Two area load frequency control with ANFIS controller for an interconnected power system

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ABSTRACT— This paper addresses the two area load frequency control by proposing better design of Adaptive Neuro Fuzzy Inference system (ANFIS) controller. The proposed method offers notable advantages, such as stable convergence properties, ease of implementation and highly efficient computational performance. The primary goal is to develop a stable and robust ANFIS controller by optimizing the PID controller. The frequencies in the two areas are compared between the PID and ANFIS controllers, demonstrating that the ANFIS controller outperforms in frequency regulation and tie-line power control. The Two-area LFC system is modelled with the MATLAB. The results confirm that the ANFIS controller reduces overshoot, makes the system less sluggish, and enhances transient performance. Further confirm the efficiency of the suggested ANFIS controller, various load perturbations are applied to the power system. Simulated results are presented for various load configurations.

***Index Terms*— PID controller, ANFIS, Load frequency control, Tie-line Power control,**

I. INTRODUCTION

In large interconnected power systems, maintaining the system frequency and managing inter-area tie line power are vital for ensuring reliability. Load frequency control (LFC) plays a crucial role, especially given the inherent variability in power demand and supply [1,2]. In deregulated markets, control areas encounter unique uncertainties and disturbances, necessitating robust control strategies that ensure frequency stability, accurate tie-power flow, and zero steady-state error.

The proportional-integral (PI) controller is commonly employed for LFC due to its straightforward design and reliable performance. However, its dependence on tuned integral parameters can limit its dynamic response in the face of varying load conditions and system changes. As highlighted in the literature, traditional PID control methods may struggle to deliver optimal performance under the complexities of nonlinear behaviors and fluctuating operating points [3,4].

The effectiveness of PID controllers is closely tied to proper tuning, which can be achieved through methods like Ziegler-Nichols, Cohen-Coon, and approaches [5-6] from Åström and Hägglund despite the introduction of new tuning methods [7], many remain underutilized due to their implementation complexities.

ANFIS merges the strengths of neural networks and fuzzy logic, offering a versatile control strategy that can adapt to uncertainties. It either learns from input/output datasets to develop a fuzzy inference system or utilizes expert-defined rules, making it effective for handling imprecise data.

This study focuses on examining LFC two-area system and performance of the ANFIS controller is compared with that of traditional PI controllers through simulations involving various load disturbances.

Simulation results demonstrate that ANFIS controllers significantly outperform PI controllers in terms of maintaining system stability and performance across a range of load conditions, underscoring their potential for enhancing load frequency control in contemporary power systems [8].

II ANFIS architecture

Figure 1 presents an ANFIS architecture featuring 3- input and 2- labels for each input. Typically, an ANFIS designed with ‘n’ inputs and ‘m’ labels given in [9-12] and [15,16,17] per input consists of five distinct layers, each serving a specific function:

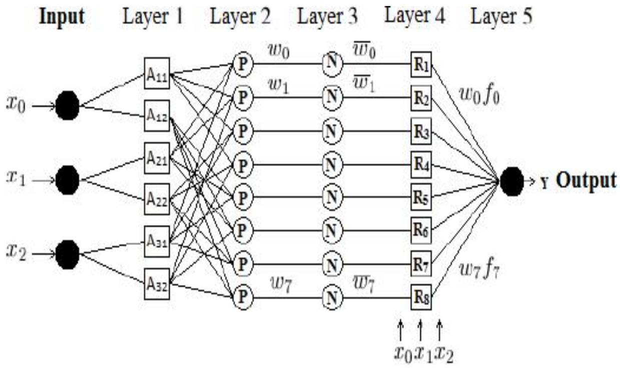

Fig 1. ANFIS structure

Layer 1: This nodes that correspond to linguistic labels (e.g., "Low," "Medium," "High"). Each node measures the belongingness to its associated fuzzy set, usually calculated through membership functions.

$$O^1_{i,j} = \mu_{A_{i,j}}(X_i) \tag{1}$$

Layer 2: Nodes in this layer evaluate the firing strength of each rule by performing an "AND" operation. The output reflects the product of membership degree from Layer 1.

