Enhanced Load Frequency Control in Isolated Micro-Grids Using ANFIS Controller for Stability and Efficiency

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Abstract: The management of load frequency control in isolated micro-grids is critical to ensuring grid stability and operational efficiency. This research paper presents an investigation into the enhanced load frequency control strategies employed in isolated micro-grids through the integration of an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. The study focuses on optimizing the performance of micro-grid systems by implementing ANFIS-based control techniques. The ANFIS controller offers a dynamic and adaptable means of regulating frequency and load, thereby enhancing grid stability and improving overall system efficiency. Through a series of simulations and experimental validations, the paper highlights the efficacy of ANFIS-based load frequency control in mitigating frequency deviations and enhancing the operational performance of isolated micro-grids. The findings demonstrate the potential of ANFIS controllers as a robust solution for the stability and efficiency of micro-grid systems.

Keywords: Load Frequency Control, Isolated Micro-Grids, ANFIS Controller, stability, Enhanced Control Strategy

1. INTRODUCTION

Electricity has become an essential need for all. The generated power must be controlled to meet actual power demand with retaining the best quality to get optimal performance from electrical equipment. Now days, the conventional power plants are unable to meet rising demand due to environmental constraints and uncertainty in power demand[1]. It can also be explained as the imbalance between system loads and generated power which reduces power quality causes 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].

Although, both reactive and active powers mutually effects frequency and system voltage. Alternators having two independent control loops Automatic Voltage Control (AGC) and Automatic Voltage Regulation (AVR) to control frequency and voltage fluctuations respectively.

Load Frequency Control (LFC) is an important function of AGC used to control frequency deviation with the active power control while, AVR is used to regulate terminal voltage with reactive power control. There are two functions of LFC, firstly to maintain frequency constant and secondly to regulate error of tie-line power exchange following a load variation in an interconnected system [3].

The increasing deployment of isolated micro-grids, often driven by the integration of renewable energy sources and the growing demand for resilient and sustainable energy solutions, has brought forth numerous challenges related to load frequency control[4-5]. These isolated micro-grids are characterized by their limited capacity, varying loads, and intermittent power generation, making precise and reliable frequency regulation a paramount concern. Effective load frequency control (LFC) is essential for ensuring grid stability, meeting consumer demand, and enhancing the overall operational efficiency of these isolated micro-grids. To address these challenges, this research paper delves into the development and application of an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller, aimed at enhancing LFC in isolated micro-grids[6].

Traditionally, LFC in isolated micro-grids has relied on conventional controllers, such as proportional-integral (PI) controllers, which are inherently rigid and require manual tuning to adapt to changing operating conditions[7]. This paper investigates the integration of ANFIS controllers, which combine the advantages of fuzzy logic and neural networks, offering dynamic and adaptive control strategies for micro-grid frequency regulation. ANFIS controllers have gained recognition for their capability to self-adjust and optimize control parameters, making them a promising solution to address the complex dynamics of isolated micro-grids[8].

2. LITEARTURE SURVEY

Load Frequency Control (LFC) is a critical component of power system operation, serving to maintain grid stability by continuously adjusting power generation to meet the variable consumer demand[9]. In isolated micro-grids, where decentralized and intermittent energy sources are prevalent, LFC becomes even more challenging due to the complex, dynamic nature of these systems. This literature survey provides an extensive overview of existing research on enhancing LFC within isolated micro-grids, with a specific focus on the application of Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers to improve grid stability and operational efficiency[10].

The challenges associated with LFC in isolated micro-grids are multifaceted. Intermittent renewable energy sources, such as solar and wind, introduce significant variability into power generation, leading to rapid frequency fluctuations that traditional control strategies may struggle to manage[11]. Moreover, the dynamic and nonlinear nature of load profiles in micro-grids, coupled with varying loads and limited capacity, exacerbates the challenges in maintaining grid stability[12].

Traditional control strategies, such as Proportional-Integral (PI) controllers and fuzzy logic controllers, have been used in LFC within micro-grids[13]. However, PI controllers have limitations when dealing with the dynamic and nonlinear characteristics of micro-grid systems. Fuzzy logic controllers can provide improved performance compared to PI controllers but often require manual tuning, lacking inherent self-adjusting capabilities[14].

The advent of ANFIS controllers represents a promising advancement in LFC for isolated micro-grids. ANFIS controllers combine the strengths of fuzzy logic and neural networks, offering adaptability and self-tuning capabilities that make them particularly suited to address the dynamic challenges posed by micro-grid environments[15]. These controllers can automatically adjust their parameters to accommodate changing operating conditions, a critical feature given the rapid variations in isolated micro-grids[16].

Recent research findings have compared ANFIS controllers with traditional PI controllers, demonstrating that ANFIS-based LFC strategies result in reduced frequency deviations and improved grid stability. Several research projects have conducted experiments in real micro-grid environments, validating the efficacy of ANFIS controllers in mitigating frequency fluctuations and maintaining grid stability. These findings collectively support the potential of ANFIS controllers as an effective solution for addressing LFC challenges in isolated micro-grids[17].

3. PROBLEM FORMULATION

The proliferation of isolated micro-grids, characterized by decentralized energy sources and intermittent power generation, has ushered in a new era of energy distribution and management. While these micro-grids offer substantial environmental benefits and energy resilience, they present unique challenges concerning load frequency control (LFC). The core issue at hand is the need to maintain grid stability and operational efficiency within the dynamic and nonlinear environment of isolated micro-grids[18].

The primary challenge in isolated micro-grids is the integration of intermittent renewable energy sources, such as solar panels and wind turbines[19]. These sources are inherently variable, causing rapid fluctuations in power generation that can disrupt the grid's frequency. To address this, effective LFC strategies must be in place, ensuring that power supply matches consumer demand in real-time[20]. Failure to regulate frequency deviations can lead to voltage instability, load shedding, and even grid collapse.

Moreover, isolated micro-grids often serve diverse loads with unpredictable demand patterns[21]. The load profiles within these micro-grids can be highly dynamic and nonlinear, making it difficult for traditional control strategies to maintain frequency stability. Inadequate LFC can result in power imbalances, which, in turn, affect the quality of power supply and the overall performance of the micro-grid[22].

Traditional control strategies such as Proportional-Integral (PI) controllers and fuzzy logic controllers have been used to address these challenges[23]. However, their performance is limited, particularly when dealing with the intricate dynamics of isolated micro-grids. PI controllers are rigid and require manual tuning, making them less adaptable to changing conditions. Fuzzy logic controllers offer improved performance but may still require manual parameter tuning[24-25].

The advent of ANFIS controllers provides a potential solution to these issues. By combining fuzzy logic and neural networks, ANFIS controllers offer self-adjusting capabilities. They can automatically adapt to changing operating conditions, offering a dynamic solution for LFC in isolated micro-grids[26-27].

