LOAD FREQUENCY CONTROL OF ELECTRIC POWER SYSTEM OF DOUBLY FED INDUCTION GENERATOR

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ABSTRACT

The majority of load frequency control (LFC) are outfitted with integral controllers. The variable speed of Doubly Fed Induction Generator (DFIG)-based wind turbines results in variable power generation and nonlinearity in the systems. Large frequency deviation resulting from increased wind power penetration. The integral gain is set to a level that strikes a balance between rapid transient recovery and low overshoot in the overall system's dynamic response. In addition, these controllers are sluggish and cannot account for changes in operating condition and nonlinearity within the generator unit. This places stress on thermal and quick-response generators (Increased requirements on system flexibility). Additionally, it lacks robustness. Therefore, controllers based on Artificial Neural Networks (ANN) can alleviate these issues. The proposed LFC study has implemented ANN-based ANFIS controllers on two area wind integrated power systems in order to simulate the dynamic response of control areas with different loading conditions. The obtained simulation results are satisfactory. The results indicate that ANN-based ANFIS controls wind-integrated nonlinear systems more effectively.

Keywords: Load frequency control (LFC), Doubly fed induction generators (DFIG), Electric power systems, Proportional Integral Derivative (PID)

1.0 INTRODUCTION

Most industries have utilised Proportional-Integral (PI) controllers as conventional frequency controllers for over a decade. Several controlling methods were utilised to determine the optimal gains for PI controllers. The Ziegler-Nichols technique is the simplest experimental method for determining the optimal value of gains (proportional (kp) and integral (ki)) for a control optimization problem, in comparison to the Bode plot.

Global penetration of Renewable Energy Sources (RES) has increased in recent years. With the increasing demand for and benefits of RES, it is advantageous to combine it with conventional power generators. By integrating renewable sources, problems such as depletion of fuels, global warming emissions, destruction of wildlife, and rising pollution levels can be resolved. RES are comprised primarily of solar, wind, tidal, and geothermal energy, among which wind power is the cleanest, most reliable, and most sustainable source for generating electricity. The frequency and voltage mismatch between these resources and the main grid is the greatest obstacle to their integration.

Controlling the frequency deviation in an integrated renewable source system is a difficult task. Previously, frequency deviation was controlled using conventional controllers. After the introduction of renewable power generators, controlling active power generation and frequency change becomes quite complicated. Renewable generators, such as wind turbines, generate variable power proportional to the speed of the turbine blades, resulting in uncertainty in power generation [1]. *Bevrani et al.* [2] discussed about fuzzy logic tuned PI control technique. This instantaneous control of changes in frequency and tie-line power is essential for the system's smooth operation in the presence of high wind penetration. The PSO method has been enhanced to incorporate parameters of membership functions. *Janaka Ekanayake et al.* [3] present the concept of an additional control loop connected to a DFIG-based wind turbine to support the inertia response by discharging the turbine's kinetic energy when the generator's frequency decreases. The paper demonstrates that large changes in rotor speed in DFIG necessitate strict frequency regulation. The additional reference power generated by the DFIG wind turbine is derived from the rate of frequency change and network inertia. This additional power from the wind turbine contributes to primary frequency control, preventing system inertia from decreasing. In addition to the generation rate constraints, *Liu Xiangjie et al.*

[4] discussed the application of predictive algorithm for the LFC. In his investigation, he employs this generalised predictive algorithm for the LFC to create a Controlled Auto-Regressive Integrated Moving Average model (CARIMA). The outcomes of his work confirmed the practicability of the proposed algorithm. *B. Franoise et al.* [5] explained the application of layered neural networks for non-linear system control. In addition, the implementation of a feed-forward neural network controller within a two-area system that can further reduce frequency variation and produce zero steady-state frequency error was discussed. The outcome demonstrated the training of the controller using back propagation and a time algorithm. *A.P. Birch et al.* [6] discussed the use of neural networks in the predictive LFC standard. In addition, the advantages of the proposed control scheme over the conventional schemes were discussed. The results validate the efficacy of the proposed technique, which can further enhance the system's overall efficiency. In his work, *D. K. Chaturvedi et al.* [7] discussed a generalised neural network that will facilitate the implementation of a nonlinear neural network. In addition, he discussed the various disadvantages of conventional schemes that can be overcome by the proposed scheme, thereby aiding in the minimization of unwanted frequency variations and enhancing both the performance and stability of the system. *A. Demiroren et al.* [8] discussed the use of an artificial neural network in the AGC of a two-area system. This paper explains the effect of computer simulation on a two-area interconnected system, as well as the effect of various parameters, such as the re-heater effect and the governor dead band effect. The obtained results demonstrate that ANN control can effectively dampen oscillations caused by load fluctuations. *H. Shayeghi et al.* [9] discussed the use of a non-linear ANN controller that depends entirely on the AGC of the power system. The simulation result demonstrated the implementation of the proposed controller, which was both highly effective and more efficient in the case of GRCs. In addition, it demonstrated that the proposed controller is more capable than conventional PI controllers. *A. Demiroren et al.* [10] described a layered ANN controller for the minimization of LFC-related problems in the power system and implemented it in three interconnected thermal and hydro regions. The study's findings demonstrated that this controller is more effective than conventional ones.

