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Load Frequency Control Using Meta-Heuristic Techniques and Penetration of Wind Energy

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Abstract:

In light of the increasingly complex nature of our power systems, it is imperative that we ensure stability under any disturbance. Load frequency control is a crucial element in regulating power flow between interconnected areas and maintaining a constant frequency. Our dissertation proposes a multi-area load frequency control system for a three-area interconnected power system network, utilizing advanced artificial intelligence techniques. Fuzzy logic, Artificial Neural Network, and Genetic Algorithm techniques are employed to fine-tune the classical PID controller for each area. The dynamic performance of the power system is assessed through step load disturbance testing. With the integration of renewable energy sources, particularly wind energy, we leverage the stored kinetic energy in the wind turbine to mitigate frequency deviation. Our results demonstrate significant improvements in the system performance with minimum overshoot/undershoot, less settling time, and a better response achieved. The controller simulation is conducted using MATLAB software.

Keywords — **Neural Network; Genetic Algorithm techniques; Simulation; MATLAB**

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I. INTRODUCTION

With the ever-increasing complexity of power system configurations, maintaining a stable frequency and active power flow has become a significant challenge. Control strategies are necessary to ensure that the voltage and frequency remain within allowable limits while efficiently and reliably supplying electricity to the network. In a control area, it is crucial for the generators to work together and adjust their speed to maintain the frequency and power angles during disturbances. Any sudden changes in load can cause frequency and tie line power deviations, which could result in blackouts and damage to equipment. Therefore, accurate frequency measurement and load frequency control are essential to prevent system instability. To maintain a stable frequency, coordination and information exchange between power system control areas are critical. Load frequency control plays a crucial role in controlling real power, frequency, and tie line power flow within limits. It is a control mechanism that helps in regulating the power output of generators, ensuring that the frequency remains constant. The load frequency control system comprises various components, including the governor, power system stabilizer (PSS), and automatic voltage regulator (AVR). These components work together to ensure that the power output of the generators is adjusted to match the load demand, thereby maintaining a stable frequency. In conclusion, load frequency control is a critical aspect of power system operation, and its proper functioning is essential to prevent system instability. It is imperative to have a well-coordinated system that ensures accurate frequency measurement and control of real power, frequency, and tie line power flow within limits. With the right control strategies and equipment, power system operators can ensure that the network remains stable and reliable. Further, with the increase in the consumption of energy and due to depletion of available conventional energy resources it has become imperative to harness the renewable sources of energy one among which is Wind Energy. As per the precursory statistics published by WWEA (World Wind Energy Association), the capacity of wind turbines has reached a record of 975GW in 2021 in the world market. The increased demand for electricity mandates the use of renewable energy sources such as the Wind Energy Conversion System (WECS), which can be interfaced with the existing grid. Increased wind energy integration necessitated an intensive consideration of frequency regulation in the power system. The possibility of doubly fed induction generator-based wind turbines to contribute in suppressing the frequency deviation when connected to a multi-area interconnected power system is also examined in this work. The objective is to reach tolerable frequency deviation. The realm of Load Frequency Control has seen several attempts over the years, with the earliest being the use of flywheel governors of synchronous machines to control the frequency of a power system. However, this technique was found to be insufficient due to the significant time constant involved. Primary control alone is not enough for frequency control, and as a result, secondary controls are required. Secondary control entails managing the loading of different plants. However, classical controllers such as Integral, Proportional Integral (PI), and Proportional Integral Derivative (PID) are slow and do not make a significant impact on the system's response. The work presented in this report aims to enhance load frequency control in multi-area power systems by utilizing different techniques such as PID and Fuzzy logic controllers. The study compares the performance of these controllers for a three-area power system with three non-reheat thermal power units. The results demonstrate significant changes, including a decrease in overshoot/undershoot, reduced settling time, and improved frequency deviation performance. In conclusion, the primary objectives of load frequency control are to guarantee reliable and stable power supply by keeping the frequency of the power system within acceptable limits. The use of advanced control techniques such as PID and Fuzzy logic controllers can significantly improve load frequency control in multi-area power systems. As such, these techniques are an important consideration for power system engineers and operators looking to enhance their load frequency control capabilities.

1. Regulation of frequency
2. Maintaining the pre-scheduled power flow through the tie lines.
3. Equitable load sharing among the generating plants.

II. Literature Review

With the growth of power system network, increase in load demand, and harnessing of RES, the complexity of the electricity grid has increased. It has become imperative to make the system stable under any eventuality/disturbance especially during the generation and demand mismatch. Load frequency control helps in regulating the power flow between interconnected areas by keeping the frequency constant. The LFC has to maintain the frequency constant in case of any change in load and to maintain the tie line power to its pre-specified value between each area [1]. Further with the integration of renewable energy resources with the existing power system network, the LFC problem becomes complex due to reduction in total inertia of the system.

In [4] Hydro thermal system has been taken for system study. Each area comprises of both hydro as well as a thermal plant. To damp the oscillations PI controller has been used and tuned with FLC method a good response is achieved in overcoming the frequency deviation in a multi area power system.