4. METHODOLOGY

In order to address the research questions and objectives outlined in the problem formulation, a well-structured research methodology is crucial. The methodology is designed to systematically investigate and analyze the application of Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers for enhancing load frequency control (LFC) in isolated micro-grids with the overarching goal of improving grid stability and operational efficiency**.**

- The initial step in this research methodology entails conducting a comprehensive literature review. This involves a thorough examination of existing studies, research papers, and relevant literature related to LFC in micro-grids, ANFIS controllers, and the challenges faced in isolated micro-grids. The insights gained from this literature review serve as the foundation for the subsequent research[28].

- To conduct empirical research, data collection is a central component. Data, both real-world and simulated, related to isolated micro-grids, including information on load patterns, energy generation, and grid stability indicators, is collected. These datasets are instrumental in validating the efficacy of ANFIS controllers in improving LFC and grid stability. The data collected is subjected to rigorous analysis using statistical and computational tools[29].
- The research involves the development of ANFIS-based LFC models, which are designed to mimic the behaviour of isolated micro-grids. These models are configured to provide dynamic and self-adjusting control over frequency deviations and power imbalances. Developing these models includes the selection of appropriate input parameters, the training of ANFIS networks, and the fine-tuning of control rules.
- The ANFIS-based models are subjected to extensive simulation and experimentation. Various scenarios and conditions are tested to evaluate the effectiveness of ANFIS controllers in mitigating frequency fluctuations and improving grid stability. These experiments are compared with traditional control strategies, such as Proportional-Integral (PI) controllers and fuzzy logic controllers, to assess the relative performance[30]

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. Here PI controller is used as a conventional controller to limit the change in frequency of different load change in the two areas interconnected systems.

4.1.1 Simulink model of two area system without wind turbines

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, it is a more reliable source to fulfil large block of loads. The Matlab / Simulink model to the PI controller for two areas system is shown in fig. 4.1

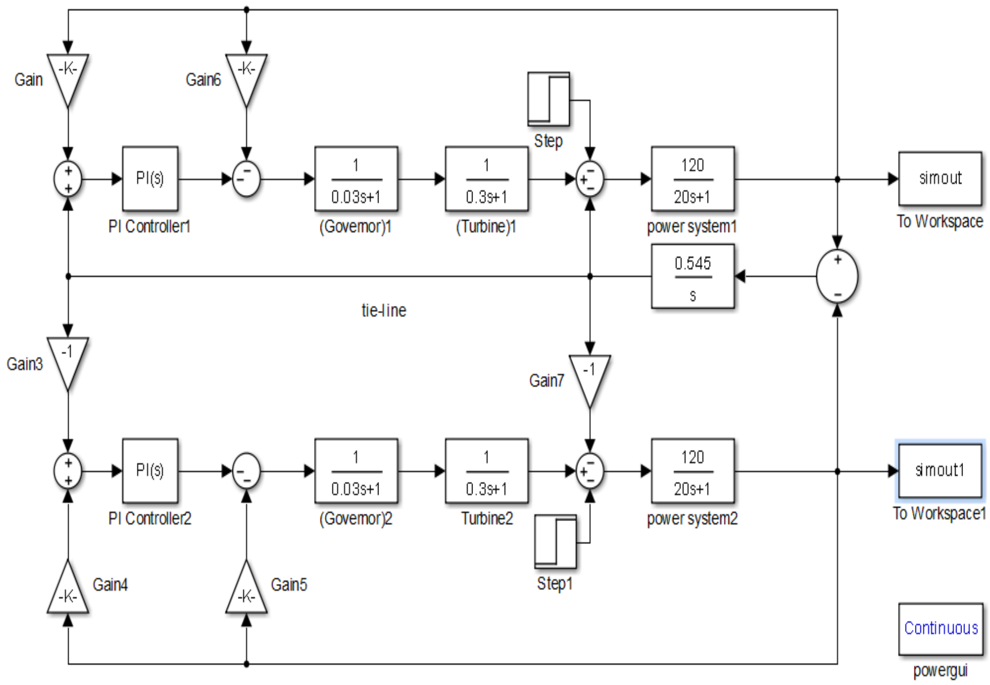

Fig 1: Simulink model of two area load frequency control with PI controller

All the optimized gains of PI controllers are set in the controllers. The optimized values of the gains are tabulated in table 4.1

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

As the conventional or non-renewable sources are available in limited volume and also costlier than renewable sources. There to fulfil the proper demand of power, at least cost the integration of renewable sources is being practiced. Although the conventional plants are used as base plants the renewable power generators plays an important role against variable power demand.

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. The both generators may be controlled independently, or there may be coordinated control for achieving better stability in the system.

The Matlab/Simulink model of wind integrated two area power system is shown in fig 4.2

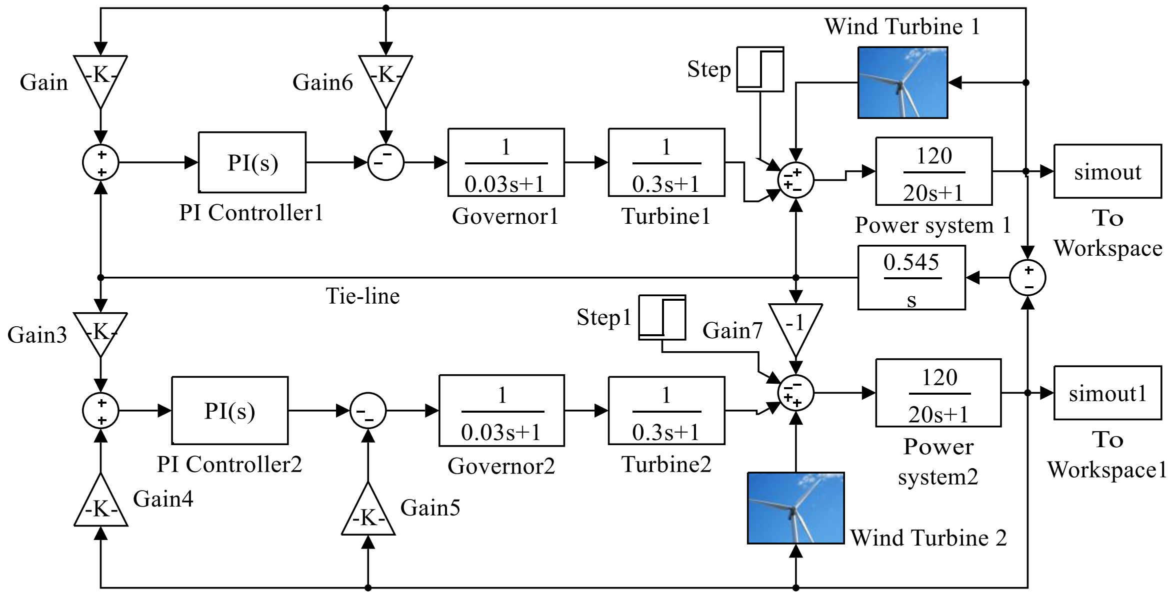

Fig 2: Wind integrated two area load frequency control model using PI controller

All the optimized gains of PI controllers are set in the controllers. The optimized values of the gains 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

