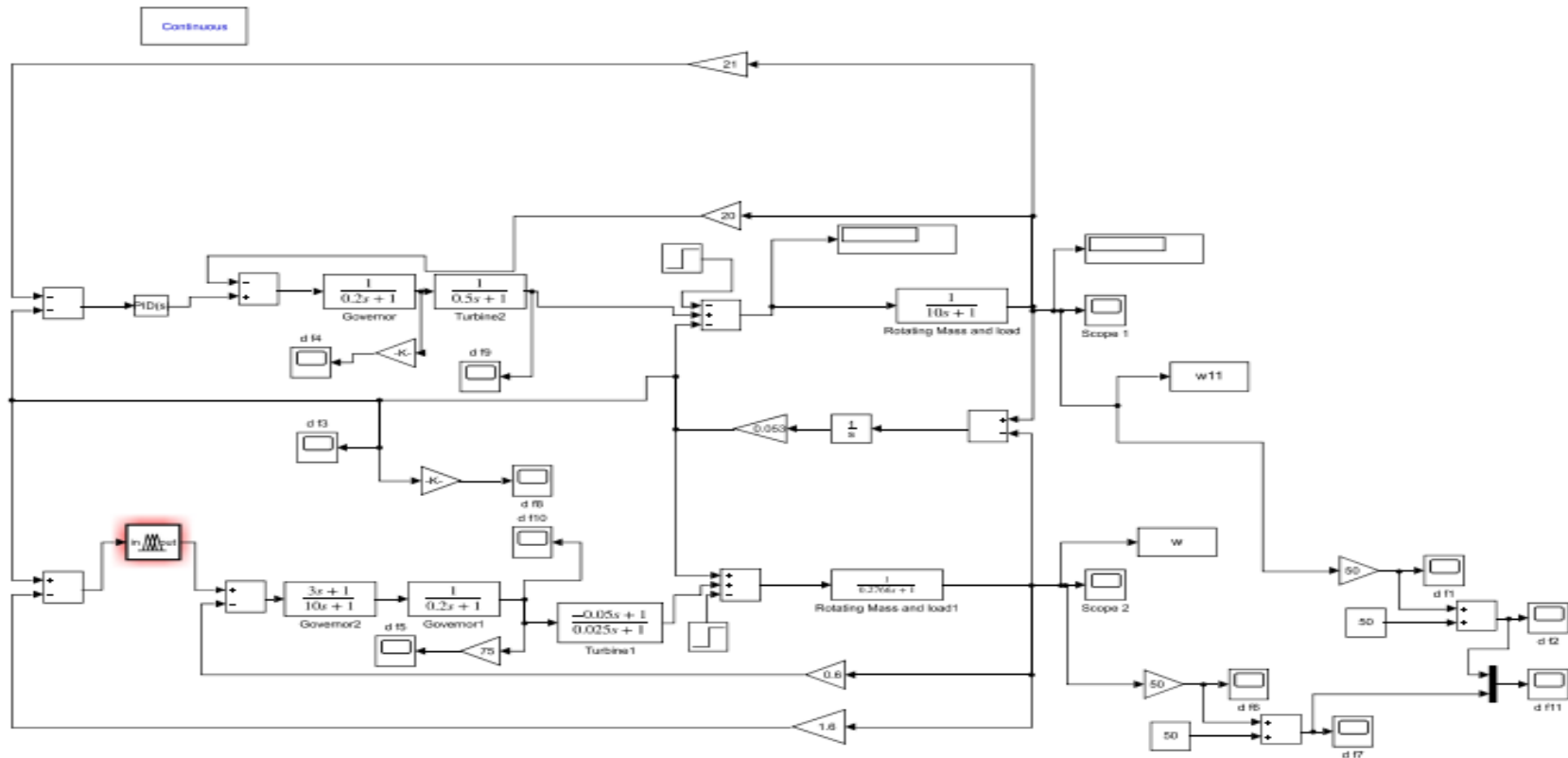


Figure 36: Simulink model for AGC with ANFIS Controller

e. MATLAB Code for Particle Swarm Optimization Algorithm

```
clear all
close all
clc

% Define the details of the table design problem
nVar = 6; % number of variables
ub = [10 1 1 1 1 1 ]; %upper Bound
lb = [0.01 0.01 0.01 0.01 0.01 0.01]; % lower bound
fobj = @tunning; % Objective function Name

% Define the PSO's paramters
noP = 15; % number of particles for initialization
maxIter = 20; % maximum iterations
wMax = 1;
wMin = 0.1;
c1 = 2;
c2 = 2;
vMax = (ub - lb) .* 0.2;
vMin = -vMax;

% The PSO algorithm

% Initialize the particles
for k = 1 : noP
    Swarm.Particles(k).X = (ub-lb) .* rand(1,nVar) + lb;
    Swarm.Particles(k).V = zeros(1, nVar);
    Swarm.Particles(k).PBEST.X = zeros(1,nVar);
    Swarm.Particles(k).PBEST.O = inf;

    Swarm.GBEST.X = zeros(1,nVar);
    Swarm.GBEST.O = inf;
end

% Main loop
for t = 1 : maxIter

    % Calculalte the objective value
    for k = 1 : noP
        currentX = Swarm.Particles(k).X;
        Swarm.Particles(k).O = fobj(currentX);

        % Update the PBEST
```

```

        if Swarm.Particles(k).O <
Swarm.Particles(k).PBEST.O
            Swarm.Particles(k).PBEST.X = currentX;
            Swarm.Particles(k).PBEST.O =
Swarm.Particles(k).O;
        end

        % Update the GBEST
        if Swarm.Particles(k).O < Swarm.GBEST.O
            Swarm.GBEST.X = currentX;
            Swarm.GBEST.O = Swarm.Particles(k).O;
        end
    end

    % Update the X and V vectors
    w = wMax - t .* ((wMax - wMin) / maxIter);

    for k = 1 : noP
        Swarm.Particles(k).V = w .* Swarm.Particles(k).V
+ c1 .* rand(1,nVar) .* (Swarm.Particles(k).PBEST.X -
Swarm.Particles(k).X) ...

+ c2 .* rand(1,nVar) .* (Swarm.GBEST.X -
Swarm.Particles(k).X);

        % Check velocities
        index1 = find(Swarm.Particles(k).V > vMax);
        index2 = find(Swarm.Particles(k).V < vMin);

        Swarm.Particles(k).V(index1) = vMax(index1);
        Swarm.Particles(k).V(index2) = vMin(index2);

        Swarm.Particles(k).X = Swarm.Particles(k).X +
Swarm.Particles(k).V;

        % Check positions
        index1 = find(Swarm.Particles(k).X > ub);
        index2 = find(Swarm.Particles(k).X < lb);

        Swarm.Particles(k).X(index1) = ub(index1);
        Swarm.Particles(k).X(index2) = lb(index2);

    end

    outmsg = ['Iteration# ', num2str(t) , ' Swarm.GBEST.O
= ' , num2str(Swarm.GBEST.O)];
    disp(outmsg);

    cgCurve(t) = Swarm.GBEST.O;
end

```

```
semilogy(cgCurve);  
xlabel('Iteration#')  
ylabel('Weight')
```

MATPOWER Code for tuning PSO

```
function cost = tuning(kk)  
assignin('base','kk',kk);  
sim('agcwithsssc112.slx');  
cost= ITAE1(length(ITAE1));  
end  
};
```

f. Calculations for Modeling AGC of Upper Trishuli 3A Hydropower Stations

$$H = \frac{\frac{1}{2}J\omega^2}{S} \dots \dots \dots \text{Equation 14}$$

Rotating mass of generator set (m)=110000 Kg

Total Moment of Inertia(J) is

$$J = \frac{1}{2}mr^2 \dots \dots \dots \text{Equation 15}$$

Radius of rotor(r)=1.75m

Therefore, from equation (13)

$$J=153125 \text{ kg-m}^2$$

Rated Speed of Rotor(N)=428 rpm

From equation (12)

$$H=4.61\text{s}$$

Let Common base MVA=2000 MVA

According to [1]

$$\text{Droop for INPS, } R1 = \frac{2000}{2000} \times 0.05 = 0.05 \dots \dots \dots \text{Equation 16}$$

$$\text{Droop for UT3A, } R2 = \frac{2000}{60} \times 0.05 = 1.667 \dots \dots \dots \text{Equation 17}$$

$$\text{Tie Line Frequency Bias for INPS, } B1 = \frac{1}{R1} + D = 21 \dots \dots \dots \text{Equation 18}$$