2.0 LITERATURE REVIEW

P. Wong [11] discussed the use of artificial intelligence in neural-related applications. In addition, the application of artificial intelligence to the power system was discussed. In addition, it discussed the artificial intelligence technique that was subsequently employed for the various conventional artificial tool applications. *Wei Zhang et al.* [12] proposed a coordinated wind turbine control strategy to enhance LFC. In addition, he designed a system with coordinated control to allow wind turbines to contribute to the multi-area LFC problem. The stability of the designed control scheme under nonlinearity and load change is verified. The coordinated unloading scheme is used to track active power demand from the system response in order to design wind-generated models. This coordinated control strategy can achieve a rapid response to load changes without incorporating pitch angle control for wind turbines. The impact of this control is investigated via simulation of system design. *D. C. Prowse* [13] discussed the use of the AGC simulation programme and the implementation of nonlinear Optimization logic, which can aid in the creation of ACE filter algorithms. The outcomes demonstrated the efficacy of the proposed technique by reducing the number of control actions and contributing to the enhancement of control performance. *Elgerd and Fosha* [14] were the pioneers in proposing the optimal frequency governor for a two-area power system. Both control areas are equipped with non-reheat steam turbines for the development of a model for load frequency control. In addition, they demonstrated optimal multi-area active power and frequency regulation. The American Power Systems Committee specifies that the frequency bias for each control area must be equal to the area's frequency response characteristic (AFRC). However, the committee failed to explain the rationale behind this practise, and the author suggested and demonstrated with optimal control methods that not only improved results, but also greater stability margins, can be obtained by adjusting the bias to a slower rate. *Fosha and Elgerd* [15] discussed the enhancement of the state variable model for multi-area load frequency issues. Mathematical equations were required for the implementation of the advanced control scheme. Also discussed was the feedback controller, which was significantly more effective in terms of construction than the controller previously designed. The result demonstrates effective methods for enhancing the dynamic response and stability limitations of the load frequency control system. *Bunker et al.* [16] discussed the impact of instantaneous variations in wind power on the operation of the system when the components were further subdivided into slow, fast, and ramp components. A long-term simulation model demonstrated that changes in wind power have a minor impact on the overall normal operation of the power system, but there is still a risk of random increases in wind power and power demand that can exceed the system's remaining capacity. In addition, it discussed the various wind-related methodologies and control area performance that can aid in connecting the primary grid to the remainder of the system. *Lei et al.* [17] discussed the implementation of a proposed DFIG wind model that employs a power converter as the controlled voltage source to regulate the flow of rotor current in order to obtain the optimal power output. *Muljadi et al.* [18] discussed the use of wind turbines with variable speed for effective pitch control. In addition, the controlling scheme for the system to minimise load while maximisi energy for improved performance was discussed. By combining a generator and a converter site, effective control of the wind turbine could be achieved during the period of low to medium wind speeds in order to extract the most energy from the wind. During periods of high speed, the turbine was well-managed in order to maintain aerodynamic power. The generator load control and pitch control were utilised for effective control. The purpose of both schemes was to regulate the wind turbine's operating region. The results demonstrated the scheme's effectiveness in minimising load while maximising energy over a broad speed range. *DE Almeida et al.* [19] discussed the control scheme for effective frequency regulation of a system that can be used by an induction feed generator. Using this control scheme, the wind generators operated in accordance with the extraction curve in such a way that the increase or decrease in wind power is entirely dependent on the unintended variations in the system's frequency.

