NOVEL INTELLIGENT CONTROLLERS FOR LOAD FREQUENCY CONTROL OF A MULTI AREA HYBRID POWER SYSTEM

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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OF

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Submitted by:

DIVYANK SRIVASTAVA

2K16/PSY/04

Under the supervision of

Dr. MADAN MOHAN TRIPATHI

ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

JULY , 2018

ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Divyank Srivastava, Roll No. 2K16/PSY/04 student of M.Tech. Power System, hereby declare that the Project Dissertation titled "**Novel intelligent controllers for Load Frequency Control of a Multi Area hybrid Power System**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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Date: 30/08/2018

ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "**Novel intelligent controllers for Load Frequency Control of a Multi Area hybrid Power System**" which is submitted by Divyank Srivastava, Roll No. 2K16/PSY/04, Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 30/08/2018

Dr. MADAN MOHAN TRIPATHI
SUPERVISOR
(DELHI TECHNOLOGICAL UNIVERSITY)

ABSTRACT

In today's world, power system become more and more complex due to lot of interconnectivity. There is a rapid increase in demand of large customer and to meet that demand is a challenging task, which also fluctuates the generation-demand equation. In power system due to abrupt change in load demand the system frequency and working voltage fluctuates, which effects the system stability. A large amount of Tie-line power interchange effects the system characteristics. , automatic generation control (AGC) have a important part in maintain the power system frequency to nominal values and also minimizing the transient deviation and make steady state error to zero with using suitable control strategies

As there is large energy demand renewable energy sources have to come into the picture to supply the required load demand. Renewable energy, such as wind and solar energy, is desirable for power generation due to its unlimited existence and environmental friendly nature. In this thesis, a intelligent Neuro-fuzzy based controller is proposed for a multi-area load frequency control with PV system, suitable for a restructured power system. The proposed controller has been compared with and without PV system. A comparative analysis of different controllers has been done in which PI, PID, FGSPI and ANFIS controllers are compared. The proposed hybrid neuro-fuzzy controller evaluates the current system situation and regulates system characteristics efficiently. The functioning of proposed scheme has been tested on multi area AC network in which two areas are diesel generator based and one area is non-conventional PV array. The suggested control technique has been validated to be better than the conventional control technique used in AGC designing. The results of proposed scheme have been compared with and without PV system.

ACKNOWLEDGEMENT

I express my heartfelt obligation towards the people who have spared their valuable time and effort helping me to complete this thesis. Gratitude is also accorded to DTU for providing all the necessary facilities to complete the research work.

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DIVYANK SRIVASTAVA

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List of Abbreviation

LFC	load frequency control
FLC	Fuzzy logic controller
ANFIS	Adaptive neuro-fuzzy inference system
PI	Proportional integral controller
FGSPI	Fuzzy Gain Scheduling of PI
ACE	Area control error
DACE	Derivative of area control error
PV	Photovoltaic generation system
GA	Genetic Algorithm
GRC	Generation rate constrain
MF	Membership function
PI	Proportional integrator
PID	Proportional integral derivative
PSO	Particle swarm optimization

List of Symbol

i	Subscript referring to area i (i = 1, 2)
H	Per unit inertia constant
Δf_i	Incremental change in frequency
ΔP_{tie}	Incremental change in tie-line power flowing out of area
D	Load frequency constant
ΔP_g	Incremental change in power generation
ΔP_d	Incremental change in load demand
T_g	Speed governor time constant
T_t	Turbine time constant
T_r	Reheater time constant
T_w	Hydro turbine time constant
R	Speed regulation parameter
P_r	Rated area power output
K_r	Reheat coefficient
T_p	Power system time constant
M	Effective rotary inertia
a_{12}	Area size ratio coefficient
B	Frequency bias constant
δ	Area power angle
T_{12}	Synchronizing coefficient

CHAPTER 1

INTRODUCTION

One of the main motives of prevailing electric power system is to deliver secure, reliable and cost effective electrical energy sources to the consumers [1]. Nowadays, there is an increase in the demand of power supply but a long term planning needed to get that demand to be met is lacking. This insufficient planning facilitates the companies to supply unsecured and degraded quality of the power supply. Therefore, there is an immediate need of improving the power system quality.

There are several sources of electricity generation known to us. These sources can be classified as renewable and non-renewable sources of energy [1]. It has undoubtedly become essential to switch to renewable sources such as solar, wind, etc. to protect our environment of the ill effects caused by using non- renewable sources of energy such as thermal, diesel, etc. Due to the aforementioned reasons it is critically important to use hybrid systems comprising a power grid employing a renewable source of energy.Advantage of commissioning such a system is that during day time the majority of load is provided by the renewable source of energy such as a PV (Photovoltaic) Array and when the sunlight is insufficient, the electric power is provided by the diesel generator plant [2]-[3].

Employment of such a hybrid system comes with its own challenges. The main issue of concern is the maintenance of constant frequency throughout. As the system frequency is reliant on the load changes, Load frequency1control (LFC) or automatic generation control (AGC) is an important issue in the field of power system operation and control (PSOC). Today’s power system processes needs reconsideration for system instability and problems related to control [4]. Dynamic performance of all conventional standard controllers like Integral, Proportional, Proportional-Integral (PI), Proportional-Integral-Derivative (PID) controllers and intelligent controllers (Fuzzy-Tuned Controller) have been discussed in the literatures [5]-[6].

1.1 OVERVIEW

The setting up of renewable energy sources is rising to supply the required demand. The renewable energy sources put near the load centres and consumers. The renewable energy source comp rises battery energy storage system, PV, fuel cell and wind energy. Renewable energy resources system combined with the concentric system also known as the hybrid power system that supply continue power and quality of service to the consumers to meet up the desired demand. It is generally depend on the controller used in the hybrid power system to control frequency. The sustain variation in the wind power outcomes the change in frequency of system, so it is important to balance the power between the demand and generation this can achieve by the automatic control of frequency to the acceptable value. Thus for this divergence in frequency, have to be considered in the controlling scheme. Increasing interest for electrical energy, controlled measure of non-renewable energy sources, and going up worries to environment required the immediate improvement in the area of RESs. The input as the mechanical power is considered for controlling the frequency of the generator, the variance in frequency as well as change in tie line power, which determines the variation in the rotor angle. The healthy power system is supposed to be capable for supplying the satisfactory levels of power by maintaining the supply frequency in acceptable limits. LFC mostly consists of control of supply frequency and true power. LFC is base of many advanced perceptions to control of the hybrid power system at a large scale. Several most recent reviews that clarifies the effects of battery energy storage (BES), SMES, photovoltaic (PV) and wind turbine (WT) control generation the dynamic implementation of the AGC system. L.Mengyan et al. [7] gave explanation and the reviews on control of tie line power with a momentous control of wind power. A strong controller has been proposed containing SMES to adjust the tie-line variation in the consistent system with wind farms [8]. Additionally, an operation of CE units has been used for the change of AGC implementation of a multi-unit and control of multi-region system includes GRCs [9]. After that, R. Oba et al. [10] explored the effect of RESs, PV in the power system to reduce the instability with the use of PID controller. An AGC scheme for hybrid power system connected MW class PV power generating system is projected in [11] whereas a control scheme for the PV-diesel single-stage self-regulating power system is represented in [12]. AI which achieves skill in taking care of the problems by taking information about particular assignments is known as intelligent system or learning based. Artificial

Intelligence was firstly proposed by E. A. Feigenbaum et al. [13]. AI comprise intelligent approach based techniques in that it deals with rule based system calculation, which employs the interface methodology and information to hold issues which are sufficiently hard for human.Scientists have enormous interest in the adaptive neuro fuzzy interference system as it treats with nonlinearities and does not need precise numerical modeling [14][15]. The innovative theory of optimal regulator for the two power system was first proposed by Elgerd [16]. Execution of advanced control technique offers great improvement in LFC. Advance control techniques have capability to supply high variation for altering conditions. They are capable to take fast decisions.

1.2 LITERATURE REVIEW

In the past frequency was being controlled by typical PI controller however currently that methodology is obscure [17]-[18]. After long analysis fuzzy logic was developed and it's currently greatly enforced in planning the controller. The wide usage of fuzzy logic created the power system additional reliable and owing to this controller the system becomes quicker. Renewable energy sources have their own issues once it involves the purpose of continuation and safety of the most grid with reference to the voltage and frequency these must be mounted and a correct stabilization. For maintaining the continuity and the efficient recover within the financial and ecological purpose of read aspects of the system, the addition of renewable energy sources involves the rescue of power systems.

Fuel cells (FCs),PV, Wind turbines (WTGs), Aqua electrolyzer and the battery storage system for immediate back-up for supply the required demand in order that unexpected fluctuation in the power can be kept away and these will be installed close to the user and joined with main grid to make a distributed generations (DGs). To realize the higher performance, the best controllers are projected [19 – 21] however this was found that the quantities of data concerning the states are measure hard to be known compeletly. Another technique supported neural networks [22] has been engaged to urge sensible dynamic performance however the large information and time desired for training. Previously, work has been done on LFC of grid by using fuzzy logic. Higu et al [23] given the usage of frequency variation and rate of modification of frequency variation using wherever as Indulka et.al [24] utilized alteration in ACE as a input to fuzzy logic controller [24].

Currently, varied analysis and outlay has been planned in hybrid facility, as Yang [25], he recommend the design of optimal control for the hybrid wind and PV system. Dihrab [26], obtained a hybrid PV and wind system as the energy sources which are used for the power generation in Asian nation. Reichling [27], developed the model of hybrid PV and wind energy generation in south western American state for a 2 year, by victimization wind speed information as well as hourly solar irradiation. Ekren [28], concluded optimum methodology of PV and wind hybrid system facility in Turkey. Variety of modelling studies on hybrid system is carried out. Along with them, Kim [29], meted out a grid-connected PV model victimization PSCAD and EMTDC for magnetic force momentary behaviour. Tsai [30], executed PV model by using SIMULINK. Gow [31], planned a PV model which executed on MATLAB. Khan [32], obtained the grid of a fuel cell-wind system and study operation of a fuel cell-wind integrated supply system.

Research was executed for the load Frequency regulation of Hydro-Thermal grid by exploitation traditional and intelligent controllers [33]-[35]. Controllers were thought of with typical PI controller for diesel and the wind hybrid grid [36] and for the wind-hydro diesel hybrid grid [37]-[38].

For different control problems fuzzy control is being used for a long time. Fuzzy control not only apply on linear models but can also be used in different non-linear and complicated models. The advantage of intelligent control technique is that it can forecast the future disturbances in the system and can apply necessary action according to that whereas the conventional control can't solve multi area frequency problem. Mojtaba et al. [39] proposed a fuzzy controller which uses GA for getting the optimum value of upper & lower band of fuzzy membership function. It was developed for Multi area system. This model gives a better result on different load changes and complex dynamic condition. Mathur et al. [40] had proposed a Fuzzy logic control implemented with GRC for saturation of mechanical power.. Juang et al. [41] had proposed a FGS approach which uses GA. According to ACE the Ki value was improved in PI controller. Simulation was done with different load variations. Chang et al. [42] proposed a FGSPI for a distributive generator area and also to get optimal value o integral controller Ki, used in multi area hybrid power system.

The ANFFIS can be applied for getting optimal values of different parameters of AGC and also improved dynamics of the system reducing settling time and overshoot. Birch et al. [43] proposed the neural network as a control strategies in different area of power system, also with conjunction of AGC. Demiroren et al. [44] proposed a multi-layer ANN considering GEC dead band for a 2-area AGC, used feed-forward and back-propagation algorithm. Chaturvedi et al.[45] proposed a non-linear ANN to control frequency deviation in hybrid power. Hemeida [46] uses WNN to reduce the frequency to operational level by controlling different parameters of AGC.

1.3 MOTIVATION

Now a day's LFC in micro-grid or hybrid power system is a booming space of analysis and research. In 2012, there's stern blackout within the immense electrically inter-connected country like Asian nation. During this year, 2 sequent blackouts occurred in Asian nation. In 1965, the northeast blackout that cropped up in North American nation, United States and lots of individuals stayed within the dark. Researchers struggled to search out the reason for these blackouts and also the new conception of load frequency regulation was created.

Recently in the today's inclination it is necessary to link the grid consequently the steadiness has to be sustained furthermore, the frequency is regulated. Now in existence, the situation is going simply towards the distribution system and network; therefore it is important to go for merging of renewable energy sources to the system. For this, to keep up power and also the reliability within power system, it's greatly required to travel for these resources. Currently, in the recent years researchers' area unit is operating in several systems so as to regulate the frequency.

1.4 OBJECTIVE

1. To develop the model of interconnected hybrid power system consist of renewable energy sources (PV cell, etc).
2. To design the FGSPI, PI, PID and ANFIS controller in order to regulate the frequency whenever the load demand changes.
3. To simulate the developed model with designed controllers for LFC.

4. To compare the performance of all proposed controllers in terms of settling time and overshoot.

1.5 ORGANIZATION OF THESIS

Chapter 1: This gives the overview of the proposed work, motivation, literature survey, objective, and scope of work and the organization of the thesis.

Chapter 2: In this chapter the overview on LFC is explained and description and modelling of the each part of the power system is explained.

Chapter 3: In this chapter modelling of PV array system for load frequency control is explain.

Chapter 4: It explains different control techniques. It gives the brief description of conventional PI controller, PID controller and intelligent controller like fuzzy logic, adaptive neuro fuzzy interface system (ANFIS).

Chapter 5: It includes the simulation and the results obtained when we applied the proposed controller on conventional power system network.

Chapter 6: It includes the the simulation and the results obtained when we applied the proposed controller on hybrid interconnected power system network.

Chapter 7: It includes the conclusion and future scope.

CHAPTER 2

LOAD FREQUENCY CONTROL

In power system when there is a change in load there is a change in system frequency and speed with governor characteristics. The generator settings need not be changed if the frequency of the system if not required to be maintained constant. The generator settings need to be altered if the frequency of the system is expected to remain constant. The maintenance of constant frequency can be done by regulating the turbine velocity by changing the governor characteristics. The maintenance of constant frequency becomes quite a complex task if the change in load is ensure through generating stations operating in parallel.

2.1 MODELING OF INTERCONNECTED POWER SYSTEM

2.1.1 Introduction

Power system modelling is of utmost importance in AGC designing. AGC parameters varies according to the power system components. Therefore, in the following chapter, modelling of various components of power system has been done. The power system components for the generation of power has been modelled and discussed in detail. Also the tie-line modelling and the modelling of parallel operation of interconnected areas has been discussed.. The transfer function considered for the modelling of a governor and power system has been described in this chapter.

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2.1.2 Generator-load model

In case of change in load demands and for increased reliability of the power system, there is a need to have interconnected power systems. The interconnected system operated in parallel implies the synchronism of the synchronous generators of the power system network. Therefore, it is essential to make all the synchronous generators run at same speed for the maintenance of synchronism. A balance needs to be maintained in a real time environment because the loads keep changing constantly.

The interconnected power system needs a speed control mechanism which can be well explained by an isolated generator. There are two types of torques experienced by an isolated generator i.e. mechanical torque (T_m) and electrical torque (T_e). In a situation when equilibrium is disturbed, the two torques lose equilibrium and hence a change in speed and frequency will be experienced by the system. The system frequency is dependent on the speed of the prime mover of the generator and an imbalance between the two torques will distort the frequency [47]. The swing equation given by eqn 2.1 and eqn 2.2.

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_L \tag{2.1}$$

$$\frac{1}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \frac{1}{2H}\left(\Delta P_m - \Delta P_L\right) \tag{2.2}$$

Equations (2.3) and (2.4) have been used to derive the generator-load model for the system. For the generator-load model, the input is taken as the change in valve setting i.e. ΔP_v and the output is taken as the mechanical power output changeΔP_m. The generator-load model for the system has been shown in eqn.2.3.

$$G_P = \frac{\Delta\omega}{(\Delta P_m - \Delta P_L)} = \frac{1}{2Hs+D} \tag{2.3}$$

The loads in a power system are of different types. The loads can be purely resistive, purely inductive, combination of RLC loads etc.[48] The motor loads that are basically rotating loads are RL loads in nature whereas the lighting equipment is basically resistive load. Block diagram of power system network is shown in Fig.2.1.

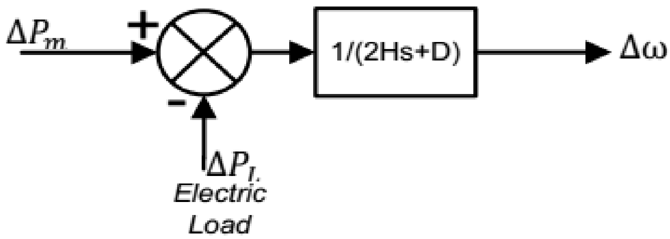

Fig. 2.1: Block Diagram of power system for Load Damping Effect

The load dependent on frequency is given by eqn 2.4.

$$(\Delta P_e = \Delta P_L + D\Delta\omega) \qquad (2.4)$$

2.1.3 Modelling of Governor

A governor governs (regulates) the speed of the rotating device i.e. the prime mover. Additionally, the governor observe and perceive the frequency variations in the power system. Therefore, the governors are effective for frequency regulation, speed of turbine or the prime mover and power regulation. Moreover, a governor's functions does to limit to regulation as it also helps starting of the turbine and to protect the system from various hazardous disturbances that can affect the system[49]. A governor basically compares the two inputs i.e. the change in reference power and the deviation in power $\Delta P_{err} = (\Delta P_{ref} - \Delta P_c)$ gives the corresponding output i.e. the valve setting changeΔP_v, as shown below in equations (2.5), (2.6) and (2.7).

$$G_G = \frac{\Delta P_v}{\Delta P_{err}} = \frac{\Delta P_v}{(\Delta P_{ref} - \Delta P_c)} = \frac{1}{1+sT_g} \qquad (2.5)$$

$$\Delta P_{err} = \Delta P_{ref} - \Delta P_c \qquad (2.6)$$

$$\Delta P_c = \frac{1}{R}\Delta\omega \qquad (2.7)$$

The abovementioned functioning of the governor to regulate the speed and frequency is known as the primary speed control[50]. The governor works as an initial adjuster of frequency and speed of the system. It is well known that the generators share load in proportion to their respective capacities. The governing mechanism of the turbine of a rotating device will typically be in the order of 2-20 seconds depending on the turbine inputs and type of turbine being used.

2.1.4 Modelling of Turbine

A turbine functions by converting a natural energy from power plants such as steam power plant or a hydro power plant, etc. A turbine is a mechanical component that rotates with a certain speed and the rotation speed of the turbine determines the strength of output energy[51]. As the turbine is coupled to the generator, the generator utilises the energy converted by the turbine which in turn runs the generator. There are several types of turbines being used. The transfer functions of turbine is given in equations (2.8) and (2.9) respectively.

$$G_{T\_NR} = \frac{\Delta P_m}{\Delta P_v} = \frac{1}{1+sT_t} \tag{2.8}$$

T_t is a time constant which shows the delayed time between switching of the valve and the instant at which the turbine torque is produced. The reheat turbine can be employed in systems where higher thermal efficiency of the system is required. The reheat turbines can be modelled as second order systems for analysis.

$$G_{T\_R} = \frac{\Delta P_m}{\Delta P_v} = \frac{F_h T_t s+1}{(1+sT_t)(1+sT_r)} \tag{2.9}$$

A hydraulic turbine can be modelled by utilizing the dynamics of water in a runaway. The response of water pressure and transitory response of the water are the two major factors which determines the modelling of turbine. The transfer function of t hydraulic turbine is shown in equations (2.10) and equations (2.11).

$$G_{T\_Hy} = \frac{\Delta P_m}{\Delta P_v} = \frac{1 - sT_W}{(1 + s(T_W/2))} \tag{2.10}$$

$$T_w = {L.v}/{g.H_r} \tag{2.11}$$

The transfer function of transient droop compensation [48] is given by eqn 2.12.

$$G_{T\_DCHy} = \frac{sT_R}{(1 + s(R_T/R)T_R)} \tag{2.12}$$

2.2 AGC MODELLING OF SINGLE AREA POWER SYSTEM

Modelling of a single area power system can be done by using components such as a governor for speed and frequency regulation, a turbine for energy conversion and the power system with frequency dependent and non-dependent load. Primary as well as secondary control is done for a single area network. Single area network is shown in Fig.2.2.

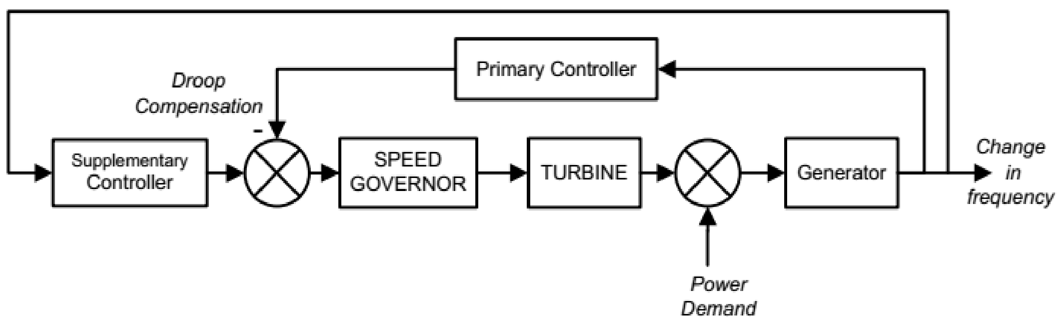

Fig. 2.2: Block diagram of single area AGC power system

2.3 MODELLING OF CONTROL AREA

The power system network comprises various components such as turbines, governors and generators. In an inter-connected power system, the generators operate in parallel. The parallel operation of the generator implies that the coupled generators will run synchronously at a single frequency and speed. These generators can be located at different areas in the network to supply for load demands at various places. This group of synchronized generators in the power system is known as the control area or control group[53]. These synchronously running paralleled coupled generators share load according to their respective capacities. For the sake of mathematical modelling, all the coupled generator can be represented as one equivalent generator. The inertia constant of all the separate generators is summed up and represented as one inertia constant (H_{eq}). Similarly, the damping constant of all the separate generators is summed up and represented as one. The equivalent inertia constant and damping constant can be represented as in equation (2.13) and equation (2.14).

$$H_{eq} = H_1 + H_2 + \cdots + H_n \tag{2.13}$$

$$D_{eq} = D_1 + D_2 + \cdots + D_n \tag{2.14}$$

The performance of all the generators connected in a network can be accounted by AGC. The speed governor of the generator shows drooping effect. The collective droop effects of the governors are responsible for composite load-frequency characteristic of a power system. Therefore, frequency change is given by equations (2.15) and (2.16).

$$\Delta f_{steady\_state} = \frac{-\Delta P_L}{(1/R_{eq}+D_{eq})} \tag{2.15}$$

$$R_{eq} = \frac{1}{(1/R_1+1/R_2 \ldots +1/R_n)} \tag{2.16}$$

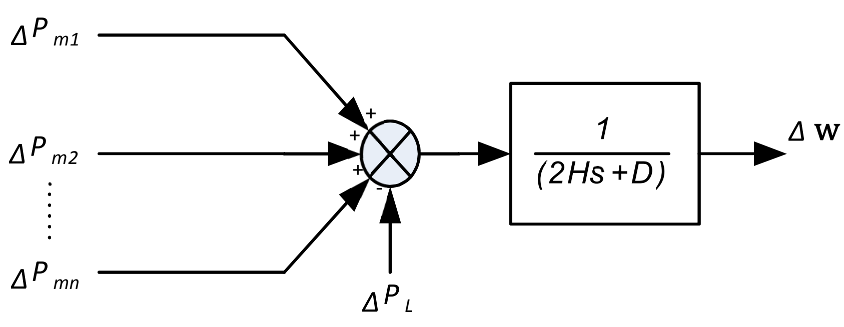

Fig. 2.3: Power system equivalent for AGC

2.4 TIE-LINE MODELLING OF INTERCONNECTED TWO AREA SYSTEM

The tie-line is used for the interconnection of two or more power systems. An area will get energy with the use of tie-lines from another area, whenever the load is changed in that area. Therefore load frequency control also requires the control on the tie-line power swap error. Power in the tie line can be calculated mathematically from eqn. 2.17 to eqn. 2.21.

