Load Frequency Control Analysis of PV System Using PID and ANFC Controller

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Abstract— **This paper deals with the Adaptive neuro-fuzzy inference system (ANFIS)–based load frequency controller (LFC). These controllers are projected for load frequency control of thermal-Photovoltaic (PV) power generation entity as a hybrid power system. In this study, random solar isolation is applied to the proposed hybrid power system. The proposed hybrid power system consists of a PV power unit with a maximum power point tracking control, a PV inverter, and an AC load. Simulations are performed with structural change in the load setting. The solar isolation results are compared with conventional proportional- integral-derivative (PID) and fuzzy logic controller (FLC). The results are then projected with an ANFIS based LFC. The simulation results observed that ANFIS attains a relatively better response for the frequency deviation profile. It typically controls the frequency deviation of a given hybrid power system and thereby advances the dynamic performances. The results also show that the performance of the hybrid power system with the use of ANFIS based neuro-fuzzy controllers attains relatively better than those which attains by the PID and FLC.**

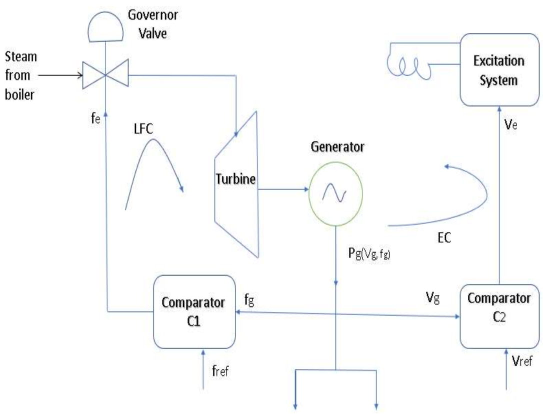
Keywords— Load Frequency Controller, Adaptive-Network- Based fuzzy inference system. Hybrid Power System, Simulation

I. INTRODUCTION

This paper deals with the LFC problem for the hybrid power system of photovoltaic with the integration of the thermal power system. There are two parameters in the power system that constantly need to monitor or control. These are voltage and frequency. The generator will generate power at some voltage and frequency. So, it is very much important to control the voltage and frequency because of the mismatch between active power generation and demand and reactive power generation and demand [1]. The main goal of power system control is to generate and deliver electricity in an economic and reliable as convincible way. This helps in preserving the power system quality such as frequency and voltage within a permissible limit [2]. Whenever the active power generated is not equal to active power consumed then the frequency of the power system needs to be controlled. However, when the reactive power generated is not equal to the reactive power consumed then the voltage of the power system needs to be controlled. So, a real-time power system is a very dynamic power system that means the active power generation failure remains constant but demands keep on varying. This is because the system never knows who is going to switch off/on the load [3]. The system can't compromise the load because it will not tell the consumer to shut down the load. Therefore, the power system needs to disturb the generation spectrum. The control of voltage or frequency can be done in two ways: a) primary control mechanism, b) secondary control mechanism [4]. Automatic generator control is present in the primary control mechanism that means voltage and frequency control can be performed only at the generator side. This helps to match the demand by varying the generation but under emergency conditions when it is not possible to control the generator then it must be controlled only at the load side. This situation leads to load shedding or load management. So, it needs to cut off the load or increase the load depending on the situation. This type of management is called load side management or secondary control mechanism. In short, it can be included that if the control mechanism is done at the generation side, then it is called primary control and if it is done at the load side then it is called a secondary control [5]. The automatic generation control (AGC) is equal to load frequency control and excitation control (EC) [6]. i.e. AGC = LFC + EC. The LFC is that control mechanism that will control the varying frequency. On the other side, the EC will control the voltage of the generator. Basically, by controlling the excitation we are going to control the reactive power generation in the system. This means that the voltage in the power system will automatically be controlled. In the LFC, the active power generation of the power system is being controlled and thus the frequency will be controlled through it [7]. The diagram shown below is the block diagram of general automatic generation control (AGC). The generator is present at the center of this diagram. This is generating active power (Pg), voltage (Vg), and having the frequency (fg). This generator is getting input power from the turbine and the turbine is getting input power from a boiler. The governor valve is placed between the boiler and the turbine to control the flow of steam input to the turbine. So, based on the load requirement this can be adjusted to meet the load requirements [8]. When the active power is been delivered to the bus, the comparator(C1) receives the frequency. This frequency from the outgoing of the generator will be sensitive. The frequency fg will be compared with the reference frequency(fref) and then the comparator will send the difference of fg and fref i.e., error signal fe to the governor valve. Here, the fref is the frequency that needs to be maintained in the system. One of the main characteristics of LFC and EC is that the time of response is faster. This means that controlling voltage in a power system is much easier as compared to controlling the load frequency. This is because load frequency control involves the governor wall, turbine steam from boilers [9]. This means that it contains mechanical parts and because of it automatically the weight or inertia of the mass of these components are high. This increases the time constant and hence the response increases. However, in the excitation control, there are some electronic circuits. The time constant of the electric circuit is always less than the mechanical circuit. Therefore, the response of EC is faster than LFC [10]. There are three conditions for valve: -

