International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10s
DOI: https://doi.org/10.17762/ijritcc.v11i10s.7635
Article Received: 04 June 2023 Revised: 30 July 2023 Accepted: 12 August 2023

Optimizing the Load Frequency of a Two-Area Interlinked Power System using Artificial Intelligence Techniques

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Abstract—Power costs are increasing on a daily basis, generating changes in system frequency and causing serious concerns with system stability. It has become a major problem to offer customers with uninterrupted and high-quality power. To mitigate these issues, a linked power system's load distribution and network frequency should be constantly reviewed. Load frequency control adjusts the generator's energy output and tie line power between prescribed limits. As well as regulating generator output power, load frequency control also adjusts tie line power. The disturbance in the frequency due to different load changes is regulated using the proposed scheme. In this article, a two-area load frequency control system is constructed and evaluated using various control approaches, including a proportional integral derivative (PID) controller, a proportional integral (PI) controller, a fuzzy logic-based controller, and an Artificial Neural Network (ANN). The goal is to assess the power system's resilience under different loading conditions with these control schemes. The performance of the controllers is compared based on peak-undershoot, peak-overshoot, and settling time, focusing on tie line power and frequency response. To achieve this, the design is implemented using MATLAB/SIMULINK software.

Keywords- LFC, PI controller, PID Controller, Fuzzy logic control, ANN control.

I. INTRODUCTION

The efficient and reliable operation of power systems is crucial for meeting the ever-increasing energy demands and ensuring a seamless supply of electricity to consumers. Among the myriad challenges faced in maintaining power system stability, load frequency control (LFC) plays a pivotal role. Load Frequency Control (LFC) plays a crucial role in maintaining the power system's frequency by continuously adjusting the generated power to meet the real-time load demand. This process becomes even more critical in interconnected power systems that encompass multiple control areas with distinct sets of generators.

This research centers on enhancing load frequency control within a two-area interconnected power system by incorporating state-of-the-art artificial intelligence (AI) methodologies. The two-area configuration represents a typical setup in large-scale power networks where power generation and distribution are managed in separate geographical regions, interconnected through tie-lines.

In the past, load frequency control (LFC) has relied on conventional control methods such as Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers. Nevertheless, due to the increasing complexity of contemporary power systems and the demand for faster and more precise control, researchers have shifted their focus towards employing AI-based approaches.

Fuzzy Logic Control (FLC) and Artificial Neural Network (ANN) Control are artificial intelligence methods that have shown promising capabilities in effectively addressing the nonlinear and dynamic features of power systems. Fuzzy Logic Control mimics human reasoning, allowing it to deal effectively with imprecise and uncertain data, while Artificial Neural

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Networks, inspired by the human brain, excel in pattern recognition and nonlinear mapping.

The primary goal of this study is to create an AI-driven load frequency control (LFC) system that can optimize and enhance load frequency regulation in a two-area interconnected power system. By leveraging the unique capabilities of Fuzzy Logic Control and Artificial Neural Networks, we aim to achieve faster response times, improved accuracy, and enhanced overall performance compared to traditional control methods.

To assess the effectiveness of the proposed approach, extensive simulations and experiments will be conducted on the interconnected power system. Various load scenarios and disturbances will be considered to evaluate the dynamic response and stability of the system. Additionally, a comparative analysis will be performed to identify the AI technique that best suits the requirements of load frequency optimization.

The potential benefits of this research are vast. An optimized load frequency control system can enhance power system stability, minimize power disruptions, and ensure high-quality load supply. With the continuous growth in electricity demand, the incorporation of AI techniques into load frequency control becomes increasingly indispensable to ensure the sustainable and dependable operation of interconnected power networks.

In the upcoming sections, we will explore the theoretical foundations of load frequency control, the fundamental concepts behind Fuzzy Logic Control and Artificial Neural Network. We will then proceed with detailing the design and execution of the AI-based LFC system for the two-area interconnected power system. By presenting the results and analysis of the experiments, we aim to demonstrate the effectiveness of our proposed approach and its capacity to revolutionize load frequency optimization in contemporary power systems.