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} sin\delta_{12} \quad (2.17)$$

$$X_{12} = X_1 + X_{tie} + X_2 \quad (2.18)$$

$$\delta_{12} = \delta_1 - \delta_2 \quad (2.19)$$

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}} |\ \Delta\delta_{12}| \quad (2.20)$$

$$\Delta P_{12} = T_{12}\ \Delta\delta_{12} \quad (2.21)$$

Tie-line power deviation takes the form, as shown from eqn 2.22 to eqn 2.26.

$$\Delta P_{12} = T_{12}\ (\Delta\delta_1 - \Delta\delta_2) \quad (2.22)$$

$$T_{12} = \frac{|E_1||E_2|}{X_{12}} cos\delta_{12} \quad (2.23)$$

$$\Delta P_{12} = T_{12}\ (\int \Delta\omega_1 dt - \int \Delta\omega_2 dt) \quad (2.24)$$

$$\Delta P_{12} = 2\pi T_{12}\ (\int \Delta f_1 dt - \int \Delta f_2 dt) \quad (2.25)$$

$$\Delta P_{12}(s) = \frac{2\pi T_{12}}{s} (\Delta f_1(s) - \Delta f_2(s)) \quad (2.26)$$

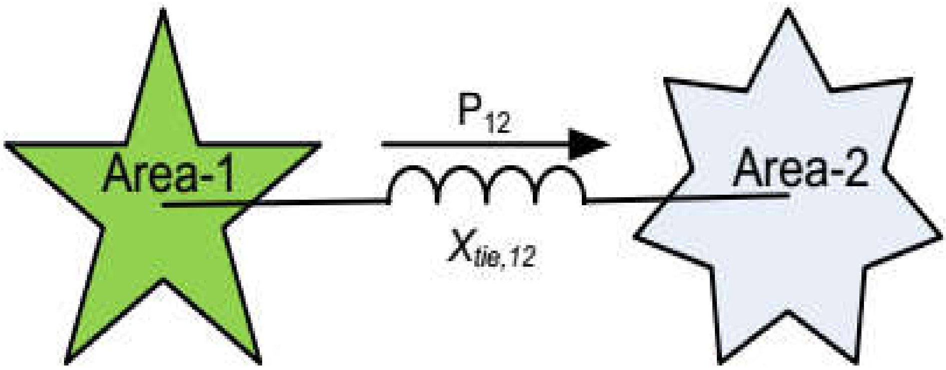

Fig. 2.4: Tie-line connecting control areas

2.5 AREA CONTROL ERROR (ACE)

Linear combination of error in the tie line power and frequency gives the area control error. ACE is a symbol of a divergence between generation of two areas and load.[54] Hence, this is vital to require the tie-line power variation as the input. Therefore, ACE is expressed as:

$$\boldsymbol{ACE_i} = \sum_{j=1}^{n} \Delta \boldsymbol{P_{tie.ij}} + \boldsymbol{B_i} \Delta \boldsymbol{f_i} \quad (2.27)$$

Where,

Δf_i= frequency error of ith area

$\Delta P_{tie.ij}$=Tie line power between ith and jth area

B_i= Bias coefficient of ith area

2.6 MODELLING OF AGC IN TWO AREA POWER SYSTEM

Two single areas can be connected through tie-line to form a Two area interconnected power system, as shown in the Fig. 2.5. Each control area fulfils demand of their user pool and the tie-line allows electric power to flow between the control areas. Each area consist of governor, turbine, reheater, generator and generator-load component as shown in fig.2.5.

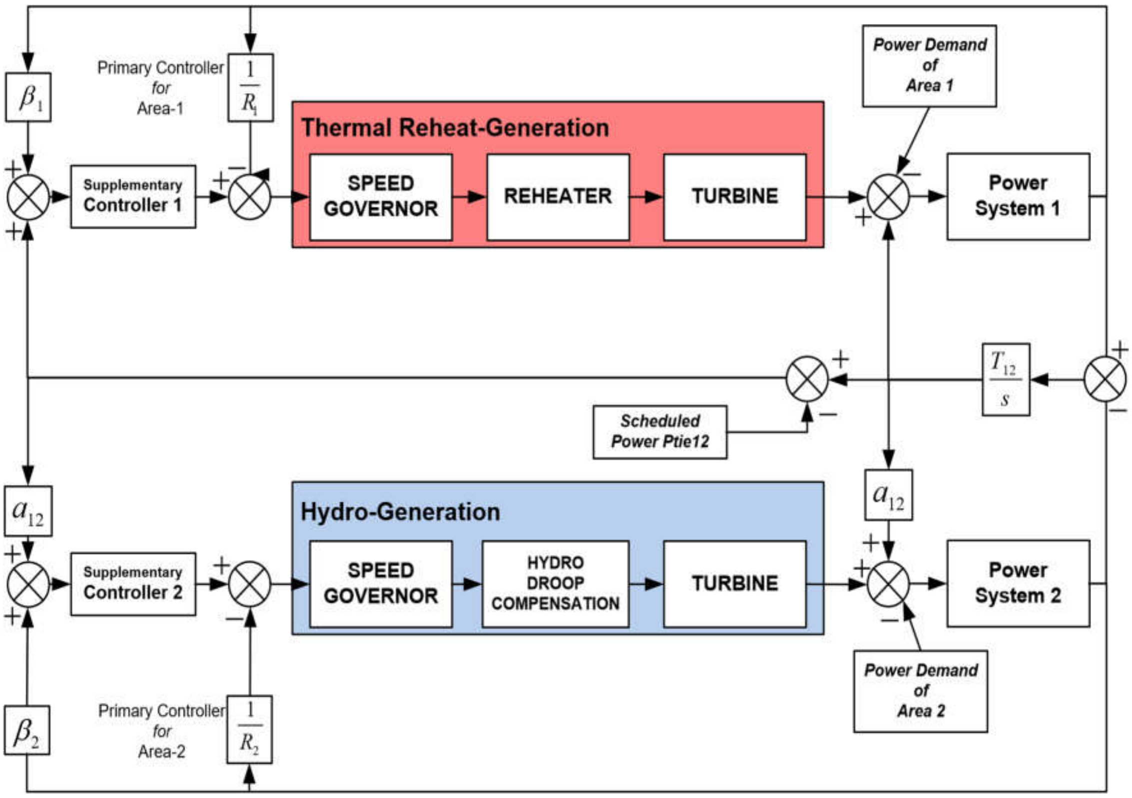

Fig. 2.5: Block diagram of two area power system

CHAPTER 3

PV SYSTEM

3.1 INTRODUCTION

This is essential in the direction of developing the acceptable models of the hybrid systems for load frequency regulation studies. During this thesis a multi area grid model with renewable energy sources in one area has been taken for the desired demand. The model expressed here is that the integral controlling action the interconnected power systems. Hybrid power grid that is intended for the implementation of traditional as well as the intelligent controllers and ascertained their stability[55]. The model of hybrid power grid is afterwards for the applying of optimum controllers for the LFC. It includes renewable energy sources and two thermal power systems. The distributed generating system in analysis contains energy resources. For example: turbine generator, BESS and PV. Dynamic response of a controlling system inside the prospect of wind energy generating system isn't comparatively an equivalent as was standard power plants. The ability output of such resources is relying upon conditions of temperature and land area. An additional unbalance is there whenever the specific wind power vary from its desired value because of variation in wind speed.

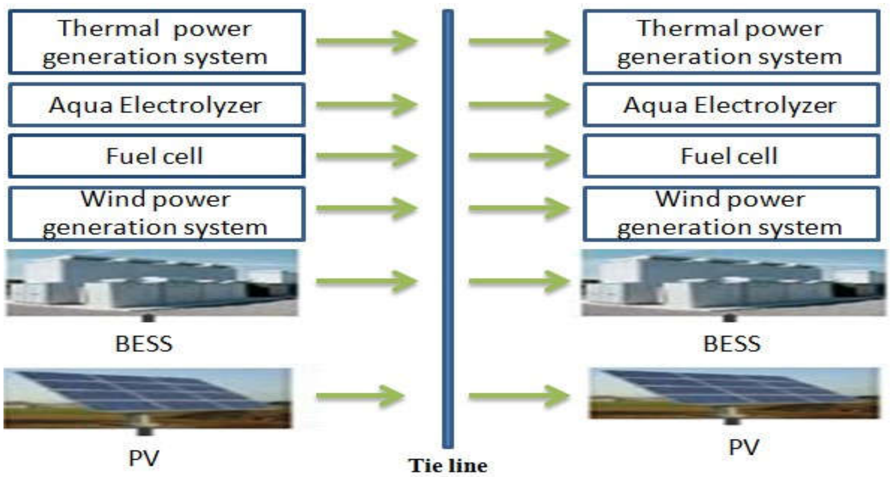

Fig.3.1 Layout of the hybrid power system

As the power generated by the wind turbine system is an irregular energy resource which is different from the conventional power plants. The controlling action of output power of wind turbine is a complicated task. Hence, bringing together controllability and the stability of active power in wind turbines has to be illustrated. A quantity of wind output power is used by AE for the creation of hydrogen, which is operated as the part of fuel cell for generating power and BESS is used for load levelling in power system. Schematic diagram of PV array is shown in fig. 3.2

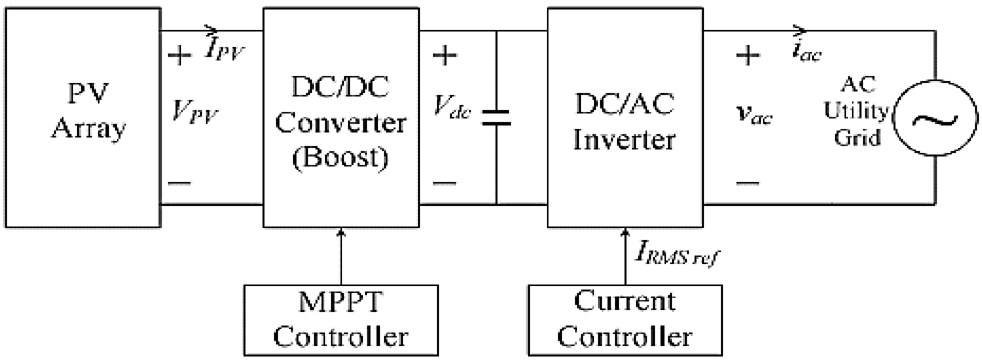

Fig:3.2 Block Diagram of AC Grid Connected PV Module

3.2 SOLAR CELL PANEL

Solar cell panel follows the photovoltaic effect in which voltage and electric current is created in a material upon exposure to light. Solar cell panel consists of numerous solar cells which are made of semiconductor and have two sides- front side and reverse side. The front side and reverse side can be differentiated by the numbers of electrons as the front side generally has an excess of free electrons whereas the reverse side has a deficiency of free electrons. The electrons remains in the bound state but upon exposure to light they absorb photon from the light source and became free to move. The photon is captured by the field in the interface. This is how the electric current generates in Solar cell. Solar cells can provide an output voltage ranging from 0.3V to 0.6V. Solar cell can Equivalent Circuit of solar cell is given n eqn.3.3.

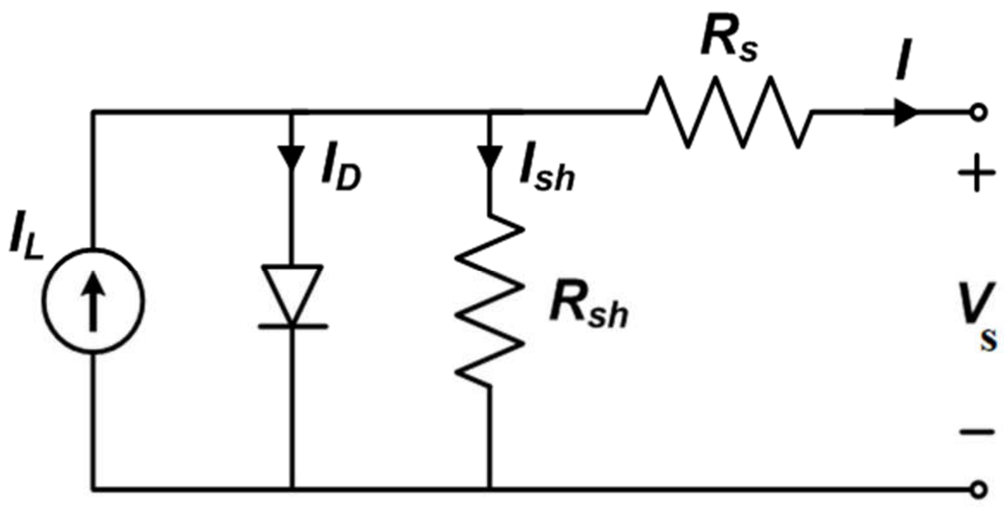

Fig: 3.3 Equivalent circuit of solar cell

The governing equation for this equivalent circuit is formulated using Kirchhoff's current law for current and I_D using shockley equation which is given by eqn.3.1 and eqn3.2.

$$I = I_L - I_D - I_{sh} \quad (3.1)$$

$$I_D = I_O \left[exp\left(\frac{V_s + IR_S}{nV_T} \right) - 1 \right] \quad (3.2)$$

n =diode ideality factor

Writing the shunt current as $I_{sh} = (V_s+IRs)/R_{sh}$ and combining this and the above equations result in the complete governing equation for the single diode model, given by eqn 3.3.

$$I = I_L - I_O \left[exp\left(\frac{V_s + IR_S}{nV_T} \right) - 1 \right] - \frac{V_s + IRs}{R_{sh}} \quad (3.3)$$

Above parameters are as follows:

I_L = Ligth Current (A)

I_D = Voltage dependent Diode current (A)

I_O = Diode reverse saturation current (A)

R_S = Series resistance (Ω)

R_{sh} = Shunt resistance (Ω)

n = Diode ideality factor (unitless)

V_T = Thermal voltage (V)

V_s= Solar Cell Voltage

3.3) MAXIMUM POWER POINT TRACKING

In solar cell panel, the utmost aspect is the efficiency of the PV panel. The efficiency or maximum power depends upon solar irradiance and temperature. MPPT is an algorithm used to extract maximum power from a PV module. When solar energy is converted into electrical energy the efficiency is less than 50%. To regulate this, MPPT algorithm is used. Under certain conditions, MPPT algorithm sets a voltage at which maximum power is extracted from the solar panel[53]-[54]. This voltage is called "Maximum power point". The problem with the low efficiency lies with impedance matching as the source impedance needs to be in par with load impedance according to Maximum power transfer theorem. This matching [53] can be achieved by varying the duty cycle of DC-DC converter. The below figures shows the Power versus Voltage characteristic of a solar panel shown in Fig.3.4.

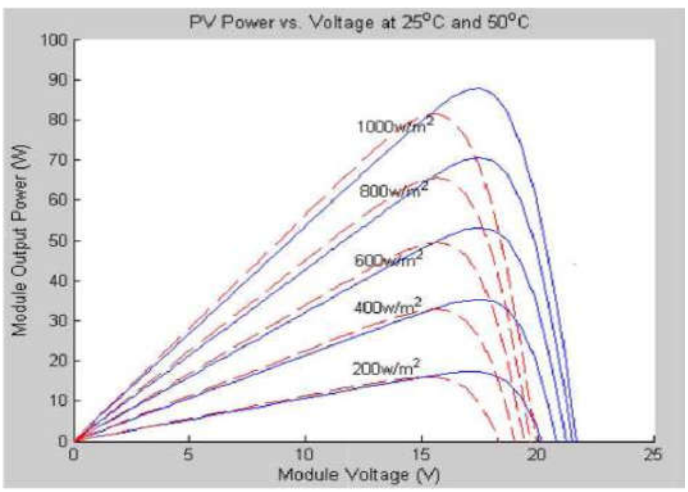

Fig: 3.4 Temperature And Irradiance Effect on P-V Characteristics

If we analyse the curve, we get a point where the power is maximized. This point is termed as Maximum Power Point (MPP). We can control the voltage of the solar panel as well. This can control the voltage as VMPP. So a single solar panel can be used with different type of loads with different voltage requirements.some MPPT techniques and their characteristics has shown in table.3.1.

a) Fractional Open Circuit Voltage method
b) Fractional Short Circuit Current methods
c) Incremental Conductance method
d) Perturb and Observe methods
e) Neural network method
f) Fuzzy logic method

Table 3.1 : Chracteristics of different MPPT technique

MPPT technique	Convergence speed	Implementation complexity	Periodic tuning	Sensed parameters
Perturb & observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current
Fractional V_{oc}	Medium	Low	Yes	Voltage
Fractional I_{sc}	Medium	Medium	Yes	Current
Fuzzy logic control	Fast	High	Yes	Varies
Neural network	Fast	High	Yes	Varies

3.4 BOOST CONVERTER

Boost converter consists of a capacitor and an inductor with energy storing capacity, and two complementary switches as shown in fig.3.5.

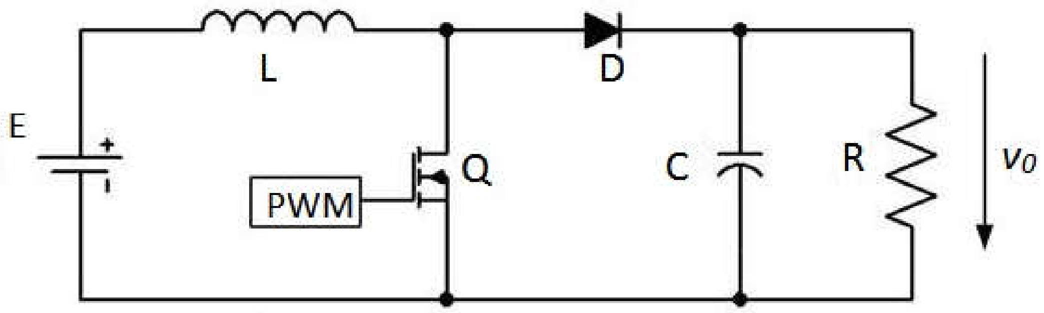

Fig. 3.5 Equivalent circuit of a boost converter

During first time interval: The diode is OFF and the transistor is ON

Here in this interval, the equivalent diagram of the circuit corresponding with the duty cycle of PWM driving cycle is presented in fig.3.6.

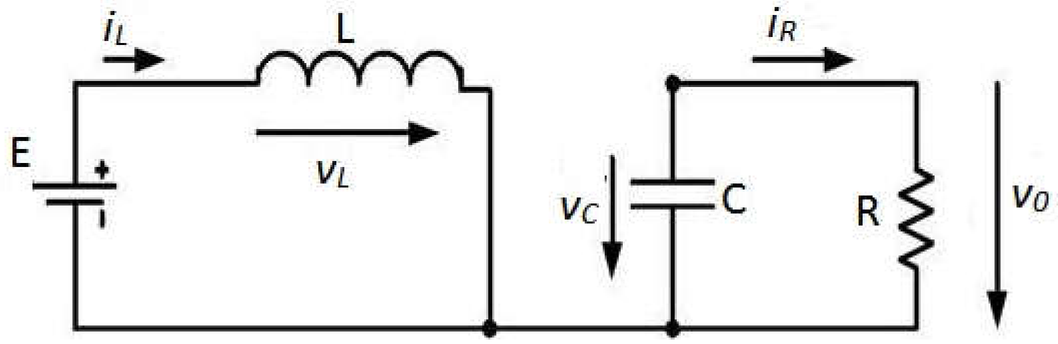

Fig. 3.6 Equivalent circuit diagram for OFF state of diode and ON state of transistor

Here the inductance L stores energy. Here V_0 and i_L satisfies the following eqn 3.10.

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{E}{L}; \\ \dfrac{dv_0}{dt} = -\dfrac{v_0}{R\,.\,C}; \end{cases} \qquad (3.10)$$

During second time interval: The diode is ON and the transistor is OFF

Here the transistor gets off the voltage across the inductor will change and the diode gets on. Equivalent diagram of converter during this interval is shown in fig.3.7.

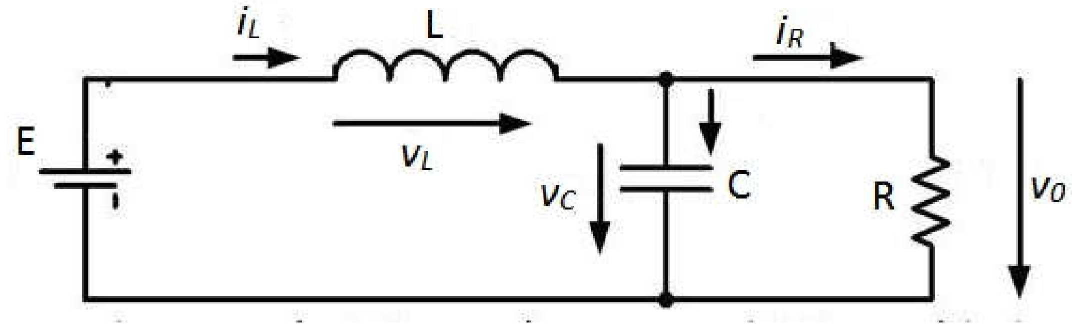

Fig. 3.7 Equivalent circuit diagram for ON state of diode and OFF state of transistor

Here V_0 and i_L satisfies eqn.3.11.

$$\begin{cases} \frac{di_L}{dt} = \frac{E - v_0}{L}; \\ \frac{v_0}{dt} = \frac{1}{C}\left(i_L - \frac{V_0}{R}\right); \end{cases} \qquad (3.11)$$

<u>During third time interval: Both diode and transistor are OFF</u>

Both diodes and transistors go in OFF state when the inductor current becomes zero before ending the diode conduction period. The diode will close naturally as the diode current becomes zero and the output capacitor will discharge on the load. This operation is termed as discontinuous current mode. Its equivalent diagram is shown below.