$$O^2_k = w_k = \prod_{i=0}^{n-1} \mu_{A_{i,j}}(X_i) \tag{2}$$

Layer 3: This normalizes the firing strengths obtained from Layer-2, ensuring they sum to one. Each node computes the ratio of a rule’s firing strength relative to total firing strengths of all rules.

$$O^3_k = \overline{w}_k = \frac{w_k}{\sum_{i=0}^{m^n-1} w_i} \tag{3}$$

Layer 4: In this layer, nodes calculate their outputs by multiplying the normalized firing strengths by corresponding consequent parameters, often represented by linear functions. This layer generates the output for each rule.

$$O^4_k = \underline{w}_k f_k = \underline{w}_k \left(\sum_{i=0}^{n-1} p_i^k x_i + r_k \right) \tag{4}$$

Where $\left(p_0^k, p_1^k, \ldots, p_{n-1}^k, r_k \right)$ are parameter set of node k.

Layer 5: The final layer sums the outputs from Layer 4 to produce the overall output of the ANFIS. This value represents the system's prediction or control action based on the provided inputs.

$$O_k^5 = output = y = \sum_{k=0}^{m^n-1} \overline{w}_k f_k = \frac{\sum_{k=0}^{m^n-1} w_k f_k}{\sum_{k=0}^{m^n-1} w_k} \tag{5}$$

III. MATHEMATICAL MODEL OF LFC TWO AREA SYSTEM

LFC system generally contains Generator, turbine and speed governor modal. Figure 1 shows two Area LFC model.

where Δf_1 *and* Δf_2 are the change in frequencies in area-1 and area-2 in Hz. ΔPd_1 *and* ΔPd_2 are the load perturbations. The model given by O. I. Elgerd [13] is used for the study. The equations of two areas LFC system can be written as follows

The area control error (ACE) of i[th] area is defined as:

$$\Delta ACE_i = \Delta P_{tie\ i} + \Delta f_i \tag{6}$$

The controller is expressed by an equation of

$$\Delta PC = Kpi.\Delta ACE + KIi.\int_0 \Delta ACE + Kdi.\frac{d}{\ } (\Delta ACE) \tag{7}$$

Where K_Pi K_Ii K_di are gains of PID controllers for the i[th] area

The system parameters of $area_1$ and $area_2$ are given in table 1. Figure 2 shows the block dia. of a two area LFC system with the controller given in [14].

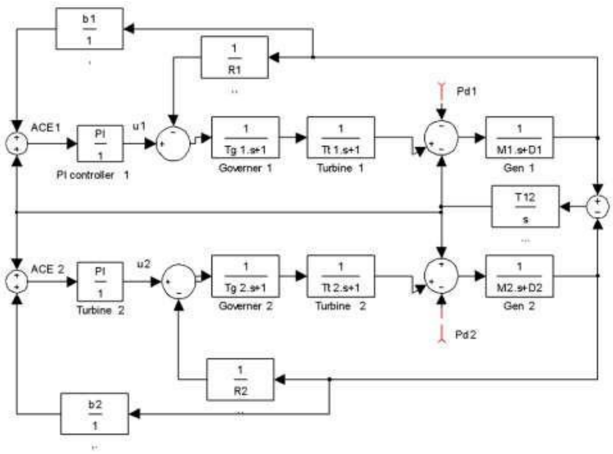

Fig.1 Block diagram of a 2- Area system with the PI controller

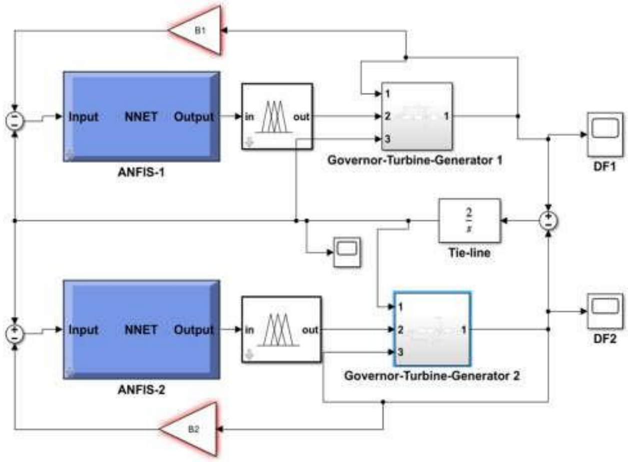

Fig.2 Block diagram of system with the ANFIS controller.

