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Load Frequency Control of Wind Integrated Power System Using Intelligent Control Techniques

Rishi Payal[1], Deepak Kumar[2]

[1] Department of Electrical Engineering, Om institute of technology and management, Hisar- 125001, Haryana, India;

[2] Department of Electrical Engineering, Om institute of technology and management, Hisar- 125001, Haryana, India;

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ABSTRACT: The load frequency control (LFC) is a serious problem to maintain constant frequency of the electric power systems operation. Most LFCs are primarily equipped with integral controllers. The integral gain is set to a level that the compromises between fast transient recovery and low overshoot in the dynamic response of the overall system. Moreover, these controllers are slow and do not allow to take in to make changes in operating condition and non-linearity in the generator unit. Doubly Fed Induction Generator (DFIG) based wind turbines run at variable speed, resulting in the variable power generation and also possess non-linearity in the systems. Large frequency deviation due to higher wind power penetration. This puts pressure on thermal and fast response generators (Increased requirements on system flexibility). Moreover, it lacks in robustness. Hence, Artificial Neural Networks (ANN) based controllers can relieve these problems. The proposed study of LFC has implemented ANN based ANFIS controllers on two area wind integrated power systems for simulation to study dynamic response of control areas with different loading condition. The simulation results obtained are satisfactory. The results suggest that ANN based ANFIS provides better control to wind integrated non-linear systems.

Keywords: Load frequency control (LFC), Proportional-integral (PI) controllers, Doubly fed induction generators (DFIG), Artificial neural network (ANN), ANFIS.

I. INTRODUCTION

Electricity has become an essential need for all. The generated power must be controlled to meet actual power demand while retaining the best quality to get optimal performance from electrical equipment[1]. Now days, the conventional power plants are unable to meet rising demand due to environmental constraints and uncertainty in power demand. It can also be explained as the imbalance between system loads and generated power which reduces power quality causing rapid disturbances in the system. During transmission process, both active as well as reactive power must be balanced between generators and loads. When this balance is violated, the power quality reduces[2].

Both reactive and active powers mutually effects frequency and system voltage. Alternators have two independent control loops, Automatic Voltage Control (AGC) and Automatic Voltage Regulation (AVR) for controlling frequency and voltage fluctuations respectively. Load Frequency Control (LFC), an important function of AGC is being used as frequency deviation control with the active power control, while AVR is used to regulate terminal voltage with reactive power control. There are two functions of LFC, first to maintain frequency constant and second to regulate error of tie-line power exchange following a load variation in an interconnected system [3].

Therefore, artificial neural network (ANN) based controllers are introduced to frequency control problem to regulate power generation against the variable demand. The ANN controllers with advance adaptive control structure is robust to control the non-linearity in power generation and enhancing power quality, system stability with narrow frequency change in the power system [4].

In this dissertation work, ANN based ANFIS controller has been preferably used to control frequency oscillations and power flow in tie-line. ANFIS controller is relatively faster control than other controllers[5]. The controller has been trained to control two areas interconnected DFIG wind penetrated system. Transient response due to sudden change in load is compared with conventional PI and ANFIS controllers.

II. LITERATURE REVIEW

The load frequency control is the vast area of research in the operational power system. In

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recent times intelligent control methods are conquering over PI controller, which was used as a conventional controller in most industrial applications to control frequency problems. The optimized tuning of these intelligent controllers with renewable penetration and non-linearity has been done using many techniques and algorithms in huge numbers of journals and research articles which is being discussed in this section.

First to suggest the optimum frequency governor of two area power system. Both the identical control areas equipped with non-reheat steam turbines for the construction of load frequency control model. They also presented optimal multi area active power and frequency control[6]. The American Power Systems Committee mentions that frequency bias for each control area should be set equal to area frequency response characteristic (AFRC). But the committee failed to explain basis for this practice and author, suggested and proved with the methods of optimal control, that not onlyimproved results but also broader stability margins can be obtained by setting the slower bias.

Discussed the improvement in state variable model for multi area load frequency problems. The utilization of mathematical equations was necessary for the implementation of advance control scheme [7]. It also discussed about the feedback controller, which was quite effective in terms of construction in comparison to the previously designed controller. The result shows the productive ways for improving the dynamic response as well as stability limitations of load frequency control system[8].

Discussed about the effect of instantaneous variations in the wind power over the system operation when the components were further divided into slow, fast and ramp components. Changes in wind power affectthe overall normal operation of power system on a smaller side was proved bylong term simulation model but still, there was also a threat of random increase in wind power as well as power demand that can further overlap the remaining capability of the complete system[9]. It also discussed about the various wind related methodologies and the control area performance that can further help by linking the main grid with the rest of the system.

Discussed about the implementation of a proposed DFIG wind model uses a power converter as the controlled voltage source to regulate the flow of rotor current to obtain the desired real and reactive power [10]. This model had a form of conventionally proposed generator model that can further utilized as the power simulation tool such as PSS/E. To verify the effectiveness of the proposed model, it was compared with the desired model designed by Dig silent. The drawbacks as well as the merits of the proposed model were also displayed for the better performance of the model in comparison to previously designed alternatives [11].

2 WIND POWER GENERATION

2.1 Wind Turbines Technology

Classification of wind turbines was done on the principle of energy conversion, i.e. aerodynamic drag and aerodynamic lift[12]. Modern wind turbines convert energy on the principle of aerodynamic lift. The blades of these turbines directly interact with wind blowing at moderate speed which results, drag force in the direction of wind[13]. Another force perpendicular to the drag is called lift force which is several times larger than the drag force which is responsible for rotor movement. There are two types of aero dynamical lift turbines based on spin axis orientation[14].

i. Horizontal axis turbine
ii. Vertical axis turbine

Fig 1: Horizontal and vertical axis type of wind turbines

the area covered by rotor is given by kinetic energy of air cylinder with radius drifting at speed of wind V_{wind}. The equation that gives wind power can be expressed as (1) [15]

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$$P_{wind} = \frac{1}{2} C_p \rho_{air} \pi R^2 V_{wind}^3 \quad (1)$$