i. If, fg = fref, the governor valve opening will be constant.
ii. If, fg > fref, fe> 0, governor valve remains closed until the error becomes zero.
iii. If, fg < fref, fe <0, the governor valve remains open until the error becomes zero.

In this way, the LFC is functioning, and this governor valve mechanism is known as the flyball mechanism.



. Figure 1. Block diagram of the automatic generation control.

The power system (HPS) that consists of two or more modes of electricity generation together is known as a hybrid power system. This system is usually using renewable technologies like solar photovoltaic and wind turbine. This system provides a high level of energy security through a mix of generation methods. It will incorporate a storage system, (i.e., Battery, fuel cells) or a small fossil fueled generator. This is to ensure maximum supply reliability and security [11]. The HPS that delivers alternating current with fixed frequency is an emerging technology for supplying electric power in remote areas. It helps in minimizing the power loss in the system. The steam engine driven turbine and a battery are combined to compensate the effects of time varying power consumption and solar energy input in power generation. The load frequency control is used to maintain a real power balance in the system. It can be done by controlling the system frequency. If the real power demand changes, then the frequency changes occur as well. This amplifies, mix and changes to the command signal. This signal is then sent to turbine governor.

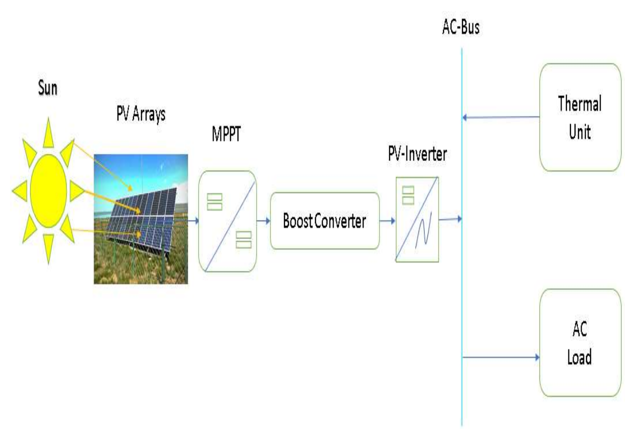
The small changes in real power are mainly dependent on changes in rotor angle. This will change the frequency. The generator excitation depends on the reactive power. The momentary change in generator speed is due to the rotor angle. It means that load frequency and excitation voltage controls are non-convertible for small changes. The cross-coupling between the load-frequency loop and the automatic voltage regulator is very small. Therefore, the load frequency and excitation voltage control should be analyzed separately.

In general, the detailed model of PV includes maximum power point tracking (MPPT), voltage source inverter, boost converter. This helps in getting the available power at the AC bus for the subsequent controller design. The controller design simply relies on the system model in the form of a matrix. This is not feasible with a detailed model of PV. The proposed load frequency controller is designed based on artificial intelligence methods. In this context, ANFIS is designed for LFC. In power systems, PV is the most extensively employed and fastest-growing renewable technology, nowadays. The PV power generation is sporadic and has variable and unpredictable characteristics [12]. Therefore, the power generation through PV is quite hard to manage completely. Its availability is also depending on sunny patterns [13].