II. LITERATURE REVIEW

Alhelou, H. H., et al. demonstrated the condition in power system load frequency regulation. He investigated the frequency range and mathematical models of diverse power systems, as well as control design methodologies like soft computing control, optimum control theory and robust control [1]. Rahim, S.A. et al. designed an LFC controller and described how there will be a frequency drop by using a conventional integral whose dynamic response shows oscillation undershoot. As a result of the use of the LFC controller, the steady state is reached quickly, and oscillations are reduced [2]. Tur, M. R., et al. used advanced ways to adjust load frequency rather than the governor control system to do so. To regulate the system, he employed PID and Fuzzy Logic. The outcomes of these systems were tested with different cases in two area linked systems, and a performance comparison of the above two controllers was produced [3]. Kouba, N. E. Y., and colleagues introduced a two-area power system utilizing High-Voltage Direct Current (HVDC) technology along with a fuzzy PID controller. They employed the Multi-Verse Optimizer, a meta-heuristic algorithm, to devise the control strategy (MVO). Consequently, the total parameters of the test system were successfully estimated [4]. Additionally, Prasad, P. V. R., and his team observed that the Fuzzy PID controller exhibited superior dynamic performance compared to traditional PID, conventional PI, and Fuzzy PI controllers. An efficient and practical way for adjusting load frequency with fast frequency responses, he found, is the fuzzy logic controller [5]. Sambariya, D. K., et al. applied fuzzy logic control evaluation to a standalone power system and an integrated power system to control load frequency. Fuzzy logic controllers have been reported to demonstrate greater effectiveness compared to PID controllers [6].

Usman, A., et al. conducted a study on automatic generation control in both single and two-area power systems. They discussed the advantages of interconnected systems over single and two-area electric power systems. He stated that tie lines quickly dampen frequency oscillations in interconnected systems [7]. Zenk, H., et al. studied two distinct zones for LFC of a power system constructed using a FLC and investigated how the system frequency is impacted by varied load changes FLC and integral controllers are used in this case, and the results of these controllers are compared [8]. The author said that the FGPI fuzzy gain PI controller produces superior dynamic responses as the load varies [9]. Because big, complex, and interconnected power systems have a high number of nonlinear characteristics, for these kinds of systems, fuzzy logic controllers are one of the best controllers. The fuzzy logic controller is employed in this article to manage the system's load frequency [10]-[13].

AI-based controller developed to dynamically analyze load frequency control in a three-zone interconnected hydrothermal power generation system [14]-[20]. A. K. Maurya et al. focused on a two-area power system employing PI, PID, and Integrator controllers [21]. Fuzzy logic gain arranging for LFC was researched in linked power systems. The comparisons between the PI and fuzzy gain scheduling controller are discussed [22]-[28]. Their approach integrates advanced control techniques, including PI, PID, and Fuzzy logic controllers, to regulate power generation in the three distinct areas of the interconnected system [29]-[35].

III. MATHEMATICAL MODELLING OF LOAD FREQUENCY CONTROL

Renewable energy can be converted into electric energy by using a power system. Electric power quality must be ensured in order for electrical equipment to operate optimally. Three-phase

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alternating current (AC) is well-known as a power transportation method. Either the active and reactive power balance is needed throughout transit. This will happen if either frequency or voltage is changed. The voltage and frequency of an electrical system should be set at the appropriate values, regardless of the random changes in load. Uncontrolled variations in voltage and frequency levels make it hard to sustain both active and reactive power. Because of load variations, a control system is necessary to keep frequency and voltage ranges. Despite the fact that active and reactive powers have such a cumulative impact on voltage and frequency, the voltage and frequency control problems can be divided.

Maintaining power systems within acceptable amplitude and current limits is essential to ensure their proper functioning and adaptability to demand changes and system disruptions. The interdependence of frequency on active power and voltage on reactive power leads to two distinct challenges in power system management. These challenges are commonly referred to as load frequency control (LFC), as they involve regulating both frequency and voltage in the power system.

When operating in India, 50 Hertz or 240 Volts are the standard. Due to changes in load requirements, system parameter variations, modelling errors, and ecological disturbances, the frequency deviates from its standard value. In this way, load frequency control (LFC) reduced frequency deviation errors, thereby eliminating load disturbance and thereby maintaining the stability of the electric grid.