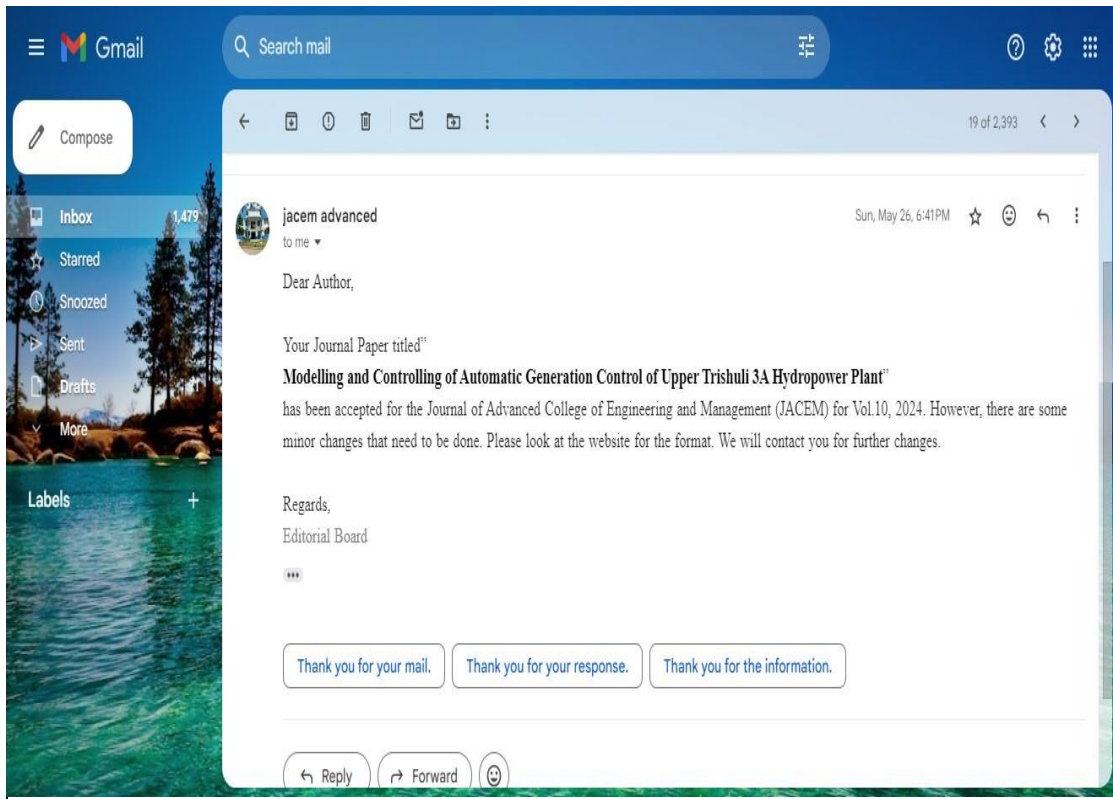
$$\text{Tie Line Frequency Bias for UT3A, } B2 = \frac{1}{R2} + D = 1.6 \dots \dots \dots \text{Equation 19}$$

According to [24]

$$\text{Inertia Constant for INPS, } H1 = 5 \times \frac{2000}{2000} = 5 \dots \dots \dots \text{Equation 20}$$

$$\text{Inertia Constant for UT3A, } H1 = 4.61 \times \frac{60}{2000} = 0.1383 \dots \dots \dots \text{Equation 21}$$

g. Paper Approval and approved Paper



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

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Abstract

With increase in load demand and causing mismatch between load and generation, only generating electrical power is not enough especially in today's modern power system. Due to mismatch between load and generation (active power) frequency of the power system becomes unstable and bringing back, the frequency of power system to its standard value within short period of time is very important and challenging task in power system which is done by Automatic Generation Control (AGC). This work comprises modelling and controlling of AGC for minimizing settling time of frequency response of UT3A hydropower plant interconnected with INPS in two area power system. Three cases are considered, according to step load input to the system with PID, PSO tuned SSSC, FLC and ANFIS controller for minimizing ACE and stabilizing the frequency response of UT3A Hydropower plant in the AGC model. Among all controller, ANFIS is found out to be superior for reducing frequency response settling time to minimum value in UT3A hydropower plant. This work also deals better with the problem of frequency instability which causes system outage due to breaking of synchronization in an interconnected system.

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

Nowadays power system across the world faces the major challenges of frequency instability, voltage instability, poor voltage profile and high system losses. Due to different technical, economic, environmental and economical constraints, the extension of our power system is not possible causing power system to operate forcefully closer to their stability limits(maximum capacity). The rule in electricity is that, generated power must be equal to load consumptions. Unbalance between generation and load demand or consumption causes unbalance in frequency because change in rotor angle or change in frequency is directly associated with change in real power demand. Therefore, most of the power system planner are becoming more concern about rotor angle stability or frequency stability. The deviation of real power and frequency is balanced by Load frequency control(LFC). Automatic Generation Control(AGC) is the process of maintaining frequency deviation negligible or zero, when power demand in power system changes. It is achieved with the introduction of secondary loop in LFC in which it contains integrator with constant [1].

Recent developments in the field of high power electronics show the use of FACTS (Flexible AC Transmission System) controllers in power systems. SSSC, a series synchronous voltage source, is one of the FACTS devices that is very effective in controlling the current in the line as well as controlling the voltage profile and stability of the system. It can change the effective impedance of the transmission line by applying a voltage with an appropriate phase angle with respect to the line current. It has the ability to exchange active and reactive power with the transmission system. For example, if the applied

voltage is in phase with the current, the voltage will exchange real power. On the other hand, if a voltage is applied in quadrature to the current then reactive power, absorbed or generated, will be exchanged. SSSC appears to be an advantageous controller over TCSC due to its ability to adjust not only line reactance but also line resistance according to power fluctuations, thereby improving generator damping and contributing to generate fluctuating power. [2] [3] [4]

Upper Trishuli 3A(UT3A) hydropower plant is located in Rasuwa district of Nepal. It is run of river (ROR) type hydropower plant with capacity of 60MW. It has two unit of 30MW equipped Francis turbine.