3.0 METHODOLOGY

3.1 POWER SYSTEM MATHEMATICAL MODELLING

Typical power system model with generating units, tie-lines, and power system loads. Power produced by a generator from natural sources, transmission lines transmit bulk power from generating units to loads, and a distribution system provides power to various loads. The fluctuating load on the power system causes disturbances that can lead to instability and, in extreme cases, blackouts. Using a mathematical model and Simulink, it is necessary to examine load change response in order to solve this issue. A mathematical model of load change is obtained by linearizing the operating point in real time. However, nonlinear differential equations must be solved for large perturbations. LFC is fundamentally reliant on small signal analysis. The linearized models of the governor, turbine, and power system, which are frequently used for modelling isolated and interconnected systems.

Generating Units

A conventional power plant generator that converts mechanical or chemical energy into electrical energy. Thermal power plants use a number of control valves to regulate the steam flow and turbine speeds in order to produce precisely the amount of power required.

Governor Model

The governor is used to regulate the speed of the power-generating machine by establishing a reference set value ref that is compared to the value of the speed sensor to determine the speed error. The load fluctuates based on the power demand. Altering the set value of the speed governor in response to a change in load, while keeping the system's frequency constant, can also be used to vary the output of a generator. The difference between generated power and scheduled power is fed back via droop R. The block diagram of the speed governing system is depicted in Fig. 1.

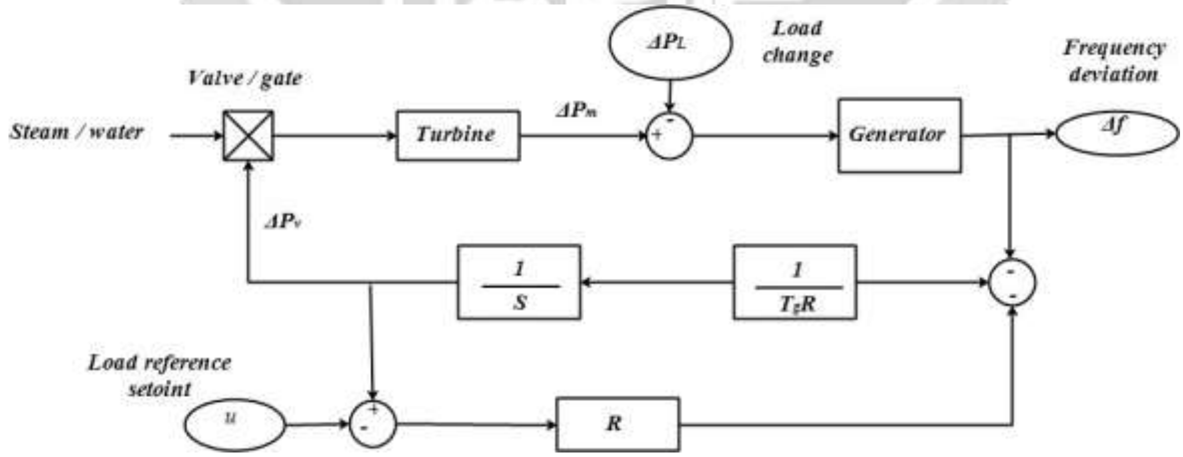

Fig 1: Speed governing system block diagram

The response of governor is given by

$$\Delta P = \Delta P - \frac{1}{\;} \Delta f \qquad \text{(i)}$$

g c R

Taking Laplace transform of equation (ii)

$$\Delta P_g(s) = \Delta P_c(s) - \frac{1}{R}\Delta F(s) \quad \text{(ii)}$$

Hence the overall transfer function of speed governor is shown in fig 2

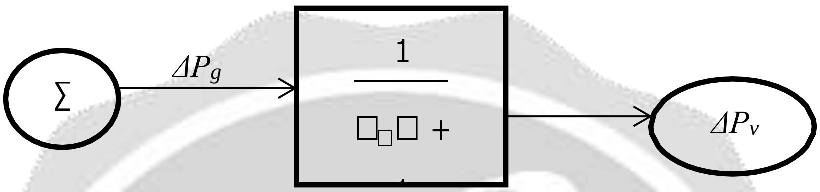

Fig 2: Transfer function of governor

3.2 WIND POWER GENERATION

Wind Turbines Technology

The classification of wind turbines was based on the energy conversion principle of aerodynamic drag and lift. Modern wind turbines convert energy using the aerodynamic lift principle. These turbines' blades interact directly with moderately fast-moving wind, resulting in drag force in the wind's direction. The lift force, which is perpendicular to the drag force and several times greater than the drag force, is responsible for rotor movement. There are two types of aerodynamic lift turbines, determined by the orientation of the spin axis.