4.2 Load 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.

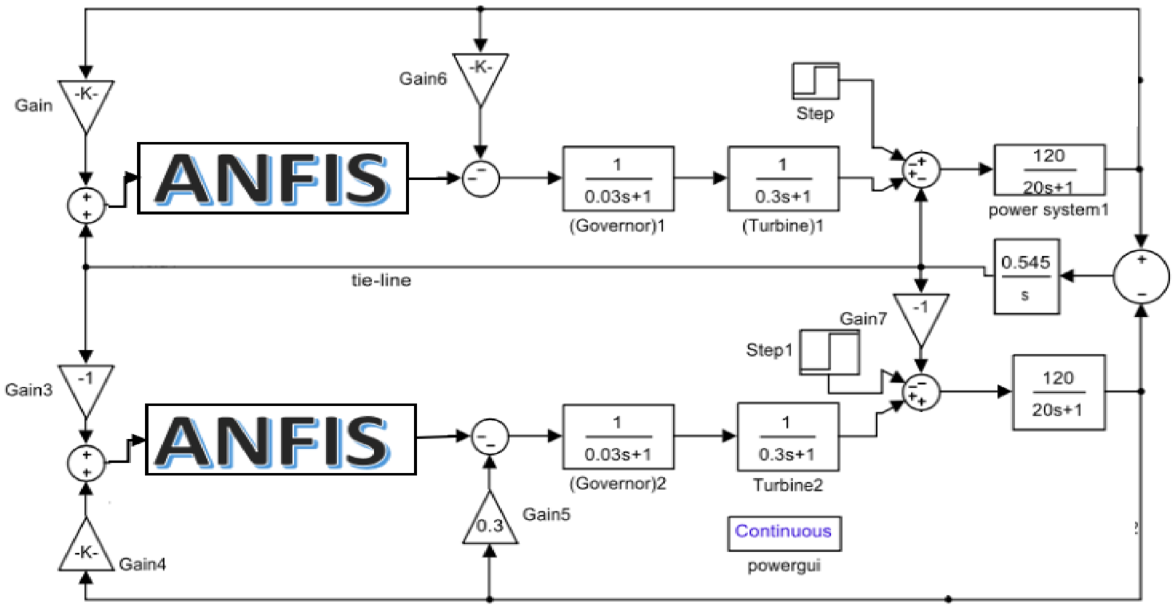

Fig 3: Simulink model of two area load frequency control with ANFIS controller

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.

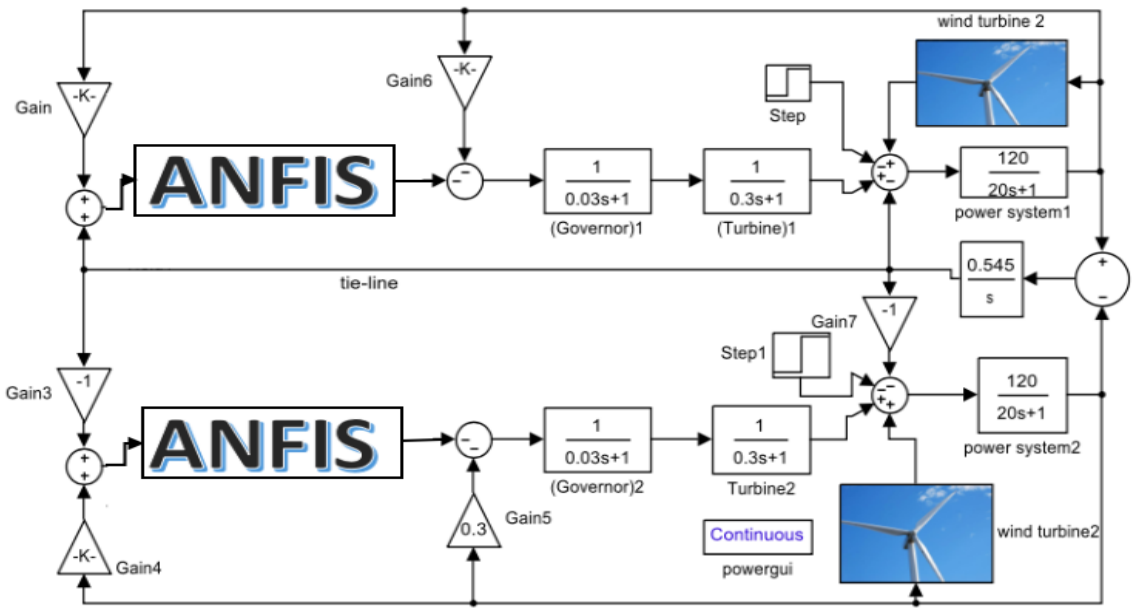

Fig 4: LFC of wind integrated two area power system using a ANFIS controller

5. RESULTS

5.1 Comparative frequency responses of the two area power system using PI and ANFIS controllers without wind turbines

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 0.05 p.u. The graphs of both controllers are plotted in same plot to easily compare the controller performance.

Case 1 Dynamic responses with 1% load change in area1

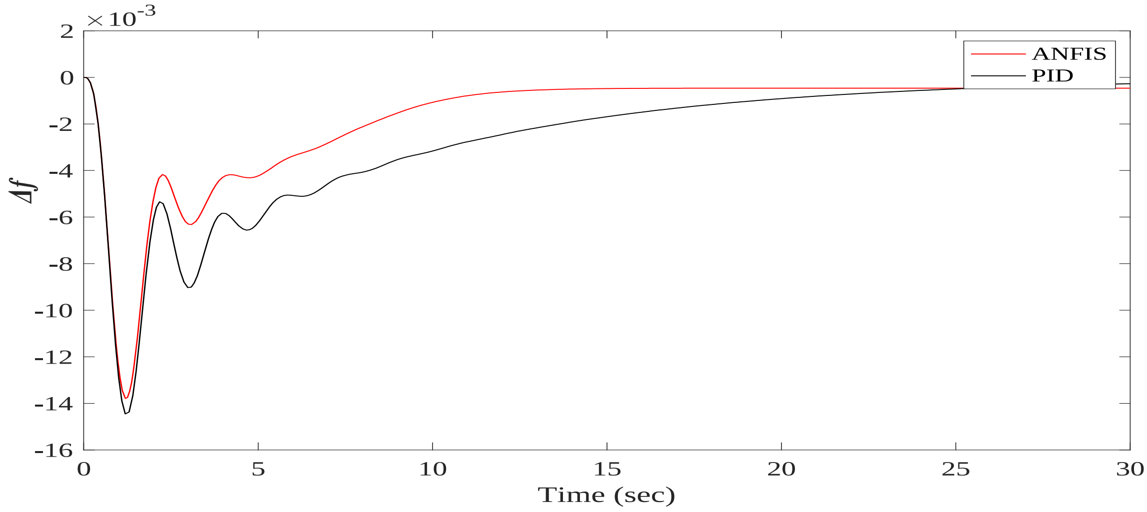

Fig. 5: Frequency response of area 1 with PI and NARMA L2 controllers with 1% load change