In [5] Fuzzy Logic Control application has been considered for observing the frequency deviations for a three area power system. For the load perturbation in areas, the transient behavior of frequency has been studied. Fuzzy logic improved the system performance with sufficient reduction in the overshoot. In [7] Hybrid generating system with various type of renewable energy sourceshave been used. Simulation of a hybrid Wind, Solar, Micro hydro power generationsystem is done using MATLAB/Simulink application. Particle Swarm Optimization(PSO) technique is used for optimization of the controller parameters. The maxi- mum frequency deviation is reduced to 0.09Hz from 0.25Hz and the disturbance is settled within 50 s for the PID controller in comparison to 150s for the PI controller.

In Artificial intelligence (AI) technique is used to optimize the parameters system having a three non-reheat thermal power units. For load frequency control design, fuzzy tuned proportional integral derivative (FTPID) controller is used. A step load disturbance of 0.01 pu has been applied to study the transient condition of three area system and improved results obtained with less overshoot and low settling time. In [10] to damp the oscillations of the system frequency, Elephant Herding Optimization (EHO) is used to design a load frequency controller for single area reheat thermal power plant. Using EHO technique the parameters of PID controller are optimized. On comparing the results of EHO based PID and PID it is observed that better performance is achieved using EHO technique.

In [11] the authors have focused on the load frequency control of a hybrid power system that combines conventional and renewable energy sources for a particular area. For optimization of parameters of Fuzzy-PID controller, GA has been implemented. The performance analysis depicts that Fuzzy-PID controller shows a better response than the conventional PID controller.

In [13] authors present a MATLAB/Simulink model for load frequency control sys- tem with demand-side control through the smart meter. From the simulation results it is observed that the demand-side control using controllable load has improved the performance of the load frequency control system.

In [15] the relationship between the de-loading capacity of the over-speed control and wind speed has been investigated on the basis of the rotor kinetic energy control based on limited over-speed de-loading curve partitioning. The control effects of this control technique are depicted and examined under various penetration levels, varying wind speeds, and varying de-loading levels. The simulation findings demonstrate that the control technique can significantly increase the wind power systems' capacity for frequency responsiveness.

In [16] for the frequency control of a wind-diesel isolated micro grid, novel double Equivalent-Input-Disturbance (EID) controllers has been proposed. In this integrated control design, one single EID controller has been incorporated to the pitchangle control system for smoothening the output power of WTG by way of control- ling the pitch angle. Also for auxiliary regulation battery energy storage system is considered. Superior flexibility and better control performance of the has been observed in comparison to the conventional PI method in the simulation results.

In [17] a model predictive control (MPC) method has been used to produce torque compensation for de-loaded WTGs. Depending upon the generator speed and the frequency variation, each WTG is allowed to respond to the disturbance differently.

As per studies carried out in the literature, it is observed that extensive study has been done to increase system stability. However, due to advancement in technologies and integration of renewable energy resources, it becomes necessary to learn and implement the optimization techniques for a sustained power system. Based on the literature review, various meta-heuristic/AI based controllers along with integration of renewable energy resource (Wind turbine) is implemented for simulation of three area interconnected power system network.

III. Objectives

Further, based on the literature review, the following objectives have been identified:-
1. Maintaining the uniformity of frequency reasonably.
2. Controlling the tie line interchange as per the schedule.
3. To distribute the load among the generators.
4. To employ different meta-heuristic /AI techniques viz. Fuzzy logic, Artificial- Neural-Network (ANN) and Genetic-Algorithm (GA) for multi-area power sys- tem.
5. To observe the impact of penetration of RES to the existing power system

IV. METHODOLOGY

1. *Proportion-Integral-Derivative (PID)*

Proportional-Integral-Derivative (PID) controller is the conventional control algorithm used in control engineering. PID controller consists of three elementary components viz. proportional, integral and derivative which is tuned to get the desired response. The proportional component works on the difference between the desired value (set point) and the process variable (measured value) which is referred to as the Error term. The proportional gain (Kp) provides the ratio of output response to the error signal. The integral component produces an output by summing the error term over certain interval. The effect of the integral control is to drive the Steady-State error to zero. The derivative control affects the steady-state error of a system provided it deviates with time. The derivative part of the controller has no effect on the process if the steady-state error of a system has a time derivative of zero (i.e., if the steady-state error of the system is constant with respect to time). While the steady-state error evolves over time, a torque is created in such a way that it reduces the error magnitude in proportion to the rate of change of the error. [3]. The output of PID controller in time domain form is given by:

$$u(t) = K\,e(t) + Ki\int_0^t e(t)dt + Kd\frac{de(t)}{dt} \tag{5.1}$$

2. *Fuzzy Logic Controller*

Fuzzy Logic Controller is a system which is used to control the working of a physical system with the help of fuzzy logic [11]. The concept of fuzziness was founded by Prof. L.A. Zadeh in 1965. The generalized structure of a fuzzy logic controller (FLC), consists of three basic modules viz. the Fuzzification unit which is the input terminal. the inference engine built on the fuzzy logic control rule base, and the Defuzzification unit which is the output terminal, as shown in Figure 5.1

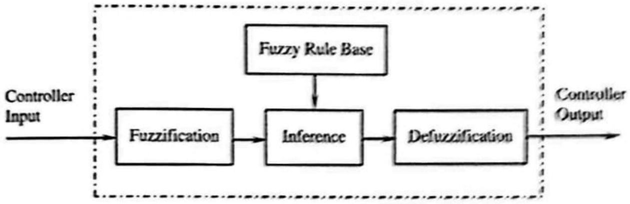

Figure 5.1: General structure of a fuzzy logic controller.

