LOAD FREQUENCY CONTROL OF MULTI-AREA POWER SYSTEM WITH RENEWABLE SOURCES BY INTELLIGENT AND OPTIMAL CONTROL TECHNIQUES

A Dissertation submitted in fulfillment of the requirements for the Degree

of

MASTER OF ENGINEERING

in

Power Systems

Submitted by

Ramanpreet kaur
801542015

Under the Guidance of
Dr. Surya Prakash
Assistant professor, EIED

2017

Electrical and Instrumentation Engineering Department

Thapar University, Patiala

(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)

Post Bag No. 32, Patiala – 147004

Punjab (India)

DECLARATION

I hereby certify that the work which is given in dissertation entitled, **"Load Frequency Control of Multi-Area Power System with Renewable Sources by Intelligent and Optimal Control Techniques"**, in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering& Technology University, Patiala is as authentic record of my own work carried under supervision of **Dr.Surya Prakash**. It refers others researchers work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any degree to any other university or institute except as reported in text and references.

(Ramanpreet kaur)
Roll No.:801542015

Place: PATIALA
Date: 17 July 2017

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

(Dr.Surya Prakash)
Assistant professor
Electrical & Instrumentation Engineering Department
Thapar Institute of Engineering& Technology University, Patiala

Date: 17 Jul 2017

ACKNOWLEDGEMENT

Foremost, I am truly thankful and wish to express my gratefulness to my supervisor **Dr. Surya Prakash** for his motivation, admirable guidance, continuing support and confidence and inspiration throughout all stages of this endeavor without which, it would not have been achievable for me to complete this successfully. I also express thanks to him for his discerning comments and suggestions which constantly helped me to develop my understanding.

I am also greatly obliged to **Dr. Ravinder Agarwal**, Head of the Department of Electrical and Instrumentation Engineering Department, Thapar University a for providing all feasible facilities towards this work and gratitude to **Ms Manbir Kaur**, Associate Professor& PG Coordinator for her motivational approach.

My whole hearted gratitude is to my parents for their constant encouragement, support, wishes and love. Above all, enormous thank who gave his blessings upon us.

Ramanpreet kaur
(801542015)

ABSTRACT

In interconnected power system, some small unexpected load change in one of the areas causes the variation of the frequencies of every area and also there is variation of power in tie line. The most important objects of Load Frequency control (LFC) are, to retain the actual frequency and the preferred power output in the power system and to control the variation in tie line power among the interconnected areas. Therefore, a LFC scheme mainly includes a suitable control system for the power system, which is capable to carry the frequency of each area and power in the tie line back to desired set point values after the load change. In this dissertation work, LFC of the interconnected power system with distributed generation has been developed. As renewable energy resources are in great demand to fulfill the requirement of power. So, the incorporation of renewable energy sources are implemented as these are effective in supplying the power but the frequency variation is more in the hybrid system. The two identical areas are taken in which each area consists of one thermal power generation system with wind turbine, Photovoltaic generation system (PV), fuel cell, battery storage system and aqua electrolyzer. LFC requires a fast and accurate controller to maintain the frequency at preferred value. This proposed research work deals with the Artificial Intelligence technique (Fuzzy PI and Neuro-Fuzzy approach) for LFC. The benefit of Neuro-fuzzy approach is to deal with non-linearities in the intervening time and it is faster than other conventional controllers. The intelligent controller output is better and faster than other conventional controllers. Then LQR is also implemented in the hybrid power system which is proven the best controller in this thesis. The performance of the three controllers is compared with the specific parameters that are settling time, maximum overshoot, and maximum undershoot.

Keywords: *Load frequency control (LFC), Area control error (ACE), Adaptive neuro-fuzzy inference system (ANFIS), Fuzzy logic controller (FLC), Linear quadratic regulator (LQR).*

TABLE OF CONTENTS Page

CHAPTER 1: Introduction

CHAPTER 2: System Model

CHAPTER 3: Control Methodology

CHAPTER 4: Simulation And Results

LIST OF FIGURES: Page

LIST OF TABLES
Page

LIST OF ABBREVIATIONS

LFC	load frequency control
FLC	Fuzzy logic controller
ANFIS	Adaptive neuro-fuzzy inference system
PI	Proportional integral controller
LQR	Linear quadratic regulator
ACE	Area control error
DACE	Derivative of area control error
BESS	Battery energy storage system
PV	Photovoltaic generation system
AE	Aqua electrolyzer
FC	Fuel cell
WTG	Wind turbine generator