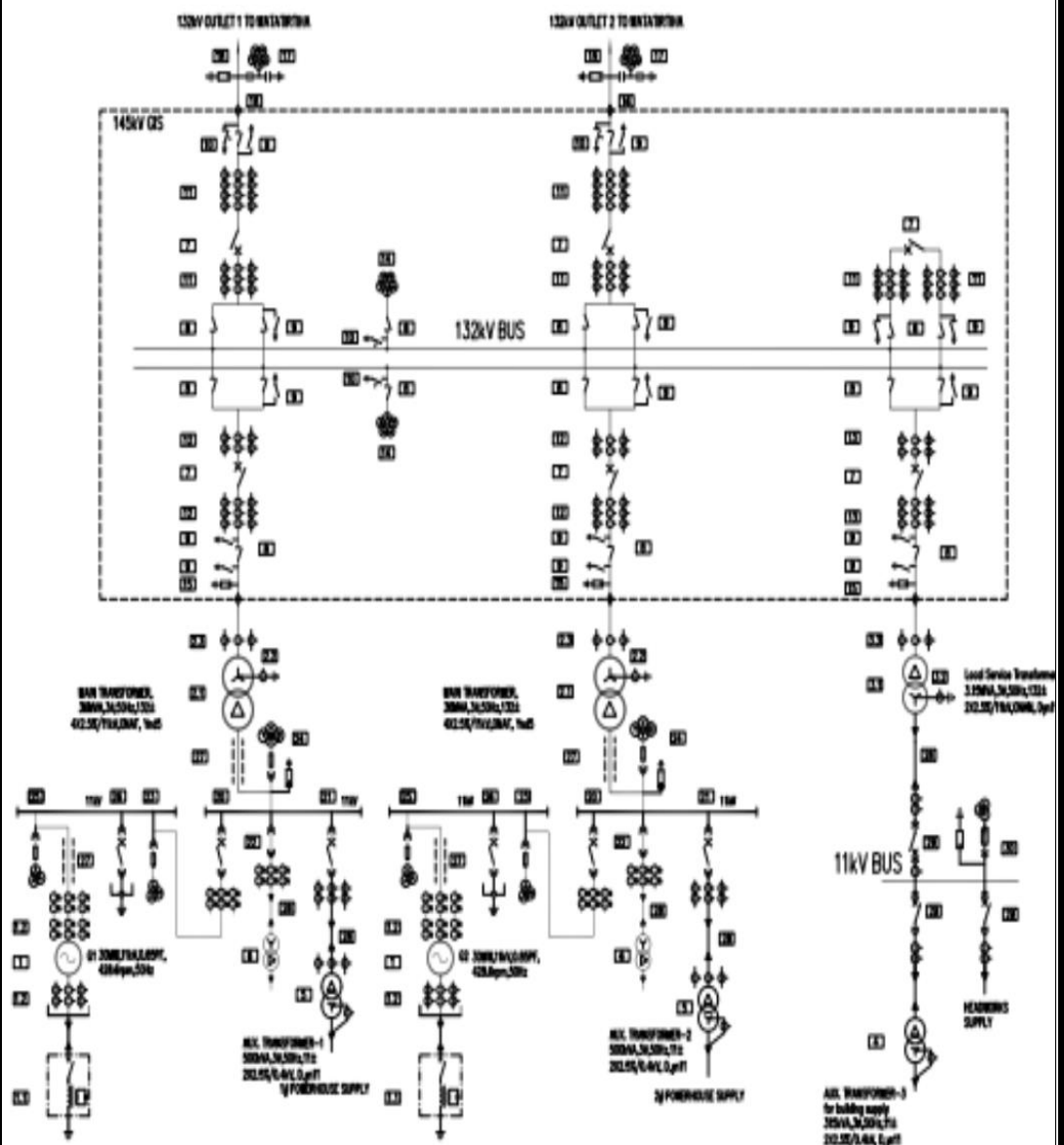


Figure 1: Single Line Diagram of UT3A Hydropower Plant [5]

1.1 Problem Statement

Frequency and voltage are key parameter in hydropower plant, and controlling them could be a major concern. The frequency depends on the genuine power generation, and it ought to be adjusted and stay consistent in numerous operating condition.

In an interconnected hydropower plants, there are a parcel of utilities that interconnect each other and trade control with neighboring plants utilizing tie lines. Alter in dynamic control parameter of one control line influences the entire system's frequency.

The development of a large generator couldn't solve the difference between load consumption and power generation due to dynamic nature of load demand causing frequency instability. Therefore, maintaining constant generation frequency and tie line flow at a desire range becomes more complex which may lead to power system instability and blackout if not solved promptly. Finally, AGC comes into play for solving above mentioned problems. The main challenging task is to make AGC for maintaining frequency stability in very short period of time.

1.2 Scope

The scope of this work includes modelling and controlling of AGC of UT3A hydropower plant interconnected with INPS using PSO tuned SSSC, FLC and ANFIS Controller at three different cases in MATLAB/SIMULINK.

1.3 Objective

The main objective of this work is to model and control the AGC of UT3A, for finding out best controller on the basis of minimum settling time of frequency response

2 Literature Review

In [6] Proposed modeling, design and experimental analysis of AGC for hydropower plants using ANFIS. Its main goal is to reduce frequency deviations that occur in the production system. Conventional PID, FLC and ANFIS controllers were studied using MATLAB. Study of the response of the AGC of a hydropower plant (in single and double area) to stepwise load changes. Simulation results show that ANFIS controller performs better than PID as well as FLC. Further results indicate that the proposed ANFIS controller accelerates the performance of the AGC of the hydropower plant.

In [7] Proposes Load Frequency Control of two area power system considering Integrated Nepal Power System (INPS) in Area 1 and Indian Power System in Area 2. This paper studies three different scenarios including the base scenario, 50% droop reduction and 50% inertia reduction as well as load change scenarios in MATLAB/SIMULINK. The results show that each area will adjust its own changes if there is a sudden load change in a area, and furthermore, the transients observed in cases I and II can be a serious problem.

In [8] Proposed AGC of a hydroelectric system linking multiple units and two regions. To compensate for such load disturbances and stabilize zone frequency oscillations, dynamic control of the current of a static synchronous series compensator (SSSC) or thyristor-controlled phase shifter (TCPS) in conjunction with Superconducting magnetic energy storage (SMES) is proposed. The integral controller and parameter gain of SSSC, TCPS and SMES are optimized using an improved version of particle swarm optimization, called crazy-based particle swarm optimization (CRPSO) due to the developed by the author.

In [9] Automatic generation control (AGC) was developed for a two-zone power system using a PSO-based PID controller. Therefore, two control signals are developed by the PSO-based PID controller, which is sent one signal to each zone to improve the frequency response. The error between the desired frequency response and the actual frequency response is calculated by mean square error (MSE)

simulation, and the comparison results show that the automatic generation control of the two-zone power system using a PSO based PID controller helps to obtain the frequency response as expected. value with load change.

In [10] FACTS devices are used in AGC to reduce zone and tie line frequency fluctuations. This paper compares the dynamic characteristics of a thyristor-controlled series capacitor (TCSC) as a damping controller with a thyristor-controlled phase shifter (TCPS) and a static synchronous series compensator (SSSC) as FACTS series damping controller. The improved particle swarm optimization (IPSO) algorithm and the integral time squared performance (ITSE) index are used to design the damping controller.

In [11] a fuzzy PID controller using the Firefly algorithm (FA) is proposed for automatic generation control (AGC) of multi-zone, multi-source power systems. Initially, a two-zone, six-unit power system is used and the gain of the fuzzy PID controller is optimized by FA optimization technique using ITAE criteria. The superiority of the proposed FA-optimized fuzzy PID controller has been demonstrated by comparing the results with some published methods such as Differential Evolution(DE) and optimal control-optimized PID controllers for identical interconnected power systems.

In [12] for AGC PI controller is compared with fuzzy controller. A two-zone system is considered with thermal plants. Different stepwise load changes were considered and the performance of both controllers was observed under different load conditions. The presented simulation results show that the fuzzy controller performs better than the PI controller.

In [13] a new fuzzy controller 1 + proportional + derivative-tilt + integral (F1PD-TI) and applied to automatic production control (AGC) of power systems (PS) with renewable energy sources (RES) is based on solar thermal energy, wind energy and fuel cells. The capabilities of this single controller were first tested on a two-zone reheat thermal energy system and then on a two-zone multi-source hydrothermal energy system. To avoid problems caused by inappropriate controller parameters, the input scaling factors and other parameters of the F1PD-TI controller are meticulously collected using the Salp Swarm Algorithm (SSA) in minimizing the value of the integral squared error (ISE) criterion. The value and contribution of the SSA optimized F1PD-TI controller is revealed by comparing the results with those provided by several newer controllers. Investigations show that the proposed method outperforms serious competitors in terms of shorter settling time, less overshoot/overshoot, and ISE values of frequency and power deviation smaller link lines.

In [14] an energy storage element based on capacitor energy storage (CES) is used to maintain balance of the generation load and suppress power frequency fluctuations. The impact of CES on AGC is also analyzed. Additionally, due to the superior performance of the fuzzy control strategy, the fuzzy PID controller with derivative filter (F-PIDF) has been shown to increase the system stability. The controllers are designed by optimization using a new biologically inspired Selfish Herd Optimization (SHOA) algorithm. The superiority of the recommended controller is demonstrated by comparing the transient response with a PID controller. It is observed that CES devices contribute to ACE mitigation by reducing system frequency and link power deviation.