Fuzzification: Converts crisp values to fuzzy values using knowledge base. Knowledge base uses membership functions to define the input variables into fuzzy variables [15].

Fuzzy Inference System: It consists of fuzzy rule base which takes fuzzy variables as inputs and generate possible fuzzy outputs, given as input to defzuzifier.

- Defuzzification: The defuzzification module functions as a transformer to co- vert the controller outputs, which are produced by the control rule base in fuzzy terms, back to the crisp values that the plant can accept. It connects the control rule base and the physical plant to be controlled.

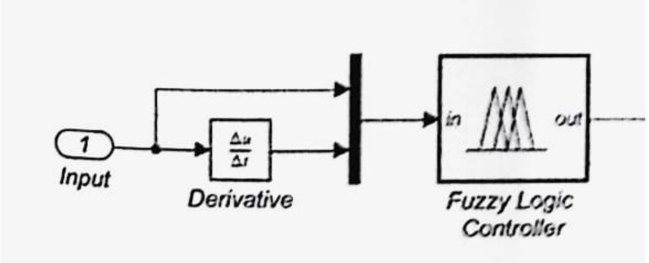

Figure 5.2: Fuzzy logic controller Simulink model

Figure 5.2 represents the Simulink model used to have the optimized value of PID controller. There are two inputs to the fuzzy block, one is the frequency deviation and other input is the rate of change of frequency. The corresponding member function plots of each input and the output are shown is Figures 5.3, 5.4 and 5.5

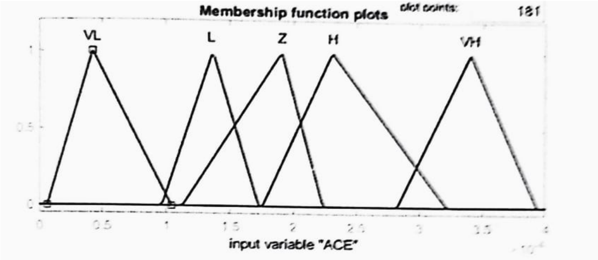

Figure 5.3: Fuzzy logic controller input 1.

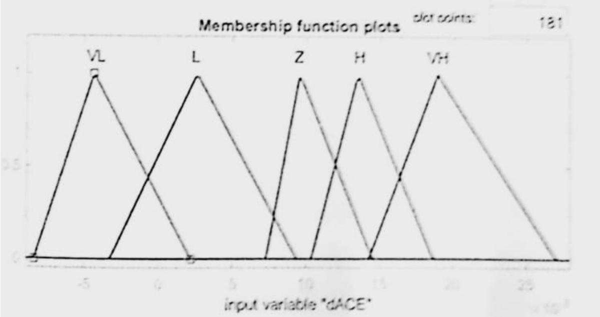

Figure 5.4: Fuzzy logic controller input 2.

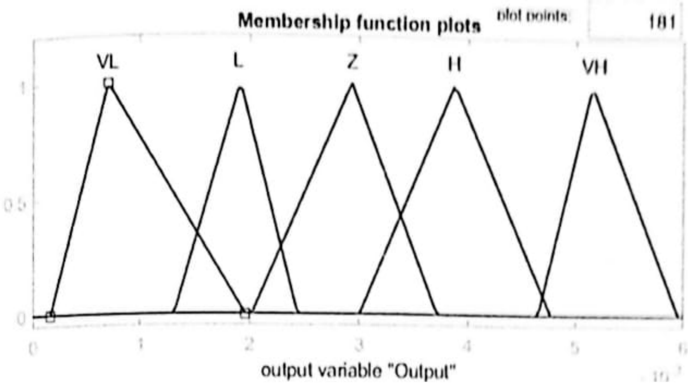

Figure 5.5: Fuzzy logic controller output.

Artificial Neural Network (ANN) tuned PID Controller

An artificial neural network (ANN) is a computational system that analyses and processes data in the same manner that the human brain does. However ANN is mostly required to perform one specific task at a one time. The ANN consists of input layer of source neuron, hidden layer and an output layer. The propagation of input signals proceeds layer by layer in a forward manner. The most common type of learning is error correction learning (ECL) in which the difference between the two outputs, known as the error, is calculated when the output of an ANN is compared to the expected output or target output value. Using the back propagation technique, at each training cycle the ECL algorithm intends to limit the error signal. The process continues until the desired threshold is achieved.