Area 1	Area 2
f=60Hz	f=60Hz
R_1=0.05Hz/per unit MW	R_2=0.065Hz/per unit MW
T_{g1}=0.2sec	T_{g2}=0.3sec
T_{p1}=20sec	T_{p2}=20sec
P tiemax=200MW	P tiemax=200MW
Base power= 1000MVA	Base Power=1000 MVA
Tt1=0.5sec	Tt2=0.6sec
D1=0.6	D2=0.9

Table 1. Specifications of the Two Area System

IV. CONVENTIONAL PI CONTROLLER DESIGN TECHNIQUE

A number of methods are there for the tuning of the PID controller. In this Ziegler Nichols [4] method is used. This tuning method gives the ultimate period Tu, and the ultimate gain Ku, from which the controller gain Kc can be computed. The ultimate gain value has been calculated to be Ku1= 2.31, Ku2= 2.31, and the ultimate period of oscillation is Pu1 =2.64 sec. The PID parameters are calculated as Kp = 0.685 Ki = 0.63 Kd = 0.17. The frequency response of the system with PID Controller has been compared with ANFIS controller in the forthcoming paragraphs.

V. ANFIS CONTROLLER DESIGN

The ANFIS controller is implemented in MATLAB. The data required for the controller are derived from the PID controller data and are utilized to train the ANFIS controllers. The Fuzzy Inference System (FIS) is constructed using 10 triangular membership functions. ANFIS is trained using a hybrid method that combines backpropagation and least squares error, yielding optimal results.

For the ANFIS-1 controller, the inputs are Area Controller 1 (ACE1) and the Change in Area Controller 1 (DACE1), both employing ten membership functions. Likewise, for Area 2, ACE2 and DACE2 serve as the inputs for the ANFIS-2 controller. The objectives include regulating the frequency of the two areas and managing inter-area tie power with effective transient response performance

VI. RESULTS AND DISCUSSIONS

During the study, Δf_1, Δf_2 and ΔP_{tie} which are used to calculate ACE_1 and ACE_2. The error and change in error data are used to train the ANFIS controllers.

A change in the load perturbation of 0.185 p.u is applied to $area_1$. The change in frequency of the $area_1$, Δf_1 is shown in figure 3. Similarly, for the same change in the load demand, with ANFIS controllers, the frequency deviation $\Delta f1$ is also shown in the figure 3.

It is observed from the figure 3 that, The ANFIS controller provides the smooth frequency response than the conventional PID controller.

It is also observed that with both the controllers ANFIS and PID the steady state error is zero but with PID controller the frequency response DF1 has more oscillations and the peak value is 0.76 Hz and more settling time 18 sec however with ANFIS controller, the response is less oscillatory, the peak value is only 0.46 Hz and less settling time of 13 sec.

Similarly, frequency deviation of the second area Df2 with both PID and ANFIS controllers are shown in figure 4. It is also seen that with PID controller the frequency response DF2 has more oscillations with peak 0.18 Hz and however with ANFIS controller the peak is 0.075 Hz with no oscillations. the settling times of both the controllers are almost same. From the above two cases it is seen that with ANFIS controller, there is high improvement in transient response.

Figure 5 shows the change in tie line power in p.u of the LFC system. It observed that with both the controllers ANFIS and PID the steady state Tie line power is zero. For a load change of 0.1875 p.u in area1 , with PID controller the maximum tie line power is 0.033 p.u however with ANFIS controller , the maximum tie line power is only 0.02 p.u . The transient response with PID controller is more Oscillatory whereas the transient response with ANFIS controller is less oscillatory and shows improved performance.