In [15] it is explained that the DFIG wind turbine can actively participate in regional frequency control in the AGC and improve frequency regulation. The PSO-fuzzy algorithm is also used to optimize the parameters of AGC's fuzzy PI controller. The results show that the controller optimized with the PSO fuzzy algorithm is capable of improving the area frequency deviation, link power variation, stabilization time, frequency amplitude fluctuation, and magnetic field. That improves the stability of the power system.

In [16] FACTS devices have been used in AGC to improve performance such as reducing oscillations of power system transient response in unregulated environments. The response is further improved when using a fuzzy controller instead of an integrated controller with FACTS devices connected to the system.

In [17] a new load frequency control (LFC) method for multi-zone power systems is developed based on the direct-indirect adaptive fuzzy control technique. The LFC for each region is designed based on

the available frequency deviation of each region and the link power deviation between regions. The approximation capabilities of fuzzy logic systems are exploited to develop adaptive control laws and parameter updating algorithms suitable for unknown interconnected LFC regions. The tracking performance criterion H_{∞} is introduced to minimize the approximation error and the influence of external noise. The proposed controller ensures the stability of the entire closed-loop system. Realistic three-zone power system simulation results demonstrate the effectiveness of the proposed LFC and show its superiority over conventional PID controllers and type 2 fuzzy controllers.

In [18] The parameters of the Proportional Integral Derivative (PID) controller of the AGC are determined using the chaos optimization (COA) method. The proposed algorithm has been tested on different connection structures of two thermal generator units, one thermal generator unit and photovoltaic system and a multi-generator system consisting of three generator units: thermal, hydro electricity and gas. Furthermore, to demonstrate the superiority of the proposed algorithm over many algorithms used in the literature, the transient performance of the AGC system was studied. Various transient parameters, such as the stability time of the observed variables, the value of the objective function, and the overshoot, were considered in the analysis.

2.1 Particle Swarm Optimization [9]

Particle Swarm Optimization as a way to fathom computer issues. Particle Swarm Optimization reenacts the social behavior of creepy crawlies, fowls running and creatures grouping where these swarms explore for food in a collaborative way. Each particle in PSO encompasses a position and a speed. The position is upgraded concurring to the encounters of the prior best particle and the global best particle. The following equation 1 & 2 are used for updating of velocity and position of particle.

$$V_i(t + 1) = w * V_i(t) + C_1 * rand1() * (P_{best\ i} - X_i(t)) + C_2 * rand2() * (g_{best} - X_i(t)) \dots \dots \dots \text{Equation 1}$$

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

P_{best} is previous best particle of the i th particle, g_{best} is the global best particle, c_1 and c_2 are two learning factors, w is weight factor, $rand1()$, $rand2()$ are two random numbers independently generated within the range of $[0,1]$. Defined as the population size, NE is the number of function evaluations, and MAX_{NE} is the maximum number of function evaluations. PSO is summarized as below.

```

Begin
  While  $NE < MAX_{NE}$  do
    For each particle  $i$  do
      Update the velocity according to equation (1);
      Update the position according to equation (2);
      Calculate the fitness value;
       $NE++$ ;
    End for
    Update the  $P_{best}$  and  $g_{best}$  in the population;
  End while
End

```

2.2 Fuzzy Logic Controller [19]

A Fuzzy Logic Controller (FLC) could be a control framework based on fuzzy logic—a scientific approach to managing with instability or imprecision. Not at all like conventional control frameworks that depend on exact scientific models, FLCs can handle unclear or vague inputs and yields.

Here's how an FLC ordinarily works:

- a) **Fuzzification:** Inputs from sensors or other sources are changed over into fuzzy sets. Rather than utilizing exact values, these sets speak to degrees of enrollment in etymological terms (e.g., "tall," "medium," "moo").
- b) **Rule Evaluation:** Fuzzy rules, regularly communicated within the frame of "if-then" articulations, are connected to the fuzzy input factors. These rules encode the master information's or heuristics approximately the system's behavior.
- c) **Inference:** The fuzzy rules are combined to decide the fuzzy yield sets. This step totals the impact of diverse rules on the input factors to create a fuzzy yield.
- d) **Defuzzification:** At last, the fuzzy yield sets are changed over back into fresh yield values. Different strategies, such as centroid defuzzification or weighted normal, can be used for this task.

FLCs have been effectively connected in different control applications, particularly in circumstances where exact scientific models are troublesome to get or when the framework flow are nonlinear or questionable. They are especially valuable in spaces such as car control frameworks, mechanical mechanization, and shopper gadgets. In any case, planning an viable FLC frequently requires space ability to characterize suitable fluffy rules and enrollment capacities.

2.3 Adaptive Neuro Fuzzy Inference System(ANFIS) [19]

An Adaptive Neuro Fuzzy Inference System (ANFIS) could be a crossover shrewdly framework that combines the capabilities of Artificial Neural Networks (ANNs) and fuzzy logic. ANFIS was presented by Jang within the early 1990s and has since been broadly utilized in various fields, counting control frameworks, design acknowledgment, and forecast [20].

The most thought behind ANFIS is to use fuzzy logic to speak to human master information within the frame of etymological rules and after that to utilize neural systems to adaptively tune the parameters of these fuzzy rules based on information. This combination permits ANFIS to successfully demonstrate complex frameworks with dubious or uncertain data.

Here's a brief process of how ANFIS works:

- a) **Fuzzification:** The inputs to the ANFIS framework are fuzzified, meaning that fresh numerical values are changed over into fuzzy phonetic items. This step allots enrollment grades to each input variable concurring according to the fuzzy sets characterized for each phonetic item.
- b) **Rule Evaluation:** In this step, the fuzzy rules are connected to the fuzzified inputs. Each run the show comprises of an predecessors (input conditions) and a resulting (yielding activity). The terminating quality of each run the show is calculated based on the degree coordinate between the fuzzified inputs and the forerunners of the run the show.
- c) **Normalization:** The terminating quality obtained from the previous step are averaged to ensure that the final yield from all rules add up to 1.
- d) **Consequent Parameter Adjustment:** The resulting parameters of each rule are balanced based on both the input information and the normalized terminating qualities of the rules. This alteration is regularly performed employing a least squares method or a gradient descent optimization calculation.
- e) **Output Aggregation:** The ensuing parameters from all rules are totaled to get the ultimate yield of the ANFIS framework.
- f) **Defuzzification:** At last, the total yield is DE fuzzified to get a fresh numerical esteem.

ANFIS has the advantage of being able to memorize from information whereas consolidating human skill through fuzzy logic rules. This makes it reasonable for modeling complex frameworks where express numerical models may be troublesome to determine. ANFIS has been effectively connected in

different real-world applications, counting budgetary determining, mechanical handle control, and therapeutic determination.