The input to the ANN is taken from the input terminal of PID controller and the weighted sum of the inputs is computed which is then passed to the activation function [14],[16] to get the desired output and is represented in the equation (5.2) and (5.3).

$$U_k = \sum_{j=1}^{p} wkj\ xj \quad (5.2)$$

where xj = Input Signal, Uk = Linear combiner Output, wkj = Synaptic Weights, Threshold, f =

Activation function, Yk = Output signal of the neuron.

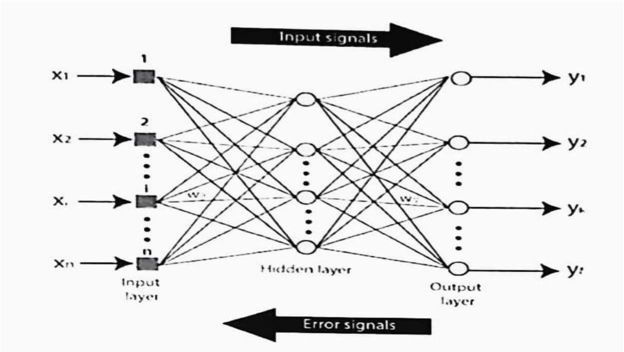

Figure 5.6: Architecture of radial basis function neural network

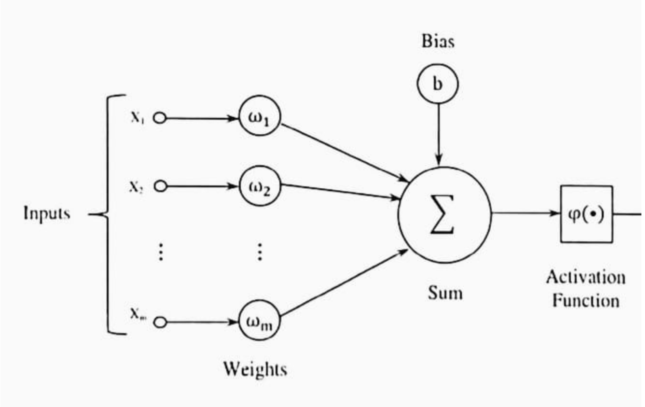

Figure 5.7: Typical artificial neural network.

The figure 5.6 and 5.7 represent the architecture of radial basis function neural network and the typical artificial neural network respectively.

Genetic Algorithm tuned PID Controller

Genetic algorithm is a search tool for finding the precise or nearly perfect resolution to optimization issues. The genetic algorithm is a type of evolutionary computation which employs mechanisms including inheritance, mutation, selection, and crossover that are based on the principles of evolutionary biology. Genetic Algorithm technique starts by selecting a population which refers to a set of solutions at an instantof searching process and on individual which refers to a single solution. Thus going from multiple solutions to a single solution which is optimal can be seen as going from population to individual. Each individual is characterized by a Set of chromosomes (which are binary coded or real coded in GA) and then Selection, Crossover, Mutation and Inversion is done to get the optimal solution [8], [13]. The flow chart of genetic algorithm is shown in Figure 5.8.

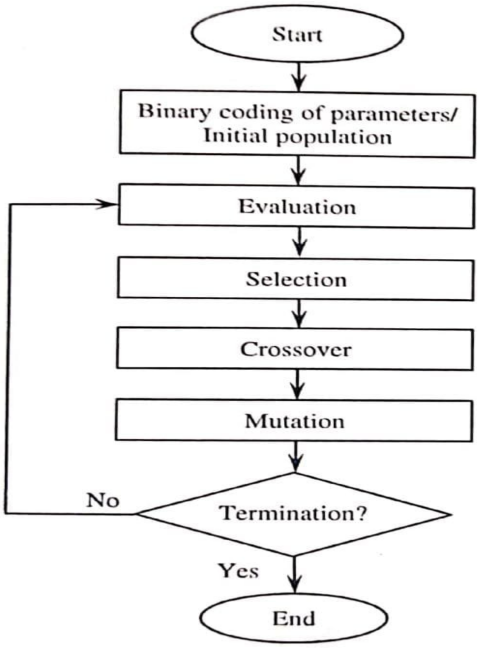

Figure 5.8: Flow chart for Genetic Algorithm.

Step-1: Formation of Chromosome- Coding and Decoding: The real system parameters are encoded into a binary string of the problem parameters in GA. Each string symbolizes a chromosome, with each chromosome describing one possible solution to the problem. A population of randomly generated elements is created after formation of encoded structure of chromosome [15]

Step-2: Genetic Operation-Crossover: Crossover or recombination operates on selected elements to build the new elements by combining the existing ones. The two elements swap their structures and results in creation of a new element containing the characteristics of their parents. During the crossover there is exchange of genetic information while production of new element. The process may be follow Single-Point, Multi-Point or Random-Point crossover.

Step-3: Genetic Operation-Mutation: Mutation averts the premature stopping of the algorithm in a local solution. Mutation works by changing a random bit value from 0 to 1 in a selected string having a low probability. During the process of reproduction and crossover there may be loss of some potentially useful genetic material, mutation provides a guarantee to recover the good genetic material.