CHAPTER 1

INTRODUCTION

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 centers and consumers. The renewable energy source comprises 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 the frequency. The variation in the load element and 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 capacitive energy (CE), battery energy storage (BES), SMES, photovoltaic (PV) and wind turbine (WT) control generation the dynamic implementation of the AGC system. L.Mengyan et al. [1] 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 [2]. 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 [3]. After that, R. Oba et al. [4] explored the effect of RESs, PV in the three-area 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 [3] whereas a control scheme for the PV-diesel single-stage self-regulating power system is represented in [6]. 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. [7]. 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 [8]. ANFIS controller has the quality to provide an enhanced performance to a system with large parameter selections [9]. The ANFIS controller is basic, robust and simple to be changed, capable to work for multi information. Use of ANFIS control over PI controller can be a dominant approach for explaining the concern of variation of the system parameters. The innovative theory of optimal regulator for load frequency control of the two power system was first proposed by Elgerd [5]. 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 and review

In the past frequency was being controlled by typical PI controller however currently that methodology is obscure [12, 13]. 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 performance of the system becomes quicker as compared to the traditional one.

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 [12 – 14] however this was found that the quantities of data concerning the states are measure hard to be known compeletly. Another technique supported neural networks [15 – 16] 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 [17] given the usage of frequency variation and rate of modification of frequency variation is taken inputs to fuzzy logic controller wherever as Indulka et.al utilized area control error and alteration in ACE is taken the inputs to the fuzzy logic controller [18].

Currently, varied analysis and outlay has been planned in hybrid facility, as Yang [19], he recommend the design of optimal control for the hybrid wind and PV system, that utilize battery storage banks to work out the system's most favorable configurations in China. Dihrab [20], obtained a hybrid PV and wind system as the renewable energy sources which are used for the power generation in Asian nation. Reichling [21], 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 [22], concluded optimum methodology of PV and wind hybrid system facility in Turkey. Variety of modeling studies on hybrid system is carried out. Along with them, Kim [23], meted out a grid-connected PV model victimization PSCAD and EMTDC for magnetic force momentary behavior. Tsai [24], executed PV model by using SIMULINK. Gow [25], planned a PV model which executed on MATLAB. Khan [26], 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 [28], [29]-[32]. Controllers were thought of with typical PI controller for diesel and the wind hybrid grid [27] and for the wind-hydro diesel hybrid grid [34]. [35]. FLC for regulating the load frequency with optimization techniques for wind–diesel hybrid grid was projected in [33].Utilizing ANFIS technique based mostly controllers for Hydro-thermal power systems are measured and given in [36] and [37] severally.

The structure dynamics is explained by the set of linear differential equations and cost function is given by the quadratic functional is known as the LQ problem. The results in the hypothesis are that the solution is offered by the Linear-Quadratic Regulator. This means that the values of gains of a regulating controller leading by the process which is found by means of a mathematical algorithm that reduces a cost function supplied via weighting parameters. The cost function is frequently explained as an amount of the variations of key measurements from their preferred values. In result of this method gets that controller setting which reduce the deviations.

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 that consists of various renewable energy sources (PV cell, wind turbine generator, battery energy storage system, fuel cell and aqua electrolyzer).

2. To design the fuzzy PI controller and ANFIS in order to regulate the frequency whenever the load demand changes.
3. To design the LQR by using MATLAB in the hybrid system for the optimal control.
4. To simulate the developed model with designed controllers for LFC.
5. To compare the performance of three controllers in terms of settling time, overshoot and undershoot.

1.5 Organization of thesis

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

Chapter 2 Here it gives the overview on AGC and the description of the each part of the hybrid power system.

Chapter 3 It explains intelligent techniques. It gives the brief description of fuzzy logic, adaptive nuero fuzzy interface system (ANFIS) and describes the Linear quadratic regulator.

Chapter 4 It includes the simulation and the results obtained by the each controller.

Chapter 5 Gives the conclusion and the future scope of the proposed work.

CHAPTER 2

SYSTEM MODEL

2.1 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 two area grid model with five renewable energy sources in each area has been taken for the desired demand. The model expressed here is that the integral controlling action the interconnected power systems. In this chapter the MATLAB model of the given hybrid power grid that is intended for the implementation of traditional as well as the intelligent controllers and ascertained their stability. The model of hybrid power grid is afterwards employed in chapter-3 for the applying of optimum controllers for the Load frequency control. In thesis two areas in the interconnected power grid is projected to regulate the frequency of the hybrid power grid. It includes five renewable energy sources and two thermal power systems. The distributed generating system in analysis contains energy resources. For example: turbine generator, fuel cell, peacock blue electrolyzer, battery energy storage system 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.