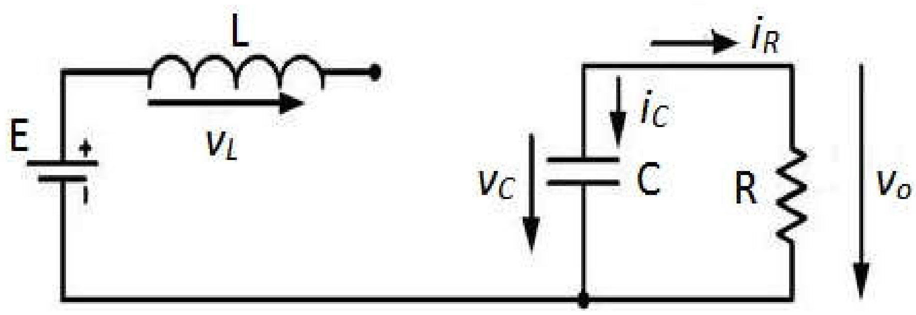

Fig. 3.8 Equivalent circuit diagram for OFF state of both diode and transistor

Here the output voltage V_0 and inductor current i_L can be calculated as shown in eqn.3.12.

$$\begin{cases} \frac{di_L}{dt} = 0; \\ \frac{dv_0}{dt} = -\frac{v_0}{R\,.\,C}; \end{cases} \qquad (3.12)$$

3.4.1 Continuous Current Mode

With the help of inductor current equation, the minimum value of inductance for continuous current mode is calculated. The waveforms for inductor voltage and current are shown in fig.3.9.

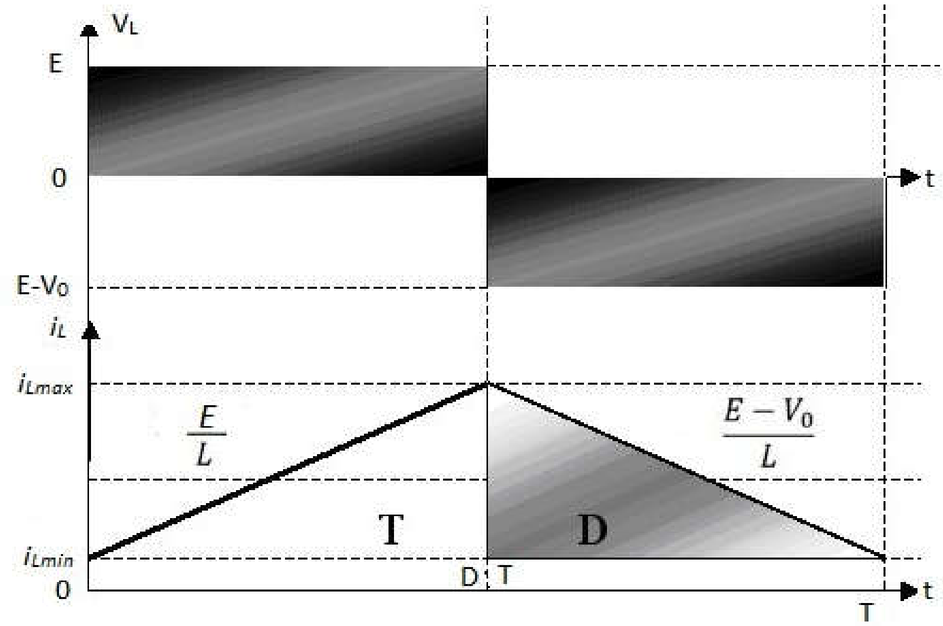

Fig. 3.9. Waveforms of inductor voltage and current in the steady state

Thus the output voltage V_0 and inductor current i_L is given by eqn 3.13 and eqn 3.14.

$$E.D.T = T.(1-D).(V_0 - E) \Rightarrow V_0 = \frac{E}{1-D} \qquad (3.13)$$

Here the maximum value of inductor current is:

$$i_{Lmax} = i_{Lmin} + \frac{E}{L}.D.T \qquad (3.14)$$

The output current and diode current are equal and can be given by eqn 3.15.

$$\frac{i_{Lmax} + i_{Lmin}}{2}.T.(1 - D) = \frac{V_0}{R}.T \qquad (3.15)$$

Based on above equations maximum and minimum inductor current can be given by eqn 3.16 and eqn 3.17.

$$i_{Lmax} = \frac{V_0}{R.(1 - D)} + \frac{E.D.T}{2L} \qquad (3.16)$$

$$i_{Lmin} = \frac{V_0}{R.(1 - D)} - \frac{E.D.T}{2L} \qquad (3.17)$$

The inductor current ripple will then be:

$$\Delta i = \frac{E.D.T}{L} \qquad (3.18)$$

For the continuous conduction mode $i_L \geq 0$ and it results in following eqn 3.19.

$$\frac{2L}{R.T} \geq D.(1 - D)^2 \qquad (3.19)$$

It can be used to determine the minimum value of inductance for particular switching period T and particular load R, which is given by eqn 3.20.

$$L_{min} = \frac{R.T}{2} D.(1 - D)^2 \qquad (3.20)$$

3.4.2 Discontinuous Conduction Mode

Here the waveforms of output voltage V_0 and inductor current i_L are shown in fig.3.10.

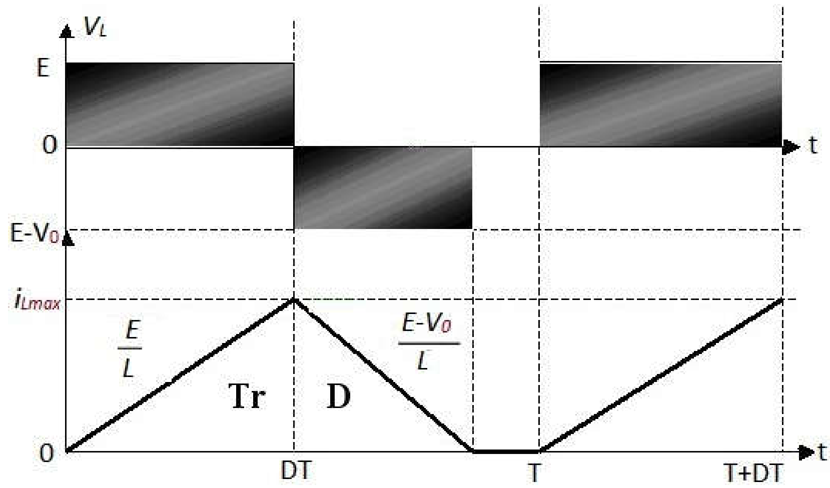

Fig. 3.10 Waveforms of voltage and inductor current in DCM

The average value of input current and inductor average current are equai and is given by eqn3.21 and eqn 3.22.

$$I_{i_{av}}.T = \frac{1}{2}.I_{L_{max}}(D.T + t_1) \qquad (3.21)$$

$$I_{L_{max}} = \frac{E.D.T}{L} \qquad (3.22)$$

From above two equations we get average current equation as shown in eqn. 3.23.

$$I_{i_{av}}.T = \frac{1}{2}.I_{L_{max}}(D.T + t_1) \qquad (3.23)$$

During the switching period the average value of inductor voltage is zero.

$$E.D.T = t_1(V_0 - E); \Rightarrow t_1 = \frac{E.D.T}{V_0 - E} \qquad (3.24)$$

Putting Eqn. (3.23) and (3.24) with the consideration that input and output power are equal and is given by eqn 3.25.

$$P_{in} = P_{out} \Leftrightarrow \frac{{V_0}^2}{R} = E.I_{iav} \qquad (3.25)$$

And it results in following eqn 3.26.

$$\frac{V_0}{E}\left(\frac{V_0}{R} - 1\right) = \frac{D^2.T.R}{2L} \qquad (3.26)$$

Placing the voltage transfer ratio $M = \frac{V_0}{E}$ equation (3.25) becomes

$$M(\,M-1) = \frac{D^2.T.R}{2L} \qquad (3.27)$$

The solution of this equation is given below in eqn 3.28.

$$M = \frac{1+\sqrt{1-4\frac{D^2.T.R}{2L}}}{2} \qquad (3.28)$$

3.5 DC-AC converter

Inverter comes into picture when we need to convert DC voltage into AC voltage. An inverter is a device which invert the Direct Current output to Alternating Current output. Inverter plays a pivotal part in Solar Panel. As the output of solar cells panel is direct Current and all the commercial equipment required an Alternating Current to function, so inverter convert it into DC. This is why it can be called as a bridge between the Solar panel system and external load. A single phase inverter can be represented by the below circuit diagram 3.11.

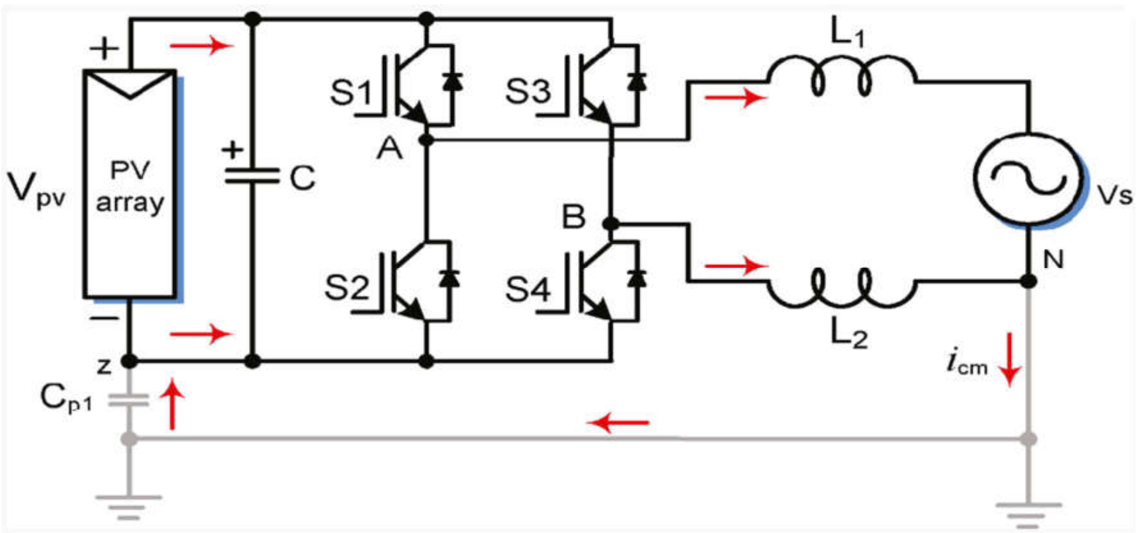

Fig. 3.11. Equivalent circuit of single phase inverter

3.6 EQUIVALENT MODEL OF PV ARRAY SYSTEM

A transfer function model is required in two area system. Each area system needs to be defined by a separate transfer function model[55]-[56]. Solar panel consists of different units such as PV array, MPPT algorithm, Boost converter, Inverter, Load etc. Each unit has to be shown by a transfer function model and the main aim is to consolidate all the transfer function model into a single transfer function model[55]-[56]. Equations 3.1 and 3.3 is used in finding out the transfer function model of the solar panel. Boost converter operates in two modes- ON state and OFF state. The states can be represented by the equations 3.10 and 3.11 respectively. By consolidating al the equation we can arrive at equation 3.29 which can be considered as the transfer function model of the solar panel. The block diagram of the transfer function model is given below:

$$G(s) = \frac{-18s+900}{s2+100s+5\ 0} \quad \text{...(3.29)}$$

Fig. 3.12. Transfer Function Model of PV Panel

CHAPTER 4

PROPOSED CONTROLLERS

4.1 CONVENTIONAL CONTROLLER

IN our grid connected power system the system frequency and voltage should always be in nominal limits for that we used different type of controllers. It is important to design more reliable and robust controller for load frequency control to attain minimum overshoot as well as settling time[57]. Here, we have suggested different controllers i.e. PI, PID , FGSPI and ANFIS for AGC. Where PI and PID are conventional controllers and FGSPI & ANFIS are intelligent controllers.

4.1.1 PI controller

There are various types of load-frequency controllers available but the PI controller is most widely used in speed-governor schemes for LFC schemes[58]. The PI controller has an upper hand on other controllers as it makes the steady-state error to zero.

$$U_i = -k_i \int_0^T (ACE_i) = -k_i \int_0^T (\Delta P_{tiei} + B_i \Delta F_i)\, dt. \qquad (4.1)$$

Take the derivative of equation:

$$U_i = -k_i (ACE_i) = -k_i (\Delta P_{Tiei} + B_i \Delta F_i) \qquad (4.2)$$

The prime application PI controller is that it keeps the error at zero at the steady state. PI controller with predetermined gains is measured at insignificant working conditions, at immense range of working circumstances it is unsuccessful to provide the optimum control performance. Block diagram of PI controller is shown in fig. 4.1.

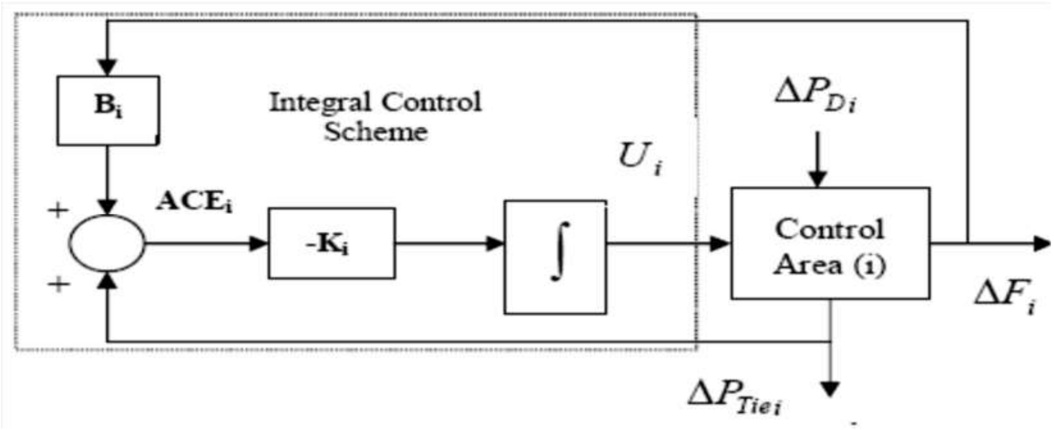

Fig.4.1. Conventional PI controller

4.1.2 PID controller

Proportional plus integral plus derivative controller is used for better dynamics of system characteristics which reduces the steady state error to zero , reduced the transient, reduces the damping constant which result in lower overshoot educe settling time which makes system faster, reduces gain margin and phase margin. Adding a pole makes our controller integral through which steady state error can be reduced to zero but that increases the damping constant which makes high overshoot so adding a zero along with it, reducing the damping constant hence overshoot. So for a good response we have to use combination of proportional , integral and derivative controller i.e. PID. In AGC modelling PID controller not only makes the steady state error to zero for transient response but also reduce the setting time as compared to PI controller. The PID controller equation can be given eqn 4.1.

$$G_{pid}(s) = K_P + \frac{K_I}{s} + sK_D \qquad (4.3)$$

4.2 INTELLIGENT HYBRID CONTROLLERS

In this thesis evaluation of different conventional controllers (PI & PID) and intelligent controllers (like FSSPI and ANFIS) with different gain scheduling has been carried out. The performance of PI and PID controllers deteriorates as the complexity of the system increased due to the nonlinearity and boilers dynamics in the interconnected power system Application of fuzzy logic in Load Frequency Control problems gives a rather promising results. Advantages of fuzzy logic is that it does not required a model identification and using intelligent control it provide a model free description. Whereas fuzzy control technique also has some limitations of selecting proper membership functions and de-fuzzification problem. Then it has been thought of a controller which can even work with nonlinearities and can give fast response. The Artificial Neural Network came in existence. By training the neurons, multiplying with weight and applying a suitable activation function, the output can be obtained. The ANN controller works better for large power system or unstructured system[59]. But this ANN controller also has some limitation of training of neural network and activation function. There is a need of such controller which has both properties fuzzy and neural then a hybrid neuro-fuzzy controller is sought. The ANFIS is having capability of training of data and application of membership function for error and change in error, fuzzy inference system and defuzzification. ANFIS controller give better settling performance than the other four types of controller discussed. Therefore hybrid intelligent control approach using ANFIS controller is better than the conventional (PI and PID) controller and intelligent (Fuzzy, ANN and ANFIS) controller. Details of intelligent controllers are given in the preceding sections.

4.2.1 Fuzzy logic controller

In present time, the FLC is extensively received attentions in a variety of applications of power system[60]. Fuzzy logic controllers are knowledge-based generally resultant from a self-organizing control architecture or knowledge acquisition process. Fuzzy systems consist of membership functions describing the fuzzy sets and fuzzy IF-THEN rules. The Fuzzy Logic Controller comparison is considered on Mamdani model.

4.2.1.1 Fuzzification

It is the strategy changing the real-valued variable to the fuzzy set variable. Fuzzy variables relied on the hybrid system’s nature wherever it's enforced.

4.2.1.2 Rule Base

The necessary a part of the fuzzy could be a knowledge base. The rule base consist the set of fuzzy rules. The information base is carrying by the membership functions. The fuzzy rule is accommodates variables and subsets explained through the membership function.

4.2.1.3 De-Fuzzification

De-fuzzification converts the fuzzy output variables into crisp value which is used by connected power system model. Crisp value is necessary in practical power system applications for controlling action[61]. The block diagram of FLC is shown in fig. 4.2.The fuzzy control action is decided by the knowledge base. For determining the performance of controller, the de-fuzzification, membership functions and knowledge base are considered.

The input variable (ΔFs) of FLC is error signal for the governor. The rule base and the membership functions consist of five linguistic variables (NB, NS, ZZ, PS, and PB) for two inputs and two outputs are shown in Figure 4.3 and Table-1 for the comparison of FLC with the proposed controller.

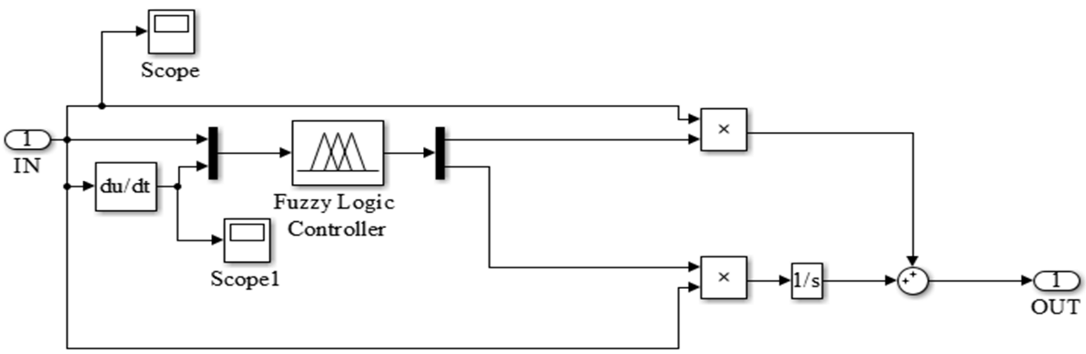

Fig. 4.2. Block diagram of fuzzy logic controller

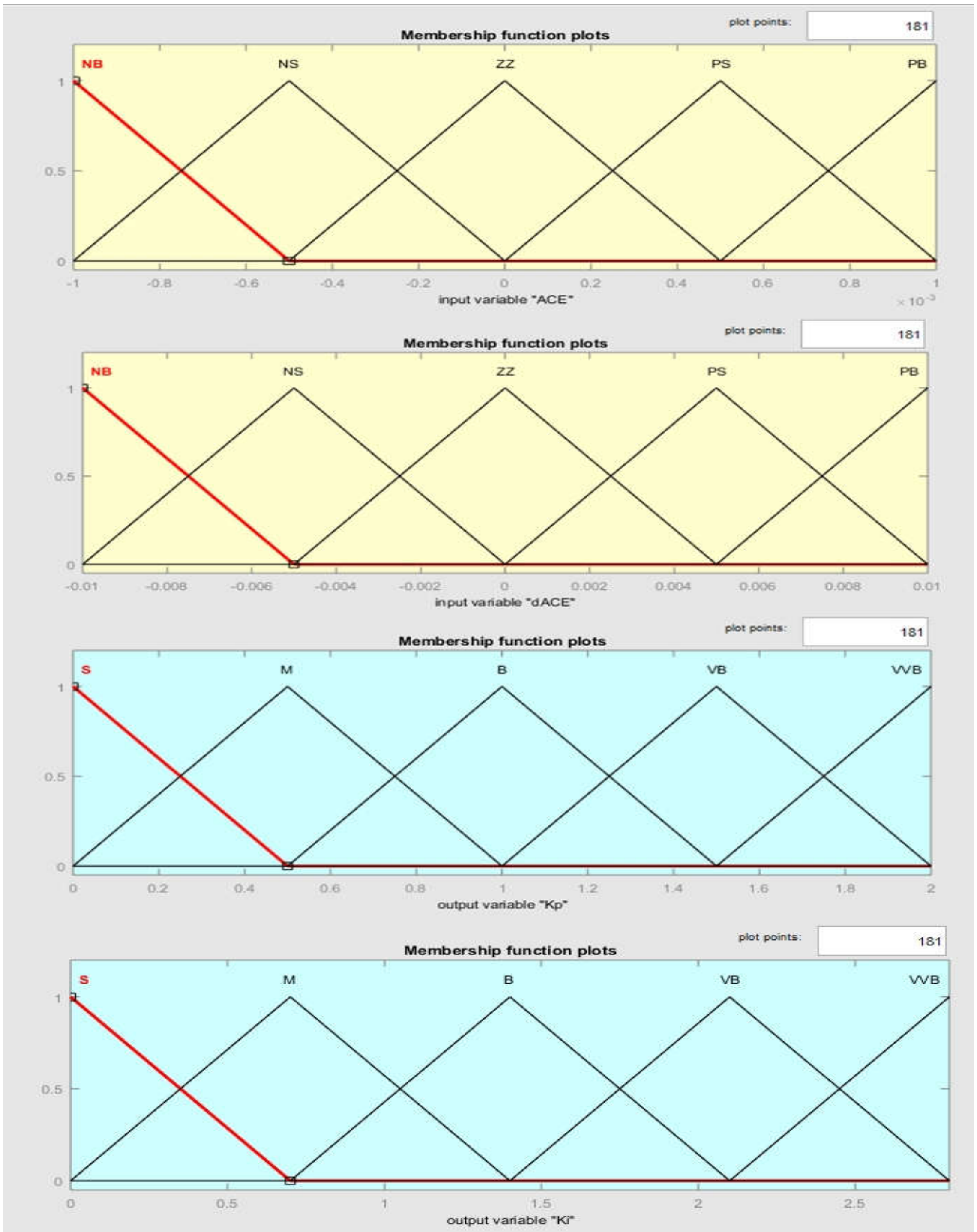

Fig. 4.3 Membership function of ACE, dACE, K_p and K_i

TABLE 4.1: Fuzzy logic rule base consisting five membership functions

ACE, dACE / Kp, Ki	NB	NS	Z	PS	PB
NB	S,S	S,S	M,M	M,M	B,B
NS	S,S	M,M	M,M	B,B	VB,VB
Z	M,M	M,M	B,B	VB,VB	VB,VB
PS	M,M	B,B	VB,VB	VB,VB	VVB,VVB
PB	B,B	VB,VB	VB,VB	VVB,VVB	VVB,VVB

4.2.2 ANFIS

4.2.1 Artificial Neural Architectures

An ANN tends to emulate the biological nervous system of the human brain is a very limited way by an electronic circuit or computer program. Different layer of artificial neuron and multi-layered artificial neural network is shown in fig .4.4.