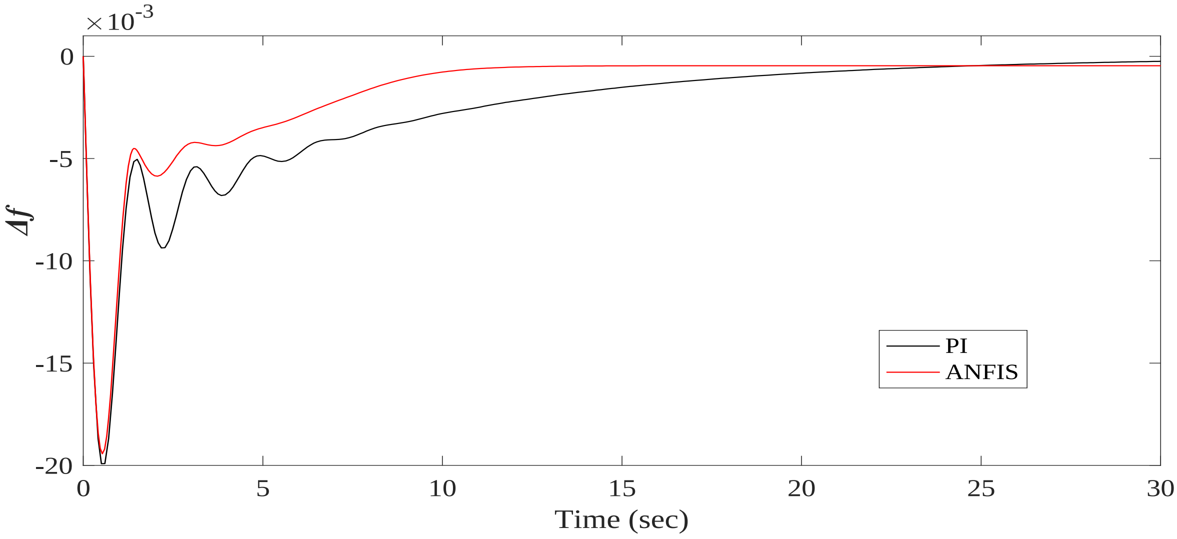

Fig 6: Frequency response of area 2with PI and ANFIS controllers

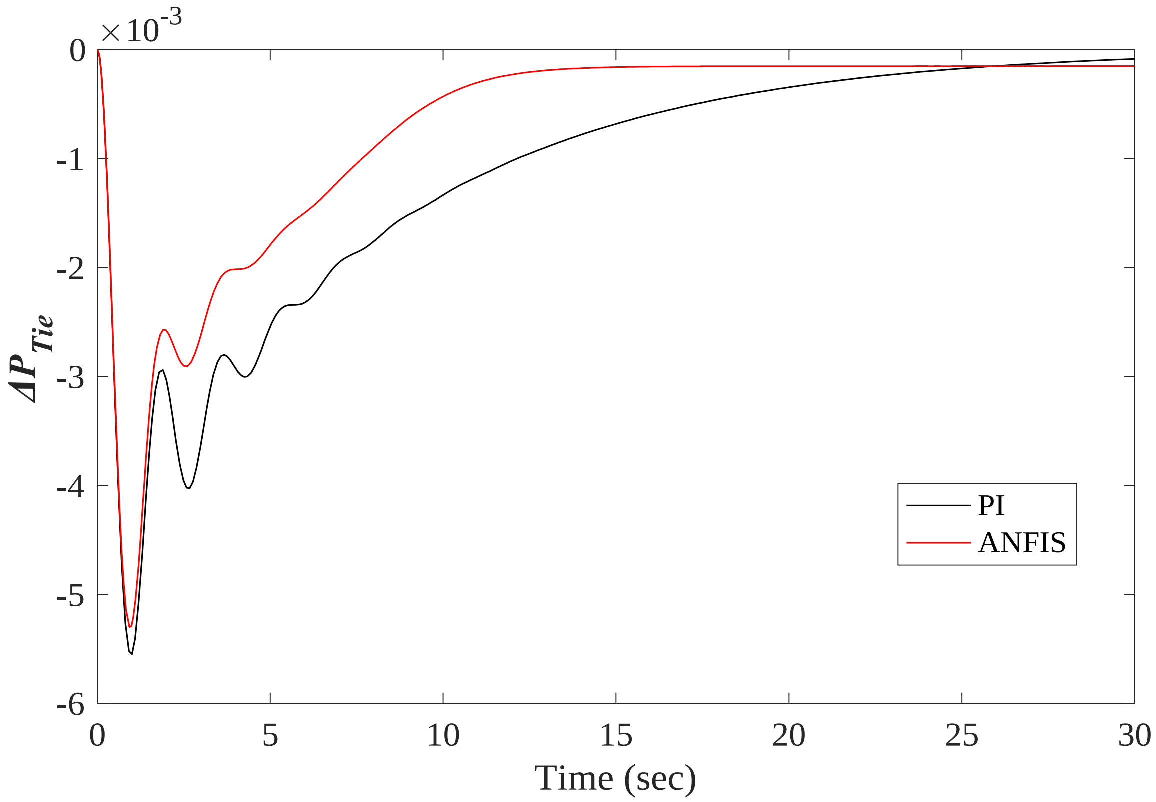

Fig 7: Change in tie- line from area 1 to 2 with 1% load change

Case 2 Dynamic response with 5% load change in area 1

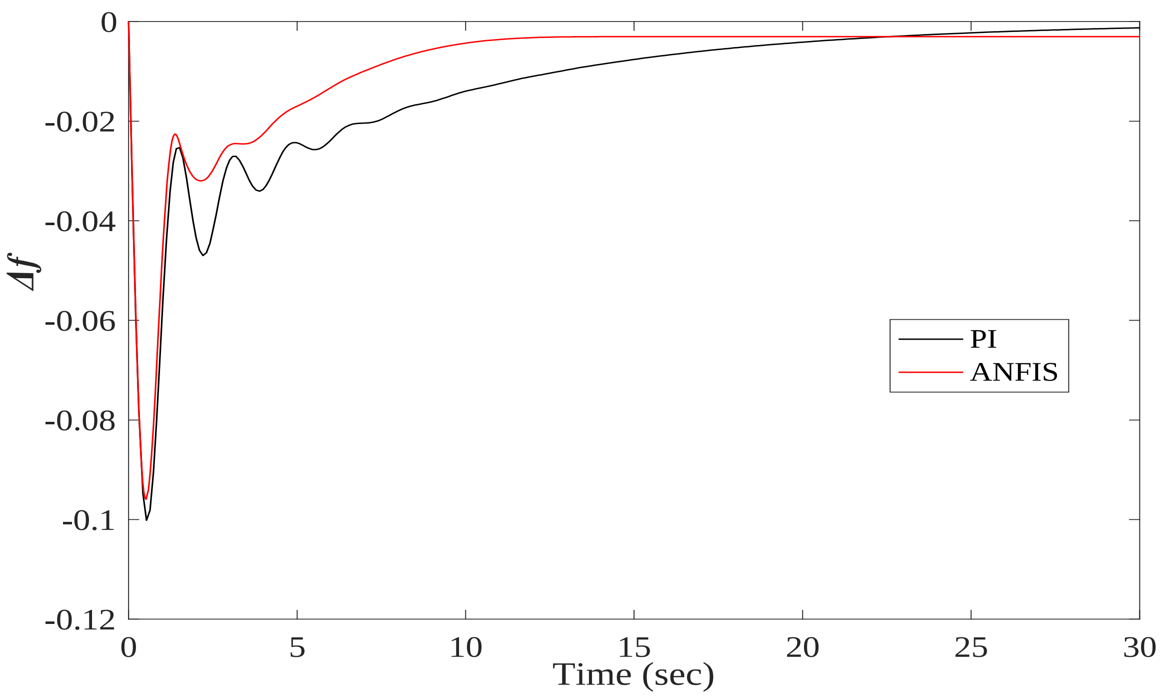

Fig 8: Frequency change in area 1 due to 5% load change in area 1

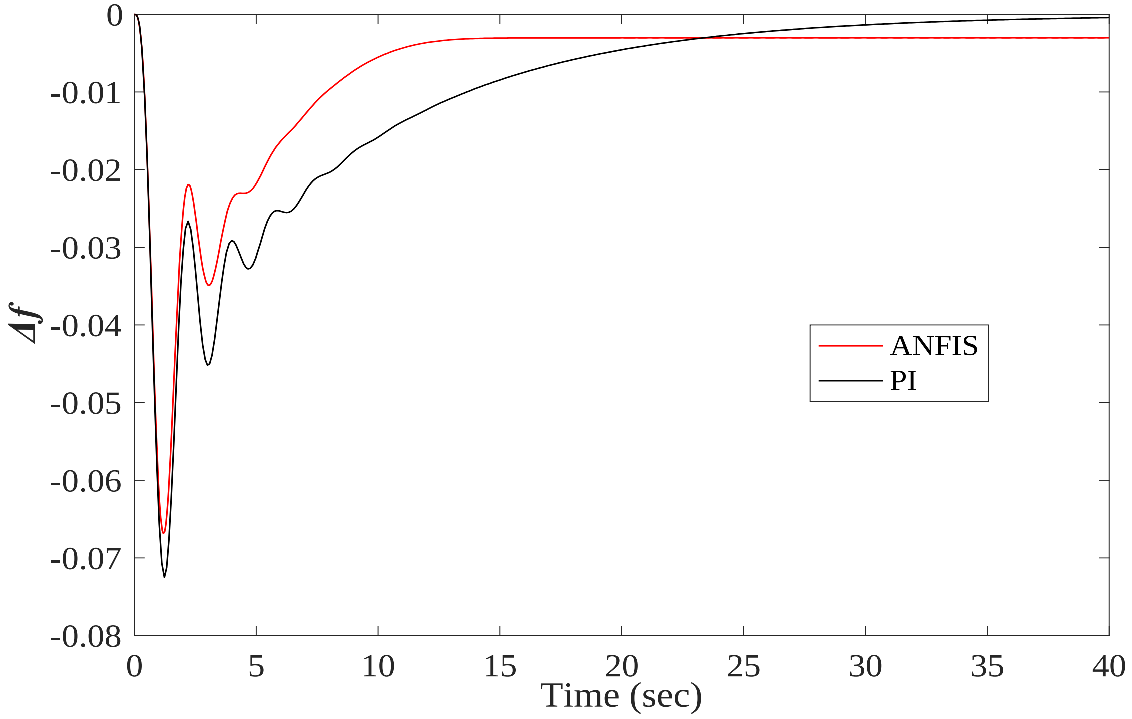

Fig 9: Frequency change in area 2 due to 5% load change in area 1

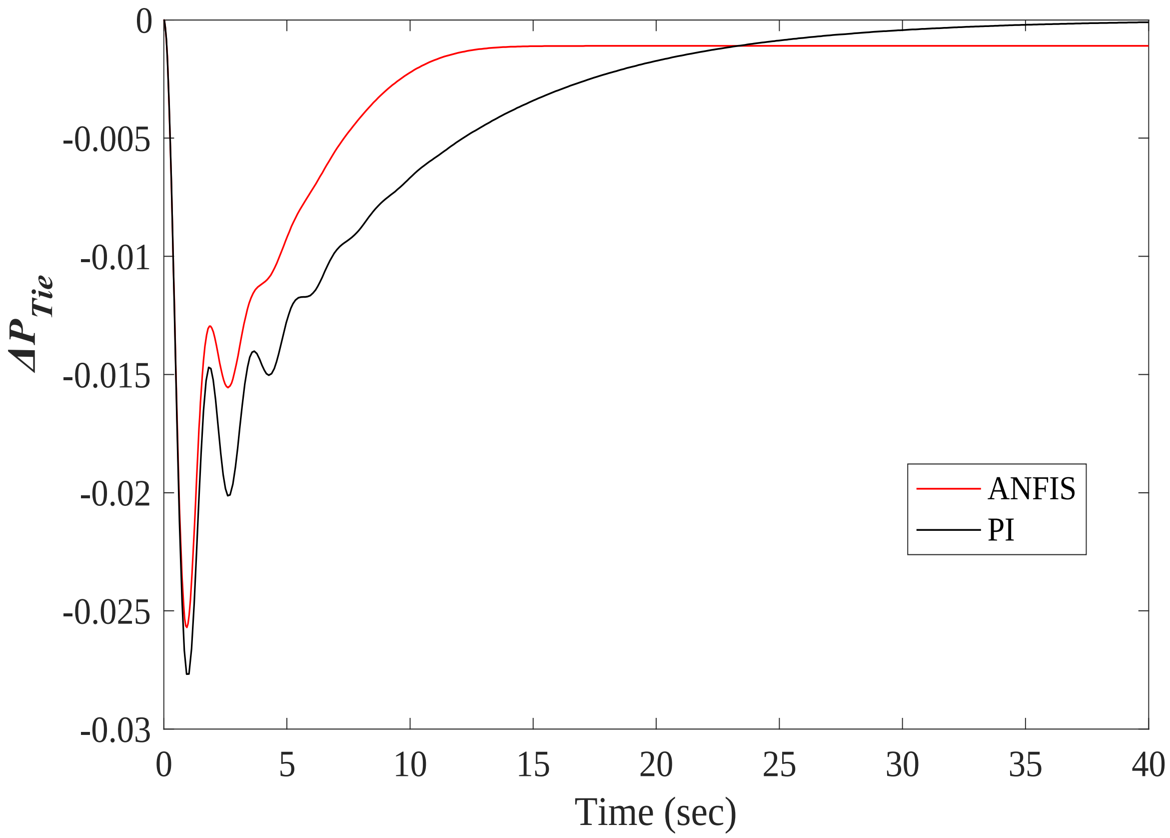

Fig 10: Tie-line power deviation from area 1 to area 2 with 5% load change in area 1

Table 3: Performance of wind integrated system PI and ANFIS in terms of peak overshoot and settling time

Load Change	PI Controller						NARMA L2 Controller					
	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%	0.016	17	0.011	20	0.0055	20	0.020	4	0.002	3	0.004	5
5%	0.065	21	0.038	24	0.013	23	0.001	5	0.005	4	0.006	7

5.2 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 help to show graphically the performance of both the controller in the presence of wind turbine.