i. Horizontal axis turbine

ii. Vertical axis turbine

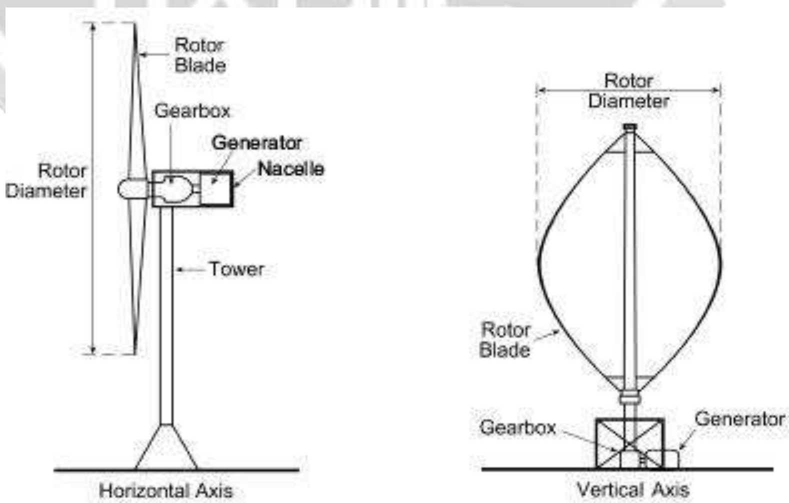

Fig 3: Horizontal and vertical axis type of wind turbines

The main shaft of the rotor in a turbine with a vertical axis is set vertically. It is advantageous to locate generators and gearboxes close to the ground in these turbines. Horizontal axis turbines are widely employed in the industrial sector. In these turbines, the axis of the rotor's rotation is parallel to the wind flow and the ground's surface. The wind blows through both surfaces of an air foil-shaped blade, but the speed is faster through the upper side and slower through the lower side, creating a low-pressure region above the air foil with respect to the lower side. Aerodynamic lift is the difference in pressure between the top and bottom surfaces. The turbine blades are fixed to move in a plane with the hub as the centre, such that rotation about the hub is caused by lift force and drag force in addition to lift force. It consists of a tower-mounted nacelle, a gearbox, and a rotor. Small wind turbines use tail vanes to orient the rotor and nacelle into the wind, whereas horizontal axis turbines typically have two or three or even more blades.

3.3 DFIG-based Wind Turbine Control Model

Fig 4 depicts a block diagram of the transfer function for a power system comprising conventional and non-conventional generators. Both generators contribute to frequency regulation. Subtracting the incremental load change active power demand (PD) from the total thermal and wind generation (PNC) yields the value of power exported from the neighbouring area, which can be expressed by the equation 2.45.

$$\Delta P_g + \Delta P_{NC} - \Delta P_{12} - \Delta P_D = \Delta P_f \quad \text{(iii)}$$