It is practically impossible to completely extract the kinetic energy from the wind as it can only happen when air is totally blocked to pass through the wind turbine, which is almost unachievable condition[16]. The wind turbine reduces speed of wind thus pulls out a small quantity of the power from the wind. This fraction of power extracted from wind is expressed as the power efficiency coefficient (C_p), of the wind turbine. Therefore according to the definition of $C_{p,}$ mechanical power output of the wind turbine can be obtained by (equation 2) and (equation 3) [17],

$$P_{mech} = C_p P_{wind} \quad (2)$$

$$P_{mech} = \frac{1}{2} C_p \rho_{air} \pi R^2 V_{wind}^3 \quad (3)$$

The maximum theoretical static limit of power efficiency coefficient(C_p) is 16 /27(0.593 approx.) which is maximum possible value i.e. 59 % of power that can be converted from wind kinetic energy and is expressed as Betz Limit[18-19]. Practically mechanical power P_{mech}extracteddepends upon three factors: rotor speed, wind speed and blade angle. Hence, $P_{mech}$and C_p are functions of these parameters (4)

$$P_{mech} = f\left(\omega_{turb}, V_{turb}, \beta\right) \quad (4)$$

III. RESEARCH METHODOLOGY

3.1 Proportional-Integral (PI) Controller

In most of the industries proportional integral PI controllers are effectively used for decades due to its simplicity[20-21]. Therefore, these controllers are known as conventional controllers. In general LFC consist two loops primary and secondary speed control in interconnected power system. The initial frequency adjustment is done by primary speed control. Due to which all generators in that area sense that load variation and divide the new demand as per their capacities[22]. The time constants of governor, turbine and power system loads limits the controlling action. On the other hand, secondary loop is responsible for adequate regulation of frequency by settling down frequency error to zero using integration operator of PI controller[23].

3.2 ARTIFICIAL NEURAL NETWORK (ANN) CONTROLLER

The artificial neural networking is an intelligent technique applied in various optimization problems[24]. ANN controllers are based on the structure of the human brain. The working of these controllers is also very similar to the brain as they learn from previous knowledge[25]. The controller saves previous information which is used to construct an enormous parallel network and trained them to solve definite problems[26]. The basic constituent of the human brain is a special kind of cell called neurons, which stores information and reflects previous experience while performing similar task. Similarly, ANN controllers are made up of neurons with a character of extremely complex parallel and non-linear processing systems[27].

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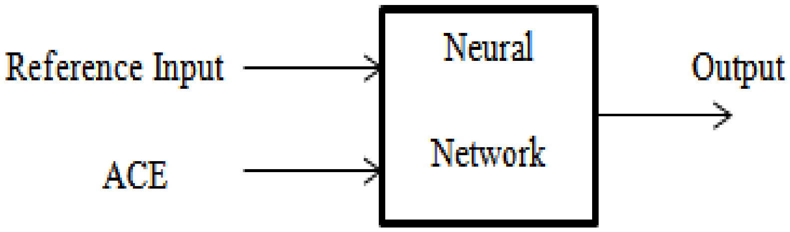

Fig 2: Architecture of Artificial Neural Network (ANN)

3.3 ANFIS Controller

Adaptive neuro-fuzzy interface system (ANFIS) applies fuzzy reasoning for the construction of neural-network architecture[28]. In this technique the adaptive and learning capabilities of neural networks are retained while using fuzzy rules to codify the structured knowledge. Expert knowledge so obtained from ANFIS thus helps in increasing learning speed and estimation accuracy. Fuzzy logic is one of the most successful applications in the control engineering field, which can be used to control various parameters of real-time systems[29]. This logic combined with neural networks yields very significant results. Thus by applying the learning power of the NNs with the knowledge representation of FL leads to the creation this new hybrid technique which is described as neuro-fuzzy networks[30]. This hybrid technique so obtained is very advantageous as it not only gives a fairly good estimation of the speed but also it is robust to parameter variation[31].

The graphical representation of the TS-FLC model represents architecture of the ANFIS model. The general ANFIS control structure for the control of any plant is presented in this section.All the components such as fits used in structure are same only NN block is altered[32]. This network structure is consist of a set of units arranged into 5 interconnected network layers, viz., 1 to 5.Functions of all the layers are given in the form of an algorithm as described below:

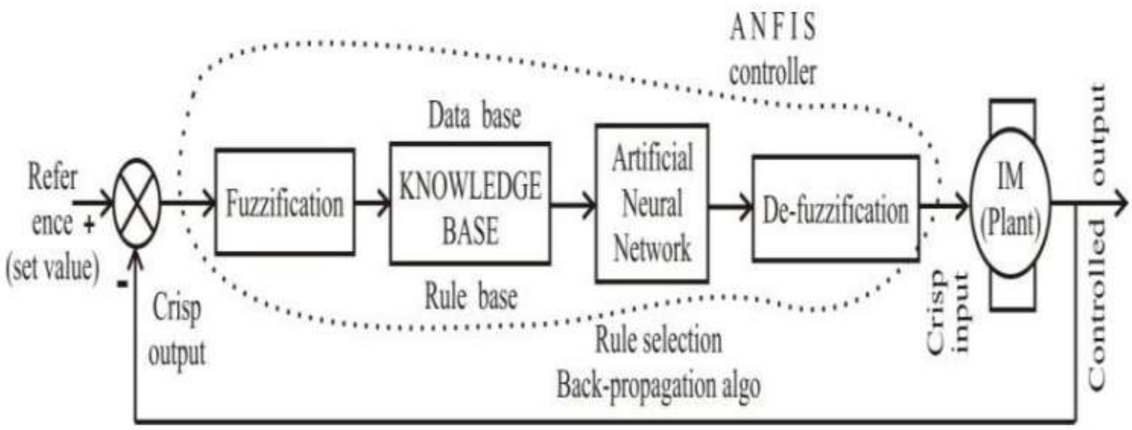

Fig 3: Block diagram of ANFIS Controller

IV. SIMULATION AND RESULTS

4.1 Load Frequency Control Using Pi Controller

The basic control method widely used in current power generating industries is proportional integral controllers over more than a decade[33]. In this work PI controller is used as a conventional controller to limit the frequency change indifferent variation in loads for the two areas interconnected systems.