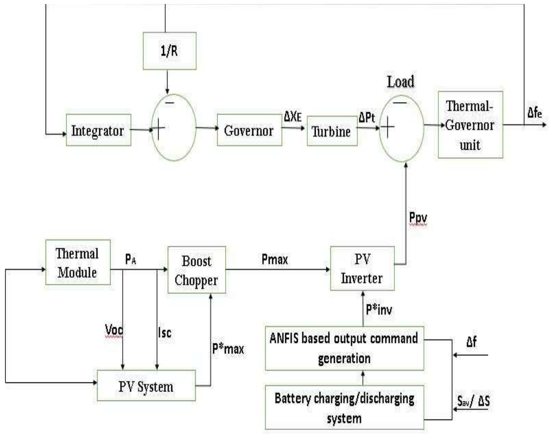
The paper is described into six topics. Part 1 deals with the introduction of the frequency control system. It describes the automatic generation control and the effects of load frequency control on it. Section 2 provides the system description and the model of the thermal PV hybrid power system. It also shows the block model of the thermal photovoltaic system. Section 3 describes the basic ANFIS controller design and ANFIS model. It deals with basic fuzzy logic and a short description of it. Section 4 deals with the fuzzy logic controllers and the rules which are used to find the results. It also shows the different views of fuzzy rules that help to understand the changes. The fuzzy rules are analyzed using MATLAB software. It shows the difference between the PID and ANFC controller design using the different fuzzy rules. Section 5 shows the result obtained from the PID controller and ANFC controller. The ANFC controller to obtain the comparative is designed in MATLAB. The analysis shows that the ANFC controller performance is better than the PID controller. Finally, section 6 concludes the paper by saying that the Solar isolations with the experimented ANFIS based LFC are done, and the result obtained from it shows that ANFC has better results as compared to PID. This helps to controls the frequency deviation of the proposed HPS.

II. SYSTEM DESCRIPTION

The proposed HPS consists of a thermal power unit, AC load, PV inverter, and a PV power unit with an MPPT control. Figure 2(a) shown below represents the block diagram of the proposed HPS. The efficiency of PV panel depends on the temperature of panel [14].



(a) Block model of Thermal -PV



(b) Model of Thermal -PV as a hybrid power system

Figure 2. Projected hybrid power system

Figure 2(b) explains the details of the proposed thermal-PV hybrid power system used for simulation purposes. The thermal module consists of PV array and MPPT. The solar isolation enters the PV arrays and MPPT. The output of PV array enters the MPPT. The output of PV array and MPPT are further connected to the boost chopper.

The transfer function of the governor, turbine, and the thermal governor is given by KG/1+ sTg, 1/1+ sTt, Kp/1+ sTp, respectively. The transient response of nonlinear system can be modeled by the Duffing equation. This is subjected to the nearest resonant harmonic excitation. When the system is undergoing free motion and a sudden harmonic excitation happens with a near resonant frequency causes the overshoot problem. This leads to a transient response during the transition to steady state. The peak value of this response depends on system parameters, input parameters, and initial conditions. The nonlinear overshoot problem is well-known averaged equations. It describes the strictly varying phase and amplitude for transient and steady state responses. For the undamped system, the problem can be reduced to a single parameter. It combines the strength of nonlinearity, frequency detuning, and force amplitude. For zero damping, the overshoot approximation is given by a root of a quartic equation. It depends on amplitude and overshoot of damped systems. Thus, the transfer function of governor, turbine, and excitation system can be substantiating the use of this linear model for this complex system.

The governor and turbine combined represent the thermal unit of the system. Following notations are used in the paper: -

S_i: - Solar insulation

I_{sc}: - Short-circuit current

V_{oc}: - Open-Circuit Voltage

P^{*max}: - Command power of MPPT

P_{max}: - Output power of MPPT

P^{*inv}: - Command power of the inverter

P_{pv}: - Inverter output power

P_{TH}: - Generated thermal power.