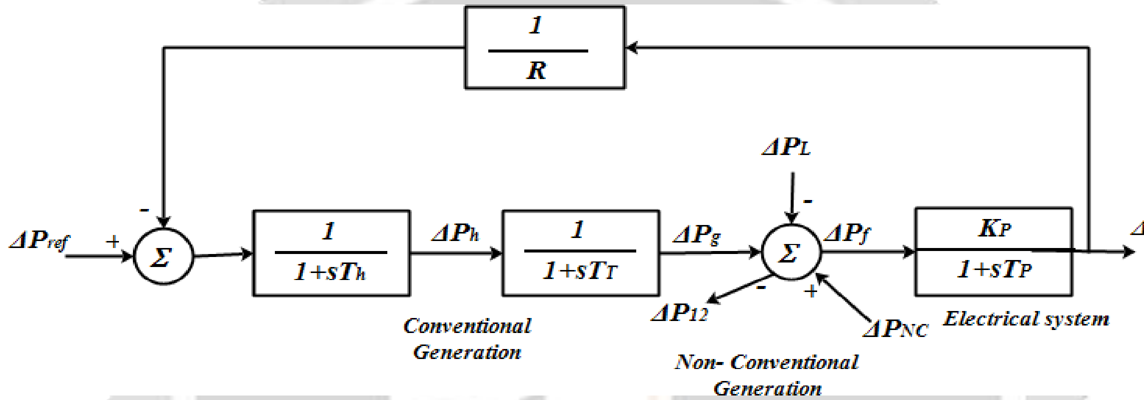

Fig 4: Dynamic model of power system with hybrid generator

$$T_P = \frac{2H}{fD} \quad \text{(iv)}$$

$$K_P = \frac{1}{D} \quad \text{(v)}$$

$$\frac{2H}{f}\frac{d\Delta f}{dt} + D\Delta f = \Delta P_f = \Delta P_g + \Delta P_{NC} - \Delta P_{12} - \Delta P_D \quad \text{(vi)}$$

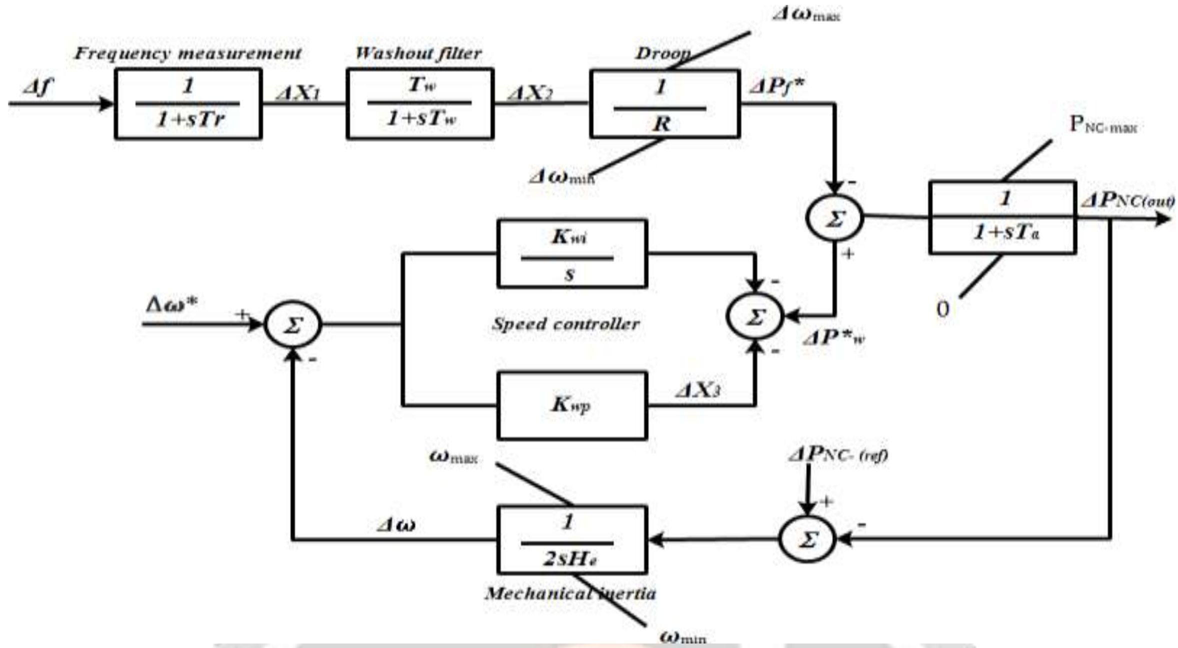

Fig 5: DFIG applied wind turbine control for frequency deviation

the use of DFIG-based wind turbines to maintain system inertia. The only difference between this figure and Fig. 5 is the addition of a second reference power dependent on the frequency change caused by the washout filter's time constant (T), which is based on the response of the conventional unit is primary control during transient.