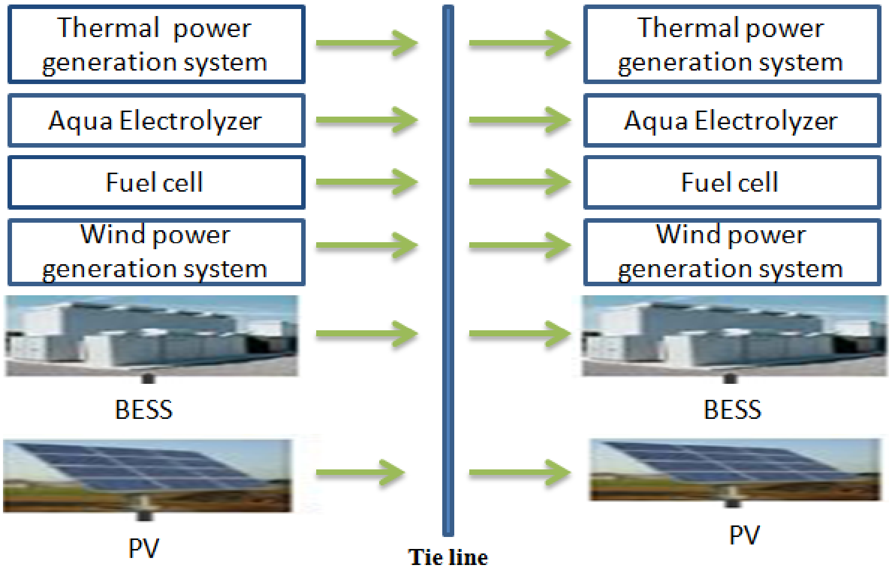

Figure 1: Layout of the hybrid power system

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. Whenever the load demand is higher than the offered wind power, then stability problem may possibly occur. 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 leveling in power system.

2.2 Model of hybrid power system

Both areas include the controller, governor, turbine and generator load model. Both units have its transfer function which is explained below. Output power of each unit is depend on input power this acquires from preceding unit.

2.2.1Turbine model

The turbine is a rotating mechanical device that extorts energy from the steam or water and transforms it to the mechanical power ΔP_m which is further given to generator. Generator is driven by the turbine. Generally, three types of turbine are used that are hydraulic, non-reheat and reheat turbines. The non- reheat turbine is simplest among these and the position of valve is related to the output of turbine. The balance between electromechanical air gap powers is maintained by the turbine power for regulating the frequency. If difference between both these powers (ΔP_T - ΔP_G) is positive then generator will accelerate on the other hand it decelerates. Increase in turbine power depends on the load variation connected to the generator.

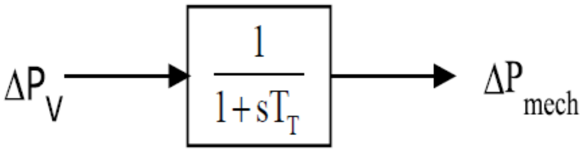

Figure 2: Transfer function of turbine

Where, T_T is time constant for the turbine model

2.2.2 Generator – load Model

The generator transforms the output power of the turbine that is it transforms the mechanical energy to electrical energy. However conversion of energy is not considered here, the main attraction is specified to the rotor speed ultimately than to frequency of the hybrid power system. The large amount of storage of electrical energy is a tough task; therefore generation and the load demand must be balanced. At the instant load is changed there is mismatch between the power generated and the mechanical power by the generator. Load is consist of number of electrical devices, that are pure resistive, motors which are prevalent part of load of electrical system. The increment power of generator depends on load variation. The increment of generator power ΔP_G changes with ΔP_D. The output of generator is always adjusted to match the load demand. Thus, $\Delta P_G = \Delta P_D$.

The following assumptions are made out in hybrid power system as the load is fed by the generator:

1. The normal frequency is f_0 and due to the power balance, system is run in its normal state.

2. The load demand is increased by adding the load objects that is ΔP_D thus generation is increased to meet the load demand i.e. $\Delta P_G = \Delta P_D$.