Step-4: Termination of the GA: Genetic Algorithm is a probabilistic approach method, so it is difficult to specify any formal convergence criteria. The process terminates once the population has converged i.e., it does not produce any new element which is significantly different from the earlier generation. If the solution is not satisfactory the GA is restarted and a fresh search is initiated [11],[17].

For best performance, the integral time multiplied absolute error (ITAE) [7] is taken as the most common fitness function. In mathematical form, the error is expressed as:

$$ITAE = \int_0^t |f| \times t \times dt \qquad (5.4)$$

For a three control area power system, the ITAE criterion comprises the deviation
in frequency and the tie line power.

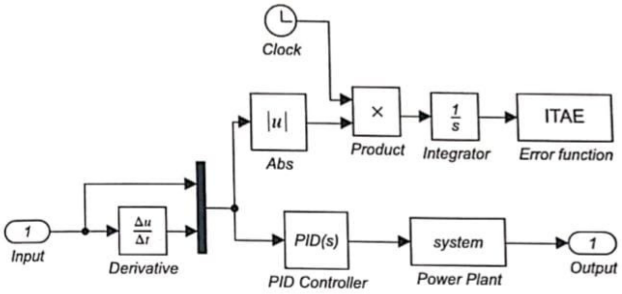

Figure 5.9: Genetic Algorithm tuned PID controller.

Figure 5.9 represents the simulink model of the genetic algorithm tuned PID Controller used for optimization of the PID controller with fitness function as ITAE given by (5.4)

Wind Energy Conversion System. (WECS)

With the increase in the consumption of energy and due to depletion of available conventional energy resources it has become imperative to harness the renewable sources of energy one among which is Wind Energy. As per the precursory statistics published by WWEA (World Wind Energy Association), the capacity of wind turbines has reached a record of 975GW in 2021 in the world market. The increased demand for electricity mandates the use of renewable energy sources such as the Wind Energy Conversion System (WECS), which can be interfaced with the existing grid. Increased wind energy integration necessitated an intensive consideration of frequency regulation in the power system. The possibility of DFIG-based wind turbines to contribute to frequency support when integrated to a multi-area interconnected power system is also examined in this work. The objective is to reach tolerable frequency deviation. One of the possibilities is to operate the wind energy conversion system below the maximum available power as per the MPPT curve so as to keep some margin (5-10%) as reserve capacity required for frequency control. Secondly the inertia emulation by way of releasing the stored kinetic energy in the rotating mass of wind turbines also helps in mitigating the frequency deviation but for a shorter time. By that time the rest of the conventional system should respond to supply the additional power and if not possible then load shedding should be resorted to for avoiding the system collapse [15].

Wind Turbine

A wind turbine is a machinery that utilizes the kinetic energy from the wind to generate the electricity. A wind turbine blades revolve between 10 and 20 times per minute at a fixed or variable speed, depending on the technology employed. In order to maximize efficiency, the rotor speed varies in accordance to the wind speed. Wind energy is converted into electricity by a wind turbine using the aerodynamic force of the rotor blades [17].

Mechanical Drive Train Model

The rotating masses, gearbox, hub, connecting shafts, and generator inertia make up the drive train system of a wind turbine. A two-mass model of the drive train is depicted in Figure 6.1 and reflects the combined impact of the wind turbine and the generator. The turbine shaft and generator rotor shaft are flexibly joined via a gearbox and coupling [18]

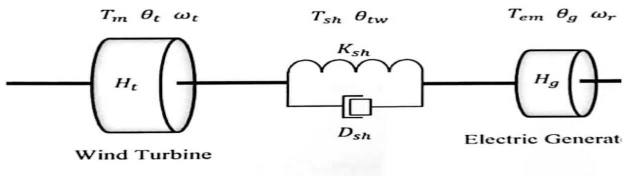

Figure 6.1: Drive train model Configuration

The equations governing the two-mass drive train model are given by:

$$2H_t \frac{dw_t}{dt} = T_m - T_{sh} \quad (6.1)$$

$$\frac{d\theta_{tw}}{dt} = w_t - w_r = w_t - (1 - s_r) \quad (6.2)$$

The power extracted from wind through a turbine is given by:

$$T_m = \frac{1}{2}\pi\rho C_p \delta R^3 V^3 \quad (6.3)$$

$$P_o = \frac{1}{2}\rho C_p A V^3 \quad (6.4)$$

The quantities wind speed, air density and the radius swept by the blades are not controllable. The performance coefficient Cp is the only variable which can be modified to maximize the energy production from the wind and the maximum turbine efficiency as determined by Betz's law is 59.3% due to geometry limits. Equation 6.9 represents the Tip Speed Ratio (7) which is equal to the ratio of turbine tip speed and the wind speed. WPG features differ greatly from those of traditional generators. Each WPG generates power differently depending on the local wind speed. As a result, accurate modeling of the WPG's operational state is necessary for the evaluation of this behavior. Using a plot of output power versus wind speed, a WTG "speed-power" curve is depicted in Figure 6.3 and can be used to estimate the power output of the machine.