4.1.1 Simulink Model of Two Area System withoutWindTurbines

Mainly thermal (steam) power generators are known as conventional plants as large parts of the power produced through it. Although these plants are having a high power generating cost apart from this fact, itis a more reliable source to fulfil large block of loads. TheMatlab / Simulink

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model tothe PI controller for two areas system is represented in fig. 4.1

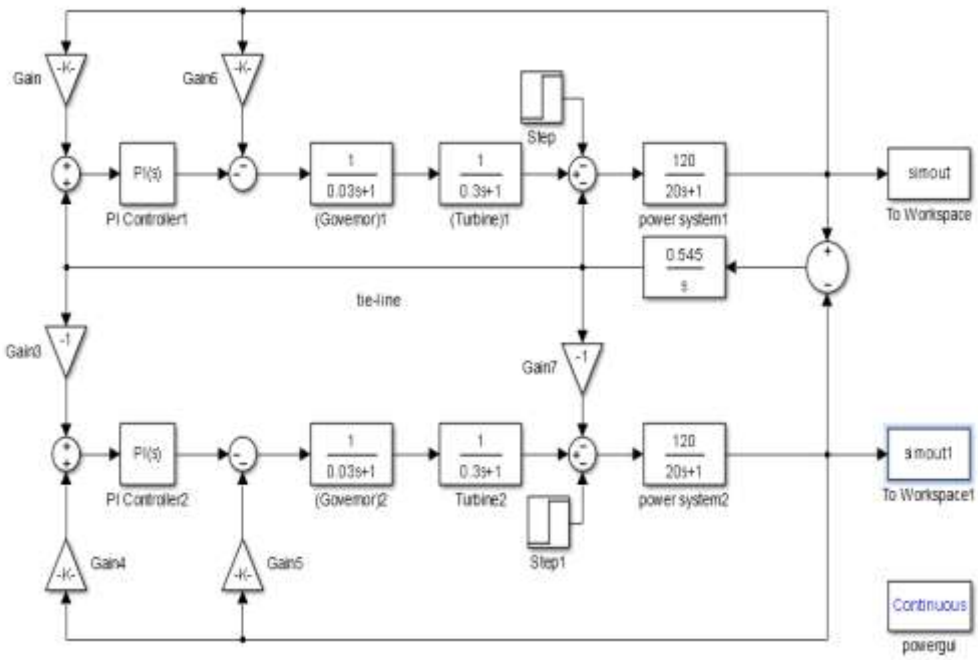

Fig 4: Simulink model for load frequency control with PI controller of 2-area system.

In the developed controller all the optimized gains of PI controllers are set. Table 4.1 below gives the optimized values of the gains.

Table 1: The values of gains of optimized PI controller in system without wind

S.No.	ΔP_L	k_{p1}	k_{i1}	k_{p2}	k_{i2}
1	0.01	0.6	0.3	0.5	0.2
2	0.05	1.72	0.75	0.8	0.6

4.1.2 Simulink Model of Two Area Systems with Wind Penetration

The wind turbines are more economical as well as reliable sources of electricity. The integration of wind turbine generators with conventional generators is done by the parallel connection of both the generators working as a coherent group in the single control area. The wind turbines may also be situated near to the load to feed them. In the system, both generators may be controlled independently, or there may be coordinated control for achieving better stability. Fig 4.2 gives Simulink model of wind integrated two area system.

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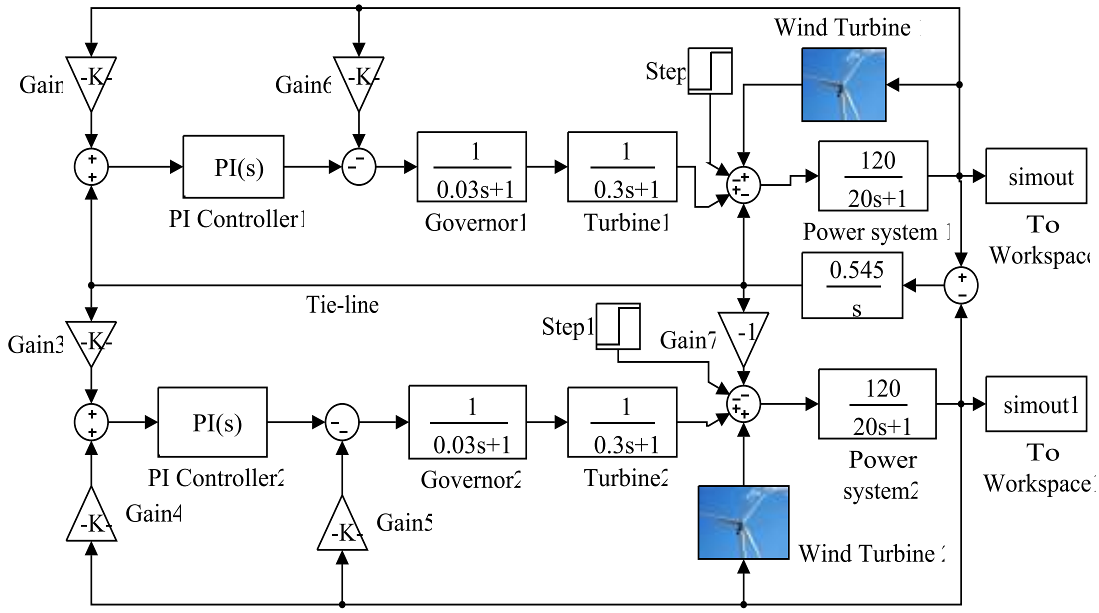

Fig 5: Wind integrated two area load frequency control model using PI controller

All optimized gains of PI controllers are set in the controllers and their values are tabulated in table 4.2

Table 2: The optimal value of gains of PI controllers in system with wind

S. No.	**ΔP_L**	**k_{p1}**	**k_{i1}**	**k_{p2}**	**k_{i2}**	**k_{pw1}**	**K_{iw1}**	**k_{pw1}**	**k_{pw1}**
1	0.01	0.6	0.3	0.5	0.2	0.3	0.08	0.3	0.08
2	0.05	1.7	0.75	0.8	0.6	0.5	1.2	1.2	0.5

4.2LOAD FREQUENCY CONTROL USING ANFIS CONTROLLER

4.2.1 Simulink Model of Two Area System without Wind Penetration

This model describes the effect of the ANFIS controller on the thermal generators of both the areas. The parameters of the controllers are set inside it to train them for the two area model. The characteristics of thermal power plant are almost linear. Therefore, The ANFIS controller is not much effective than PI in this case.