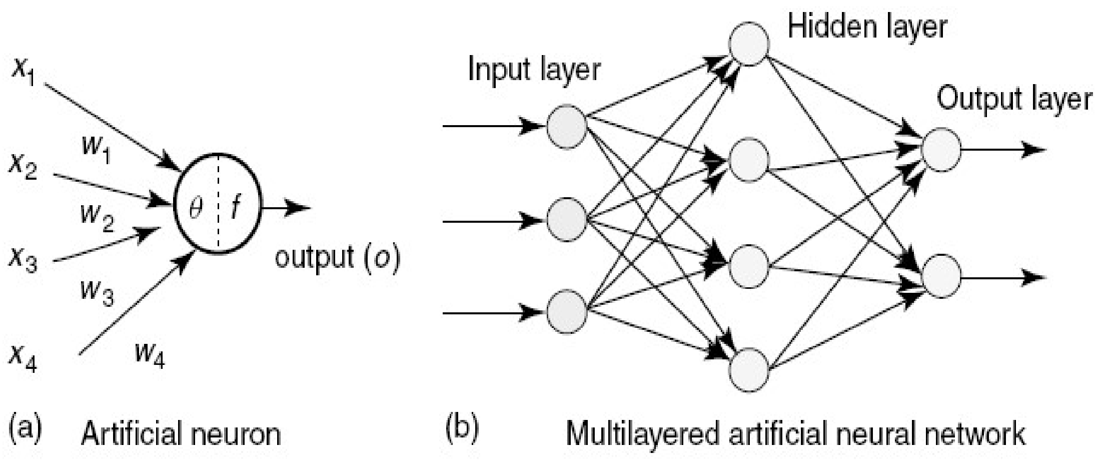

Fig. 4.4 Architecture of an artificial neuron and a multi-layered neural network

However inferior the ANN model of the biological nervous system, it resolve many issues. An ANN (also defined as a neuro-computer or connectionist system in the literature) solve problems that are difficult to solve by conventional digital computer. Pattern recognition or input/output mapping constitutes the core of neuro computation. Basically, this mapping is possible by the associative memory property of the human brain. There is a very old and fascinating history behind the ANN Technology[62]. After reviewing neural network concept it is mainly emphasized on applications in power electronics, power system and the drives area will be described from the literature. The MATLAB structure of ANFIS is shown in Fig. 4.5.

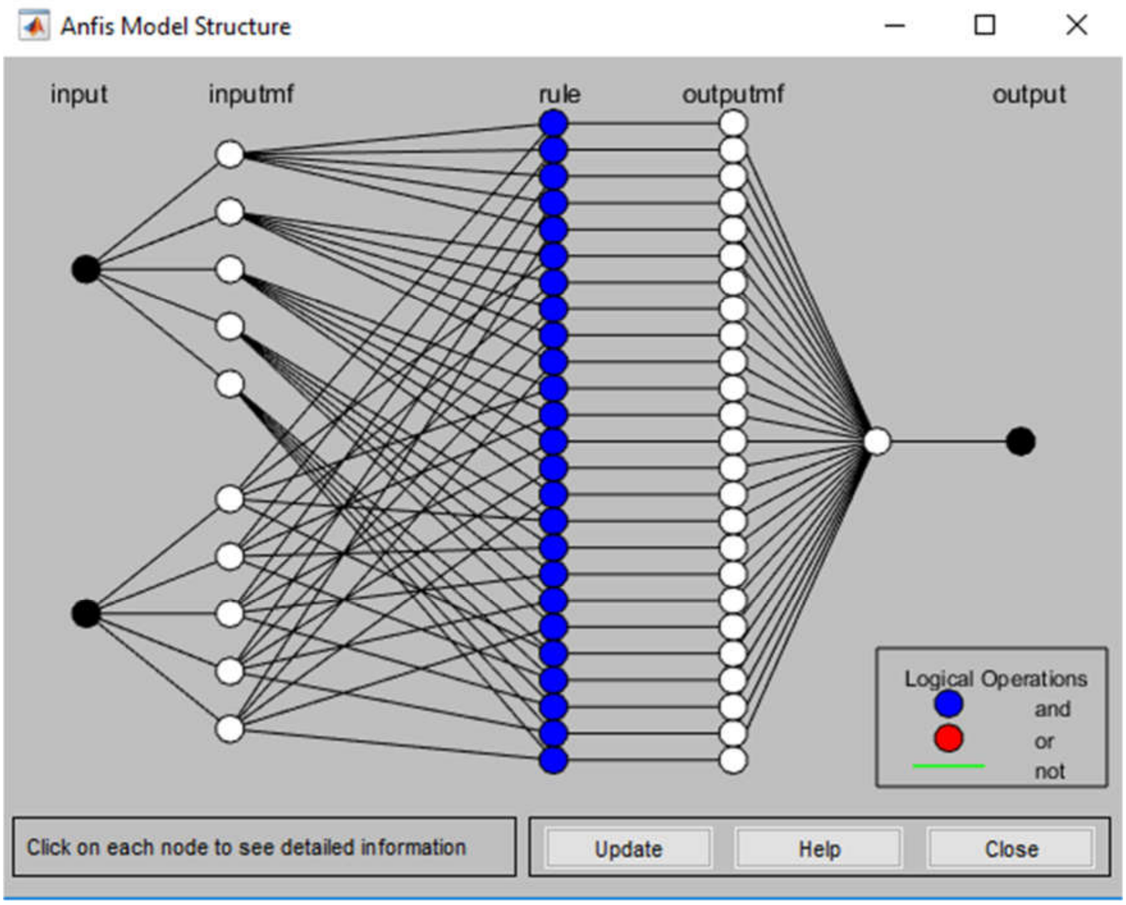

Fig. 4.5 MATLAB Structure of ANFIS

4.2.3 Adaptive Neurro-Fuzzy Interface System (ANFIS)

ANFIS (Adaptive neuro-fuzzy inference system) is defined as the multi-layer labile neural system supported the fuzzy system [15]. The algorithm of ANFIS is prepared by neural systems and fuzzy logic, the neural system consists of 5 layers to hold out distinctive node functions to be trained and tuned parameters in FIS structure exploit hybrid learning mode. The least square error strategy estimation, with premise stable parameters, is utilized to update the successive parameters for forward passing and used for passing the error into the backward pass. The resultant parameters are measured and gradient descent approach is used to renew the successive parameters into the backward pass. Successive and premise parameters is known by the membership function and FIS due to the repetition of the forward and the backward passes [63]. A ANFIS is fuzzy Sugeno models place in the configuration of adaptive system to persuade the learning and modification [64]. That structure formulates FLC extra logical and a lesser amount of dependable on proficient information. Consider the two-fuzzy rules to characterize the ANFIS architecture supports on a Sugeno model of first order.

Where inputs are x and y, fuzzy sets are Ai and Bi, f_i is the output contained by the fuzzy section which is given by the fuzzy rule. The design parameters are pi, qi and ri that are acquired throughout the training process.Block diagram of ANFIS is shown in fig.4.7.

The first and the fourth layers are adaptive nodes on the contrary, the second, third and fifth layers are fixed nodes. The adaptive nodes are coupled with their particular parameters and get modernized in the next iteration but the fixed nodes are not having any parameters. The two rules of ANFIS architecture is shown in Fig.4.6.

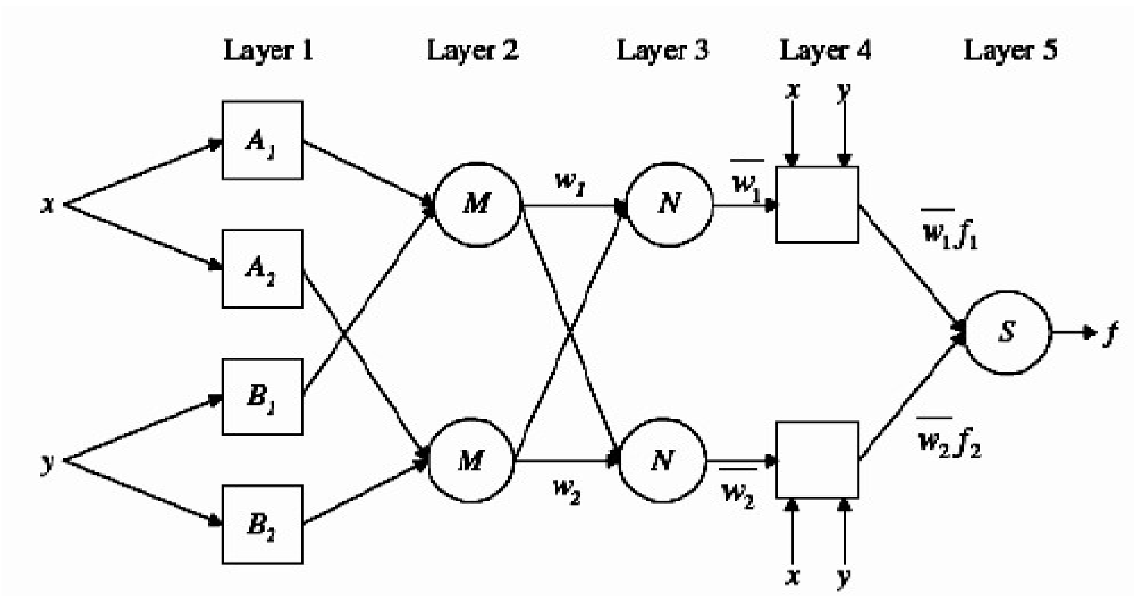

Fig.4.6. ANFIS architecture

Layer 1: Fuzzification layer: Node I is fixed node which is adaptive node. Output of layer 1 gives the membership grade of the inputs, which are given by:

$$O_i^1=\mu_{Ai}(x) = 1 / \left[1 + \left|\frac{x-c_i}{a_i}\right|^{2bi}\right] \quad \text{For } i = 1, 2 \qquad (4.4)$$

A is the linguistic label (e.g as small, big, negative big) and (a, b, c are the parameters that changes the shape of membership function[65].

Layer 2: Rule layer: The fixed node named as M, the product of all the incoming signals is obtained its output, and the outputs of this layer are representing as:

$$O_i^2= \mu_{Ai}(x).\, \mu_{Bi}(y) \quad \text{For } i=1, 2 \qquad (4.5)$$

Layer 3: Normalization layer: A circle node is labeled as N; it is also a fixed node.

$$O_i^3= \overline{w_i} = \frac{w_i}{w_1+w_2} \quad \text{For } i=1, 2 \qquad (4.6)$$

Layer 4: Defuzzification layer: The output of node is simply the product of a first order polynomial the standardized firing strength.

$$O_i^4 = \overline{w_i}f_i = \overline{w_i}\,(p_i x + q_i y + r_i) \quad \text{For } i=1, 2 \qquad (4.7)$$

Layer 5: Summing up neuron a fixed node that determines the entire output by summation of all incoming signals.

$$O_i^5 = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i f_i} \quad (4.8)$$

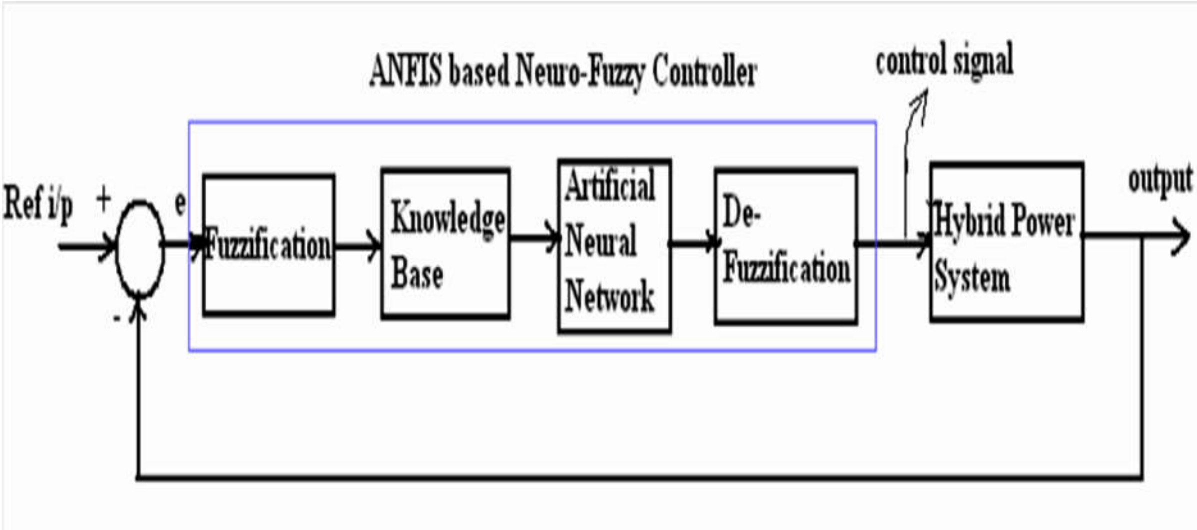

Fig. 4.7. Block diagram of ANFIS controller

4.2.4 Model Learning and Inference through ANFIS

The basic steps trailed for designing the ANFIS controller in MATLAB/Simulink is outlined:

1. Construct the Simulink model which is having Fuzzy logic controller (Takagi-Sugeno model) and simulate the model with the two inputs and with seven membership functions (error signal and rate of alteration in the error) along with the fuzzy rule base.
2. Group the data for training throughout the simulation and from FLC is used to predict the Neuro-Fuzzy controller.
3. The frequency deviation and rate of deviation in frequency error are the two inputs and output signal provides the training data.
4. Develop "anfisedit" for composing the Neuro-Fuzzy FIS file.
5. The grouped data is loaded in Step.2 and the FIS file for neuro-fuzzy is exported to the workspace.
6. The hybrid learning algorithm is selected.
7. The grouped data is trained up to a particular number of Epochs with created FIS file.

Training and testing of a ANFIS model in MATLAB environment is shown in fig. 4.7 and fig. 4.8..

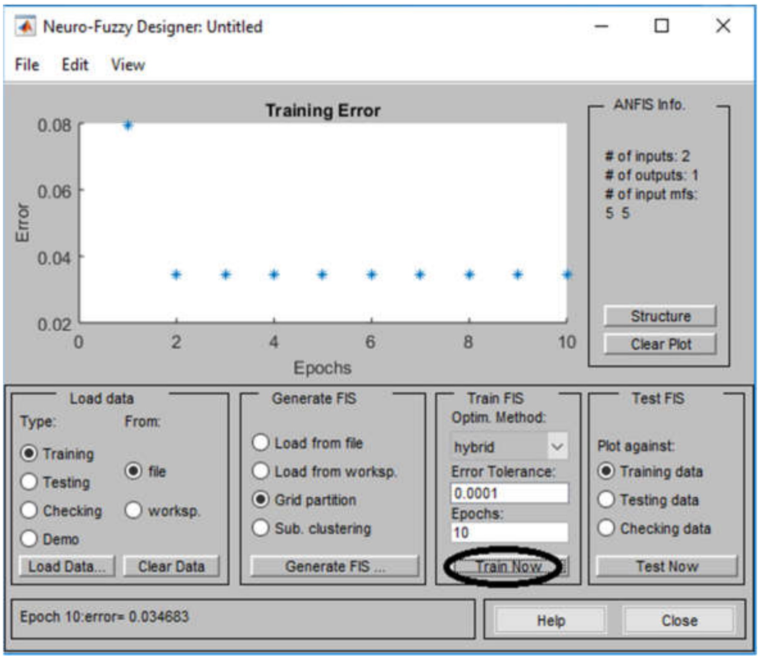

Fig. 4.8. Training of a ANFIS FIS file

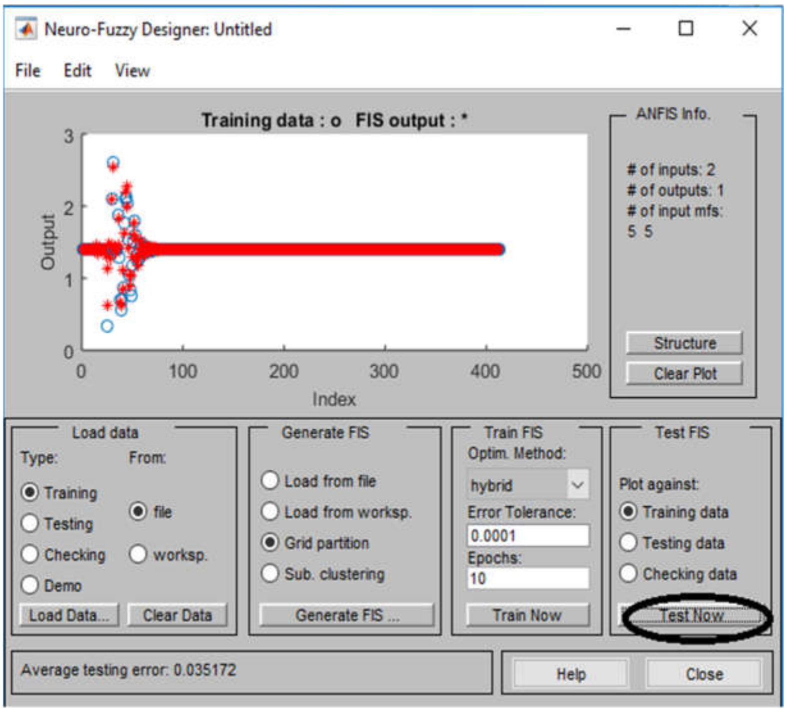

Fig. 4.9 Testing of trained FIS in ANFIS toolbox

CHAPTER -5

PROPOSED CONTROLLERS FOR 2 AREA POWER SYSTEM

5.1 GENERAL

In this chapter load frequency control of conventional power system is simulated with the use of proposed controller. There are different models of AGC in which 1^{st} one is single area thermal power system controlled with both PI and PID controller, 2^{nd} one is a two area hydro-thermal power system using PI controller. It is important to developed a novel and hybrid controller for AGC to improved its system dynamics, to make our power system more reliable and to reduce the settling time as well as peak overshoot some proposed controller are:

(i) PI Controller
(ii) PID Controller
(iii) FGSPI with Mumdani model
(iv) Neuro-fuzzy controller i.e. ANFIS controller.

To test this four controller we create a two area diesel power plant which is having some characteristics in both the areas., so that the exact comparison can be carried out. The performance of the proposed controller has been evaluated and comparison and effectiveness of all proposed controller will be evaluated.

5.2 SIMULATION AND RESULTS OF DEVELOPED MODEL OF LFCs

5.2.1 Single Area Thermal-reheat Power System using PI controller

The transfer function model of single area thermal reheat power system developed in Matlab Simulink is given in the Fig.5.1. The values of different components are put up in Matlab model .The nominal standard parameters are taken for testing.

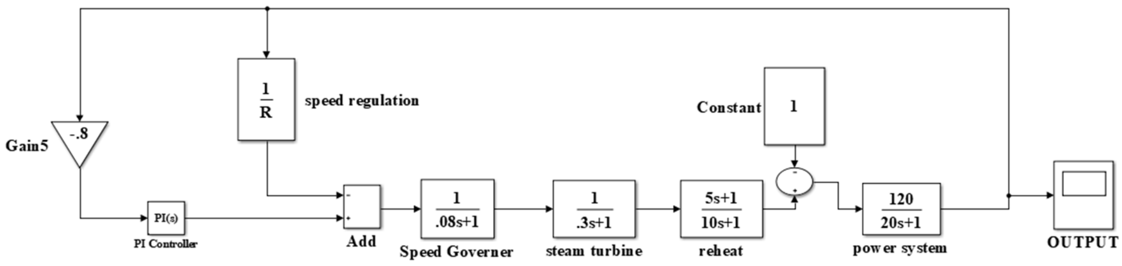

Fig.5.1 MATLAB model of single area thermal power system with PI controller.

Change in frequency of thermal power plant for a step change is obtained and output of single area system with PI controller is shown below in fig.5.2.