Wind Turbine Power Curve

The power curve of wind turbine is a plot indicating the electrical power output as a function of wind speed as shown in Figure 6.2. For various wind speeds the power curve involves three specific points viz:

- Cut-in wind speed: The minimum wind speed at which the turbine begins to produce the output power.
- Rated wind speed: The speed of wind at which the turbine la capable of delivering the rated power.
- Cut-out wind speed: The highest wind speed that a turbine is permitted to use to generate the power.

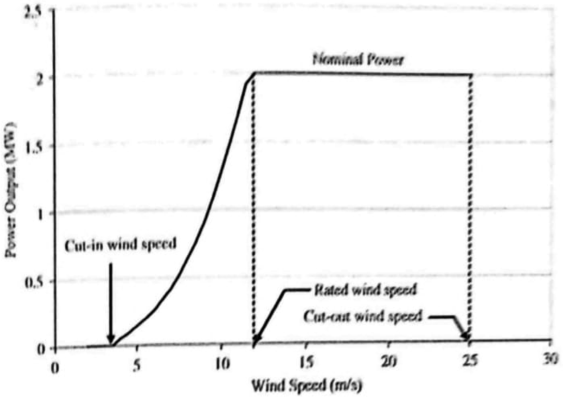

Figure 6.2: Wind turbine power curve for a 2MW machine.

When the wind speed is below the cut-in nearly 5m/s there is no power output. Above the cut-in wind speed, the power output increases with the wind speed in accordance to equation 6.7 till it gives the rated output and is limited via control action to reduce the mechanical load on the drive train. At the cut-out wind speed (approximately 25m/s), the rotor is then stalled, or permitted to hover at low speed for safety concern [18].

Variable Speed Wind Turbine

Depending upon the wind speed, the tip speed ratio for a particular wind turbine speed varies widely. The wind turbine power output can be maximized by running it at its maximum performance coefficient and can be achieved by modifying the tor speed to correspond to changes in wind speed. This is possible by adopting the variable speed DFIG technology. Numerous types of wind turbine technology have been created over the evolution of wind power and DFIG type WT is themost common form deployed in wind farms which have the advantages of minimal investment and flexible control [16]

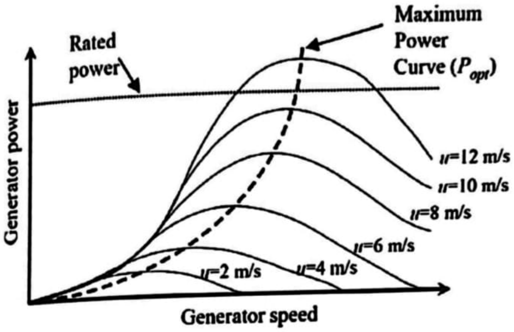

Figure 6.3: Power output of generator at various wind speeds

Doubly Fed Induction Generator

The classical configuration of a DFIG wind turbine is represented in Figure 6.4. DFIG type wind turbine generators are the most popular technology and have gained recognition across the globe. The converter and rotor winding are connected to a wond-rotor induction generator by slip rings. By applying an adjustable voltage to the rotor at the desired slip frequency, variable-speed operation is made possible. A DFIG's stator is often directly linked to the power grid, and regulated voltage source converters feed the rotor winding power back from the stator terminals.

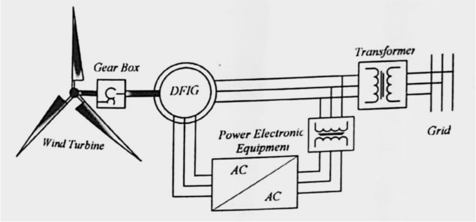

Figure 6.4: DFIG wind turbine model.

A DFIG based wind turbine can transfer the electrical power to the network both through the converters and the stator of generator. In super-synchronous mode the rotor delivers the power to the network through the converters while in sub-synchronous mode the rotor absorbs power back from the network via the converters. Since the converters only provide the DFIG exciting current, their capacity is only about 20-25 percent of what the device is rated for. Further the feedback converters are built on insulated gate bipolar transistors (IGBT), the DFIG can be controlled in a variety of ways, and the controllers have a big -impact on the dynamic properties of the WT with DFIG. The active and reactive power flow to the grid from the stator of the DFIG directly controlled by the rotor side converter. The magnitude, phase angle and frequency injected into the rotor is controlled by voltage source controller. The three phase voltages at grid frequency is controlled in magnitude and phase by grid side converter which also regulates the DC link voltage and provides the grid with additional reactive power support.

RESULTS AND DISCUSSION

In order to analyze the dynamic behavior of a three-area power system, a step load disturbance of 0.01pu has been applied to the power system presented in this dissertation. Simulations were conducted to examine the effect on frequency deviation in the three control areas using different controllers viz. "PID, Fuzzy logic, Artificial Neural Network and Genetic Algorithm based PID controller". The effect of wind power penetration has also been examined by emulating inertia simultaneously using ANN based PID controller as secondary control. It is observed the wind tur- bine contributes to mitigate the frequency deviation by release of its kinetic energy although for a shorter time. All simulations were done using MATLAB/Simulink software.