A.Speed Governing System

Generator Mathematical Modeling:

By employing the swing equation of a synchronous machine for small perturbations, we obtain the following

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

Alternatively, in terms of a slight change in speed

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

Laplace transforms gives,

$$\Delta\Omega(s) = \frac{1}{2H_s}(\Delta P_m(s) - \Delta P_e(s))$$

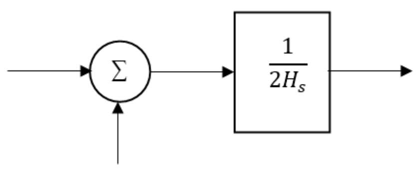

Figure.1 Block diagram for a generator mathematical modelling

Load Mathematical Modelling:

In a power system, electrical drives are used to generate electricity. The load's load speed characteristics are given by:

$$\Delta P_e = \Delta P_L + D\Delta\omega$$

In the context of the equation, DΔω represents the frequency-sensitive load change, ΔPL signifies the non-frequency-dependent load variation, and D is the ratio of the percentage change in load to the percentage change in frequency.

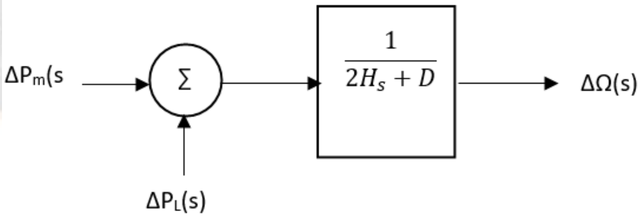

Figure.2 Block diagram of Load Mathematical modelling

Prime Mover Mathematical Modelling:

The origin of electricity lies in the prime mover, which can be various energy sources, including hydraulic turbines located near steam turbines or waterfalls, or the burning of gas, coal, and other fuels to generate power. The turbine model couples changes in mechanically power production ΔPm to variations in steam valve position ΔPV.

$$G_T = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau S}$$

0.2 - 2.0 sec is the range in which the turbine constant exists.

Governor Mathematical Modelling:

As the electrical load increases rapidly, it surpasses the mechanical power supply. The kinetic energy of the windmill compensates for the power deficit on the load side. To make up for this speed difference, the governor sends the signal to feed more water, steam or gas into the machine.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f$$

In S – domain

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta f(s)$$

$$\Delta P_V = \frac{1}{1+\tau g} - \Delta P_g(s)$$

To create a single isolated area system, we combine the previous block diagrams:

$$\frac{\Delta\Omega(s)}{-\Delta P_L} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2H_s + D)(1+\tau_g s)(1+\tau_T s) + {}^{1}/_{R}}$$

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Above equation represents the change is frequency due to change in load. Negative sign indicates as the load increases frequency decreases.

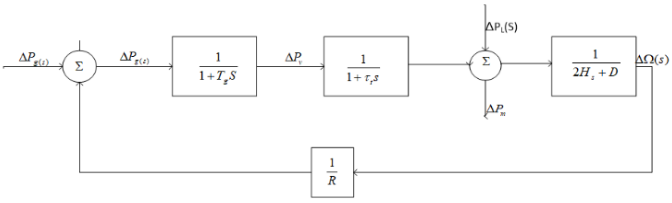

Figure.3 Complete block diagram of a single area power system

***Plant Description*:**

Typically, power systems are vast experience with complicated dynamic behavior. They can, however, be linearized all around operating conditions for relatively small load disturbances.

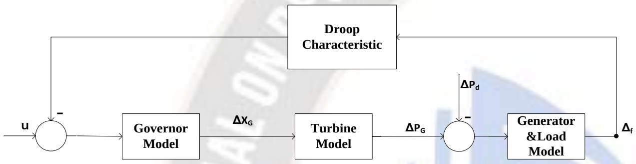

Figure.4 Single area power system

The dynamics of these subsystems are

$$G_g(s) = (T_G S + 1)^{-1}$$

$$G_t(s) = (T_T S + 1)^{-1}$$

$$G_p(s) = K_p(T_p S + 1)^{-1}$$

$$G(s) = \frac{G_g(s)G_t(s)G_p(S)}{1 + \frac{G_g(s)G_t(s)G_p(S)}{R}}$$

$$= \frac{K_p}{T_P T_T T_G s^3 + (T_P T_T + T_T T_G + T_P T_G)s^2 + (T_P + T_T + T_G)s + (1 + \frac{K_p}{R})}$$

$$\Delta f(s) = G(s)u(s) + G_d(s)\Delta P_d(s)$$

The above equation clearly shows that LFC is essentially a disturbance rejection (regulator) problem with the goal of evaluating the control rule.