R: - Drop Characteristics

K_i: - Integral control gain

T_g: - Governor time-constant

T_t: - Turbine time-constant

K_p: - System gain

T_p: - System time-constant of the thermal-governor unit

P_L: - AC load

Δf: - Deviation in frequency

Psys: -Output power of thermal-PV

HPS: - Hybrid Power System

III. ANFIS CONTROLLER DESIGN

A. Simple Fuzzy Logic Model

The fuzzy logic was introduced in 1965 by Lotfi Zadeh. It is a generalization of standard logic. In this, a concept can possess a degree of truth anywhere between 0.0 to 1.0. Standard logic applies only to concepts that are either completely true or false. On the other hand, fuzzy logic applies concepts for reasoning about inherently vague concepts. The application of fuzzy logic has become an advantageous approach to solving various problems related to the power system. Therefore, it is gaining remarkable momentum in this area. The common rule of “if-then” is adopted and the fuzzy set is made through the membership function. The basic structures of fuzzy logic comprise three blocks, namely, fuzzification, knowledge base, and defuzzification, as shown in figure 3. Fuzzification is the process that converts a crisp value into a fuzzy value. This fuzzy value then performed actions based on the rules provided in the knowledge base. Defuzzification is the process that converts the fuzzy rule into a crisp value as the real world only accepts the crisp output. The rules are made to govern the fuzzy controller actions. There are many methods used for fuzzification and defuzzification which are used depending on the problems.

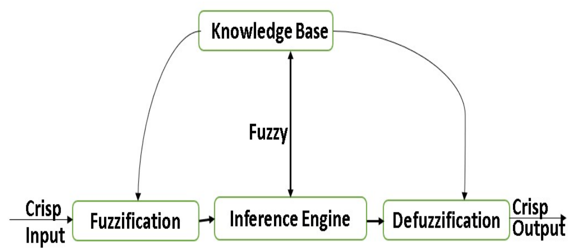


Figure 3. Block Diagram of a simple fuzzy logic controller.

B. ANFIS Model

The common process involves fuzzy system modeling is fuzzification, fuzzy inference, and defuzzification. The utmost common type of fuzzy inference system is Mamdani-type inference and Sugeno-type inference. The block diagram of the proposed ANFIS based neuro-fuzzy controller is shown in figure 4. To increase the efficiency of the solar systems, it is must to keep the grid voltage within the values. This standard helps to produce reactive and active power [15].

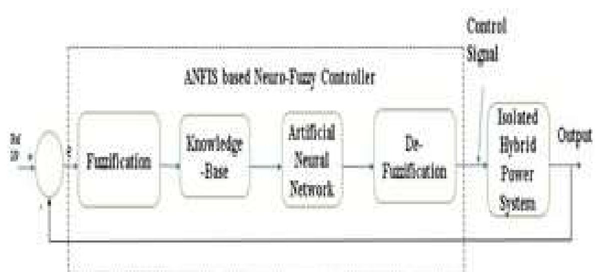


Figure 4. Block diagram of ANFIS based ANFC.

IV. CONTROLLER DESIGN

A. Fuzzy Logic Controller (FLC)

Fuzzy logic controllers can help to cop up the uncertainties. The fuzzy neural networks result to provide good accuracy for the hybrid system [16]. The fuzzy logic controller is designed to simulate the fuzzy logic expert system simulation. In Simulink, there are two inputs and one output for the fuzzy logic controller block. The typical design of FLC involves four steps: - a) fuzzification of the input variables, b) the development of a suitable inference mechanism, c), the definition of the sound fuzzy rule base, d) defuzzification of the controller outputs. Figure 5 provides the output power command generation system constructed on fuzzy logic. This is done to govern the PV output power. Two controllers are used to realize this control method. Fuzzy I have two inputs, i.e., average solar insolation (Sav) and frequency deviation (Δf). On the other hand, fuzzy II has two inputs, i.e., change in solar insolation (ΔS) and frequency deviation. The output power command P*inv is generated.