The Figure 7.1 represents the system response without any controller with undershoot of 0.0215 and settling time of 6.87 Secs. Figure 7.2 and 7.3 illustrates the frequency deviation of each area after application of PID, Fuzzy tuned PID controllers. Figure 7.4 represents theresponse of ANN based PID controller Significant improvement is observed in parameters viz oscillations, overshoot and settling time.

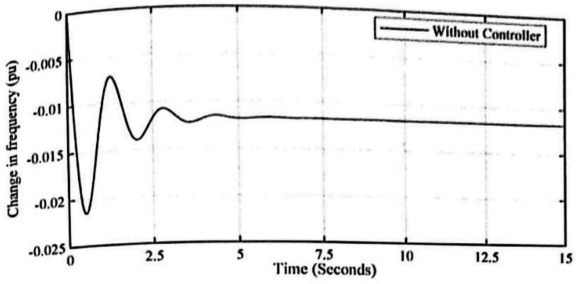

Figure 7.1: System response without any controller

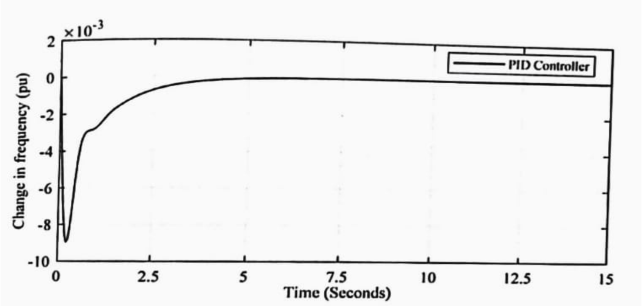

Figure 7.2: System response to PID controller.

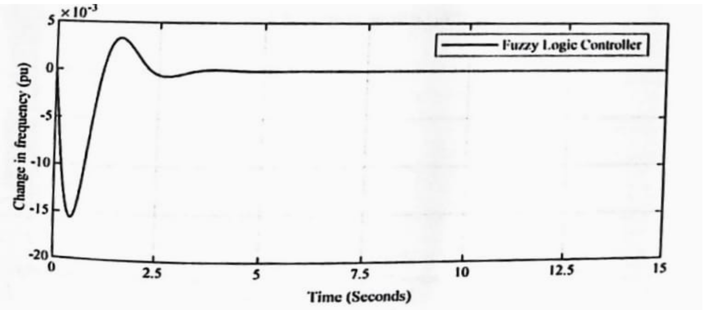

Figure 7.3: System response to Fuzzy Logic controller.

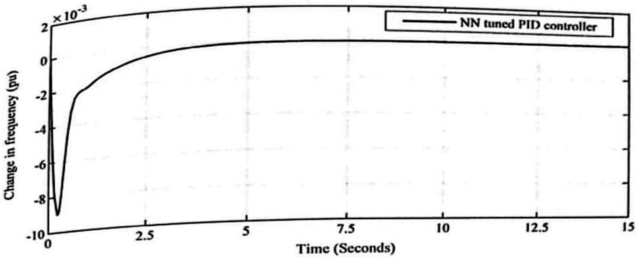

Figure 7.4: System response to ANN tuned PID controller

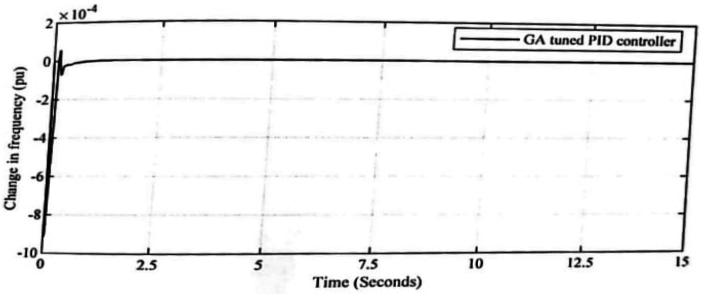

Figure 7.5: System response to GA tuned PID controller

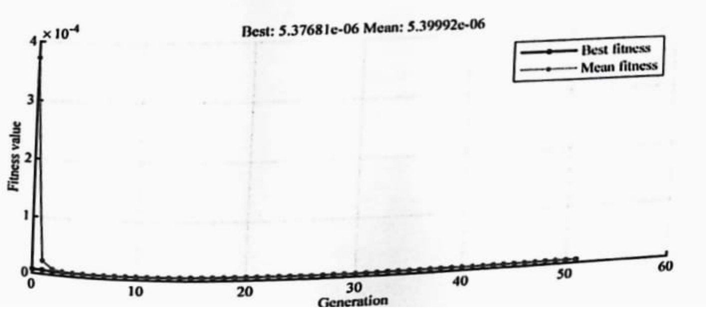

Figure 7.6: Convergence plot of genetic algorithm

The results in Figure 7.5 shows that GA tuned PID controller in interconnected power system gives a better dynamic performance with reduced frequency deviation, steady state error and oscillations with settling time of 0.54 Secs. The relevant convergence trend is depicted in Figure 7.6. It is evident that the fitness value is convergent towards the optimal while moving from one generation to next.