3.4 Primary Frequency Control Applying DFIG-based Wind Turbine

The small perturbation model in Fig 6 represents the dynamic response of the thermal (non-reheat) and DFIG wind turbine integrated power system. This model simulates the primary frequency regulation using system parameters such as the time constants (Th and Tt) of the governor and turbine, the damping factor (D), the inertia (H), and the regulation droop (R) respectively. Kp and Ki of a DFIG-based wind turbine represent the system behaviour that is dependent on the values of the system parameters and the speed controllers. In the case of multiple generators that are interconnected, the equivalent regulations can be expressed as

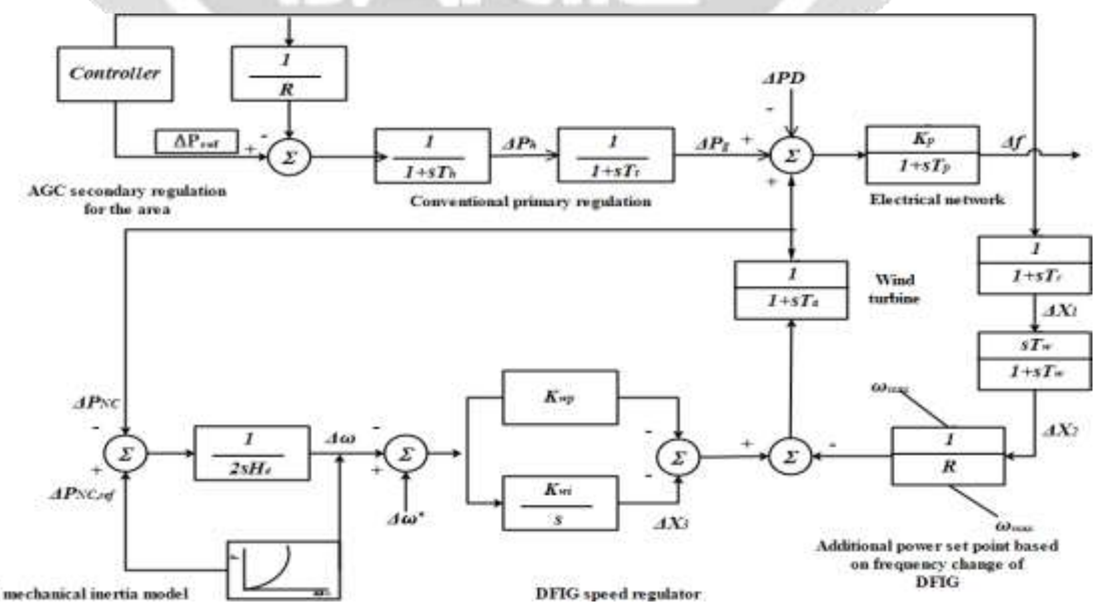

Fig 6: Dynamic Model for LFC with DFIG based Wind Turbines

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

Complex is the mathematical comparison of the frequency response of both controllers. Visualization and extracting the maximum and minimum values from graphs are facilitated by a graphical representation, which simplifies this study. The research was conducted under two distinct load-changing conditions: 0.01 p.u. and 0.05 p.u. The graphs for both controllers are plotted on the same graph in order to compare their performance.