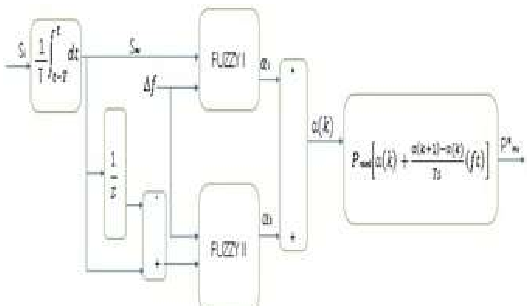


Figure 5. Fuzzy logic controller

The fuzzy controller I: - In this controller, S_{av} and Δf is selected as input and the S_{av} is defined as:

$$Sav = \frac{1}{T}\int_{t-1}^{t} Sidt \qquad ...1$$

where T represents the integral interval, t is present time, and S_i is the instantaneous insolation of the PV system.

The fuzzy controller II: - In this controller, Δf and ΔS is selected as input. ΔS is defined as

$$\Delta S = S_i(t\text{-}1)\text{-}\ S_i(t) \qquad ...2$$

The output power command P^*_{inv} is generated by the sum of both the fuzzy output. This act as central power command and described as: -

$$P^*_{inv} = P_{rated}\ [\alpha(k) + \frac{\alpha(k+1)-\alpha(k)}{Tc}(f_t)] \qquad ...3$$

Here, T_S represents the sampling time, *f(t)* is a periodic function such that *f(t)=t* (0<t<T_S) and P_{rated} is the rated power of the PV system. Figure 5 explains the output power command generation system. It is constructed on fuzzy logic to govern the PV output power. For this purpose, two controllers are used. The benefit of having two separate fuzzy logic controllers is:

a. Both the FLCs are designed with the different rules to have different membership functions.

b. The parameters of the FLCs are different which can be figure out from the diagram. This helps to optimize the system complexity and the average insolation and change in insolation can be figured out from the same system.