$$u(s) = -k(s)\Delta f(s)$$

Mathematical Modeling:

Table 1: Model Parameters

Frequency	60Hz
Base Power	1000MVA
Change in Load	187.5 MW
Synchronizing power coefficient P_s	2 pu

Parameters	Area-1	Area-2
Inertia Constant (H)	5	4
Governor Time Constant (T_g)	0.2	0.3
Speed regulation (R)	0.05	0.0625
Turbine Time Constant (T_t)	0.5	0.6
Frequency Sensitive Load Coefficient (D)	0.6	0.9

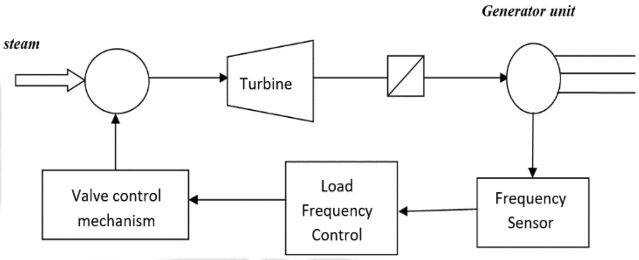

Figure.5 A synchronous generator's LFC schematic design

IV. RESULTS AND DISCUSSIONS

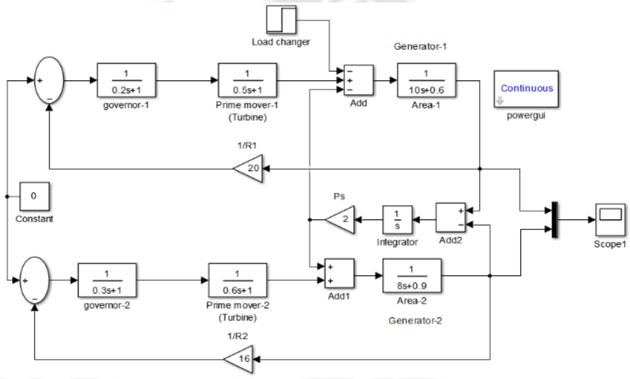

Figure.6 Two-area system without any controller

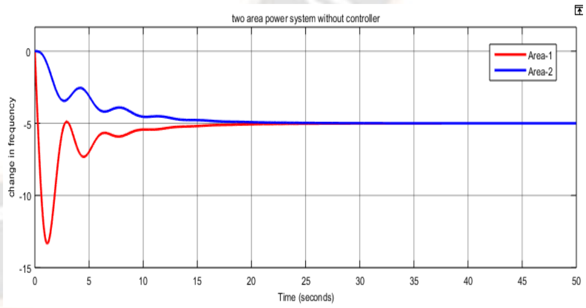

Figure.7 Simulation result of two area system without controller

Because there is no controller in the two area power systems, it does not achieve its steady state position (Δf=0) following a load variation in area-1.

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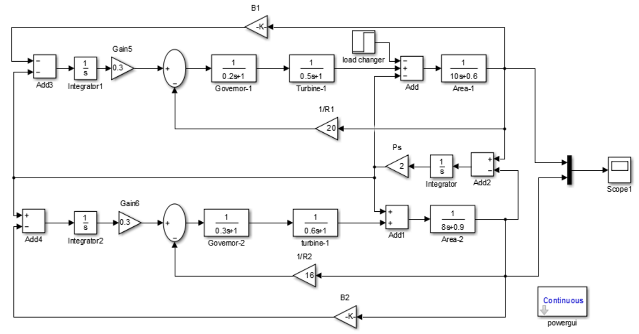