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

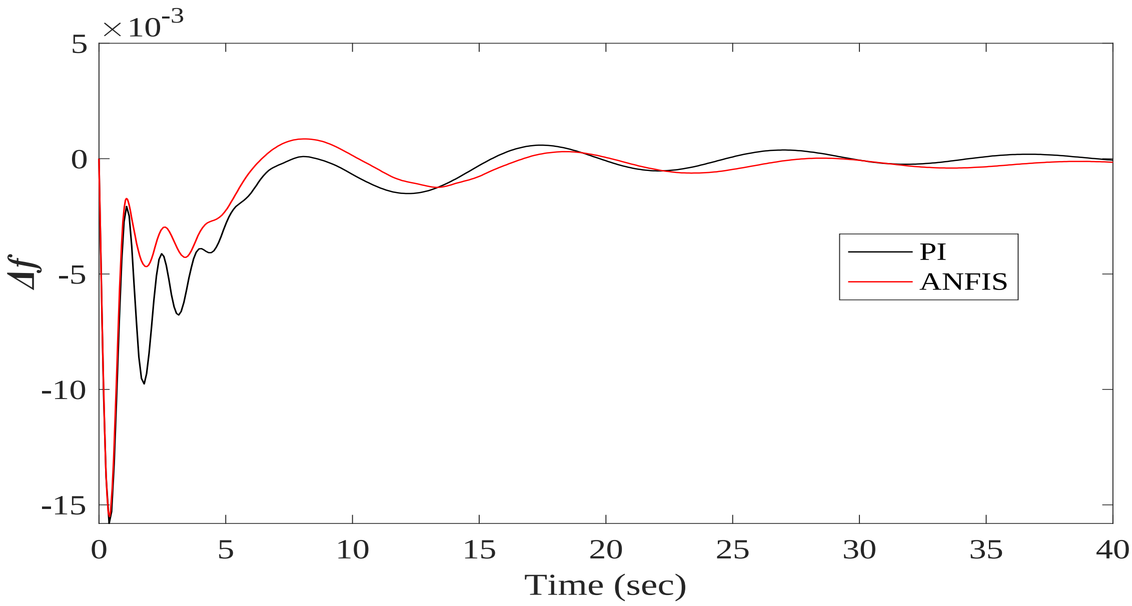

Fig 11: frequency response of area 1 with PI and ANFIS controllers

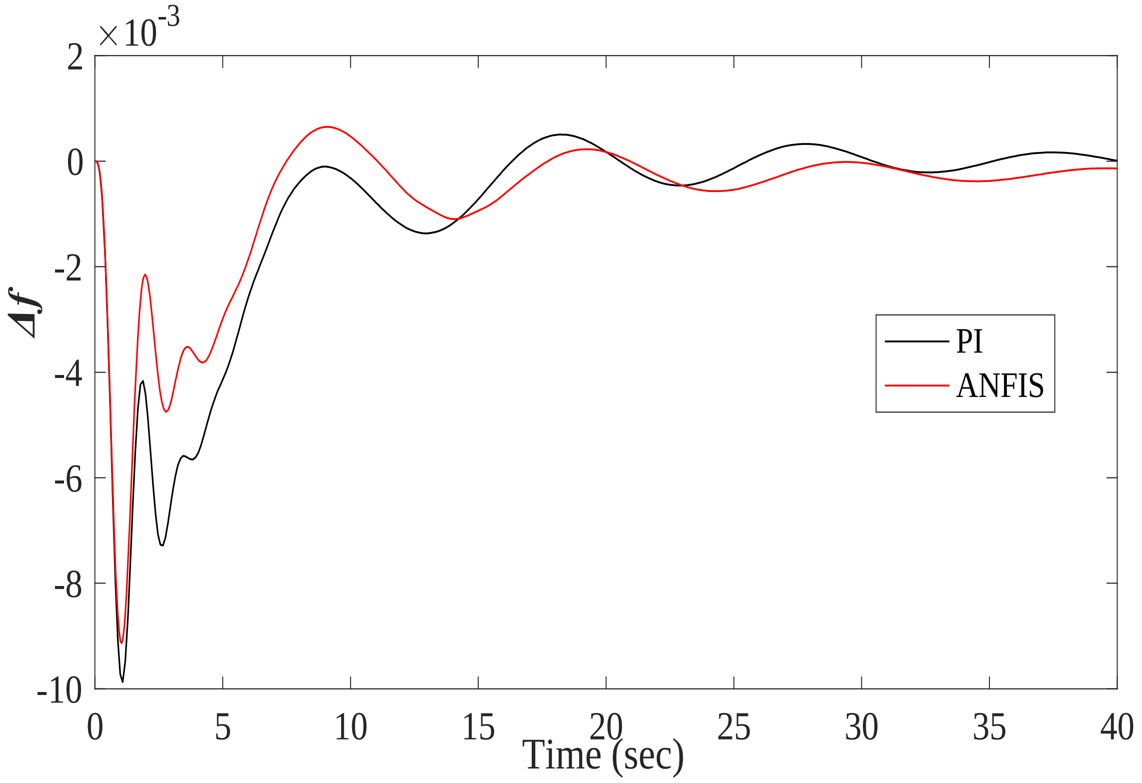

Fig 12: frequency response of area 2 with PI and ANFIS controllers