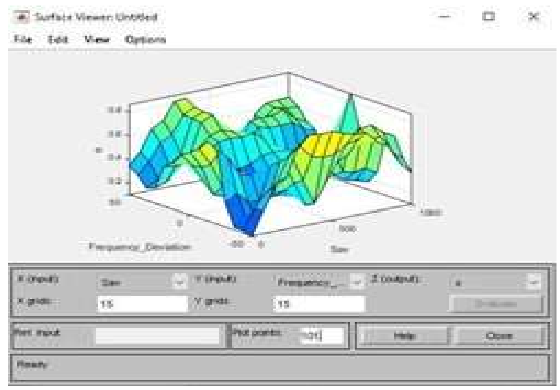


Figure 6. The surface view for the fuzzy rule of ANFC-I

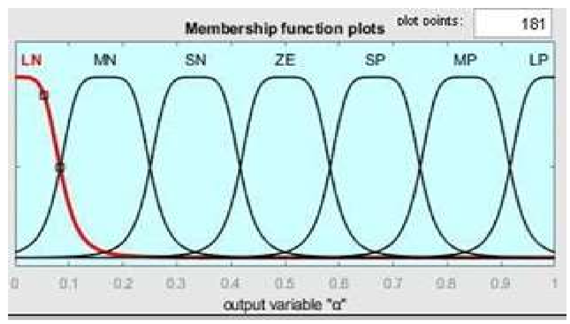


Figure 7. gbell membership function of α

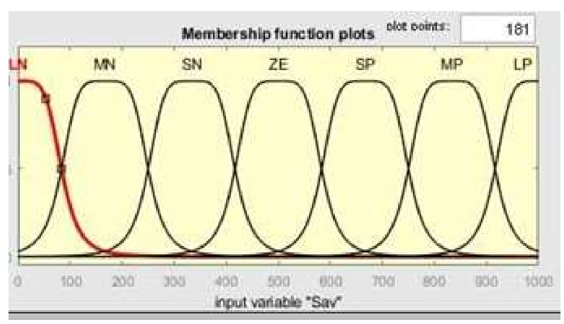


Figure 8. gbell membership function of S_{av}

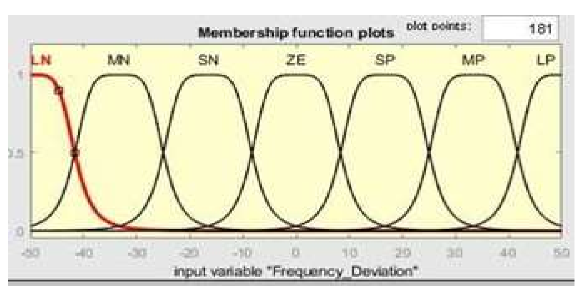


Figure 9. gbell membership function of Δf

B. Adaptive Neuro-Fuzzy Controller (ANFC)

In this proposed method, an ANFIS control structure-based control strategy is developed. This is done to control the deviation in frequency of the proposed hybrid power system. There are two ANFC are developed to control the deviation in frequency of the proposed system. As stated above, the deviation in frequency (denoted as Δf) and average solar isolation are (denoted as S_{av}) considered as input of ANFC-I. On the other hand, Δf and change in isolation (denoted as ΔS) are considered as inputs of ANFC-II. The output of this is the corresponding signal to the inverter. The proposed ANFC is designed by using seven gbell MFs with 49 rules. The first step of this design is the training of ANFIS. A large amount of data is composed in the view of load fluctuation of 0.0 to 0.01pu for training the ANFIS. The training sets consist of 3000 elements.

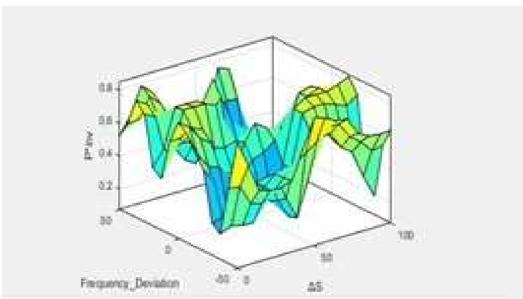


Figure 10. The surface view for the fuzzy rule of ANFC-II

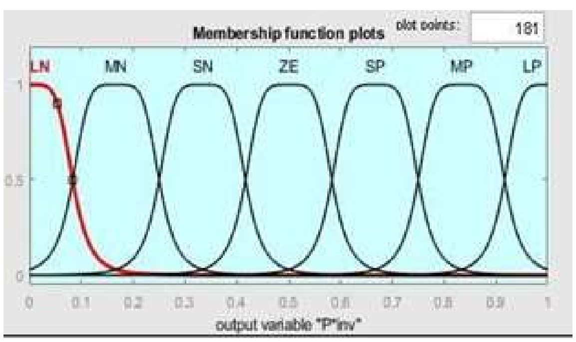


Figure 11. gbell membership function of P^*_{inv}

Fuzzy rule table for ANFC-I

		Δf						
		PN	MN	SN	ZE	SP	MP	LP
S_{av}	PN	PN	PN	MP	SP	ZE	MN	SN
	MN	ZE	LP	ZE	MN	ZE	SN	SP
	SN	LP	SP	MN	PN	SP	MP	LP
	ZE	LP	MN	MN	SN	SP	PN	ZE

Fuzzy rule table for ANFC-II

		Δf						
		PN	MN	SN	ZE	SP	MP	LP
ΔS	LN	LP	MN	SP	MP	SN	MP	ZE
	MN	ZE	MN	MN	SP	MP	SP	MP
	SN	ZE	ZE	SN	SN	MP	ZE	PN
	ZE	LP	SN	MN	SP	MN	LP	MN
	SP	MN	SP	MP	ZE	ZE	MN	MP
	MP	SP	ZE	MP	MP	PN	SN	SN
	LP	SP	PN	LP	ZE	MN	PN	MN

In the above tables, PN is prodigious negative; MN is medium negative; SN is small negative; LP is the large positive; MP is medium positive; SP is small positive; ZE is zero. The unit for S_{av} and ΔS is W/m^2, and the frequency is Hz. The P*inv unit is the watt.

V. SIMULATION RESULTS

The simulations were performed using the conventional PID controller and proposed ANFC for the mentioned thermal power system. This section deliberates the simulation analysis through different case studied. This is done on the above-designated controllers in the thermal-PV hybrid power system.

The described controller response is verified for step load and random load change. The step response of the given system is shown in figure 15 using the PID controller.