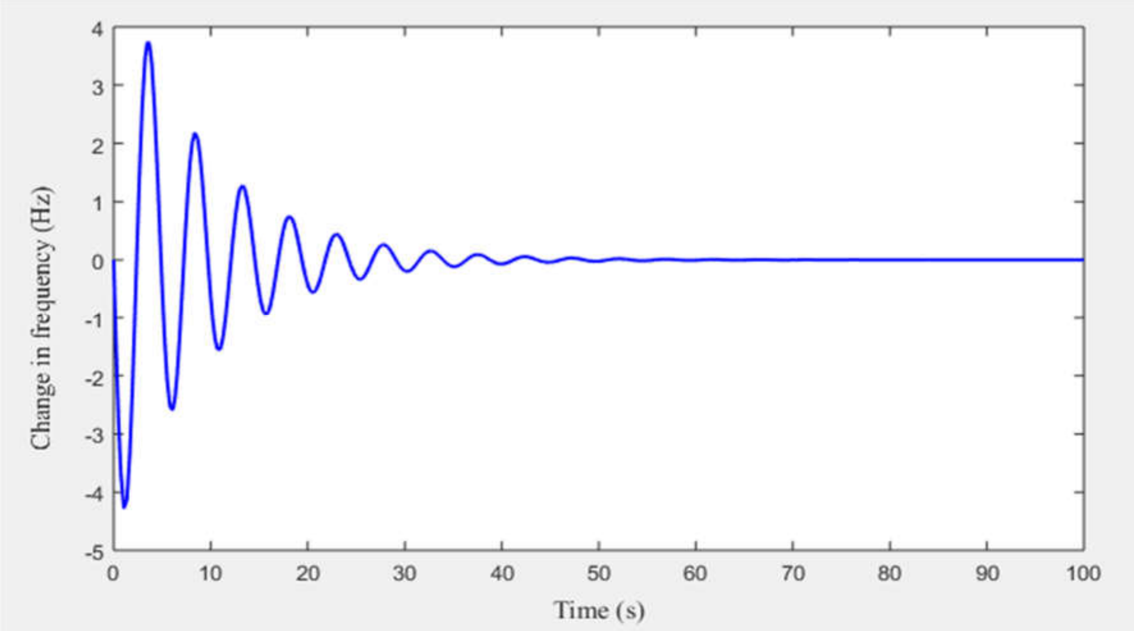

Fig.5.2. change in frequency of single area thermal power system using PI controller

After simulating the single area power system with PI controller, results are obtained as shown in fig.5.2. in which the steady state error become zero because of PI controller and settling time as well as peak overshoot is reduced. In this simulation method the steady state error is reduced to zero by tuning the value of K_i. However at K_i =-0.98 error is minimized to zero, therefore this value is optimum value of K_i. Settling time is obtained as 60 seconds. The maximum overshoot in frequency deviation is limited to -4 in per unit for thermal power system.

5.2.2 Single area thermal reheat power system with PID Controller

The transfer function model of single area thermal reheat power system developed in Matlab Simulink is given in the Fig.5.3. The values of different components are put up in Matlab model .The nominal standard parameters are taken for testing.

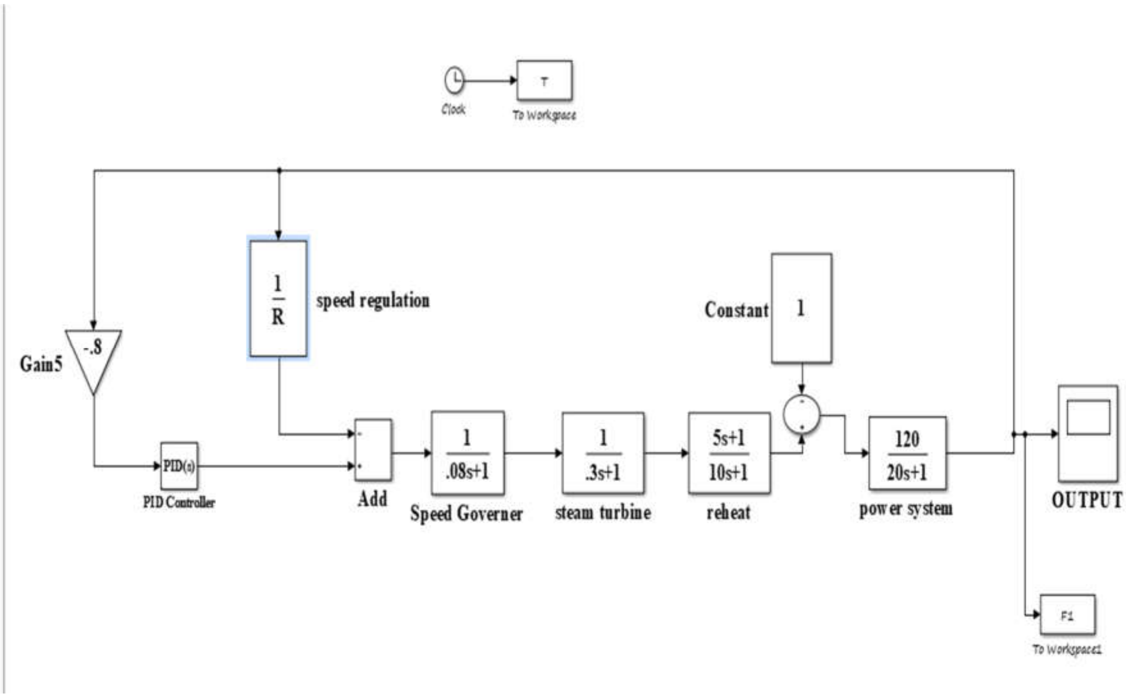

Fig.5.3 MATLAB model of single area thermal power system with PID controller.

Change in frequency of thermal power plant for a step change is obtained and output of single area system with PID controller is shown below in fig.5.4.

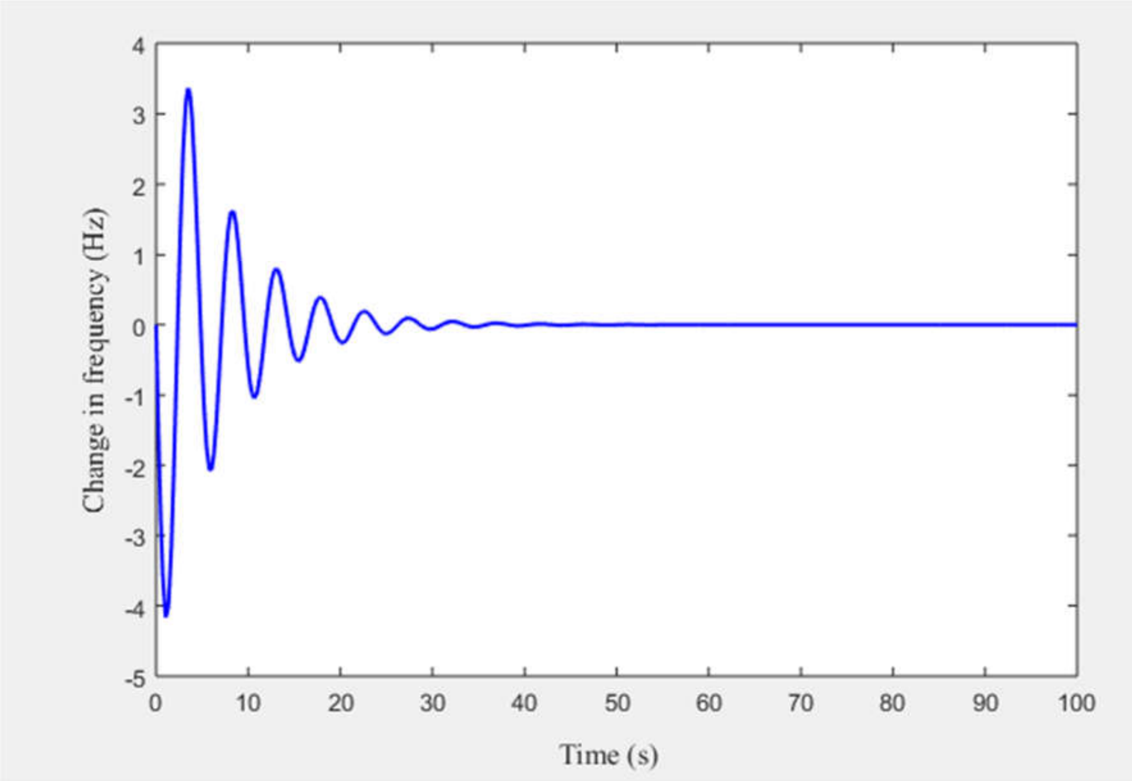

Fig.5.4. change in frequency of single area thermal power system using PID controller

After simulating the single area power system with PID controller, results are obtained as shown in fig.5.4 in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced due to the use of derivative control. In this simulation method the steady state error is reduced to zero by tuning the value of K_i and K_d. However at K_i =-0.85 and K_d = .002 error is minimized to zero, therefore this value is optimum value of K_i.and K_d settling time is obtained as 50 seconds. The maximum overshoot in frequency deviation is limited to -4.1 in per unit for thermal power system.

5.2.3 Two Area Hydro Thermal-reheat Interconnected Power System

In MATLAB Simulink two area transfer function model of hydro-thermal interconnected power system is developed, which is given in the Fig.5.5 Area-1 is thermal reheat power system and area-2 is hydroelectric power system. The values of different components are put up in Matlab model .The nominal standard parameters are taken for testing.

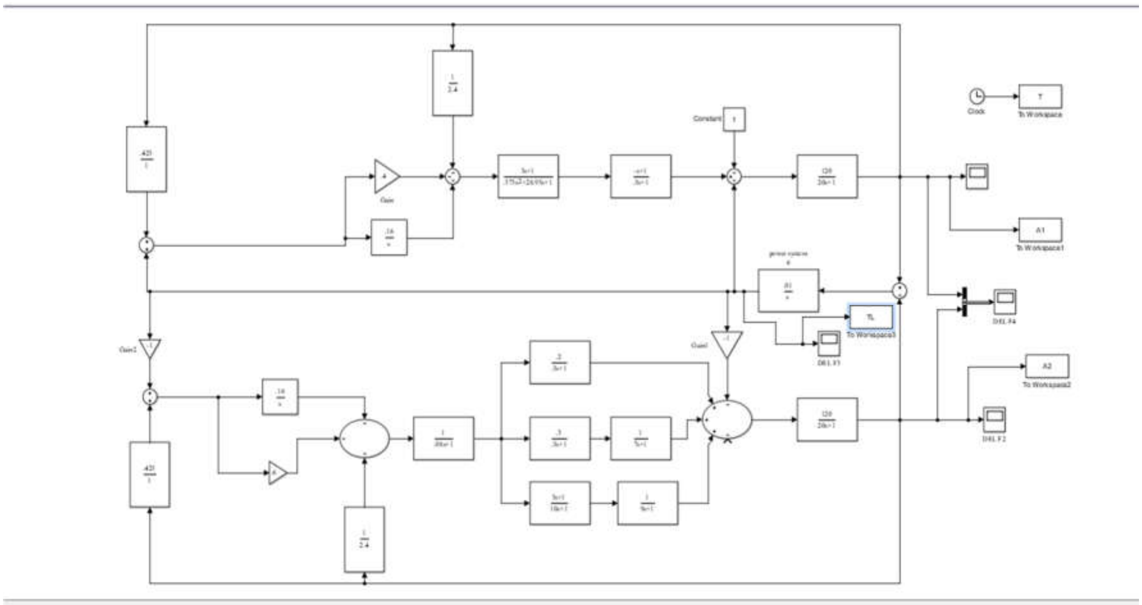

Fig.5.5. MATLAB model of two area hydro thermal interconnected system.

In this presented work,model of two area hydro-thermal reheat interconnected power system have been developed by using PI controllers to illustrate the performance of load frequency control using MATLAB/SIMULINK package.

Change in frequency of thermal and hydro power plant for a step change is obtained and output of two area system with PI controller is shown below in fig.5.6.

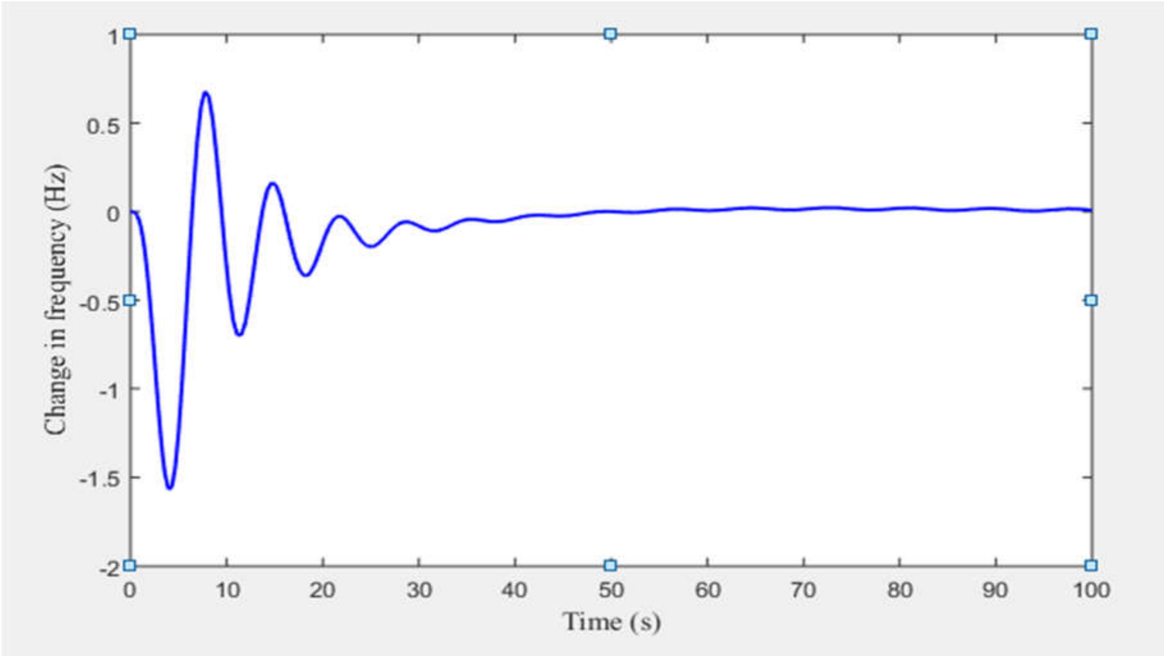

Fig. 5.6 Change in frequency of Thermal plant with PI controller in two area system

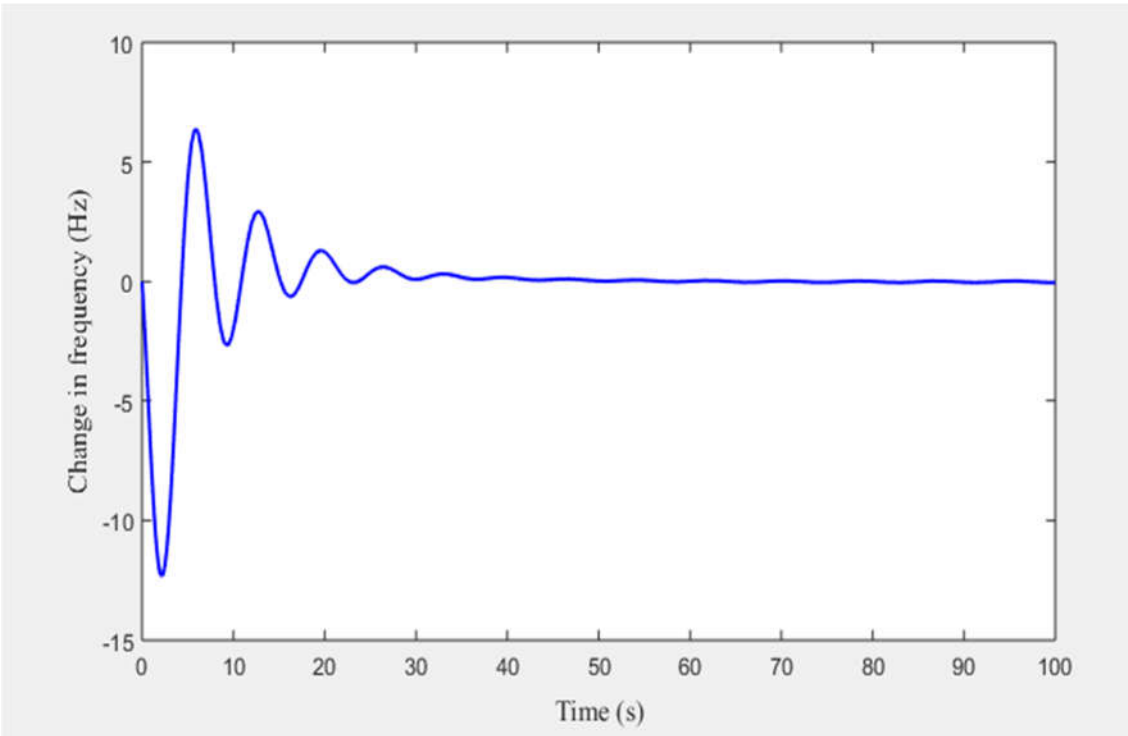

Fig.5.7 Change in frequency of hydro plant with PI controller in two area system

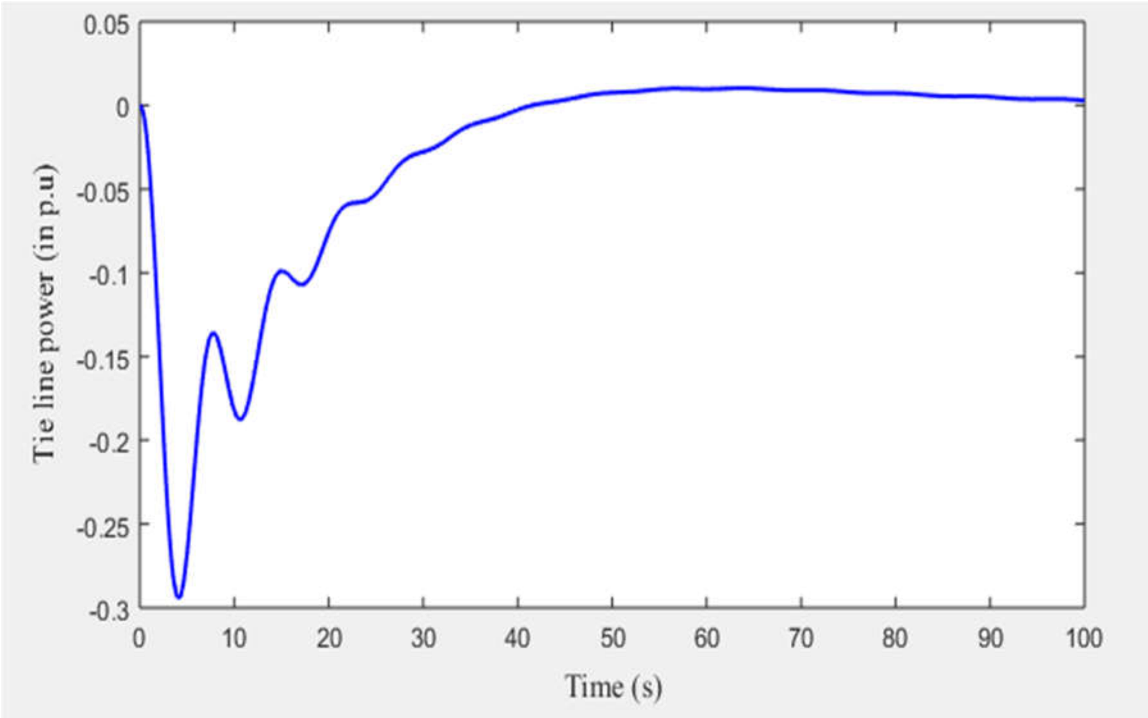

Fig. 5.8 Change in Tie-line power (hydro-thermal plant) with PI controller in two area system

After simulating the two area hydro-thermal power system with PI controller, results are obtained as shown in fig.5.6-5.8, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced. In this simulation method the steady state error is reduced to zero by tuning the value of K_i . However at K_i =0.16 error is minimized to zero, therefore this value is optimum value of K_i. Settling time is obtained as 50 seconds. The maximum overshoot in frequency deviation is limited to -1.6 in per unit for thermal power plant and -12 p.u for hydro power plant.

5.2.4 Two Area Diesel Interconnected Power System

Next we discussed the two area diesel power system in which both the areas are diesel power plant and we put a step change in both the areas so due to that the change in tie-line power in each case comes to zero p.u. and performance evaluation of all the four proposed controller has been carried out and their comparison is done at the end.

In MATLAB Simulink two area transfer function model of diesel interconnected power system is developed, which is given in the Fig.5.9 Area-1 as well as area-2 both are diesel plant power system. The values of different components are put up in Matlab model .The nominal standard parameters are taken for testing.

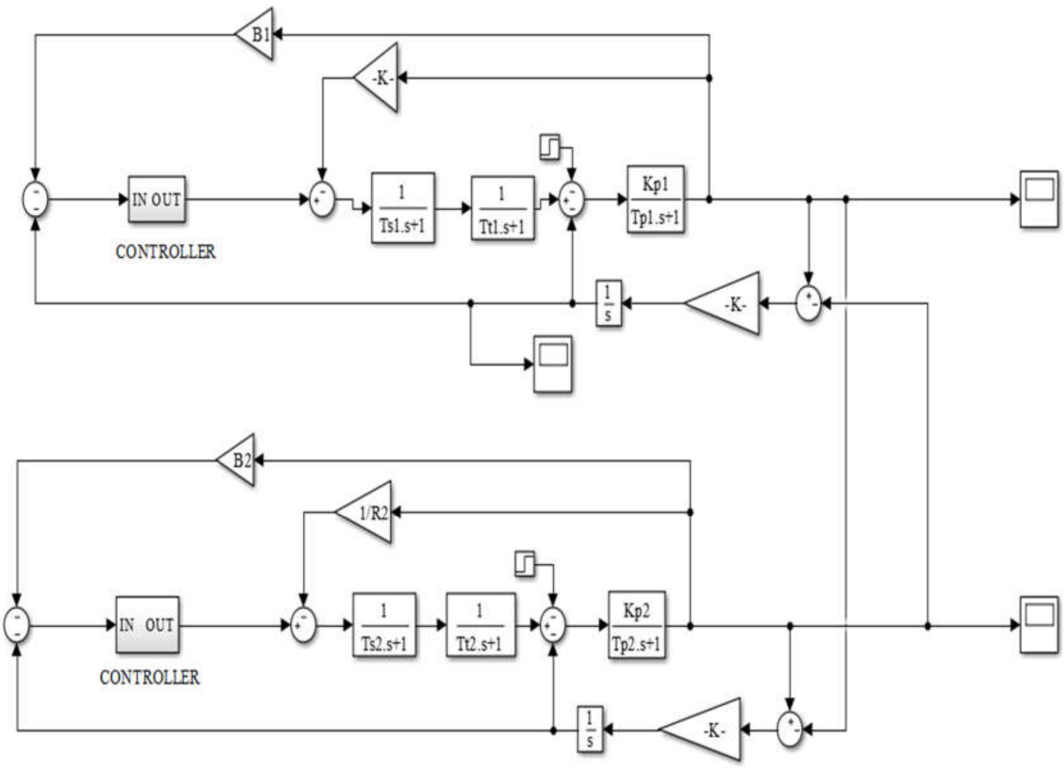

Fig.5.9. MATLAB model of two area diesel power plant interconnected power system.