Controller	DF_1 in Area 1		DF_2 in Area 2		DP_{tie}	
	Settling time (sec)	Peak value (Hz)	Settling time (sec)	Peak value (Hz)	Settling time (sec)	Peak value (p.u)
PID	18	0.76	24	0.18	8.4	0.0037
ANFIS	13	0.46	24	0.075	2.6	0.00237

Table 2. Comparison of ANFIS and PID Controller For 0.1875pu Load at Area 1

Controller	DF_1 in Area 1		DF_2 in Area 2		DP_{tie}	
	Settling time (sec)	Peak value (Hz)	Settling time (sec)	Peak value (Hz)	Settling time (sec)	Peak value (p.u)
PID	26	0.18	22	0.105	8.4	0.046
ANFIS	20	0.10	7	0.068	2.6	0.032

Table 3. Comparison of ANFIS and PID Controller For 0.1875 pu Load at Area-2

Table II and III represents the comparison of ANFIS and PID specifications for a load perturbation of 0.1875 p.u at $area_1$ and $area_2$ It shows that the ANFIS controller significantly minimizes the peak value by a substantial margin.

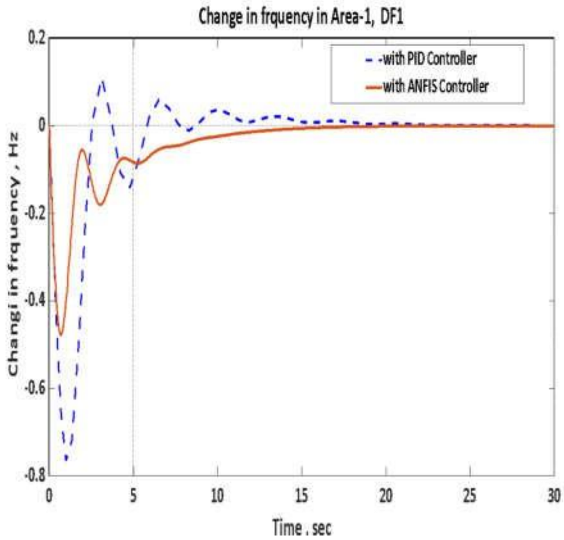

Fig.3. Frequency in area 1 for a Load of 0.1875 p.u at Area 1

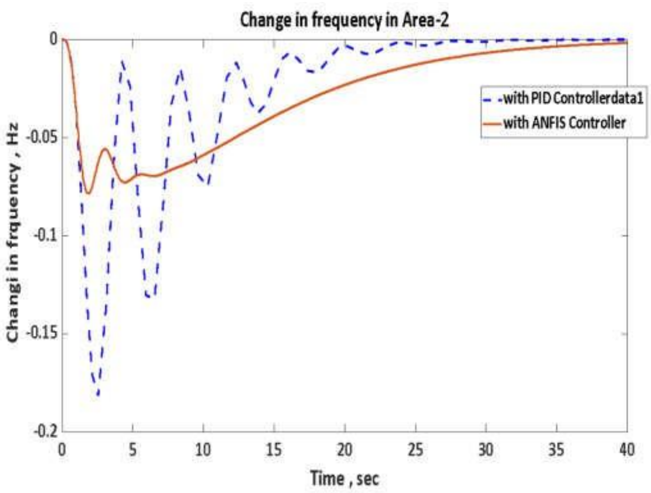

Fig 4. Frequency in area 2 for a Load of 0.1875 p.u at Area 1

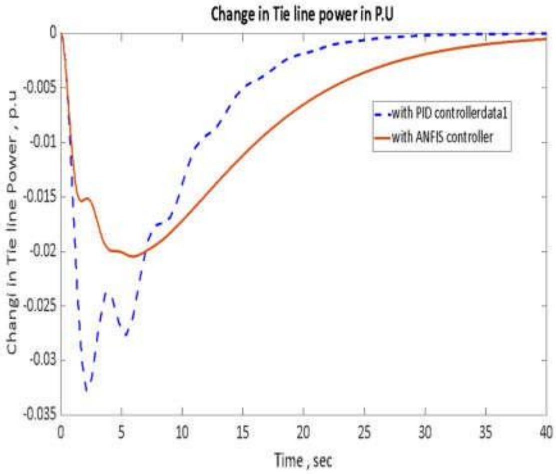

Fig 5. Change in the Line Power for a Load Perturbation of 0.1875 at Area-1

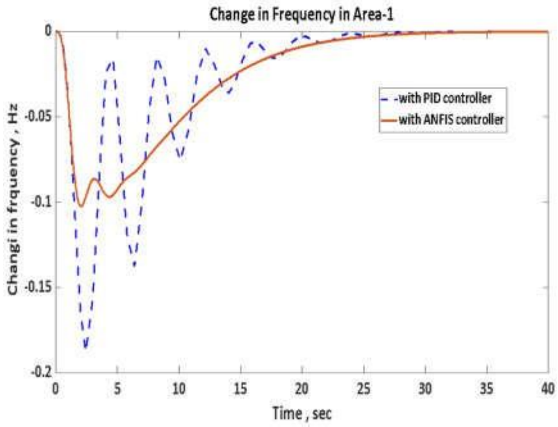