3 Methodology

3.1 Flowchart of the Project

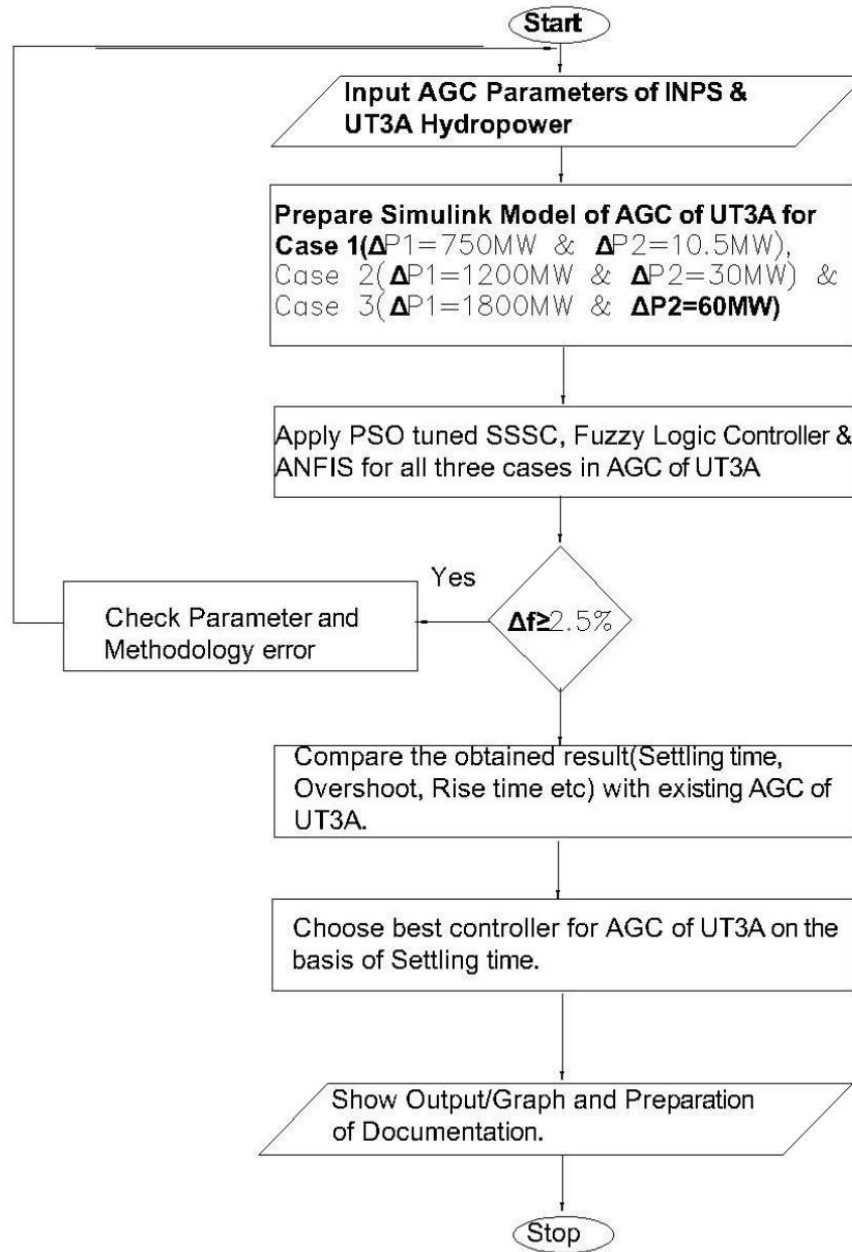


Figure 2: Flowchart of the Project

3.2 Modelling of Hydropower Plant

3.2.1 Modelling of Speed Governor

The fluctuation in speed of hydropower plant is identified by a turbine speed governor which is utilized to control the input of the valve of the turbine. The Governor is modelled as appeared in Figure 3: [6]

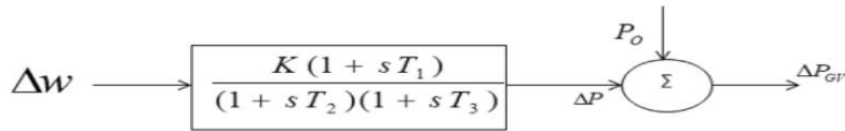


Figure 3:Block diagram of Speed Governor.

3.2.2 Hydro Turbine Modelling

The tangent property of a hydro-turbine is calculated by the dynamics of water flowing through the penstock. The hydro turbine is modelled as appeared in figure 4: [6]

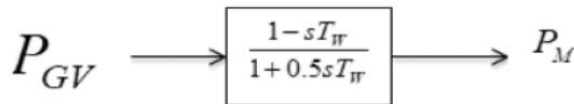


Figure 4:Block diagram of Hydro Turbine

3.2.3 Synchronous Generator Modelling.

A generator in a hydropower plant is utilized to help the water powered control unit to turn the turbine which empowers vitality era. A mechanical torque is connected to extend turns, whereas an electrical drive is utilized to diminish revolution. When an electrical load rises a mechanical torque less than the electrical torque, it causes the whole turn of the framework to begin to diminish. In this manner, it is fundamental to reestablish the mechanical torque to its balance point [1].

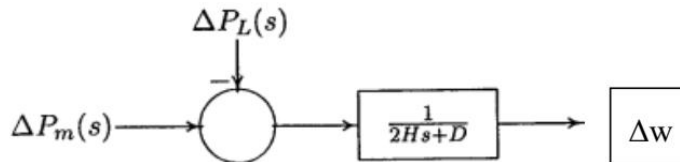


Figure 5:Synchronous Generator Modelling [1]

3.2.4 Modelling of Tie-Line

The equation used to model the tie lines is given by as below:

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

3.2.5 Modelling of SSSC based damping controller

Suitable dynamic modeling and control of the SSSC are basic to support in the tie-line power trade and to soggy the oscillations successfully in Power System. The SSSC based damping controller has been expressed in equation below [21]

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

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

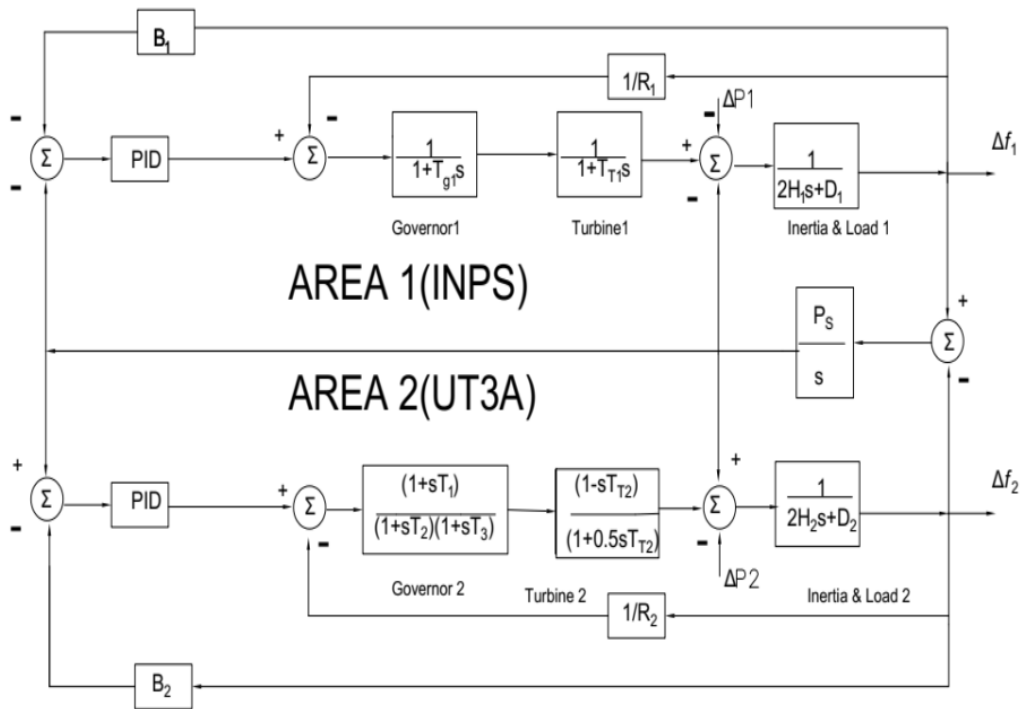


Figure 6:Block diagram for AGC

The various parameters of upper trishuli 3A hydropower plants, are obtained by studying its 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] Since, the current peak demand of INPS is around 1900MW therefore base value is taken as 2000 MVA. The important data required for AGC of hydropower plant is as follows:

Table 1:Parameter for Area 1 and Area 2 [5] [7] [1] [22]

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

Within control framework, the essential targets of AGC i.e., damping the area frequency and tie-line error power oscillations to zero stay unaltered. To realize as much conceivable superior time domain damping characteristics, selecting a fitting standard performance index is basic. The integral of time multiplied squared error (ITSE) performance index is utilized here to minimize efficiently the oscillations [10]. Subsequently, the ideal plan of the proposed controllers is defined as a minimization issue.