5.2.4.1 Simulation with PI Controller

Change in frequency of two area interconnected diesel power plant for a step change is obtained and output of two area system with PI controller is shown below.

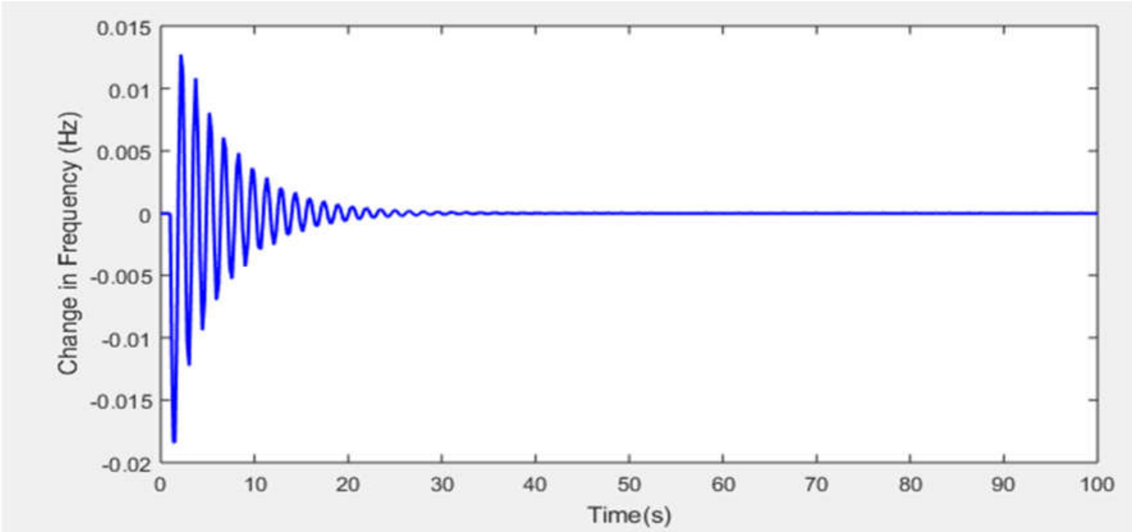

Fig.5.10. Change in frequency of diesel plant with PI controller in two area system

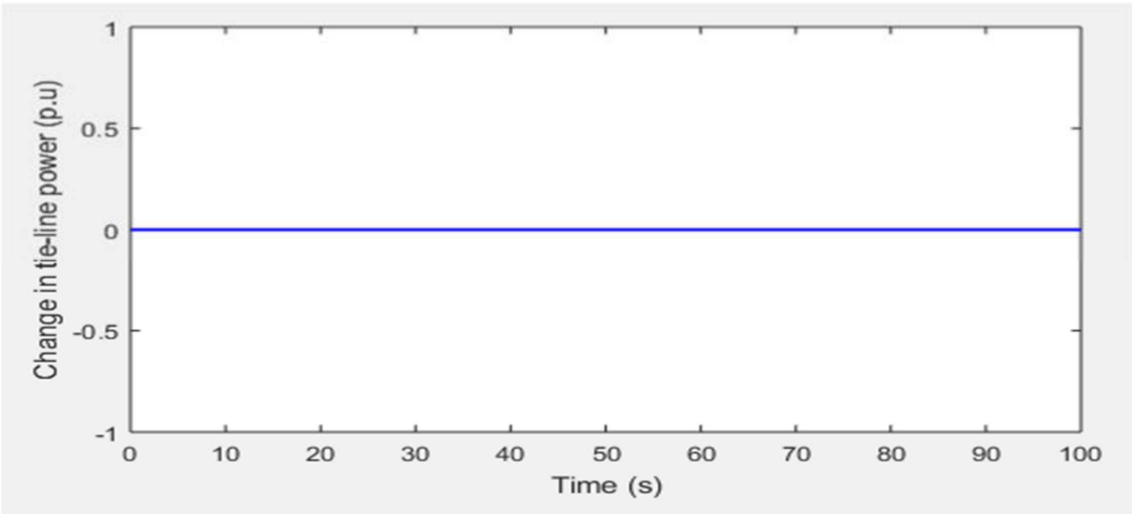

Fig.5.11. Change in Tie-line power of diesel plant with PI controller in two area system

After simulating the two area Diesel power plant system with PI controller, results are obtained as shown in fig.5.10-5.11, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced. In this simulation method the steady state error is reduced to zero by tuning the value of K_i . However at K_i =.98 error is minimized to zero, therefore this value is optimum value of K_i. Settling time is obtained as 38 seconds. The maximum overshoot in frequency deviation is limited to -0.018 in per unit for diesel power plant. Results of Area-1 and Area-2 are same because the system characteristics and constant of both the areas are same, because of this the change in tie-line comes to zero.

5.2.4.1 Simulation with PID Controller

Change in frequency of two area interconnected diesel power plant for a step change is obtained and output of two area system with PID controller is shown below.

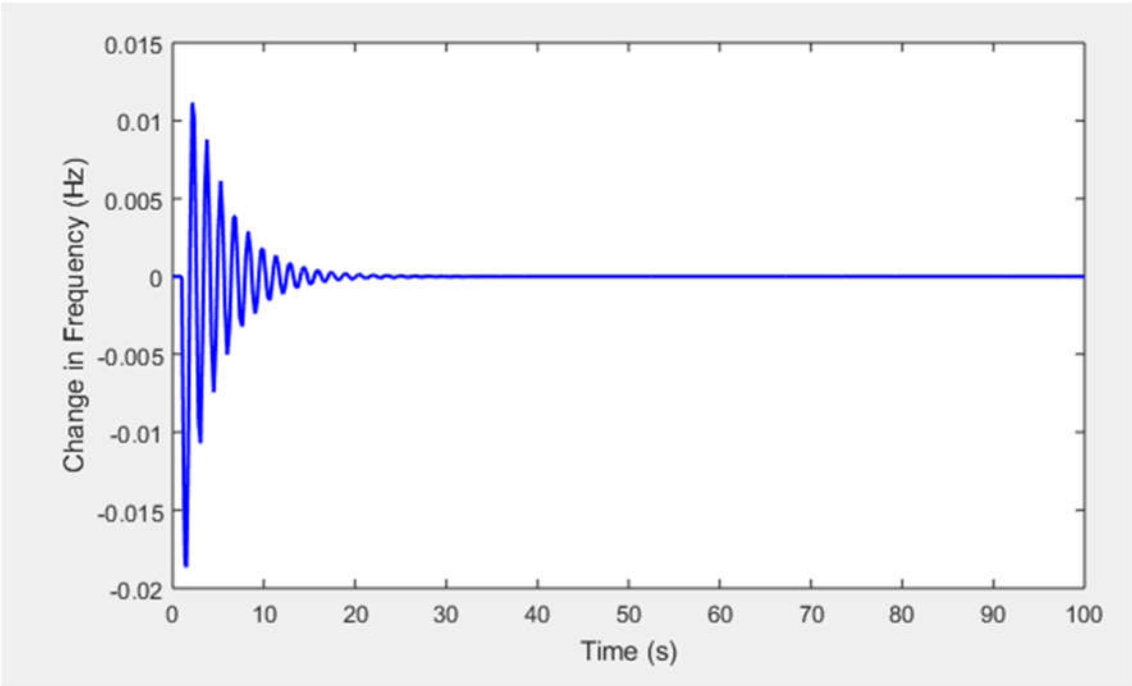

Fig.5.12. Change in frequency of diesel plant with PID controller in two area system

After simulating the Two area diesel power plant system with PID controller, results are obtained as shown in fig.5.12 in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced due to the use of derivative control. In this simulation method the steady state error is reduced to zero by tuning the value of K_i and K_d. However at K_i =-0.86 and K_d = .002 error is minimized to zero, therefore this value is optimum value of K_i.and K_d settling time is obtained as 30 seconds. The maximum overshoot in frequency deviation is limited to -0.018 in per unit for diesel power plant system.

5.2.4.3 Simulation with FGSPI Controller

Change in frequency of two area interconnected diesel power plant for a step change is obtained and output of two area system with FGSPI controller is shown below.

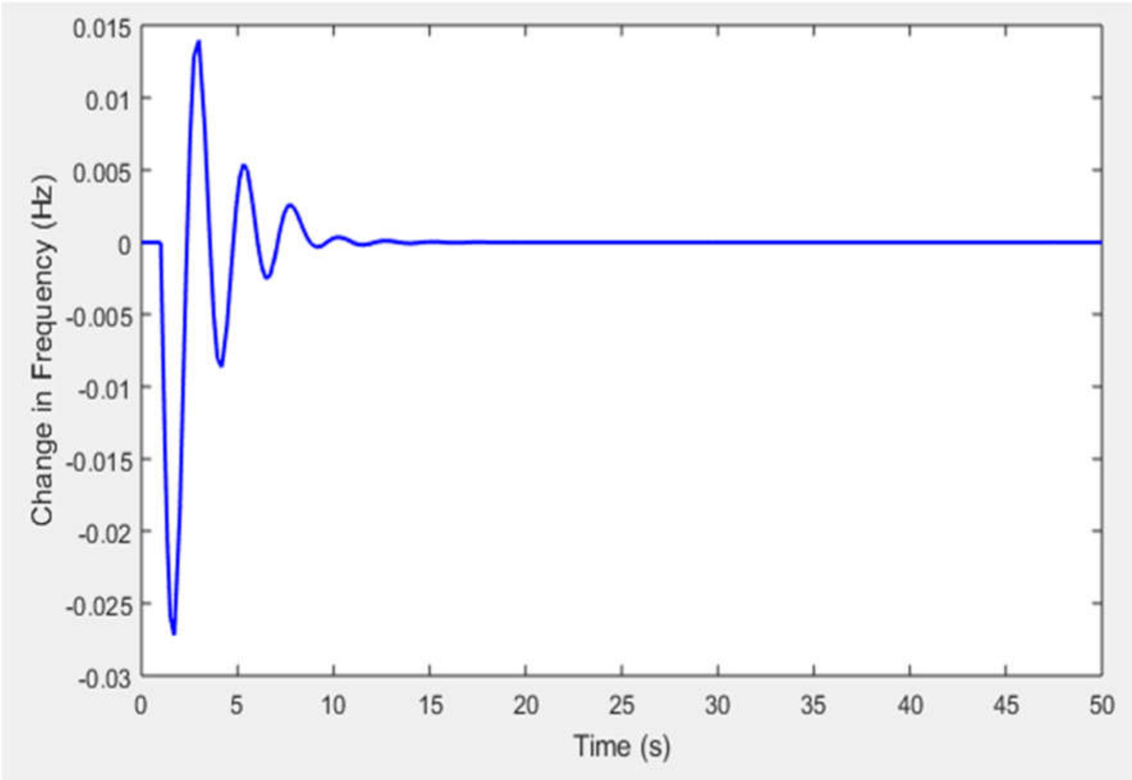

Fig.5.13. Change in frequency of diesel plant with FGSPI controller in two area system

After simulating the Two area diesel power plant system with FGSPI controller, results are obtained as shown in fig.5.13 in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced due to the use of fuzzy control. In this simulation method the steady state error is reduced to zero by tuning the value of K_i and the optimal value of K_i is obtained from fuzzy gain scheduling of integral constant. Settling time is obtained as 15 seconds. The maximum overshoot in frequency deviation is limited to -0.027 in per unit for diesel power plant system. As seen from the result that settling time is much lesser with FGSPI controller as compared to PI and PID controller.

5.2.4.4 Simulation with ANFIS Controller

Change in frequency of two area interconnected diesel power plant for a step change is obtained and output of two area system with ANFIS controller is shown below.

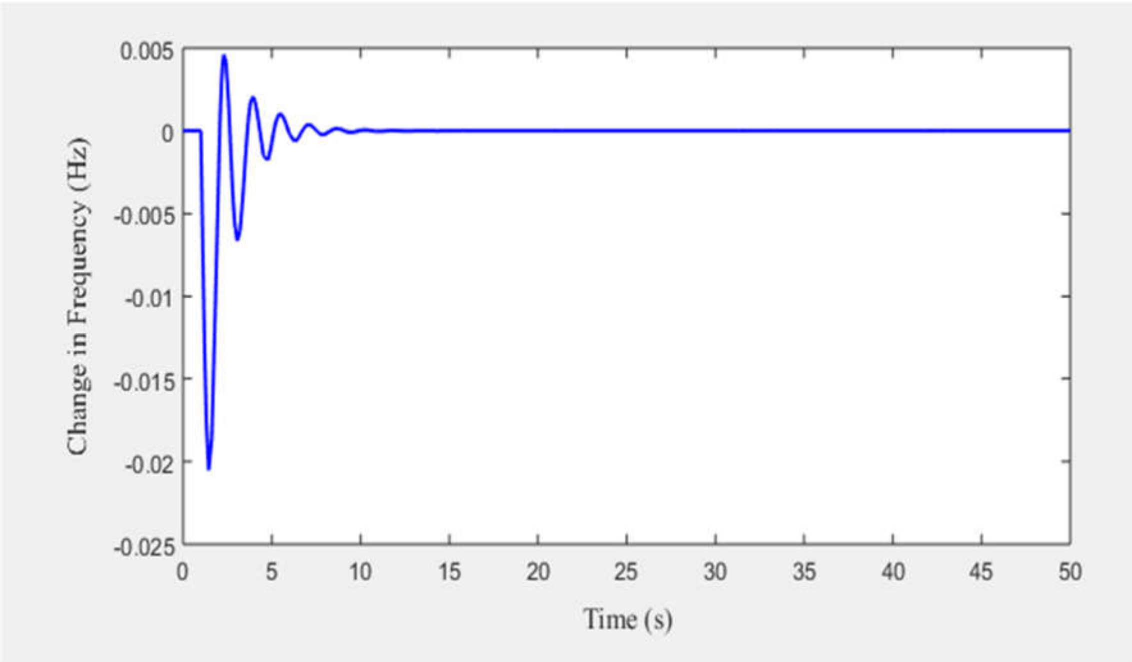

Fig.5.14. Change in frequency of diesel plant with ANFIS controller in two area system

After simulating the Two area diesel power plant system with ANFIS controller, results are obtained as shown in fig.5.14 in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced due to the use of hybrid neurro-fuzzy control. In this simulation method the steady state error is reduced to zero by tuning the value of K_i and the optimal value of K_i is obtained from ANFIS controller. Settling time is obtained as 11 seconds. The maximum overshoot in frequency deviation is limited to -0.021 in per unit for diesel power plant system. As seen from the result that settling time is much lesser with ANFIS controller as compared to PI, PID and FGSPI controller.

Table 5.1 Comparative Study of Settling Time and Peak Overshoot: Two Area System

Controllers	Settling Time (Diesel Power Plant) (sec)	Peak Overshoot (Diesel Power Plant) (p.u.)
PI	38	-0.018
PID	30	-0.018
FGSPI	15	-0.027
ANFIS	11	-0.021

It can be concluded from the table.5.1 that ANFIS controller gives minimum settling time as compared to FGSPI, PID and PI controllers. Whereas the peak overshoot is more when we use intelligent controller as compared to conventional PI and PID controller but that is almost negligible, so the proposed intelligent control technique of hybrid artificial neurro-fuzzy interface system is more accurate and faster as compared to FGSPI, PID and PI controller for complex dynamical system.

CHAPTER 6

PROPOSED CONTROLER FOR MULTI-AREA HYBRID POWER SYSTEM

6.1 GENERAL

In this chapter simulation of the developed model of load frequency control of interconnected power system will be discussed. There are different model of LFC, the first one is two area interconnected hybrid power system with one thermal reheat power plant and one PV Array system interconnected with tie-lines and second one is multi area interconnected power system in which two areas are thermal reheat power system and one is PV array system. It is important to design more reliable and robust controller for load frequency control to attain minimum overshoot as well as settling time. Some proposed controllers are,

(i) PI Controller
(ii) PID Controller
(iii) FGSPI with Mumdani model
(iv) Neuro-fuzzy controller i.e. ANFIS controller.

First we developed a two area hybrid model to test how a power system is working with renewable sources after hybridization (using simple PI controller). After that these four controllers are tested with developed multi area model of interconnected power system, in which output of both thermal as well as PV system are shown and compared.. The performance evaluation has been carried out to show the effectiveness of the proposed controller and also to find out the best control approach for the hybrid (thermal-PV) interconnected power system.

6.2 Two Area Hybrid (diesel and solar PV) Interconnected Power System

The transfer function model of two area interconnected Hybrid (diesel and solar PV) power system developed in Matlab Simulink is given in the Fig.6.1 Area-1 is diesel based conventional power system and area-2 is renewable PV array power system. The values of different components are put up in Matlab model .The nominal standard parameters are taken for testing.

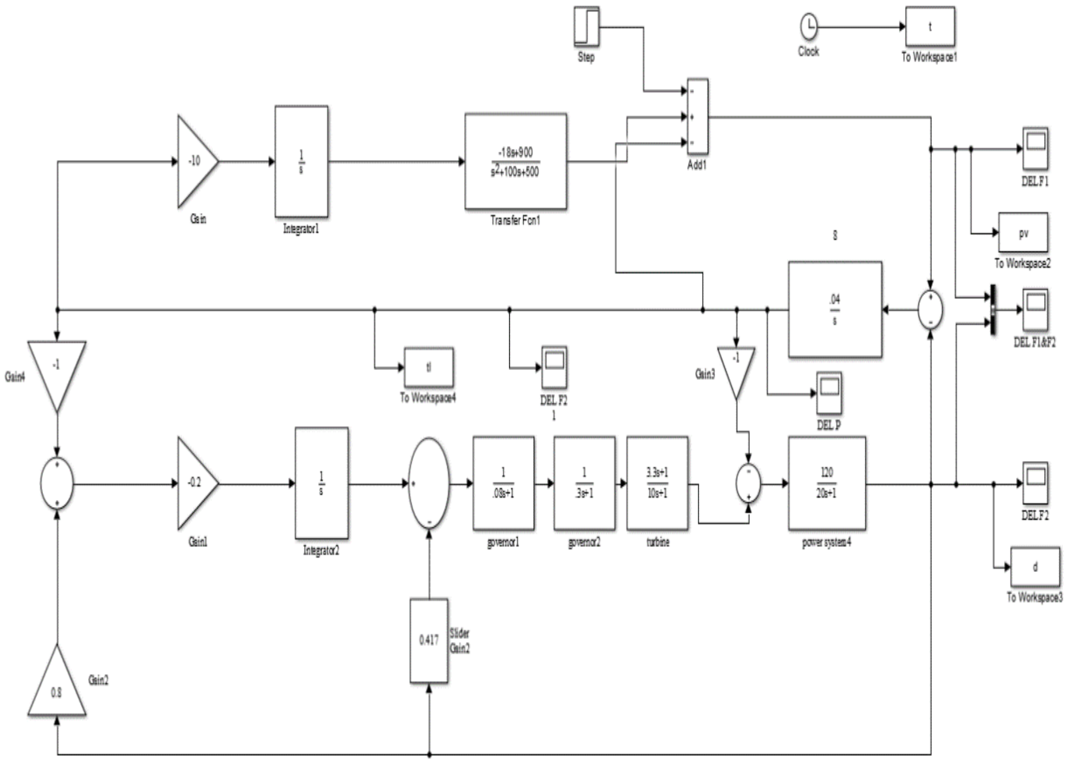

Fig.6.1. MATLAB model of two area Hybrid (diesel and solar PV) interconnected system.

The above MATLAB/SIMULINK model consist of a hybrid interconnected power system network in which one is thermal power plant and one is PV system, which control the frequency deviation using PI controller.

Change in frequency of two area interconnected diesel power plant for a step change is obtained and output of two area system with PID controller is shown below.