Fig 6. Frequency in Area-1 for a Load Perturbation of 0.1875pu at Area-2

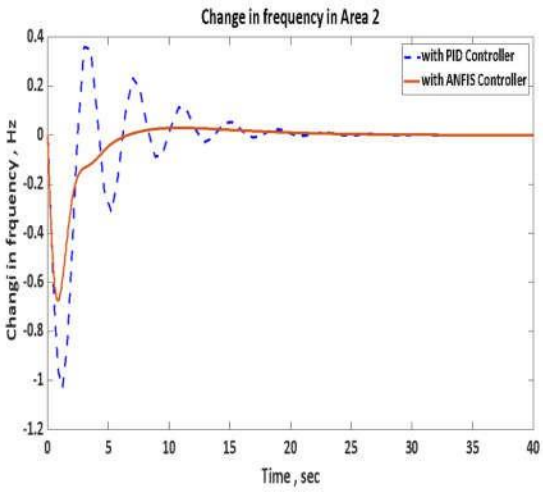

Fig 7. Frequency in Area -2 for a Load Perturbation of 0.1875pu at Area-2

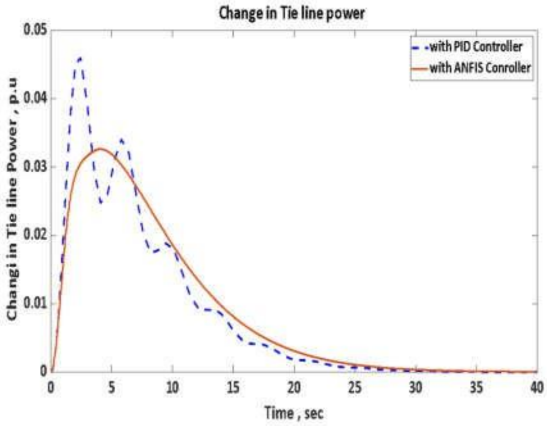

Fig 8. Change in the Line Power for a Load Perturbation of 0.1875pu at Area-2

VII.CONCLUSION.

In this study, a novel ANFIS controller has been applied for 2-Area System. It is demonstrated that there is significant in the performance specifications.

It is observed from the figure 3 that, The ANFIS controller provides the smooth frequency response than the conventional PID controller.

It is also observed that with both the controllers ANFIS and PID the steady state error is zero but with PID controller the frequency response ΔF1 has more oscillations and the peak value is 0.76 Hz and more settling time 18 sec however with ANFIS controller, the response is less oscillatory , the peak value is only 0.46 Hz and less settling time of 13 sec.

So the proposed ANFIS controller is shown to outperform the PID controller. Hence this controller is recommended for the production of high quality electrical energy, more over the ANFIS controller is straight forward and easy to implement.

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