$$Min\{ITSE\} = \int_0^{Tsim} t[\Delta f_1^2 + \Delta f_2^2 + (\Delta P_{12}^{error})^2]dt \dots \dots \dots Equation 5$$

Subjected to the following constraints related to the adjustable parameters:

$$0 \leq K_{11}, K_{12}, K_{SSSC}, K_P, K_T, K_I, K_D \leq 5$$

$$0 \leq T_{SSSC}, T_1, T_3 \leq 1$$

$$0 \leq \lambda, \mu \leq 1$$

where Tsim demonstrate the simulation time. In comparison with the integral of squared error (ISE) and integral of absolute error (IAE) performance indices, the integral of time multiplied absolute error (ITAE) and ITSE put a cost on the long-lasting oscillations due to using the time factor and hence effectively helps in diminishing the settling time. A weak-point of the IAE and ISE indices is that they may bring approximately a reaction with a long settling time since they weigh all errors consistently over the time. The ITAE and ITSE indices diminish the oscillations which proceed for a long time than those at starting. Consequently, Hence, the ITAE and ITSE indices diminish the settling time, which cannot be achieved with IAE or ISE based altering. Be that as it may , impediment of the ITAE is that it comes about in reactions with generally expansive oscillations. Owing to the higher control of the error terms, the ITSE index diminish the deviations more than the ITAE index to play down the opportunity of expansive oscillations, successfully. Appropriately, the ITSE index is utilized here as an suitable objective function to diminish the expansive and long-lasting oscillations, viably. To alter the tunable parameters of the considered controllers, the ITSE index is diminished by applying particle swarm optimization (PSO) . The heuristic optimization algorithms are coded as .m file and are connected with the SIMULINK model to discover the optimal set of adjustable parameters by solving the optimization problem, i.e., minimizing the ITSE index.

3.4 System Considered, Tools and Software to be used

Upper Trishuli 3A (UT3A) Hydropower Station, a run of river type hydropower with capacity of 60MW(2 unit, each capacity 30MW) having vertical Francis Turbine is considered as case study For AGC, a two area system is considered, area one considers INPS and area two considers UT3A hydropower plant. To model and design AGC of UT3A hydropower station MATLAB2019/Simulink software is used in a PC having processor Intel(R) Core(TM) i5-7200U CPU @ 2.50GHz 2.70 GHz, 4GB RAM and 256 SSD. The modelled and designed AGC in MATLAB/Simulink is in Appendix of this report.

4 Results and Discussions

For selection of best controller, three cases are considered i) Case I (ΔP₁=750MW & ΔP₂=10.5MW), ii) Case II (ΔP₁=1200MW & ΔP₂=30MW) & iii) Case III (ΔP₁=1800MW & ΔP₂=60 MW). The result obtained from all three cases are explained as follows:

4.1 CASE I ($\Delta P_1=750\text{MW}$ & $\Delta P_2=10.5\text{MW}$)

First of all a condition is created where step input of 750MW is applied in Area 1(INPS) and step input of 10.5MW is applied in Area 2(UT3A).

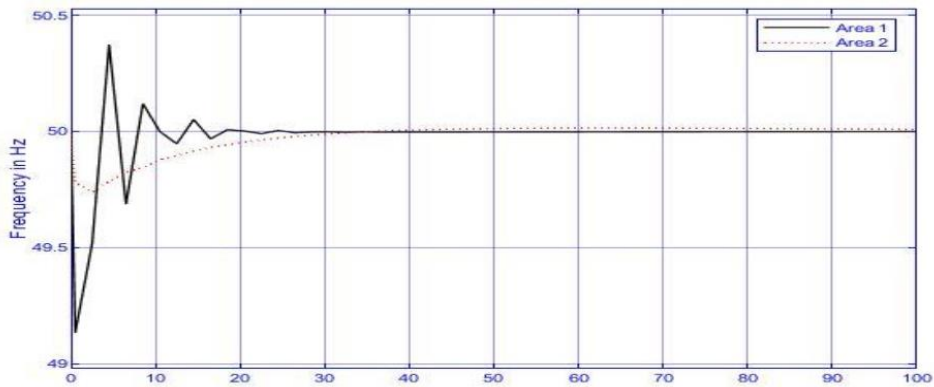


Figure 7: Frequency deviation of system with PID controller

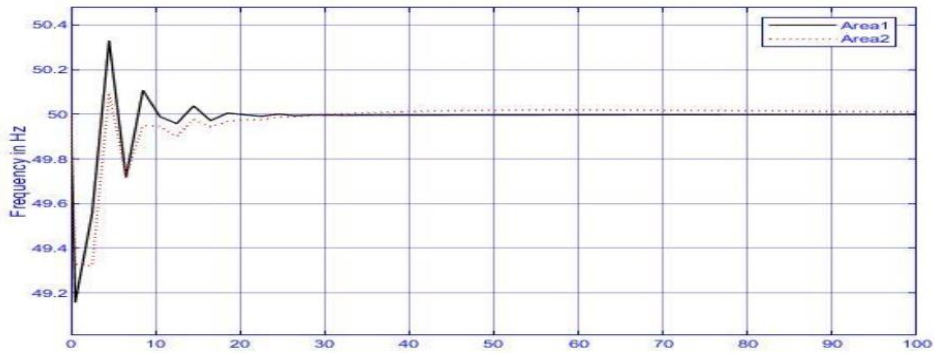


Figure 8: Frequency deviation of system with SSSC

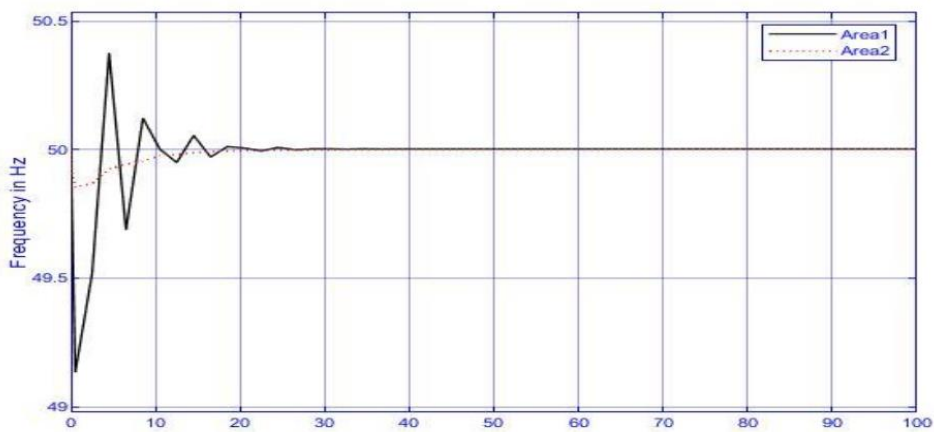


Figure 9: Frequency deviation of system with FLC

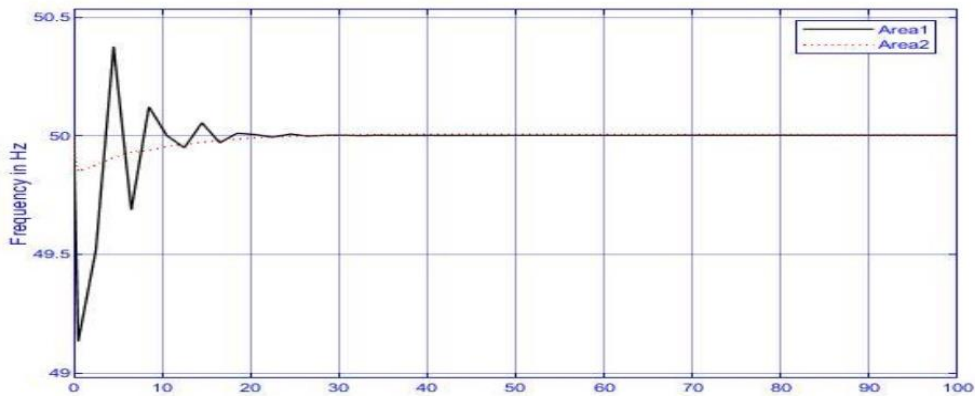


Figure 10: Frequency deviation of system with ANFIS.