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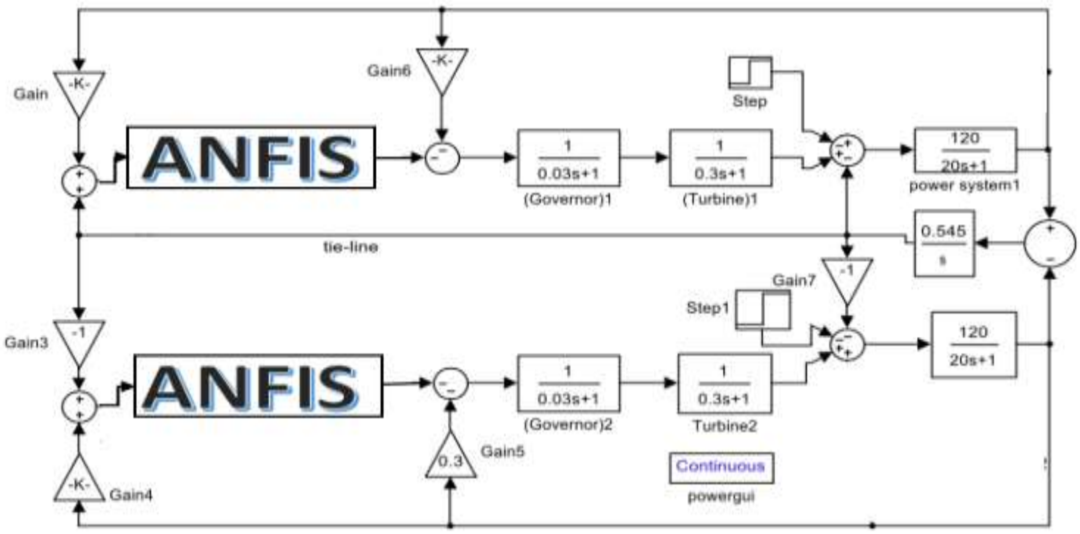

Fig 6: two area load frequency control with ANFIS controller

4.2.2 Simulink Model of Two Area System with Wind Penetration

The model includes wind turbine in each area which participate in frequency and real power control. The wind turbines inject non-linearity in the system. Therefore the role of ANFIS controller becomes highly decisive to respond against non-linearity in power generation control. The parameters for the ANFIS controllers are set inside it to train them for each load disturbance.

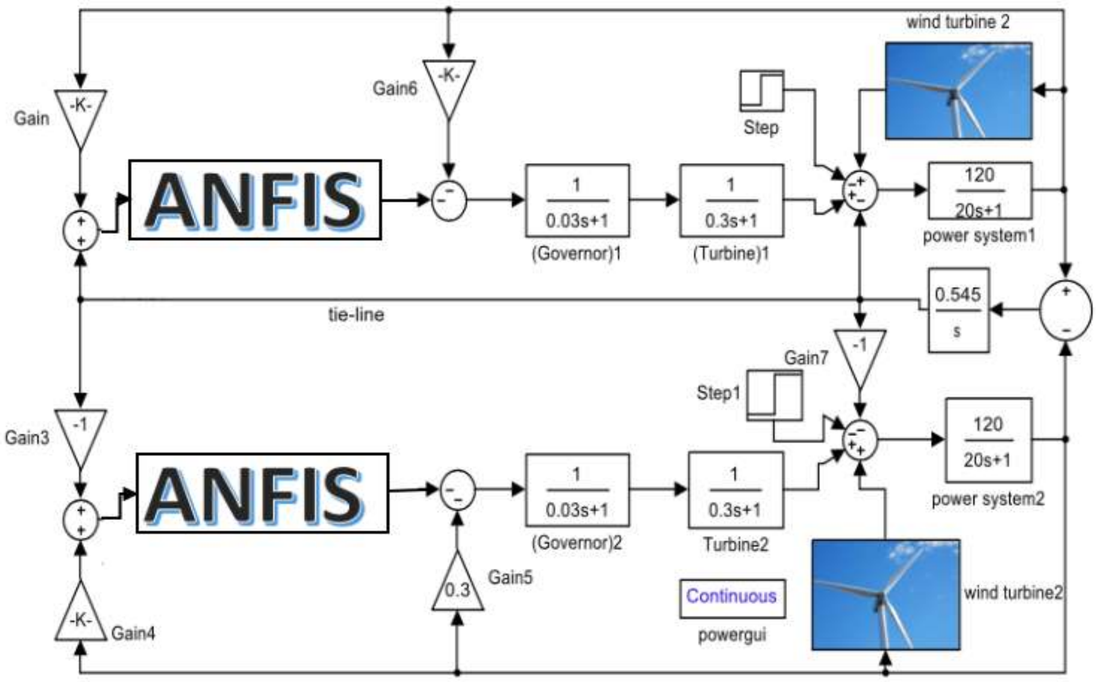

Fig 7: LFC of wind integrated two area power system using a ANFIS controller

4.3 Results

4.3.1 Comparative Frequency Response using PI and ANFIS Controllers without Wind Turbines for Two Area Power System

The mathematical comparative study of the frequency response of both the controller is complex. A graphical plot makes this study easier through visualization and taking out the maximum and minimum values from graphs. The study has been done for two different load changing conditions 0.01 p.u. and 0.05p.u. The graphs for

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both controllersare plotted in same plot to easily compare the controller performance.

Case1 Dynamic responses with 1% load change:

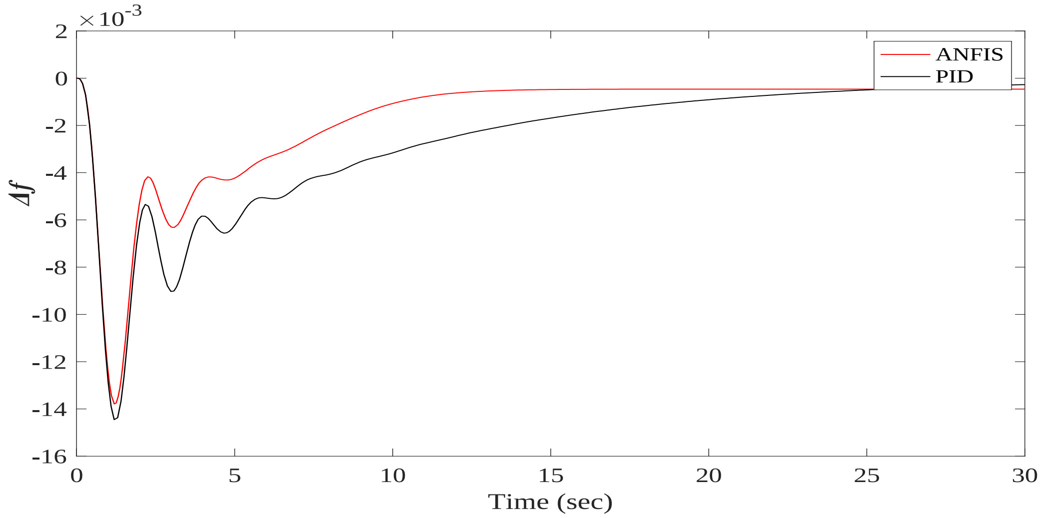

Fig.8: Frequency response with PI and ANFIS controllers with 1% load change of area1.