Figure. 8 Two area system with PI controller

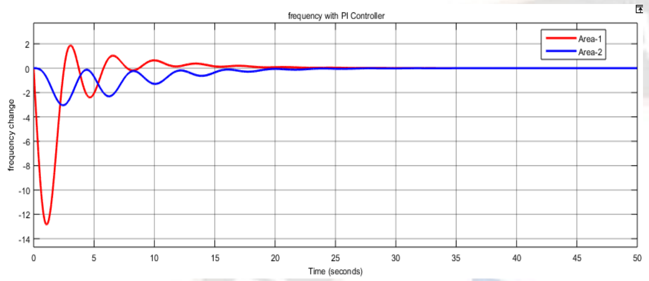

Figure. 9Simulation result of two area system with PI controller

Since the two-area electrical system uses a PI controller, the frequency shifts to f=0, showing that the system has attained steady state, regardless of the load fluctuates (at area-1). The settling time is Ts=27 seconds. Even if it has reached a stable condition, the oscillations are too large and need to be reduced.

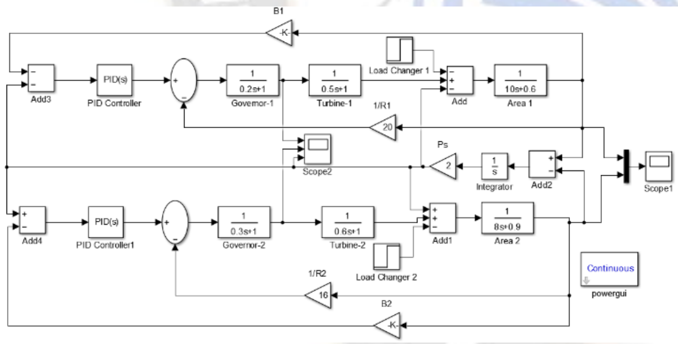

Figure. 10 Two area system with PID controller

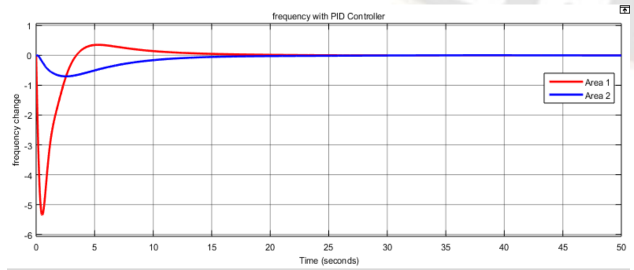

Figure. 11 Simulation result of two area system with PID controller

This is due to the fact that a PID controller is being used to regulate power system frequency and its steady state position ($\Delta f=0$) following a load shift. Load change is only provided in area-1 of this system. In this case, we can also see that steady state is attained faster than with the PI controller, and peak overshoots and peak undershoots are minimised. Ts=22Sec is the settling time.

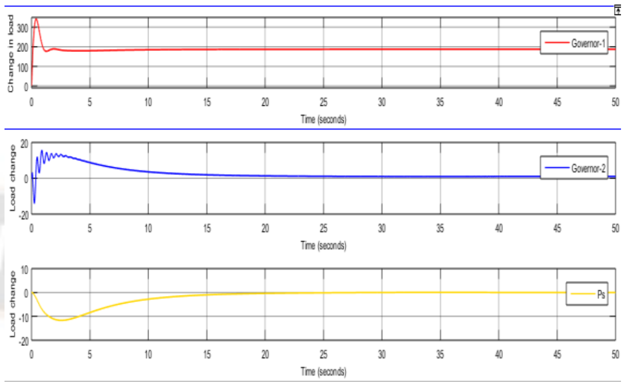

Figure. 12 Simulation result of change in load at Governor–1, Governor–2 and Tie line power

A. Fuzzy Logic Controller

Fuzzy control systems rely heavily on empirical principles and are becoming increasingly useful in a variety of applications. Adding additional rules to a fuzzy system is a simple way to extend its functionality. By adding a layer of thought to the standard control procedure, fuzzy control can improve upon traditional control systems. The Fuzzy Inference System Editor is at the heart of the Fuzzy logic controller and is used extensively throughout the planning and modeling of a soft switching circuit. In this editor, VCr and ICr are the linguistic variables that determine the system's behavior and serve as inputs to the fuzzy controller. The Fuzzy logic controller provides precise control by assessing the variables in question and their interrelationships and then outputting a sharp value. A number of different editors, such as the Membership Function Editor, FIS Editor, Rule Viewer, Surface Viewer and Rule Editor, are part of this graphical user interface.