The settling time of a system having ANFIS as controller has best settling time i.e 26.4583s than previous all controller settling time.

4.2 CASE II ($\Delta P_1=1200\text{MW}$ & $\Delta P_2=30\text{MW}$)

A condition is created where step input of 1200MW is applied in Area 1(INPS) and step input of 30MW is applied in Area 2(UT3A).

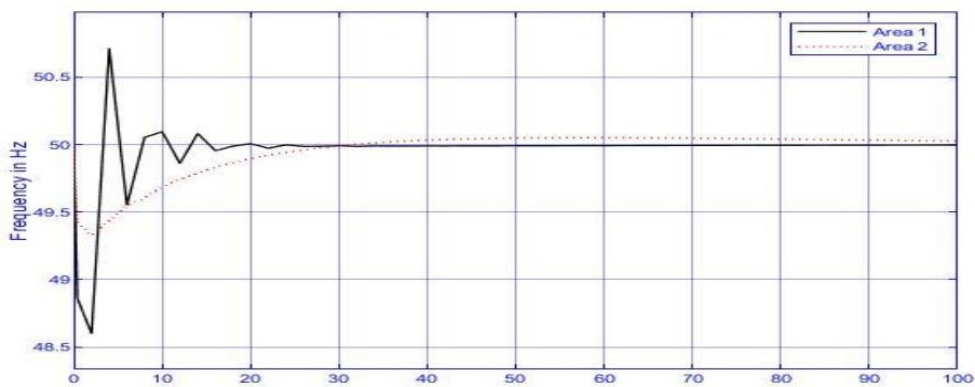


Figure 11: Frequency deviation with PID Controller

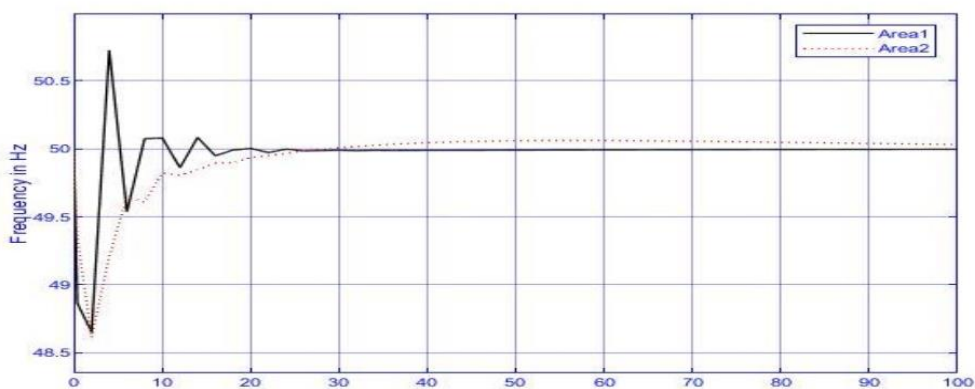


Figure 12: Frequency deviation with SSSC

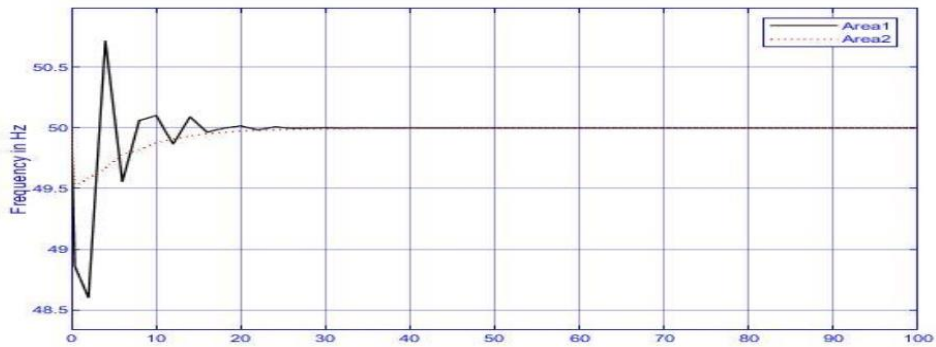


Figure 13: Frequency deviation with FLC

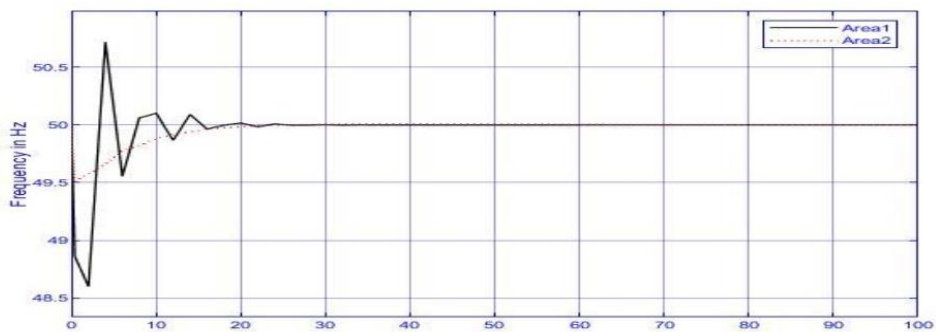


Figure 14: Frequency deviation with ANFIS

The settling time of a system having ANFIS as controller has best settling time i.e 21.6742s than previous all controller settling time.

4.3 CASE III ($\Delta P_1=1800\text{MW}$ & $\Delta P_2=60\text{MW}$)

A condition is created where step input of 1800MW is applied in Area 1(INPS) and step input of 60MW is applied in Area 2(UT3A).