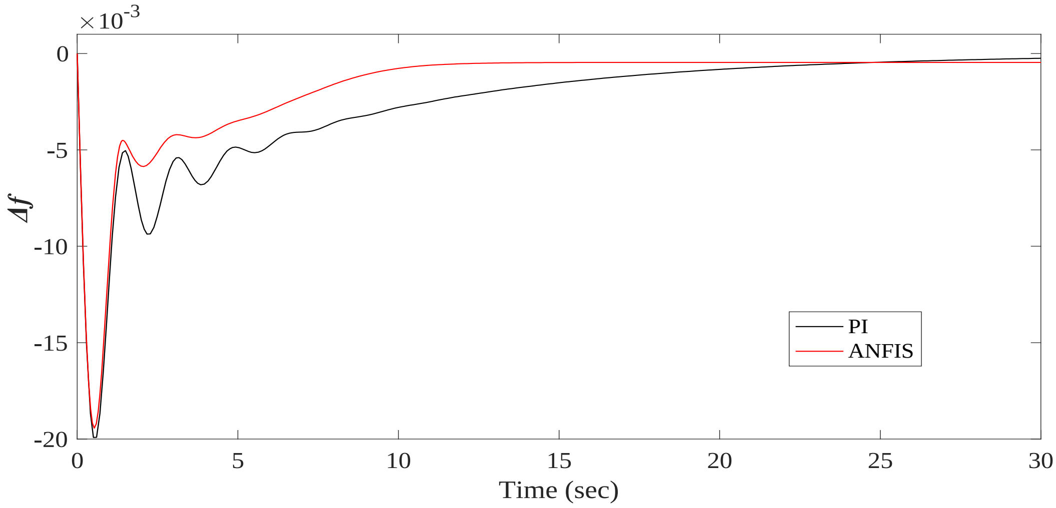

Fig 9: Frequency response with PI and ANFIS controllers for area2.

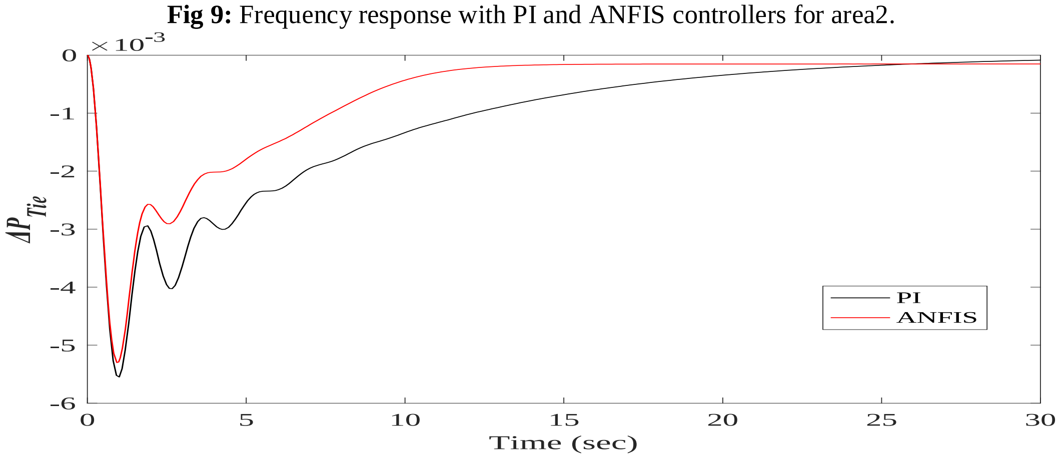

Fig 10 : Change in tie- line with 1% load change

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Case2 Dynamic responsewith 5% load change :