Case 1 Dynamic responses with 1% load change

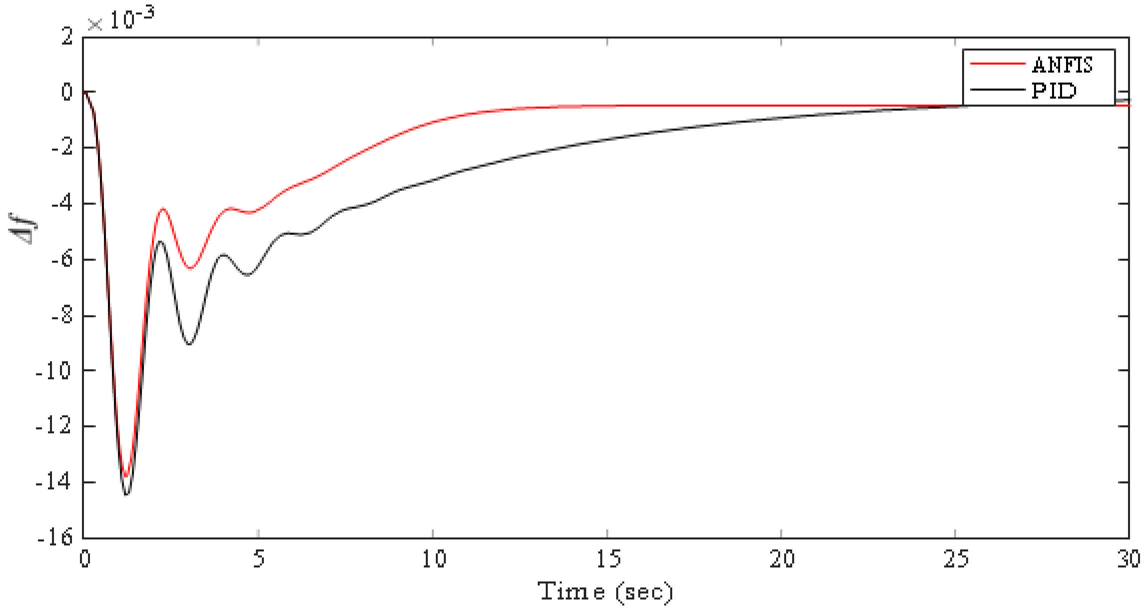

Fig.7: Frequency response with PI and ANFIS controllers with 1% load change of area

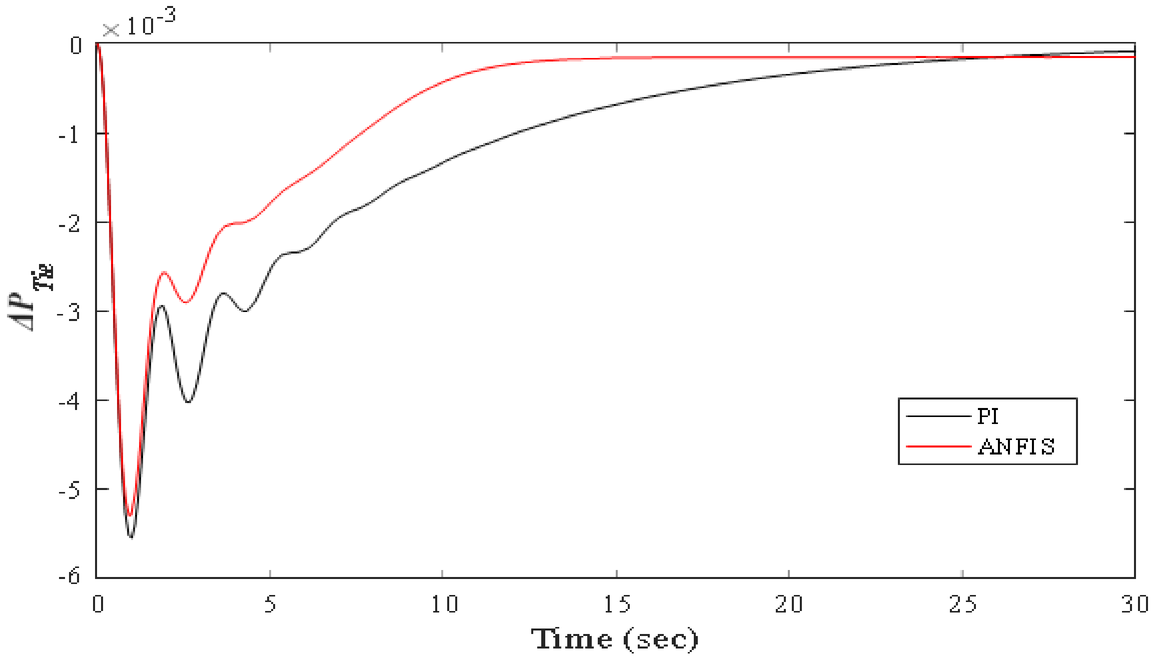

Fig 8: Change in tie- line with 1% load change

5.0 CONCLUSIONS

A model of a two-area wind-integrated transfer function with minor perturbations has been developed. The conventional PI controller tuned using the Ziegler-Nichols method yields satisfactory results for LFC in the absence of nonlinearity in the system. Nevertheless, wind turbines introduce a non-linearity into the system that cannot be ignored in the LFC problem. Therefore, the intelligent DFIG-based controller is introduced to address the control area's complexity. PI controller and ANFIS controller performance have been compared. The graphical results demonstrate that ANFIS reduces peak overshoot and settling time. Also, it is essential to note that ANFIS reduces settling time as system load increases

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