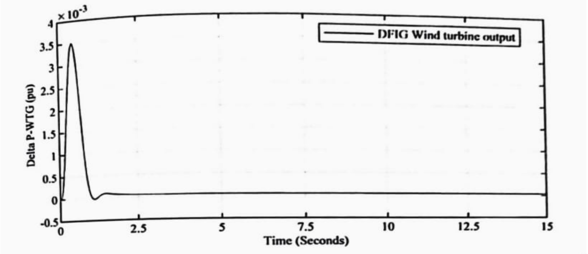

Figure 7.7: Active power deviation response of wind turbine

Figure 7.7 shows the power output of DFIG based wind turbine generated during the inertia emulation by releasing the kinetic energy for a period of 1.82 seconds. This amount of wind power is added to the power system and it is shown in Figure 7.8 that the settling time reduces to 1.51 seconds with overshoot of 0.0014 (pu).

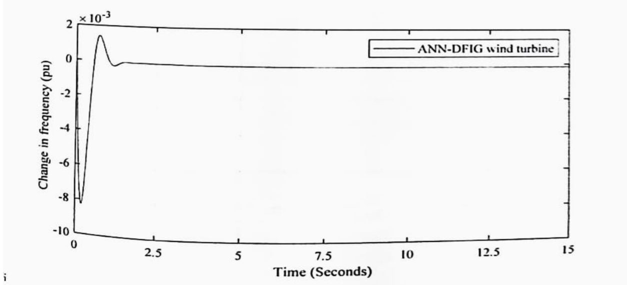

Figure 7.8: System response to ANN tuned PID controller with DFIG integration

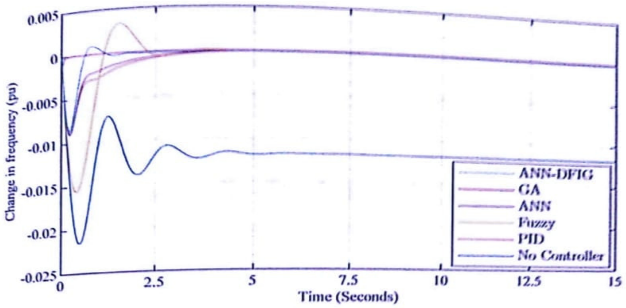

Figure 7.9: Combined System response to different controllers

Table 7.1: Comparison of Results

Controller Type	Peak Overshoot (pu)	Peak Undershoot (pu)	Setting Time (Secs.)
No Controller	0	0.0215	6.87
PID Controller	0	0.0089	6.03
Fizzy Logic Controller	0.003	0.015	3.45
ANN tuned PID Controller	0	0.0009	4.75
GA tuned PID Controller	0.000054	0.0009	0.54

Table 7.2: DFIG-WT Result

Controller Type	Peak Overshoot (pu)	Peak Undershoot (pu)	Setting Time (Secs)
ANN-DFIG	0.0014	0.00825	1.51

CONCLUSION

The load frequency control performance analysis is done in this work for them non-reheat power system. The effect of different artificial intelligence based PID con trollers is tested to investigate the performance of the power system. The result of the different controllers used have been compared as shown in Table 7.2. It is noticed that a better Load Frequency Control performance has been achieved using Artificial Intelligence based controllers in comparison to the conventional PID controller The number of oscillations has reduced substantially. Significant improvement in overshoot, undershoot and lower settling time is attained using Genetic Algorithm and Neural Network based PID controller, but GA based PID controller has been found more efficient controller having better overall system response with overshoot(0.0054%), undershoot (0.09%) and lower settling time of 0.54 seconds Further, with the increased demand for electricity mandates the use of renewable energy sources such as the Wind Energy Conversion System (WECS), have beeninterfaced with the existing grid. With the increase in global capacity of wind turbines which has reached a record of 975GW in 2021 and its integration with the existing system, it has necessitated an intensive consideration of frequency regulation in the power system. The possibility of DFIG- based wind turbines to contribute in frequency regulation when connected to a multi-area interconnected power systemhas been simulated. For a three area interconnected power system, the A used controller and simultaneous integration of DP16 based wind turbine area has been examined by way of inertia emulation pose to send kinetic energy by way of reduction in speed to regulate the frequency. It is seen that there is increased system response by way of reduction in be settling time.

Future Scope

The future scope of this work is as follows

1. New AI based controllers including hybrid algorithms can be applied for further improved and optimized response,
2. Integration of other renewable energy sources for mitigating the frequency deviation.
3. Impact of RES on equivalent inertia of the power system along with incorporation of special protection schemes.
4. Incorporating Intelligent load shedding scheme to avoid blackout in extra cases.

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