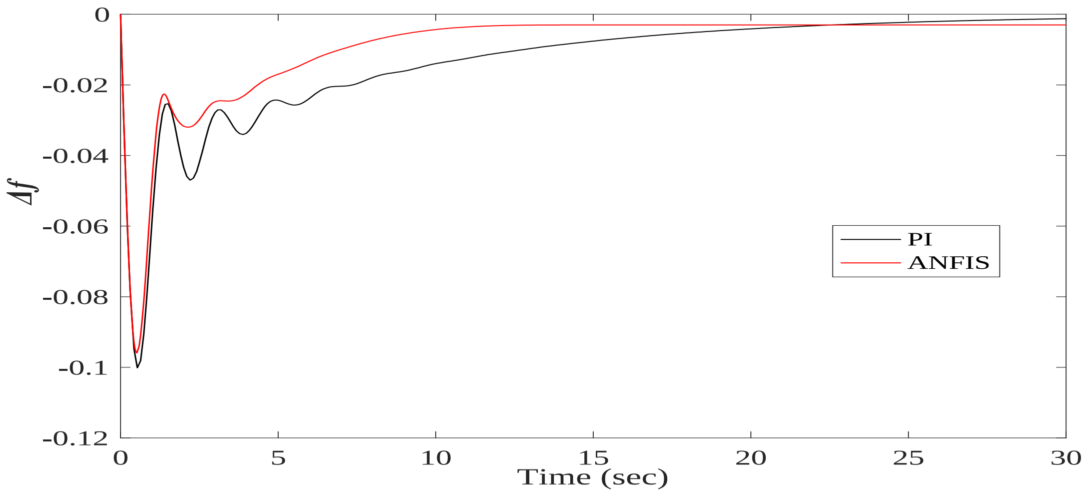

Fig 11: Frequency changedue to 5% load change in area 1

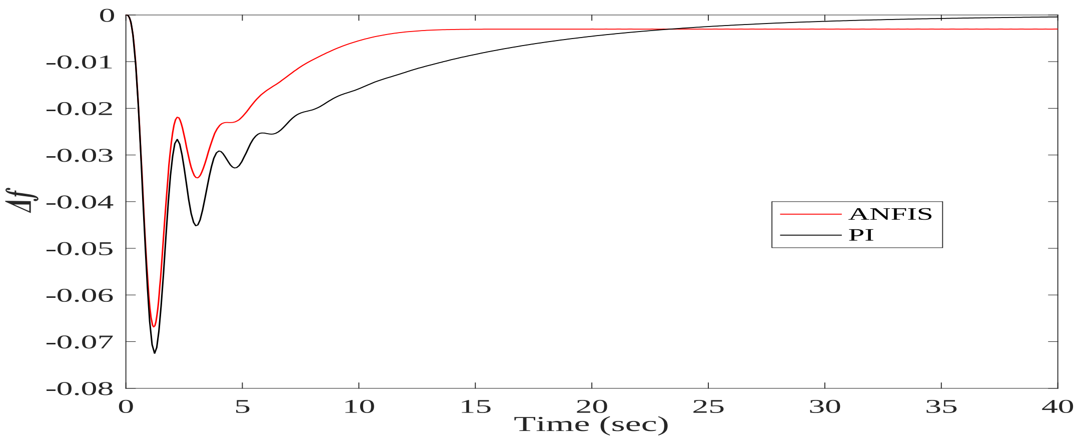

Fig 12: Frequency change due to 5% load change in area 2

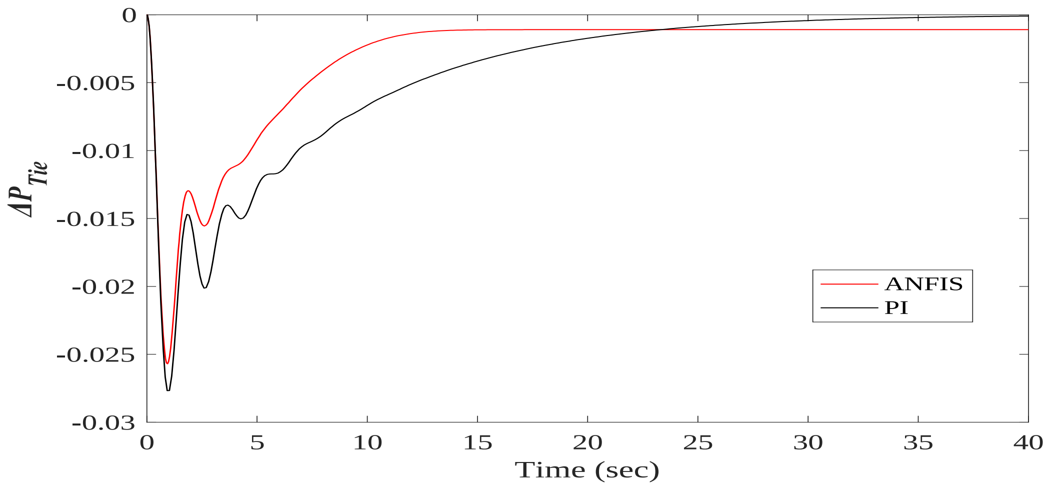

Fig 13: Tie-line powerdeviation from area 1 to area 2 with 5% load change.

Table 3: Performance of windintegrated system PI and ANFIS in terms of peak overshootand settling time

Load Change	PI Controller						ANFISController					
	Area 1		Area 2		Tie-lines		Area 1		Area 2		Tie-lines	
	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s
1%	0.014	25	0.021	20	0.0055	20	0.013	10.0	0.0056	18	0.0052	12
5%	0.1	20	0.072	23	0.027	24	0.094	13	0.064	13	0.025	12

4.3.2 Comparative Frequency Responses of the Power System using PI and ANFIS Controllers with Wind Penetration

Similarly for DFIG wind turbine integrated system the frequency response by both the controller has been plotted in the same graph for each area for different loading condition. These plots will give the graphically representation of effect of wind turbine on the performance of both the controller .