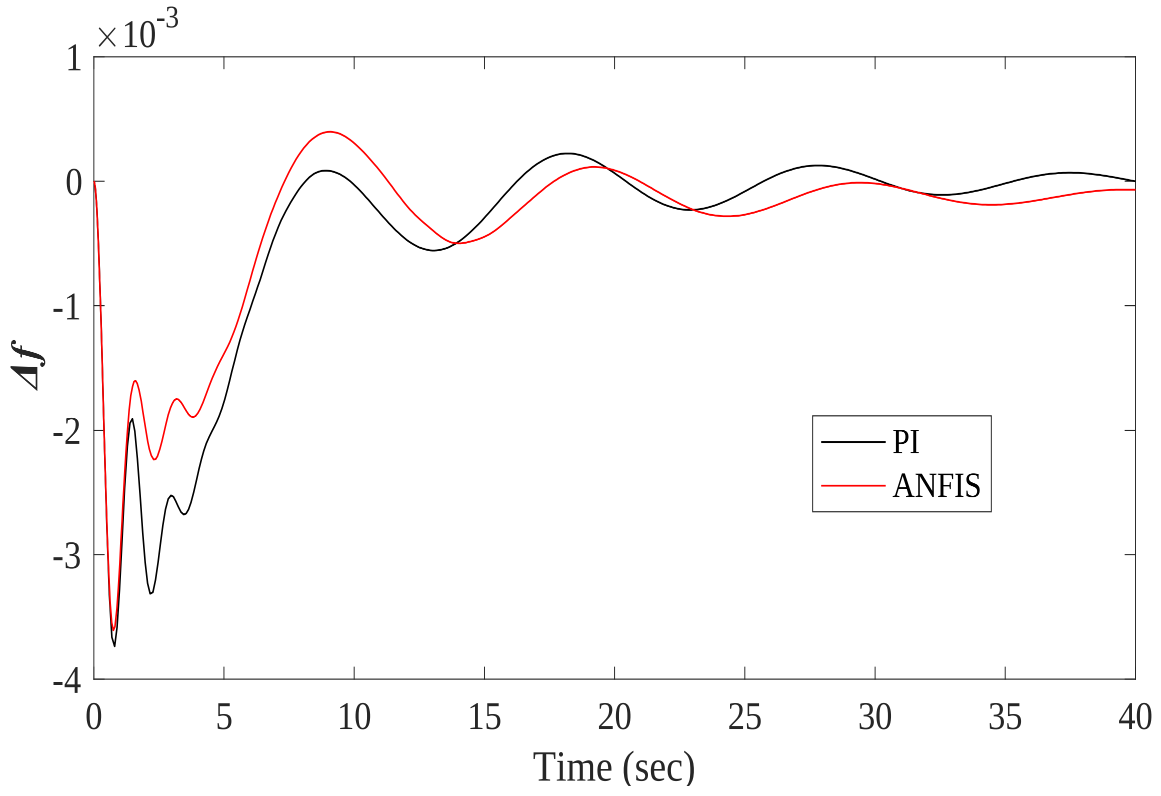

Fig 13: Tie-line power deviation from area 1 to area 2 with 1% load change

Case 2 with 5% (0.05 p.u.) load change in area 1

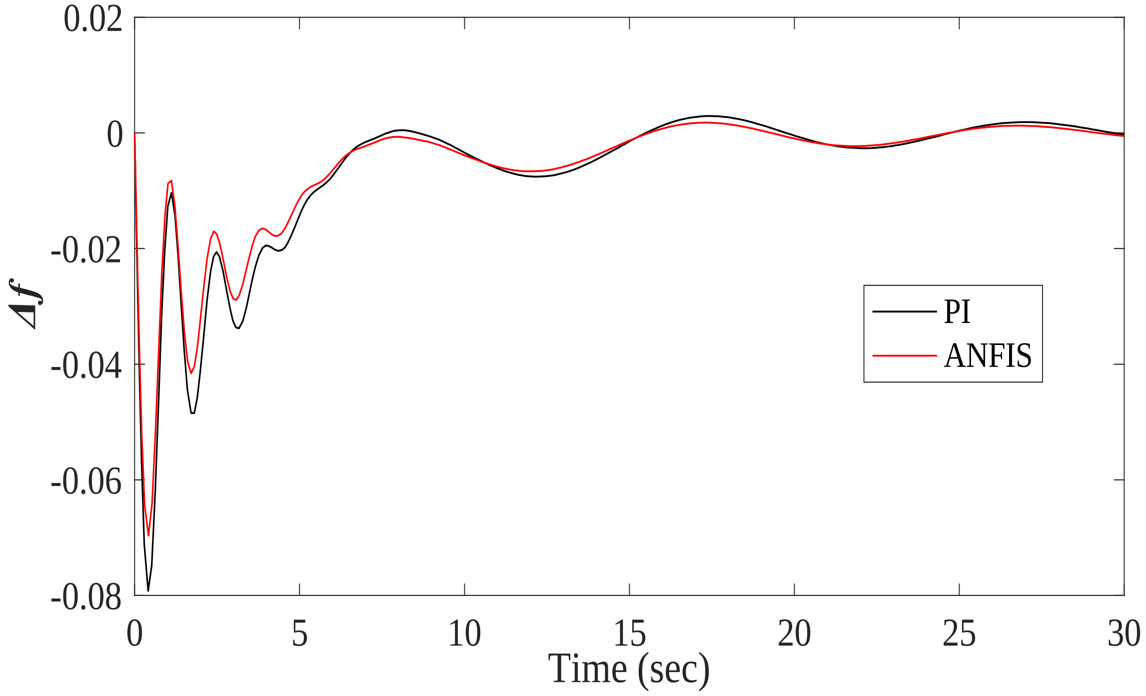

Fig 14: Frequency response of area 1 of two area system with 5% load change in area 1