Fuzzy Inference Diagram

The fuzzy-inference framework is the result of combining many simpler diagrams from earlier discussions of this topic. It also serves as an example of every facet of the fuzzy initiation procedure that we've discussed so far. Information is transmitted via the nebulous, hypothetical contour. Fuzzy inferring is the process of using fuzzy logic to construct a connection from a given input to an output. At that point, the mapping serves as a basis for making decisions and identifying designs. The fuzzy induction method encompasses all of the elements discussed previously: enrollment capacity, fuzzy logic administrators, and, if applicable, regulations.

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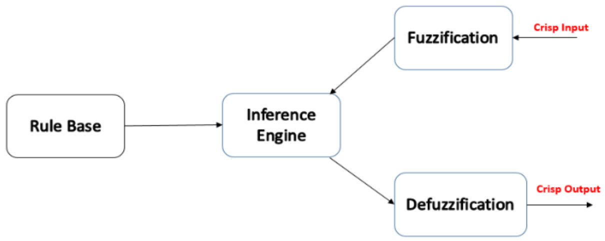

Figure. 13 Fuzzy Inference System

Table 2: Three Variable Rule Base

Δe \ e	MF1	MF2	MF3
MF1	MF1	MF1	MF2
MF2	MF1	MF2	MF3
MF3	MF2	MF3	MF3

Furthermore, defuzzification is done, which is the process of converting inferred proposed fuzzy actions into crisp control methods. The Centre of area technique is used in this case.

Fuzzy defuzzification frameworks have found successful application in a wide range of domains, including but not limited to programmed control, information grouping and computer vision. Fuzzy deduction frameworks are known by a variety of names due to their interdisciplinary character.

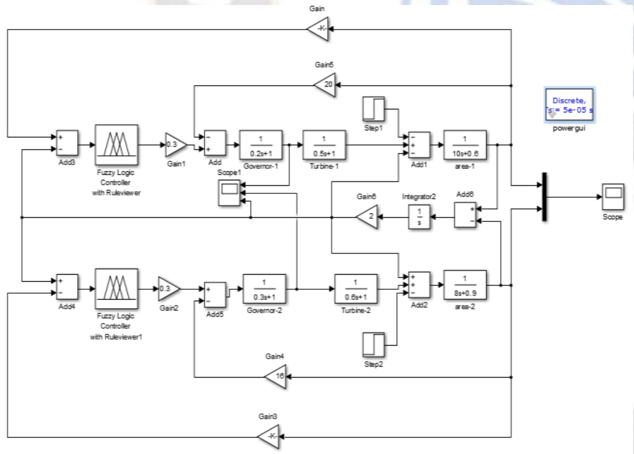

Figure. 14 Two area system with Fuzzy logic controller

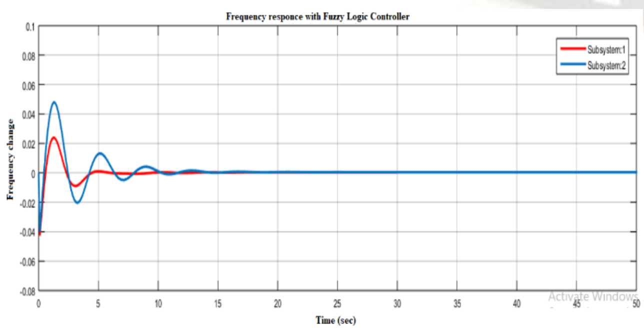

Figure. 15 Simulation result of two area system with Fuzzy logic controller

In this case, we can also see that steady state is attained faster than with the PI controller, and peak overshoots and peak undershoots are minimised. Ts=18 Sec is the settling time.

B. Artificial Neural Network

The human brain serves as the foundation for biological neural networks, and the term "Artificial Neural Network" draws inspiration from this natural structure. Similar to the human brain, Artificial Neural Networks consist of interconnected neurons organized into different layers within the network. These interconnected neurons are referred to as nodes.