Case1: Dynamic response with 1% (0.01 p.u.) load change for area1

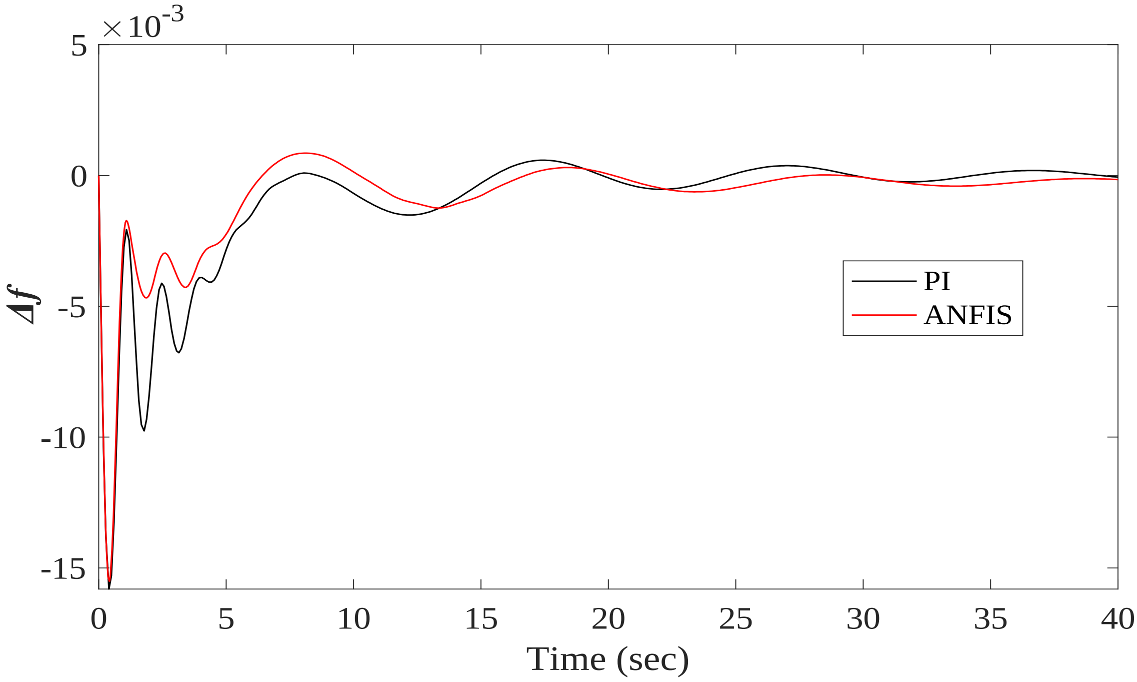

Fig 14: frequency response of area 1 with PI and ANFIS controllers

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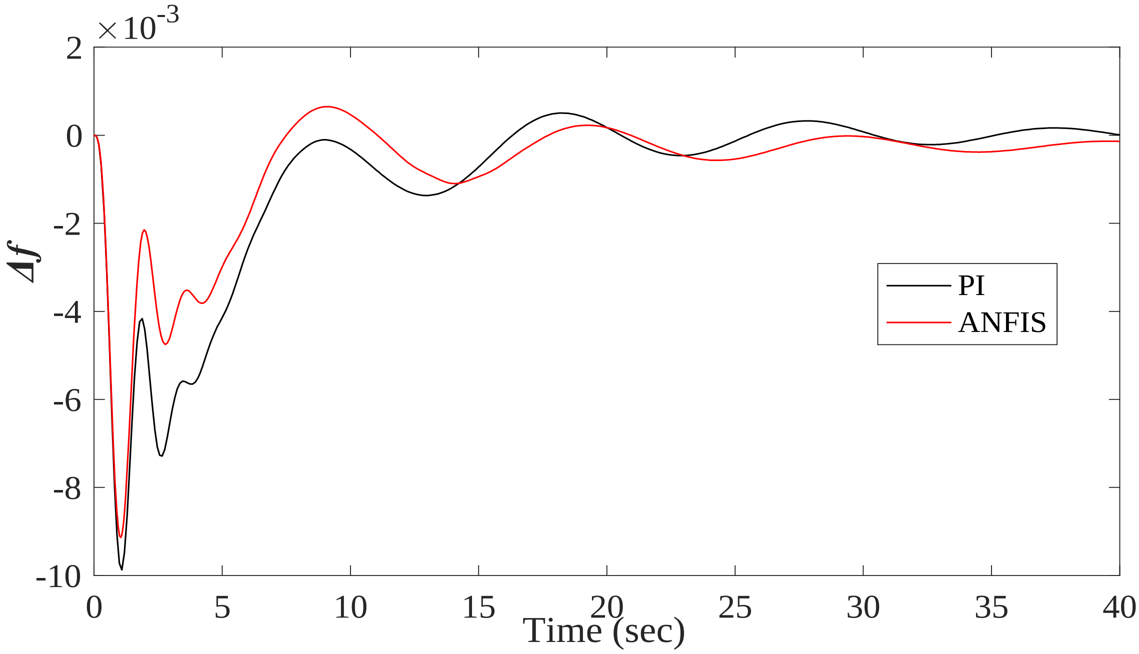

Fig 15: frequency response of area 2with PI and ANFIS controllers

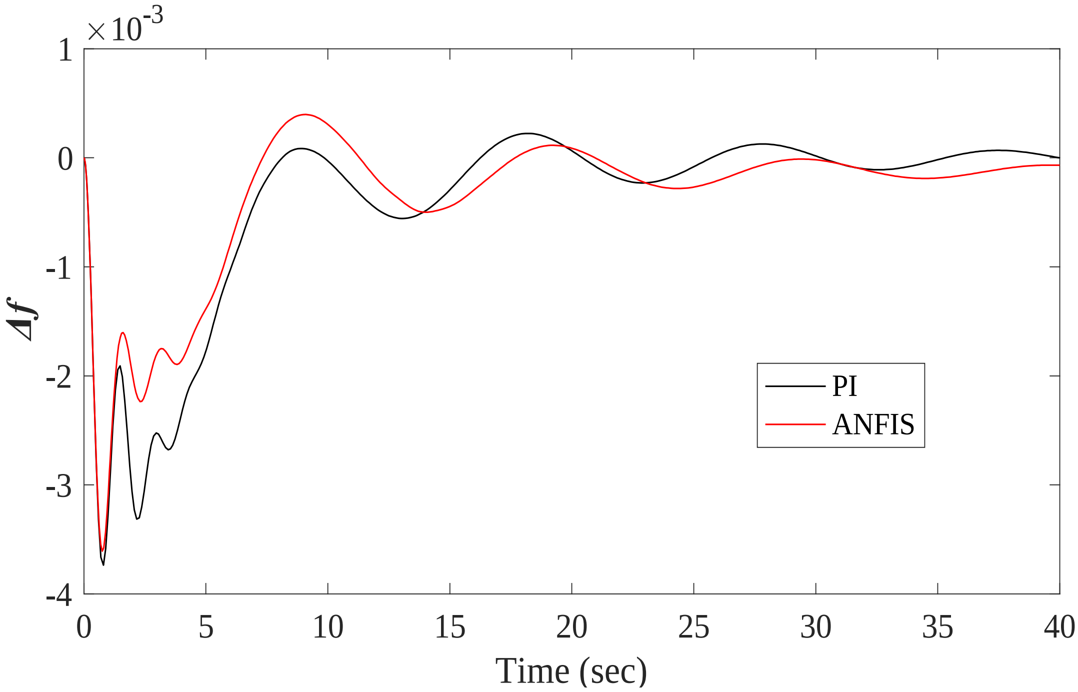

Fig 16: Tie-line power deviation from area 1 to area 2 with 1% load change

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Case2: Dynamic response with 5% (0.05 p.u.) load change.