3. The kinetic energy is depended on speed as the square of speed then kinetic energy is written as:

$$W_{kin} = W_{kin}^0 \left(\frac{f}{f^0}\right)^2 \qquad (2.1)$$

4. Since the frequency varies, when the motor load is changed because this is speed sensitive , the rate of change of the load with respect to the load is contant.

$$B = \frac{\partial P_D}{\partial f} \qquad (2.2)$$

Write the power balance equation

$$\Delta P_T = \Delta P_D + \frac{d(W_{kin})}{dt} + B\Delta f \qquad (2.3)$$

As, $f = f^0 + \Delta f$

By neglecting Δf, the kinetic energy is written as,

$$= W_{kin}^0 \left[1 + \frac{2\Delta f}{f^0} + \left(\frac{\Delta f}{f^0}\right)^2\right] \approx W_{kin}^0 \left(1 + 2\frac{\Delta f}{f^0}\right) \qquad (2.4)$$

$$\Delta P_T - \Delta P_D = \frac{2W_{kin}^0}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \tag{2.5}$$

At specified frequency, the stored kinetic energy is

$$W_{kin}^0 = H \times P_r$$

Now by dividing equation by P*ᵣ*

$$\Delta P_T - \Delta P_D = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \tag{2.6}$$

The advantage of H parameter is that it is independent of system size.

Equation (2.6) can also be written as

$$\Delta P_T - \Delta P_D = 2H\frac{d}{dt}\left(\frac{\Delta f}{f^0}\right) + Bf^0\left(\frac{\Delta f}{f^0}\right) \tag{2.7}$$

Laplace transform of equation (2.6) gives

$$\Delta P_T(s) - \Delta P_D(s) = \frac{2H}{f^0}s\Delta f(s) + B\Delta f(s) \tag{2.8}$$

$$\Rightarrow \Delta f(s) = G_p(s)\left[\Delta P_T(s) - \Delta P_D(s)\right] \tag{2.9}$$

Where

$$G_p(s) = \frac{K_p}{1 + sT_p} \tag{2.10}$$

$$T_p = \frac{2H}{f^0 B} \tag{2.11}$$

$$K_p = \frac{1}{B} \tag{2.12}$$

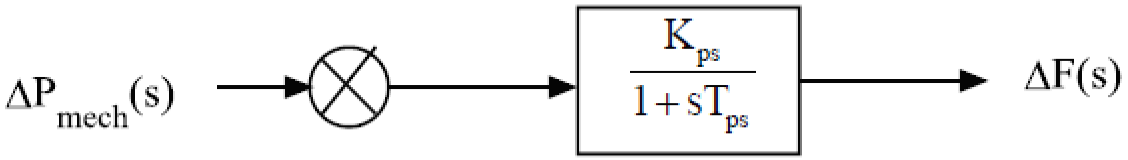

Figure 3: Transfer function model of generator -load

2.2.3 Governor model

Governor or it is known as speed limiter, is used for regulating and measuring the machine speed. Use of governor within the hybrid power systems as a result, this regulates turbine speed, power of turbine and facilitate in control the frequency. For beginning purpose of rotary engine, governor is employed. The load cannot stay steady but change as the load demand. Divergence among the demand and therefore the generation causes deviation in the frequency ensuing to regulation of generation. Once frequency is varied there's reduction in power quality. The governing system offers essential modification with the controlled steam flow getting into to the turbine. The governor is that the isochronal governor which maintains the input valve to position that keep the frequency to value.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad (2.13)$$

$$\frac{\Delta P_v}{\Delta P_g} = \frac{1}{1+sT_g} \qquad (2.14)$$

2.2.4 Wind power turbine

Wind speed is accountable for the wind turbine power. It is time variable. The wind turbine output mechanical power is changing with cube of speed of the wind. The power of the wind turbine is

$$P_{WP} = \frac{1}{2}\rho A_R C_P V_W{}^3$$

Where ρ is the density of air (kg/m^3); A_R is the blade's swept area (m^2); C_P is power coefficient and V_W is the speed of wind.

System of wind turbine has variety of nonlinearities. The power at the output changes whenever the wind turbine is regulated the frequency with the pitch controller. Limitations of divergence in the output power settle on the set position of pitch angle. The nonlinearities establish in the power system by the pitch system which can be adjust the pitch angle according to the wind speed. The wind turbine transfer function is :

$$G_{WTG}(s) = \frac{K_{WTG}}{1+sT_{WTG}} \tag{2.15}$$

2.2.5 Aqua Electrolyzer

Some part of the power of wind turbine generator is used by the aqua electrolyzer for producing hydrogen which is supplied to the fuel cell for generating power.