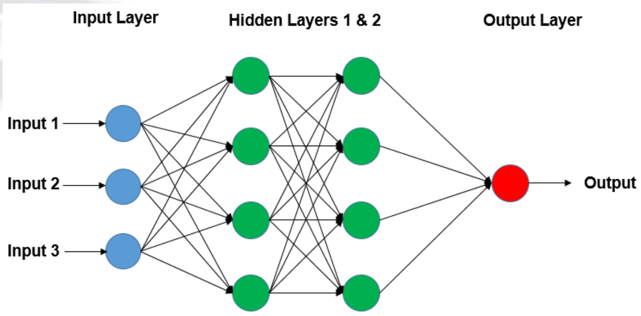

Figure. 16 Artificial Neural Network

In the context of Artificial Neural Networks, inputs are represented by dendrites, nodes are analogous to cell nuclei, weights are depicted as synapses, and outputs are akin to axons in biological neural networks.

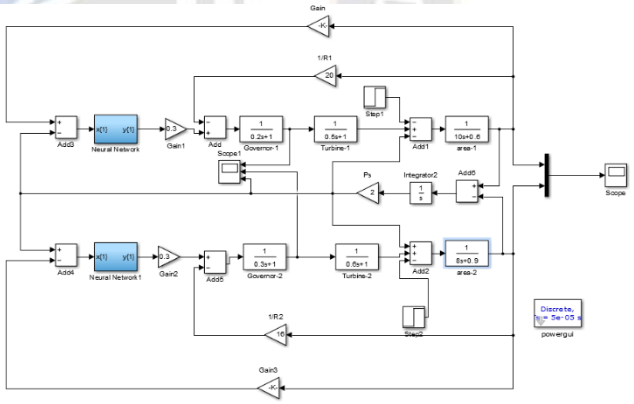

Figure. 17 Two area system with Artificial Neural Network

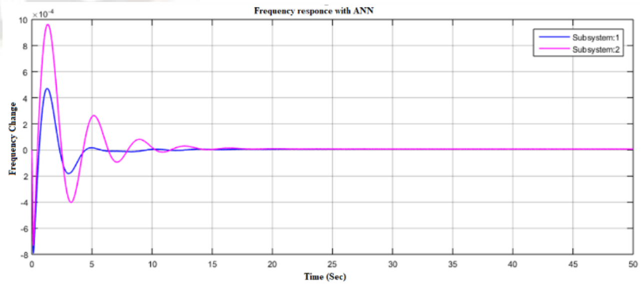

Figure. 18 Simulation result of two area system with Artificial Neural Network

In this case, we can also see that steady state is attained faster than with the PI controller, and peak overshoots and peak undershoots are minimized. Ts=18Sec is the settling time.

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Table3: Comparison between the controllers

S.No		Without Controller	PI Controller	PID Controller		Fuzzy Logic Controller	ANN Controller
				Load at area-1	Load at area-1 & area-2		
1	Settling Time	Not settled	27 sec	22 sec	22 sec	18 sec	18 sec
2	Peak Overshoot	_-	12 Hz	0.3 Hz	-	0.04 Hz	0.0095 Hz
3	Peak Undershoot	-13 Hz	-13 Hz	-5.2 Hz	-3.5 Hz	-0.04 Hz	-0.0008 Hz

V. CONCLUSIONS

When compared to standard PID, PI and Fuzzy controller in power systems, which give zero steady-state frequency variation with step load escalation but have low performance characteristics, Artificial Neural Networks offer better dynamic performance and to reduce frequency deviation oscillation. In the presence of parameter fluctuation and non-linearity, additional oscillations and setup time are required. As a result, the attempt made here was effective. The findings provided above demonstrate that the proposed method provides a superior dynamic response compared to the conventional PI, PID, and Fuzzy controllers. When compared to conventional controllers like the proportional-integral-derivative (PID) and fuzzy controllers, the dynamic response provided by an artificial neural network is far superior. As a consequence of the foregoing findings, we can infer that using an Artificial Neural Networks (ANNs) are a cost-effective and efficient method of managing load frequency with enhanced dynamic responsiveness. Peak overshoot and oscillation numbers are used to demonstrate that the Artificial Neural Network's output is superior to that of conventional and fuzzy controllers. A three- or four-area power system may make good use of the aforementioned control approach.

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International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10s
DOI: https://doi.org/10.17762/ijritcc.v11i10s.7635
***Article Received:** 04 June 2023 **Revised:** 30 July 2023 **Accepted:** 12 August 2023*

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