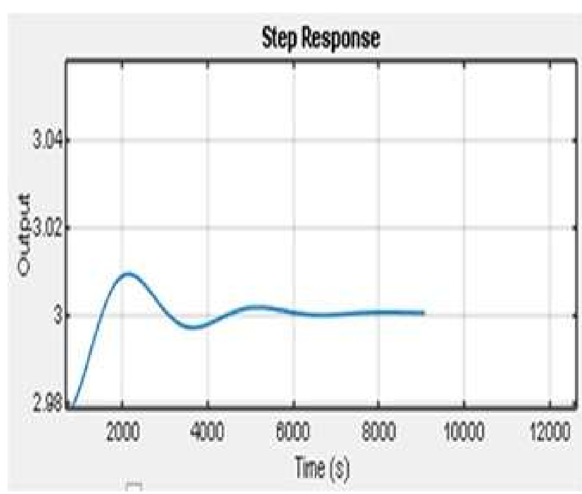


Figure 12. Step response using the PID controller.

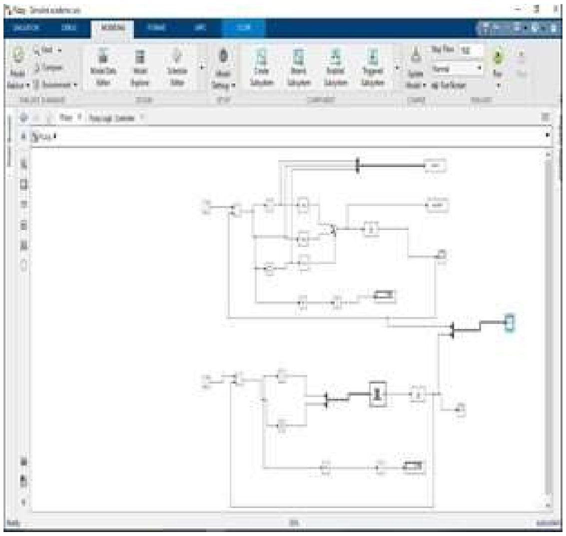


Figure 13. ANFIS AND ANFC controller based on the proposed rules.

Figure 16 shows the MATLAB simulation circuit diagram of the controllers. The result seen in the scope after using the described fuzzy rules is shown in figure 17. The yellow line represents the ANFC controller of the hybrid system, and the blue line represents the PID controller.

The result shows that the performance of the ANFC controller attains relatively better than that of the PID controller. The simulation results show that the performance of ANFC attains relatively better frequency contour. The performance of the ANFC system remains extremely robust and it is against arbitrary change in solar isolation as a disturbance.

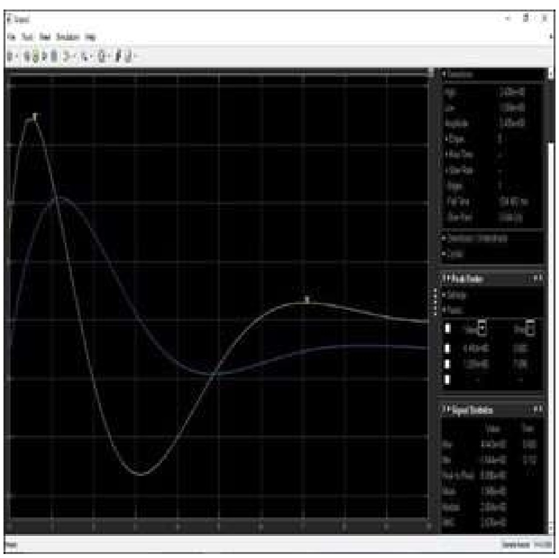


Figure 14. Comparison between the ANFC controller and the PID controller.

VI. CONCLUSIONS

ANFIS-based load frequency controllers are projected for the LFC of the thermal power generation entity. This acts as a hybrid power system. The 49 fuzzy rules are given to the ANFIS which leads to the design of ANFC. The fuzzy inference analysis has been obtained. Simulations are performed with varying load settings and frequencies. The Solar isolations with the experimented ANFIS based LFC are done, and the result obtained from it shows that ANFC has better results as compared to PID. This helps to controls the frequency deviation of the proposed HPS. This ANFC advances the dynamic performance of the HPS. The performances of the used controller are superior to PID controllers. The simulation is performed in MATLAB Simulink.

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