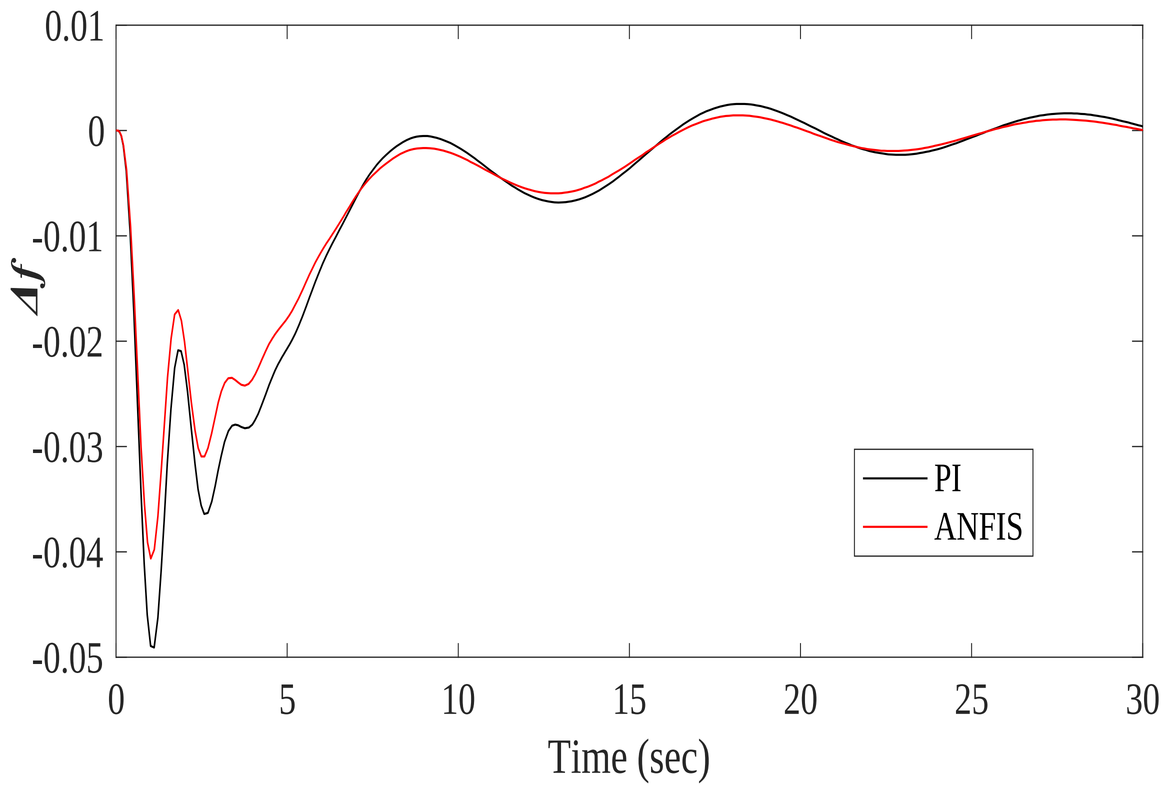

Fig 15: Frequency response of area 2 of two area system with 5% load change in area 1

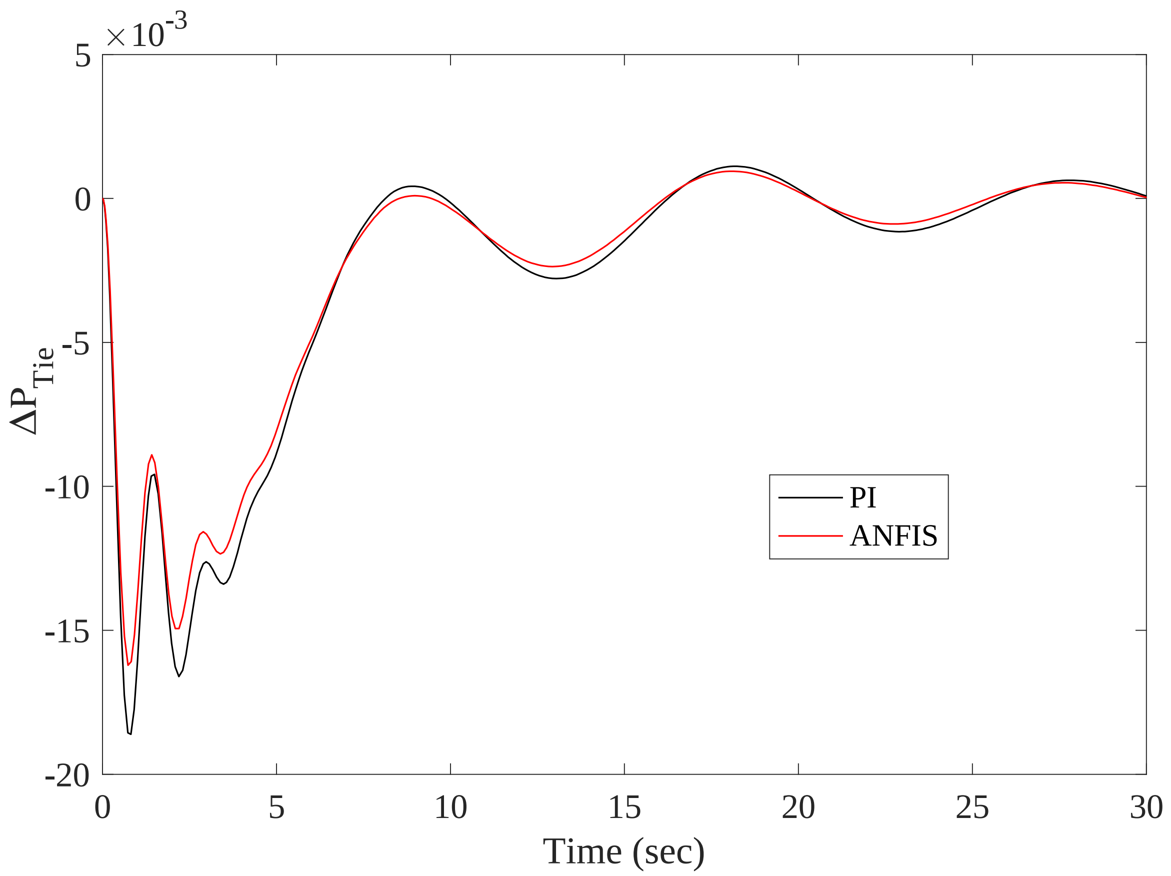

Fig 16: Tie line power deviation from area 1 to area 2 with 5% load change

Table 4: Performance comparison of wind integrated PI and NARMA L2 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%	0.056	18	0.01	33	0.038	34	0.01	6	0.006	17	0.0021	10
5%	0.058	19	0.028	17	0.01	20	0.03	12	0.008	12	0.0025	14

6. 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. Both PI 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 ANFIS leads in terms of minimizing peak overshoot and settling time. Also, it is important to notice that ANFIS reduces settling time with raising system load.

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