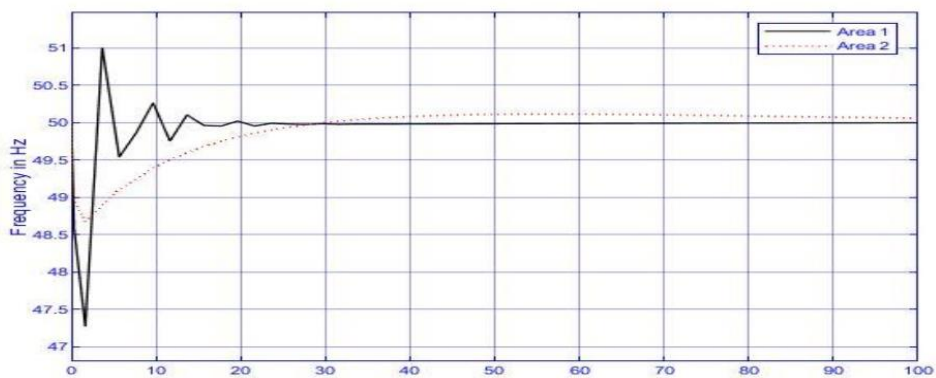


Figure 15: Frequency deviation with PID Controller

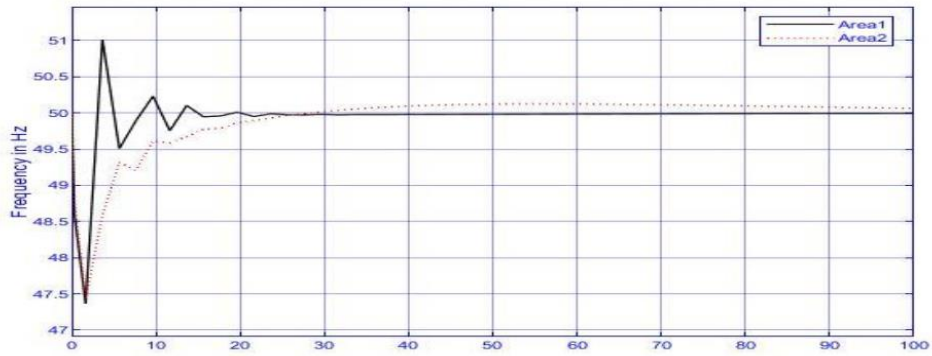


Figure 16: Frequency deviation with SSSC

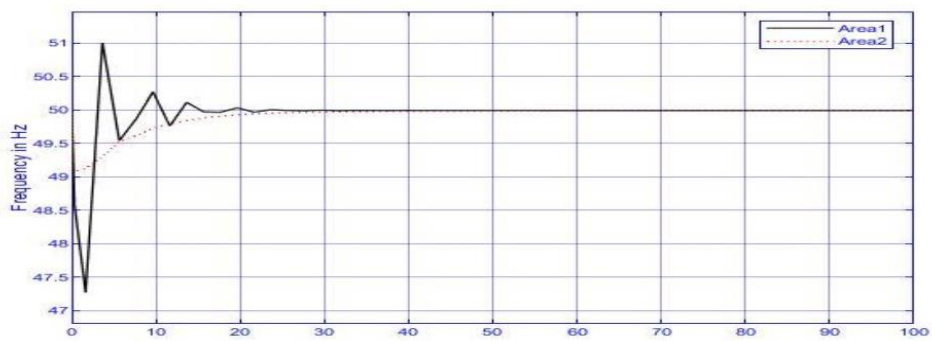


Figure 17: Frequency deviation with FLC

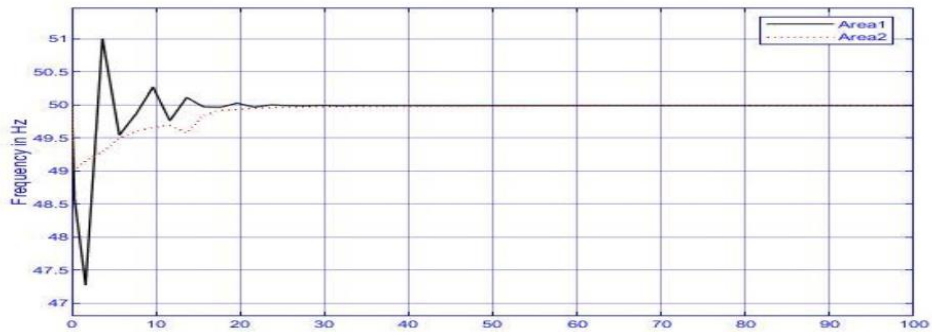


Figure 18: Frequency deviation with ANFIS

The settling time of a system having ANFIS as controller has best settling time i.e 27.6870s than previous all controller settling time.

4.4 Result Comparison

The step response characteristics of all the Cases and controller are compared to evaluate better performance of a controller. The comparison result is as shown in following table..

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

Different Methods	CASE I				CASE II				CASE III			
	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	5.51e ⁻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	1.69e ⁻⁰⁴	-0.01	3.49e ⁻⁰⁵	7.12e ⁻⁰⁵	5.40e ⁻⁰⁴	6.22e ⁻⁰⁴	-0.0097	2.06e ⁻⁰⁵	0.001	0.001	-0.02	-0.02
Settling Max	2.91e ⁻⁰⁴	0.002	3.82e ⁻⁰⁵	1.31e ⁻⁰⁴	0.001	0.001	-3.73e ⁻⁰⁵	1.34e ⁻⁰⁴	0.002	0.003	-1.92e ⁻⁰⁴	2.32e ⁻⁰⁴
Overshoot	72.28	818.4	0	83.67	93.54	95.01	2.59e ⁻⁰⁴	515.03	100.42	98.85	9.55e ⁻⁰³	8.32e ⁺⁰³
Undershoot	3.09e ⁻⁰³	6.5e ⁻⁰³	7.62e ⁻⁰³	4.19e ⁻⁰³	2.48e ⁻⁰³	4.45e ⁻⁰³	0	4.45e ⁻⁰⁴	2.73e ⁻⁰³	4.09e ⁻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

From above table, it is seen that ANFIS controller has lowest settling time, than other controller in all three cases. Therefore, ANFIS controller is recommended for AGC in Upper Trishuli 3A Hydropower Plant.

4.5 Existing output response of Upper Trishuli 3A Hydropower Plant at step input of $\Delta P_1=750$ MW in INPS & $\Delta P_2=10.5$ MW in UT3A

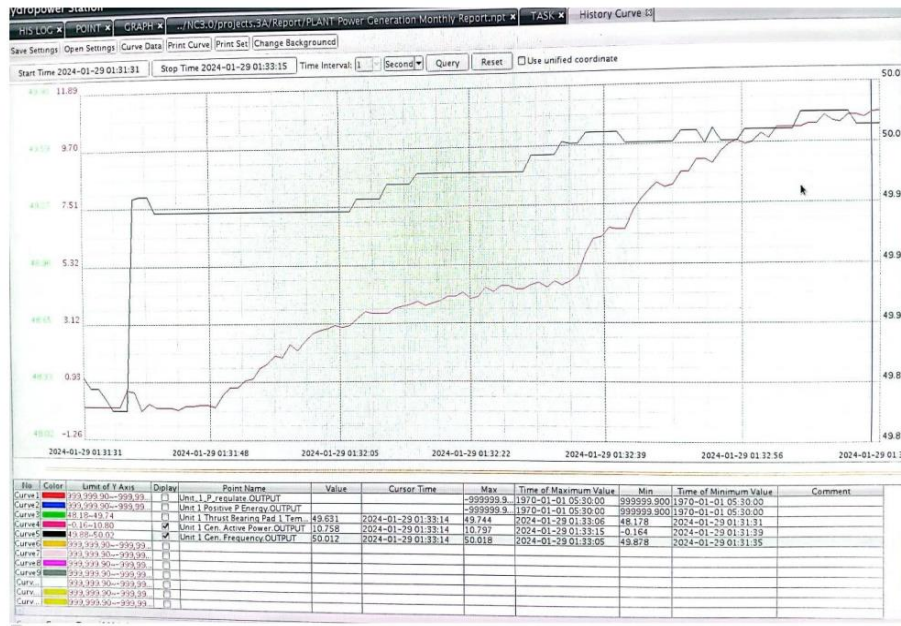


Figure 19: Existing frequency response of UT3A at step input of 10.5MW & system load of 750MW.

The frequency and power curve at step input of $\Delta P_1=750\text{MW}$ and $\Delta P_2=10.5\text{MW}$ is obtained from SCADA of Upper Trishuli 3A Hydropower Plant and is as shown below. The PID parameter of UT3A PID Controller for AGC is calculated according to load and frequency is stabilized.

From above figure, when step input of 10.5MW is applied to generator of Area2(UT3A) at load of the system i.e INPS was around 750MW, it took about 82 sec to settle frequency from 49.86Hz to 50 Hz. The same condition is applied and simulated in MATLAB/SIMULINK, where the settling time obtained was 72 seconds(refer to Table 2,Case I, With PID) which is very close to actual value, which validates model with actual system. Little error in settling time between actual system and Simulink model occurred, may be due to some difference in PID values in Simulink model and actual system. Now we got even better AGC with the use of ANFIS controller. And it is also seen from above result that, with the use of SSSC or FLC or ANFIS gives almost better result than existing system at UT3A HPS for AGC and settling time by using ANFIS controller is lowest among all controller as mentioned in this work.

5 Conclusion

In this work various methods and controllers are applied such as PSO tuned SSSC, FLC & ANFIS controller to the existing system model of UT3A hydropower plant AGC at three different cases(according to load demand) which gives better result than existing result of AGC at UT3A HPS

With the help of SSSC , damping of frequency instability is also improved. Settling time by using ANFIS is smallest among all 26.45sec(Case I) and settling time by using FLC is also less. Therefore, either ANFIS or FLC is recommended in UT3A HPS to obtain better result in AGC to give better performance than existing response.

Thus, this thesis work finds the applicability of the improving AGC of hydropower plant in Nepal which could reduce the power system outage due to frequency instability in an interconnected power system.

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