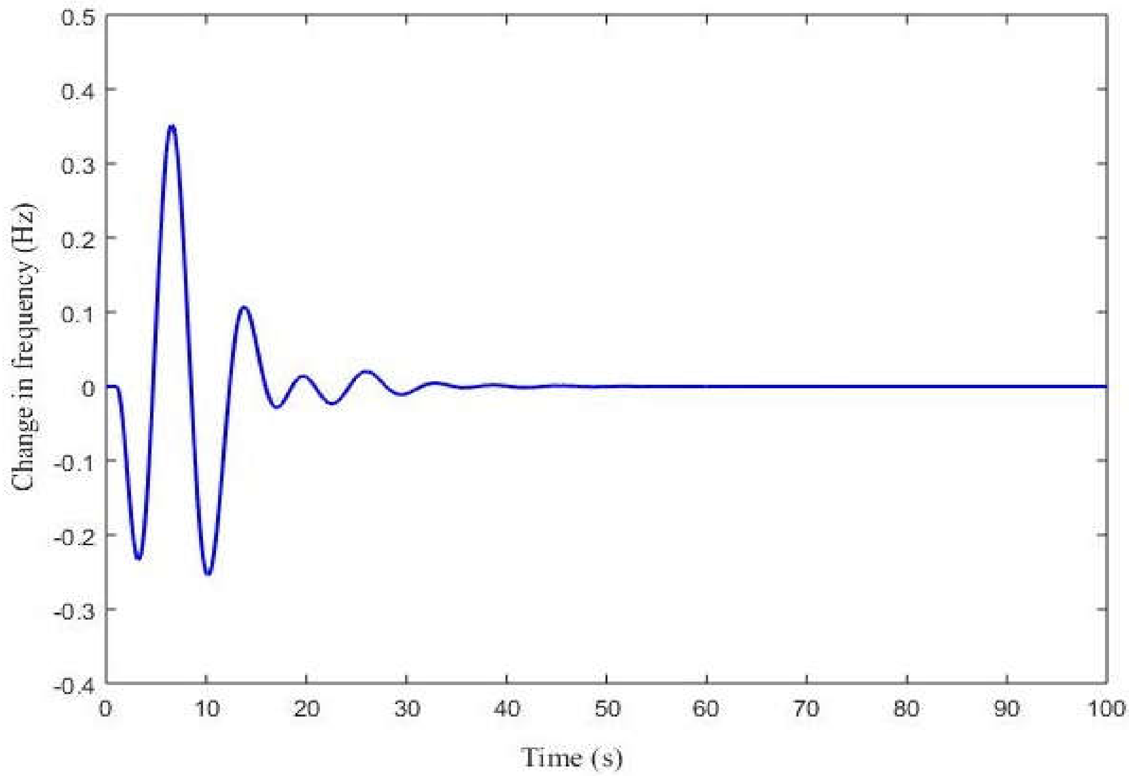

Fig.6.2. Change in frequency of diesel plant with PI controller in two area system

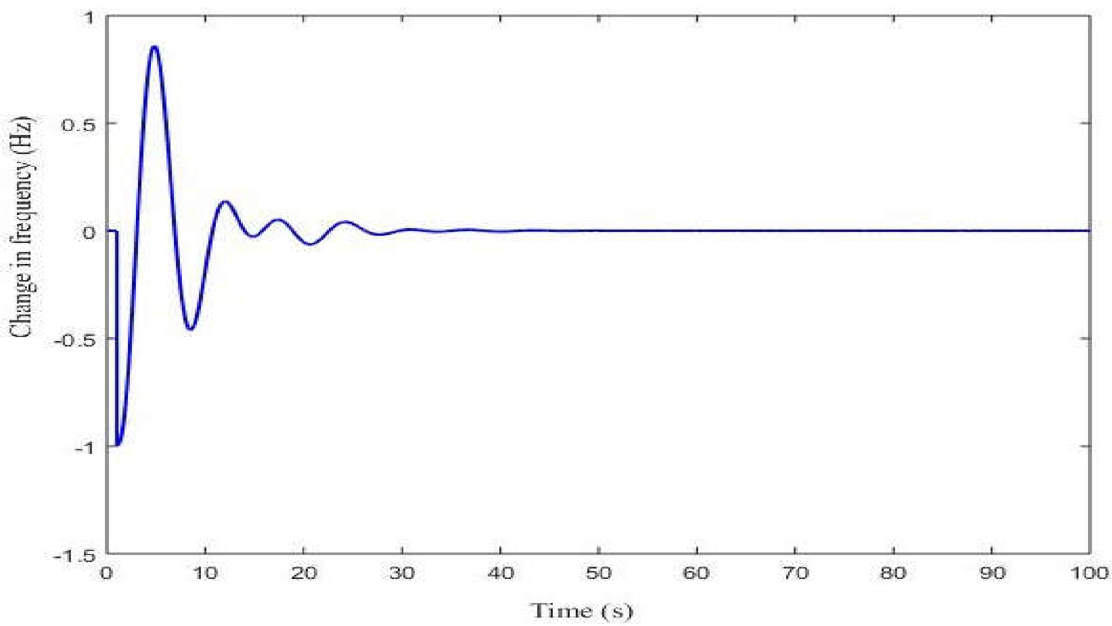

Fig.6.3. Change in frequency of PV system with PI controller in two area system

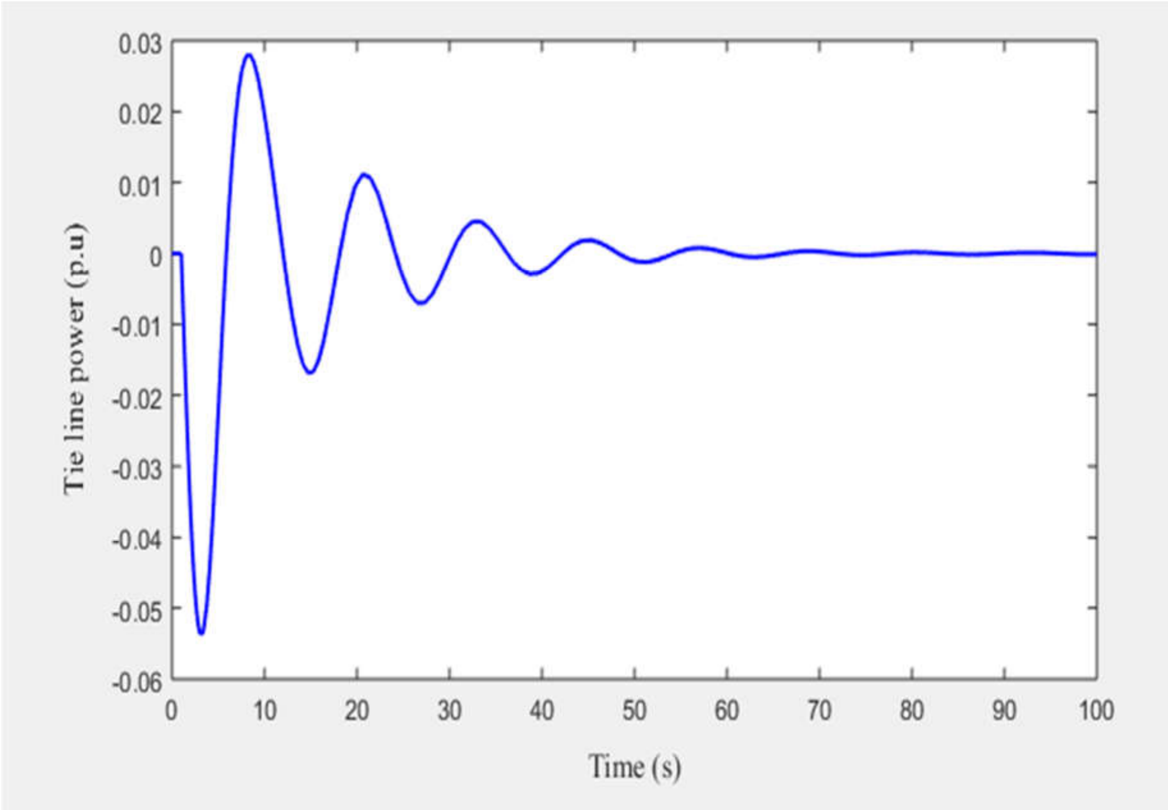

Fig.6.4 Change in Tie-line power of Hybrid (diesel and solar PV) with PI controller in two area system

After simulating the two area hybrid interconnected power system with PI controller, results are obtained as shown in fig.6.2-6.4, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced. In this simulation method the steady state error is reduced to zero by tuning the value of K_i . However at K_i =0.2 error is minimized to zero, therefore this value is optimum value of K_i. Settling time is obtained as 35 seconds. The maximum overshoot in frequency deviation is limited to -0.36 in per unit for thermal power plant and -1 p.u for PV system. Deviation is tie-line is 65 seconds.

6.3 Three Area Hybrid Interconnected Power System

The transfer function model of three area interconnected power system with tie-lines is shown in Fig.6.5 developed using MATLAB software. Area-1 is a renewable PV system and area-2 & area-3 are conventional diesel plant. Parameters of area-2 and area-3 are same so there outputs i.e frequency deviation and tie-line powers are same.

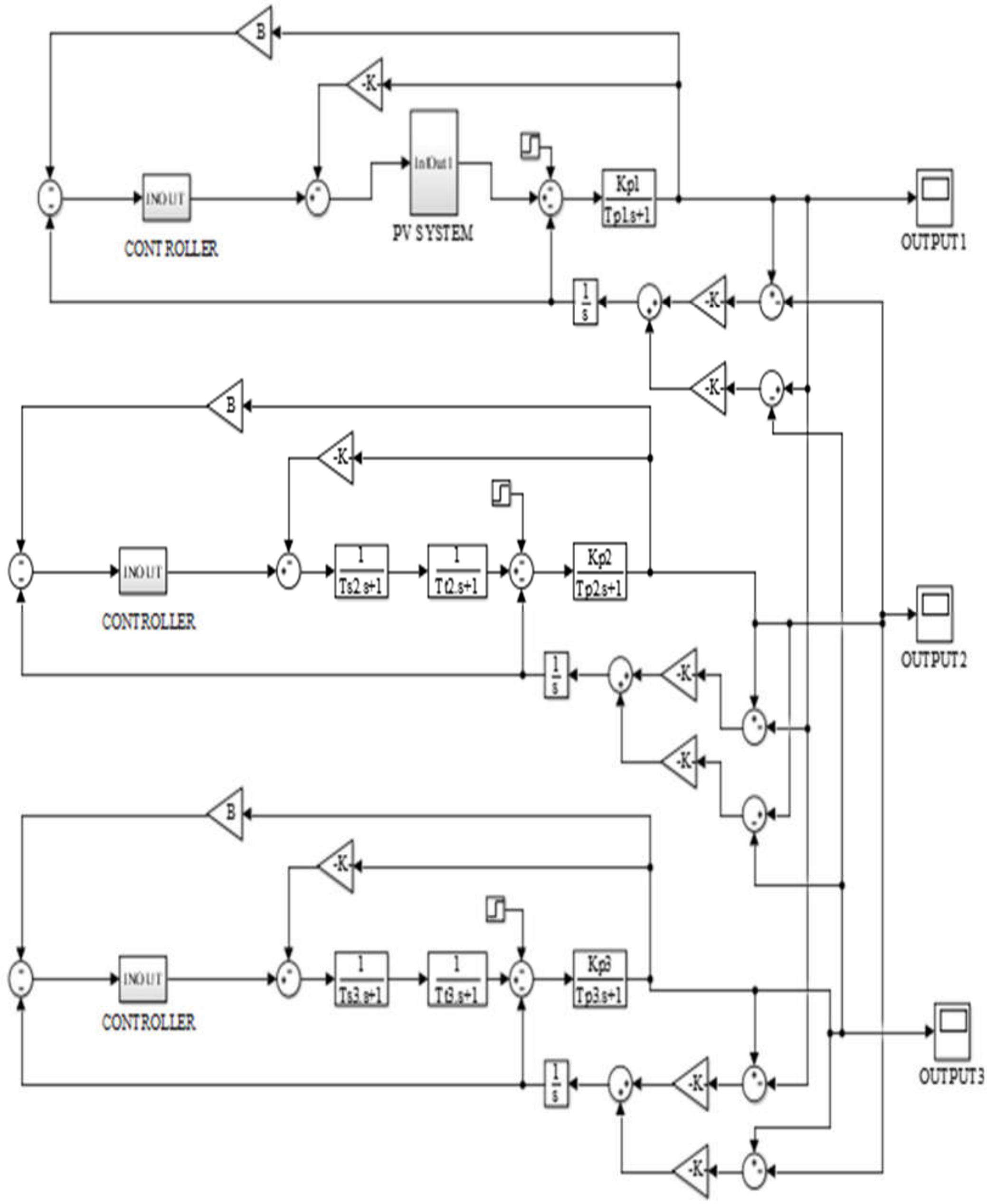

Fig.6.5 MATLAB model of three area hybrid power system

The above MATLAB/SIMULINK model consist of a hybrid interconnected power system network in which area-1 is a renewable PV system and area-2 and area-3 are diesel power plant. Further this model is simulated using all proposed controller i.e. PI, PID, FGSPI and ANFIS. Their performance comparison is done at the end. Change in frequency of three area interconnected hybrid power system for a step change is obtained and output of multi area system is shown in further section.

6.3.1 Simulation with PI Controller

After simulation of above model with PI controller the obtained results are shown below:

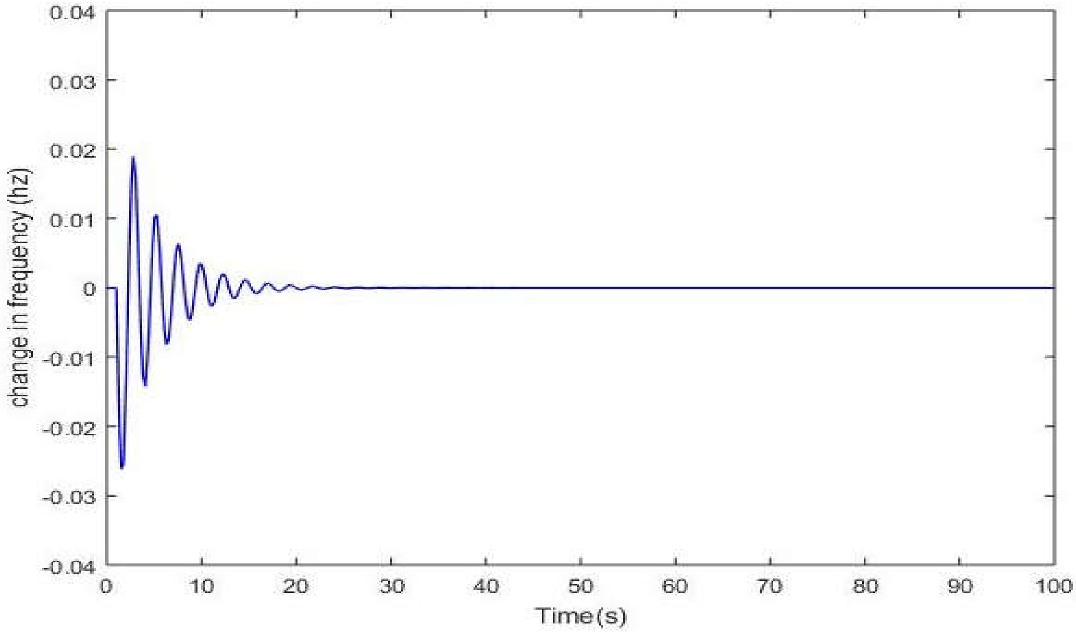

Fig.6.6. Frequency deviation (diesel generator) with PI controller in three area system

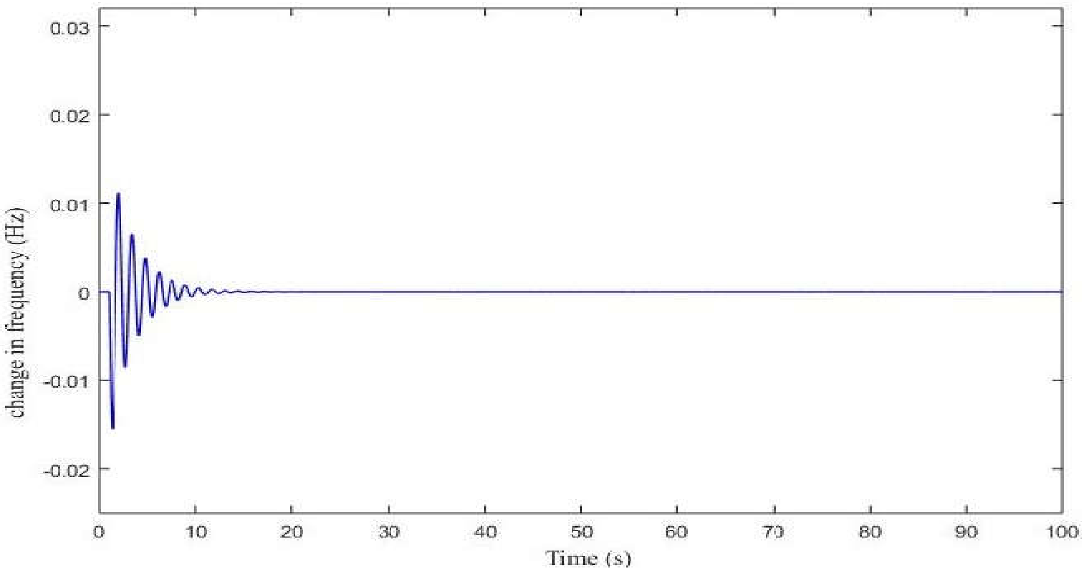

Fig.6.7. Frequency deviation (PV system) with PI controller in three area system

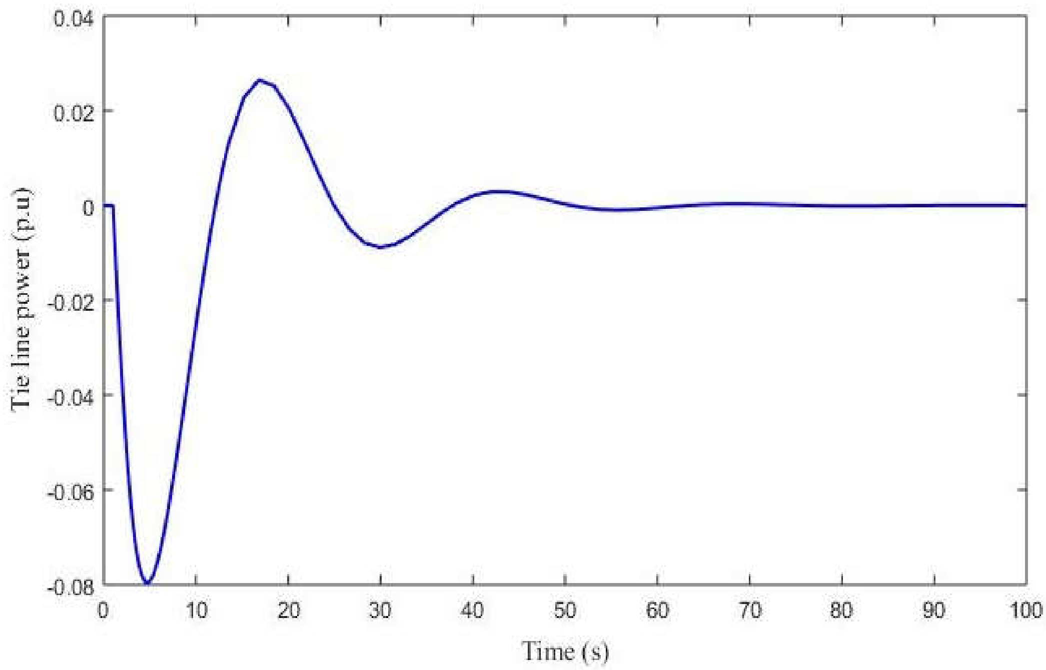

Fig.6.8 Tie-line power deviation (diesel-PV system) with PI controller in three area system

After simulating the multi area hybrid interconnected power system with PI controller, results are obtained as shown in fig.6.6-6.8, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced. In this simulation method the steady state error is reduced to zero by tuning the value of K_i. Settling time is obtained as 29 seconds in diesel power plant and 19 sec in PV system. The maximum overshoot in frequency deviation is limited to -0.025 in per unit for diesel power plant and -0.015 p.u for PV system. Deviation is tie-line is 60 seconds.

6.3.2 Simulation with PID Controller

After simulation of hybrid model with PID controller the obtained results are shown below:

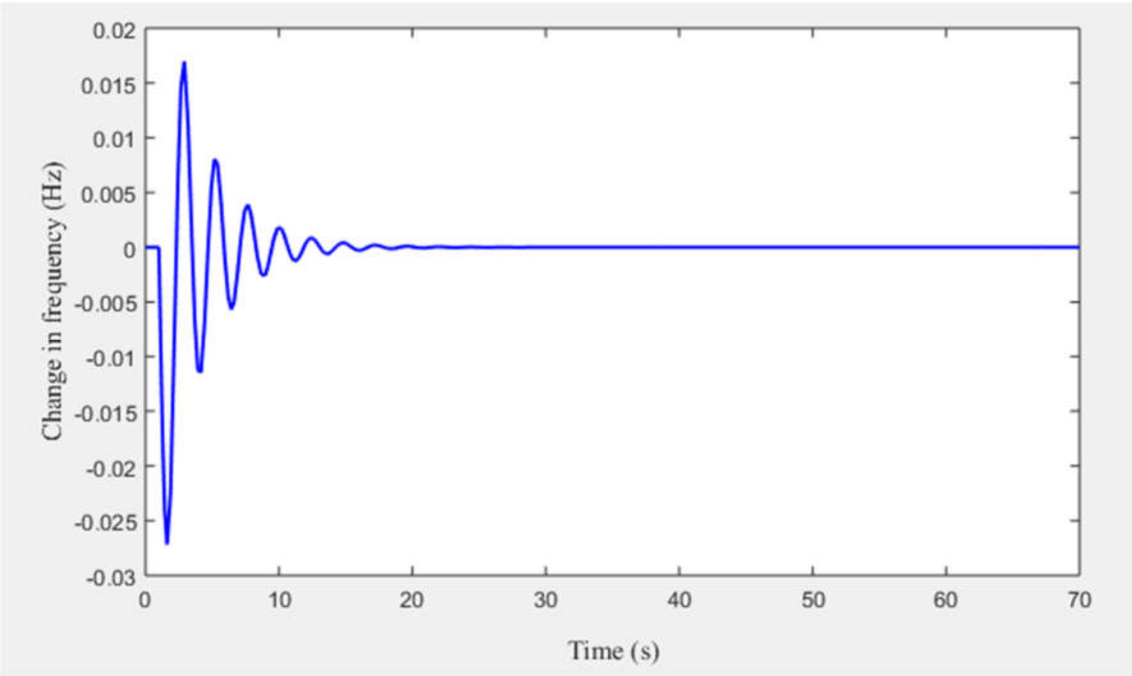

Fig.6.9. Frequency deviation (diesel generator) with PID controller in three area system

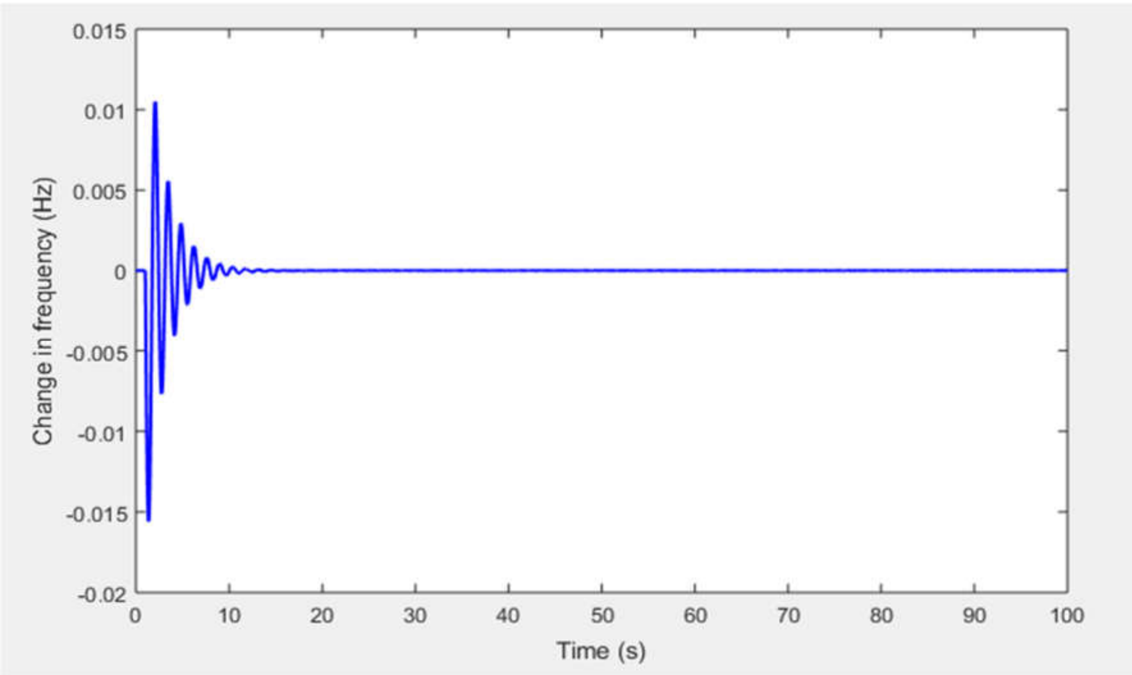

Fig.6.10. Frequency deviation (PV system) with PID controller in three area system