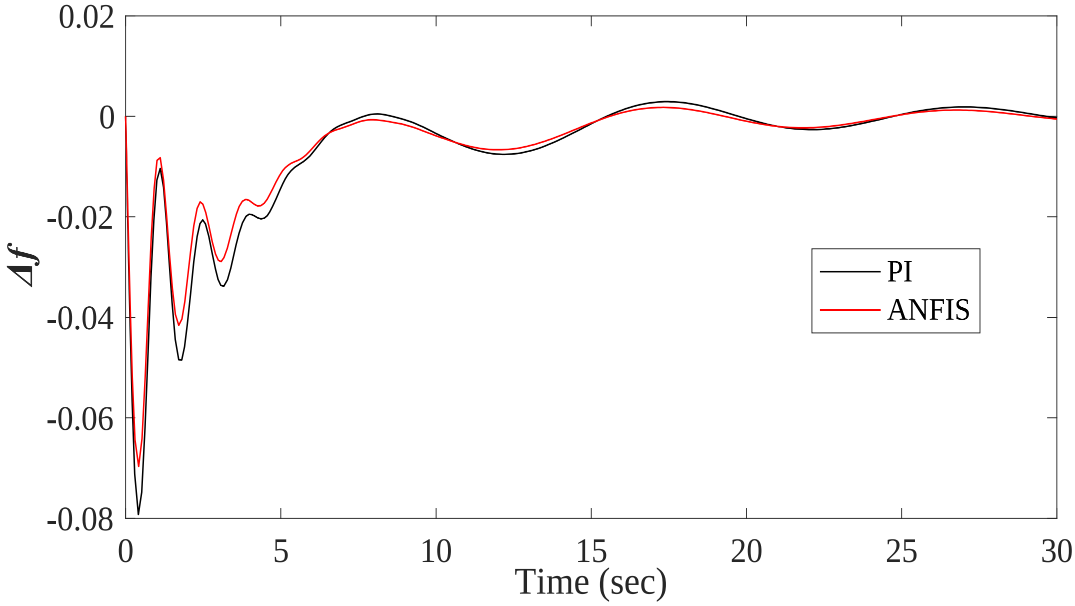

Fig 17: Frequency response of two area system with 5% load change for area 1

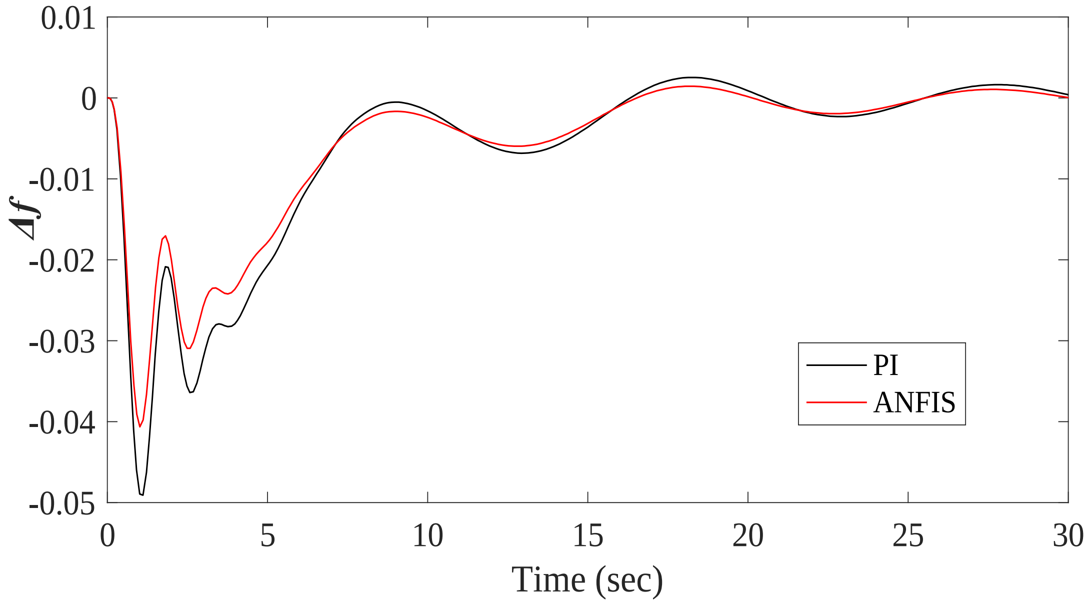

Fig 18: Frequency response of two area system with 5% load change in area2

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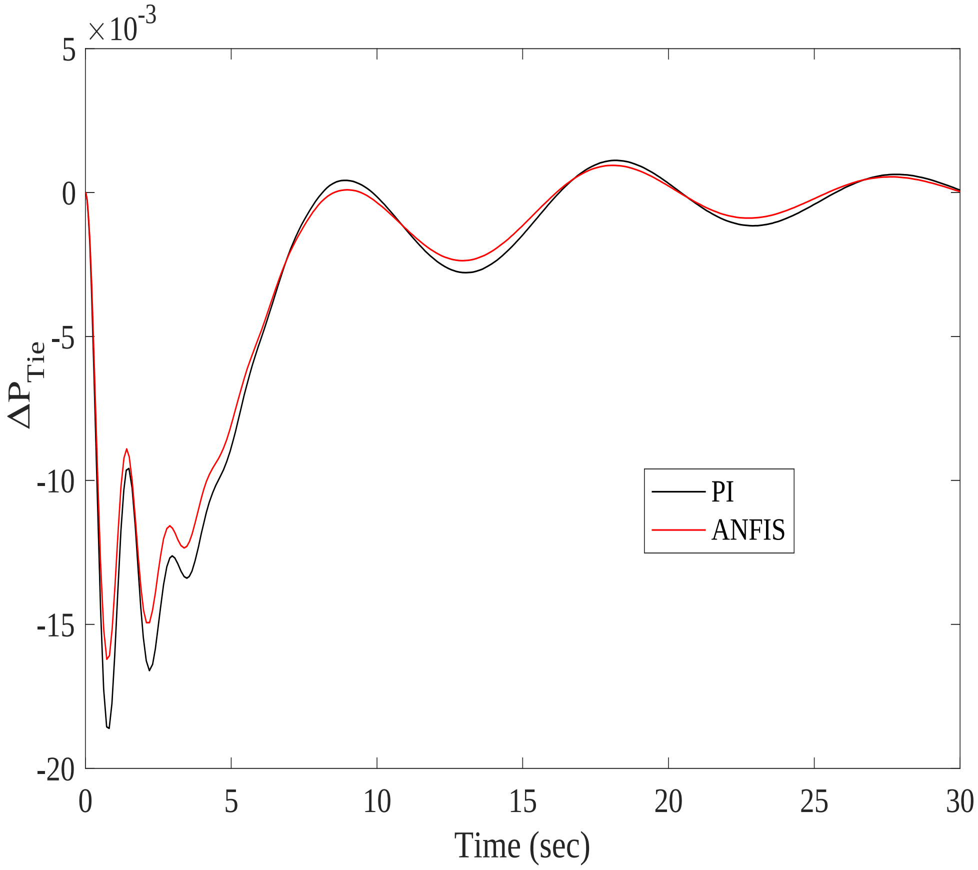

Fig 19: Tie line power deviation with 5% load changefrom area 1 to area

Table 4: Performancecomparison of wind integrated PI and ANFIS controllers

LOAD CHANGE	PI CONTROLLER						ANFIS					
	Area 1		Area 2		Tie-lines		Area 1		Area 2		Tie-lines	
	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s	M_p	t_s
1%	0.015	14	0.010	15	0.0038	14	0.015	13	0.009	13	0.0034	14
5%	0.083	17	0.052	17	0.018	22	0.074	16.8	0.041	16	0.016	18

V. CONCLUSION

This work recommends neural network based ANFIS controller for wind penetrated power system. The training process of ANN based ANFIS have been described in details. The model of two area wind integrated system is developed and employed to test robustness of ANFIS controlled system following load disturbances. BothPI and ANFIS controllers are simulated for two different load changes and results have been plotted.Two area wind integrated transfer function model with small disturbances has been developed. The conventional PI controller tuned using Ziegler-Nichols method provides satisfactory outcomes for LFC without any non-linearity in the system. However, wind turbines introduce non-linearity in the system which cannot be ignored in LFC problem. Therefore, the intelligent ANN based controller is introduced to tackle the complexity of the control area. The performances of ANFIS controller over PI controller have been compared.The graphical results show thatANFIS helps in decreasing peak overshoot and settling time. Also, it is important to notice that ANFIS reduces settling time with raising system load.

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