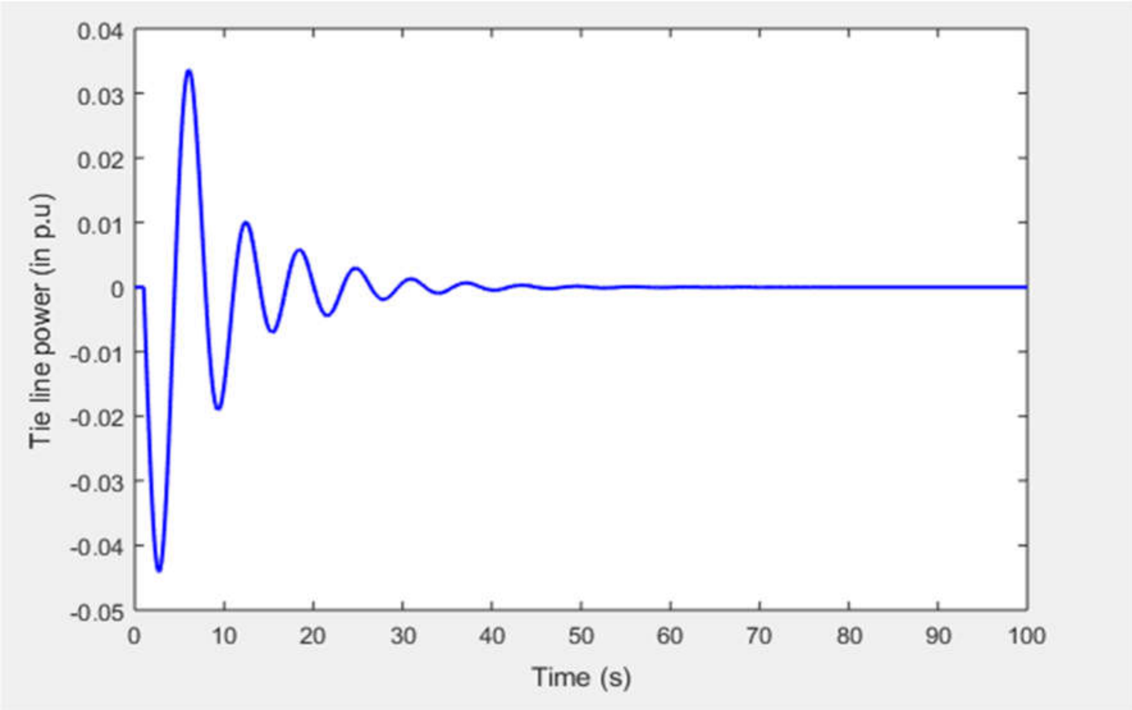

Fig. 6.11. Tie-line power deviation (diesel-PV system) with PID controller in three area system

After simulating the multi area hybrid interconnected power system with PID controller, results are obtained as shown in fig.6.9-6.11, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced (reducing number of oscillation). Settling time is obtained as 23 seconds in diesel power plant and 16 sec in PV system. The maximum overshoot in frequency deviation is limited to -0.027 in per unit for diesel power plant and -0.016 p.u for PV system. Deviation is tie-line is 52 seconds.

6.3.3 Simulation with FGSPI Controller

After simulation of hybrid model with FGSPI controller the obtained results are shown below:

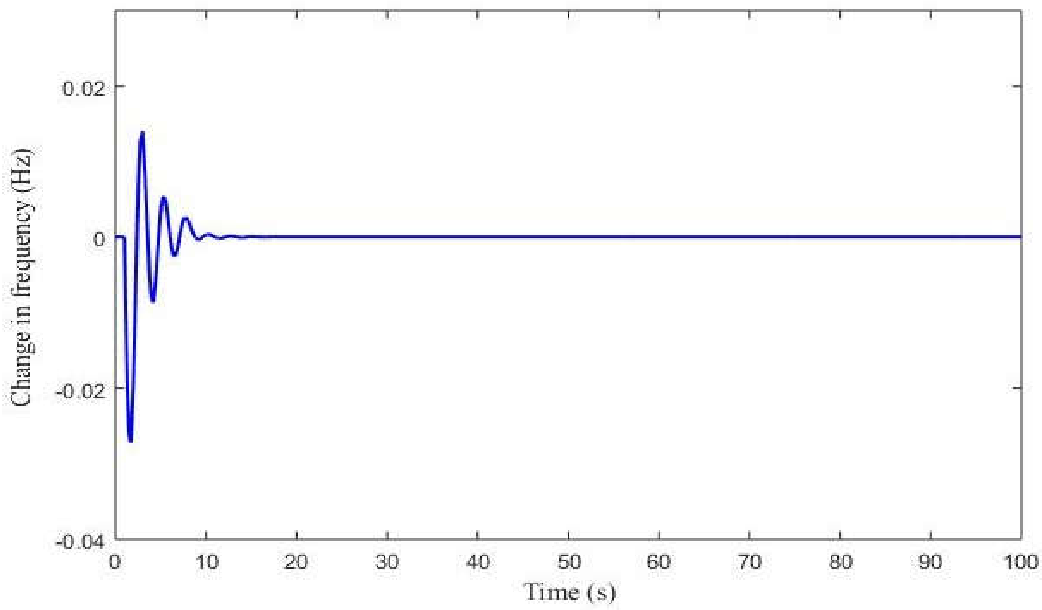

Fig.6.12. Frequency deviation (diesel plant) – with FGSPI controller in three area system

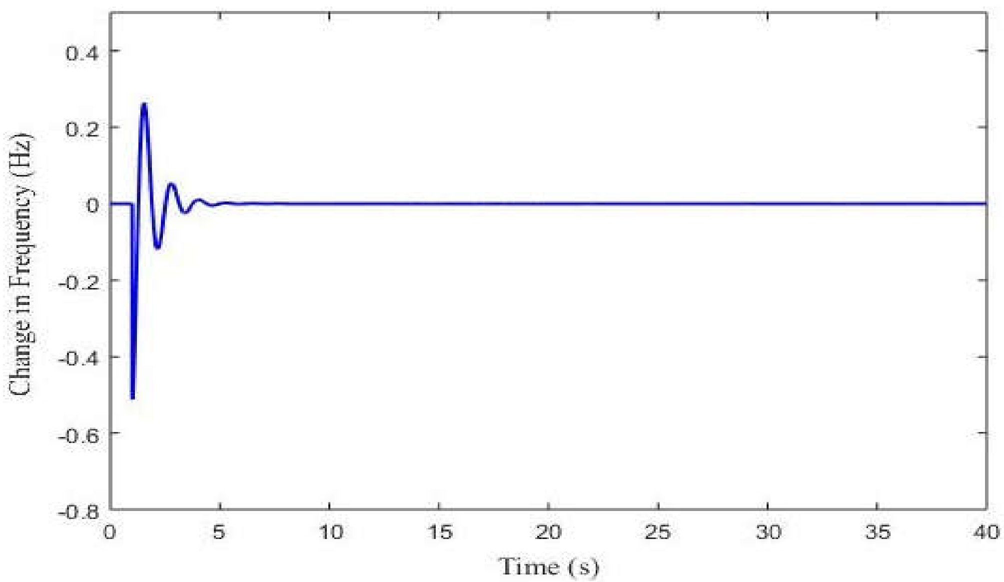

Fig.6.13. Frequency deviation (PV system) with FGSPI controller in three area system

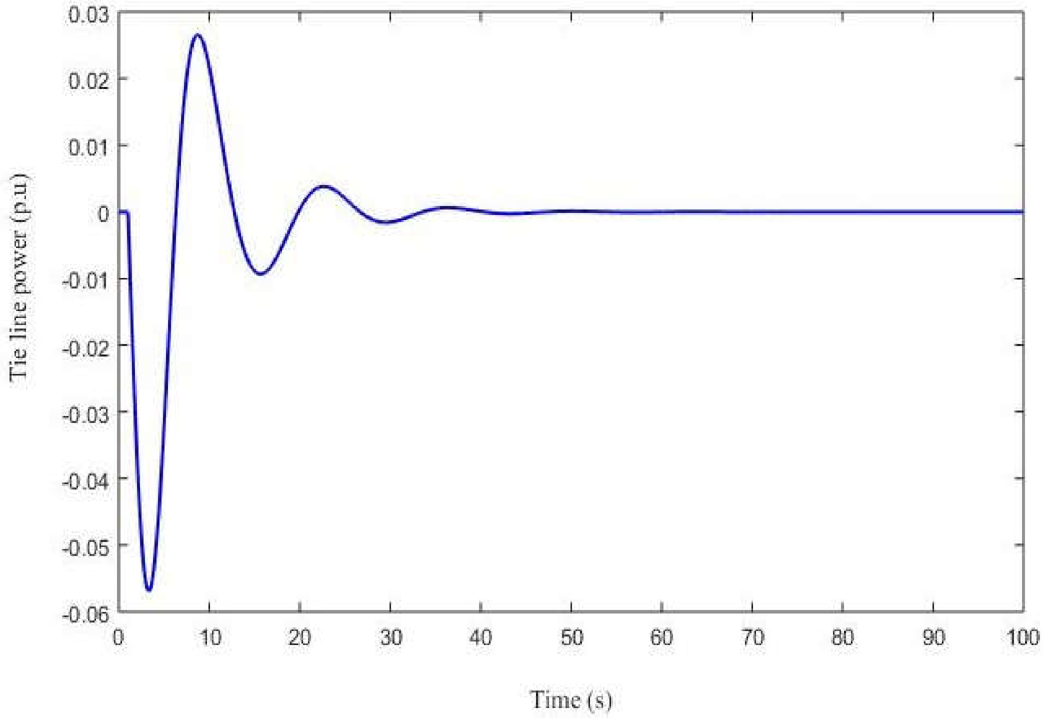

Fig.6.14. Tie-line power deviation (diesel-PV system) with FGSPI controller in three area system

After simulating the multi area hybrid interconnected power system with FGSPI controller, results are obtained as shown in fig.6.12-6.14, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced (reducing number of oscillation). Settling time is obtained as 15 seconds in diesel power plant and 7 sec in PV system. The maximum overshoot in frequency deviation is limited to -0.03 in per unit for diesel power plant and -0.055 p.u for PV system. Deviation is tie-line is 40 seconds.

6.3.4 Simulation with ANFIS Controller

After simulation of hybrid model with ANFIS controller the obtained results are shown below:

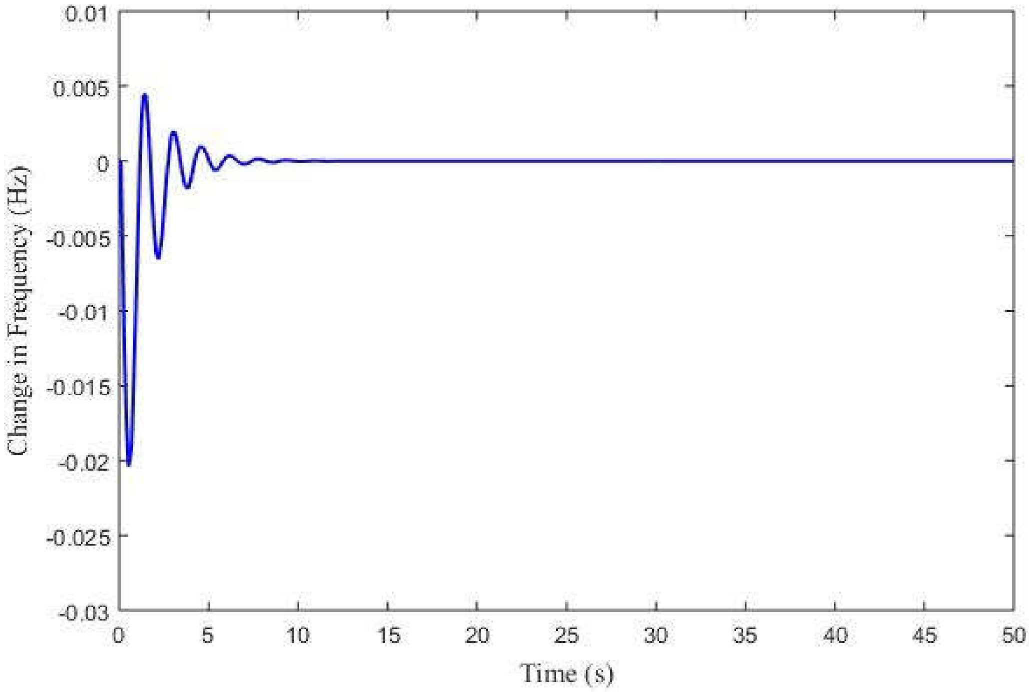

Fig.6.15 Frequency deviation (diesel plant) with ANFIS Controller in three area system

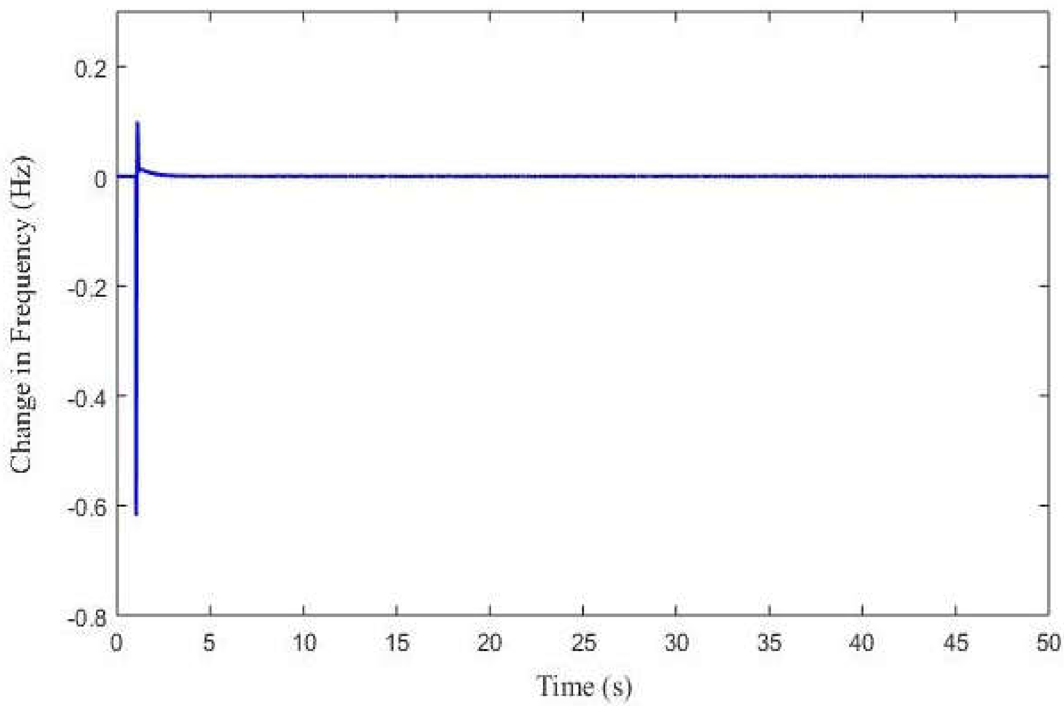

Fig.6.16. Frequency deviation (PV system) with ANFIS Controller in three area system

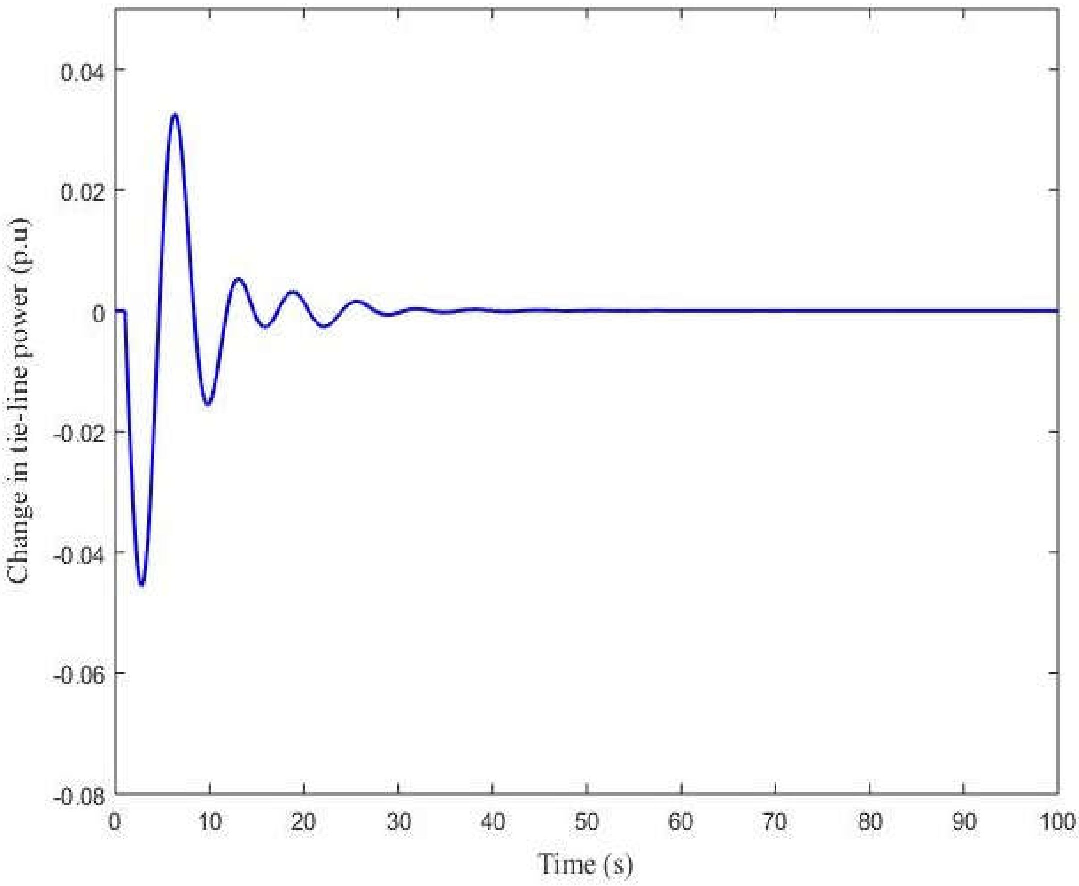

Fig.6.17. Tie-line power deviation (diesel- PV system) with ANFIS Controller in three area system

After simulating the multi area hybrid interconnected power system with ANFIS controller, results are obtained as shown in fig.6.15-6.17, in which the steady state error become zero because of integral controller and settling time as well as peak overshoot is reduced (reducing number of oscillation). Settling time is obtained as 11 seconds in diesel power plant and 4 sec in PV system. The maximum overshoot in frequency deviation is limited to -0.02 in per unit for diesel power plant and -0.061 p.u for PV system. Deviation is tie-line is 40 seconds. The settling time in ANFIS is much lesser than the PI, PID and FGSPI controllers. Only disadvantage of using ANFIS controller that is increases the overshoot.

Table 6.1 Comparative Study of Settling Time: Three Area System

Controllers	Area 1 (PV system) (sec)	Area 2(Diesel plat) (sec)	Area 3(Diesel plant) (sec)	ΔP tie PV-Diesel (sec)
PI	19	29	29	60
PID	16	23	23	52
FGSPI	7	15	15	40
ANFIS	4	11	11	38

Table 6.2 Comparative Study of Peak Overshoots: Three Area System

Controllers	Area 1 (PV system) (pu)	Area 2(Diesel plant) (pu)	Area 3(Diesel plant) (pu)	ΔP tie PV-Diesel (pu)
PI	-0.015	-0.025	-0.025	-0.080
PID	-0.160	-0.270	-0.270	-0.045
FGSPI	-0..055	-0.030	-0.030	-0.055
ANFIS	-0.610	-0.045	-0.045	-0.042

Form the above table 6.1 and 6.2 it is clear that FGSPI gives lesser settling time than PI and PID controller and ANFIS gives least among all, it is expected that the proposed ANFIS controller will work effectively on different load change in different areas consisting of different types of power sources.

CHAPTR 7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

The controller being adaptive and intelligent are the most important factor for power system operation and control. The proposed intelligent controller is not only unique in design but also easy to implement. The Model of the interconnected hybrid power grid is developed with special characteristics for the traditional and the optimal control techniques. The traditional and artificial controllers are better in LFC but when the non-linearities are increased in the power system then, the response these controllers become sluggish. However, optimal technique has the big functions over the control engineering. It is concluded from above figures and tables that ANFIS shows better performance in the frequency regulation as the non-linearities are increased in the hybrid system. The settling time by ANFIS is very less as compared to the intelligent and conventional controllers. One important point it can be noticed that the settling time by ANFIS reduces with the load increase which cannot achieved by other two controllers. Therefore by means ANFIS, the steadiness of the supply frequency is acquired which has been demonstrated as the efficient regulator in this projected work. As it is seen from the results that FGSPI gives lesser settling time than PI and PID controller and ANFIS gives least among all, it is expected that the proposed ANFIS controller will work effectively on different load change in different areas consisting of different types of power sources.

The different models of interconnected power system have been developed with all types of proposed controllers and simulated using MATLAB/SIMULINK package. The performance of the intelligent controllers FGSPI and ANFIS have been compared with the conventional PI and PID controllers for all the cases.

7.2 FUTURE WORK

1. In this proposed work the load variation is used fixed in nature. As a result in the future this research work can be carried to dynamic load disturbances.

2. The parameters in this project work have been used constant all through the entire operation. However, here may be factors uncertainty due to the temperature variation, wear and tear, limitation of the component, atmospheric changes, aging effect etc. So at the stage of controller designing the deviation of factors may be in concern.

3. The load frequency control of the hybrid power system can be considered by using of optimization techniques.

4. In the present work training of ANFIS controller is done only once, so for better result the training may be done number of times until a optimal value of Ki ia achieved.

List of publication (communication)

1. Divyank Srivastava, Madan Mohan Tripathi, "Novel intelligent controllers for Load Frequency Control of a Multi Area hybrid power System" International conference of Power Electronic, Intelligent Control and Energy system.
2. Divyank Srivastava, Madan Mohan Tripathi,"Transformer Health Monitoring System Using Internet of Things" International conference of Power Electronic, Intelligent Control and Energy system.

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