The transfer function of Aqua electrolyzer is:

$$G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}} \tag{2.16}$$

2.2.6 Fuel cell

The fuel cell changes the chemical energy (hydrogen from the aqua electrolyzer) into electrical energy by combining the gaseous hydrogen and air with no combustion. It is measured the major resource in the hybrid power system as it has variety of advantages like higher efficiency and the lesser amount of pollution. Fuel cell generator has also nonlinearities. For the low frequency analysis, the transfer function of fuel cell is:

$$G_{FC}(s) = \frac{K_{FC}}{1+sT_{FC}} \tag{2.17}$$

2.2.7 Battery energy storage system

The BESS is supplying high order of power damping to the hybrid power system swing for maintaining the both transient and dynamic stability. The power of wind turbine is constantly varying and power variations for the small time cause big problems in the operation of hybrid power system. There is explanation for usage of battery energy storage systems in power system.

The BESS has excellent technical characteristics therefore this can accumulate enormous amount of wind power. The transfer function of BESS is:

$$G_{BESS}(s) = \frac{K_{BESS}}{1+sT_{BESS}} \tag{2.18}$$

2.2.8 Photovoltaic power generation system

The electric circuit of PV is including a photocurrent, diode, a series resistor and a parallel resistor as shown in figure 3. The array behavior of PV is depending on the module of PV model with $N_S \times N_P$ modules is expressed by the equation given below:

$$I_A = N_P I_{SC} - N_P I_0 \exp\left(\left[\frac{V_A + I_A R_S}{n N_S V_T}\right] - 1\right) \quad (2.19)$$

Where

I_0 = Diode saturation current (A)
R_S = series resistance (Ω)
I_A = PV Array output current (A)
n = diode ideal constant
I_{SC} = PV module short circuit current (A)
V_T = PV module thermal potential (V)
V_A = PV array terminal voltage (V)

$$G_{PV}(s) = \frac{K_{PV}}{1 + sT_{PV}} \quad (2.20)$$

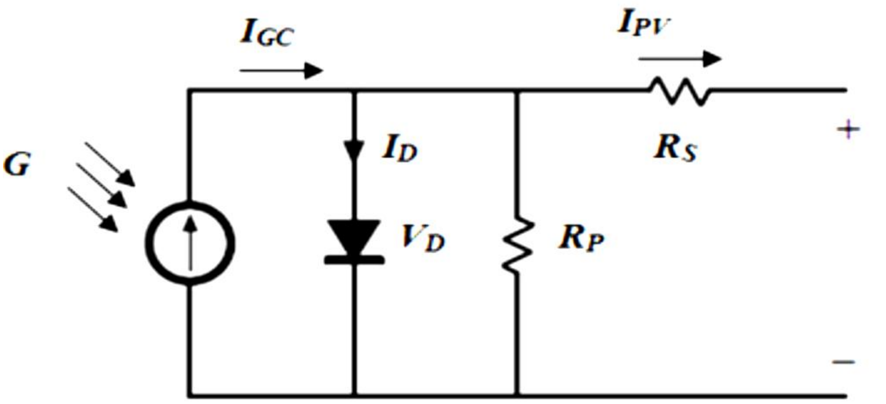

Figure 4: Electric circuit of PV module.

2.3 Two area interconnected power system

The tie-line is used for the interconnection of two or more power systems. The flow of electric power between two areas is because of the tie line. 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. Error in the power of tie line is the integral of the frequency variation among two areas. Power in the tie line can be expressed mathematically as

$$P_{12}^0 = \frac{|V_1^0||V_2^0|}{X} \sin\left(\delta_1^0 - \delta_2^0\right) \quad (2.21)$$

Where

$\delta_1^0 \delta_2^0$ =power angles of equivalent machines

For small deviations in the angles the tie-line power changes to

$$\Delta P_{12} = T_{12}\left(\Delta\delta_1 - \Delta\delta_2\right) \tag{2.22}$$

Where

$$T_{12} = \frac{\left|V_1^0\right|\left|V_2^0\right|}{X}\cos\left(\delta_1^0 - \delta_2^0\right) \text{ is the synchronizing coefficient} \tag{2.23}$$

Frequency deviation Δf is related to reference angle by

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}\left(\delta^0 + \Delta\delta\right)$$

$$= \frac{1}{2\pi}\frac{d}{dt}\left(\Delta\delta\right)$$

$$\Delta\delta = 2\pi\int \Delta f dt \tag{2.24}$$

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

Taking Laplace transformation of above formula gives

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

2.4 Area control error

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. The purpose of load frequency control is to reduce the error in frequency of both areas as well as to remain error in the tie line power to preferred value which is not an easy task in because of fluctuating load. The error in frequency ought to maintain at zero and the steady state errors within the frequency of the power system is that the outcome in error in tie-line power as a result of the tie line power error is that the integral of the frequency variation between each areas.

Hence, this is vital to require the tie-line power variation as the input. Therefore, ACE is expressed as:

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

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

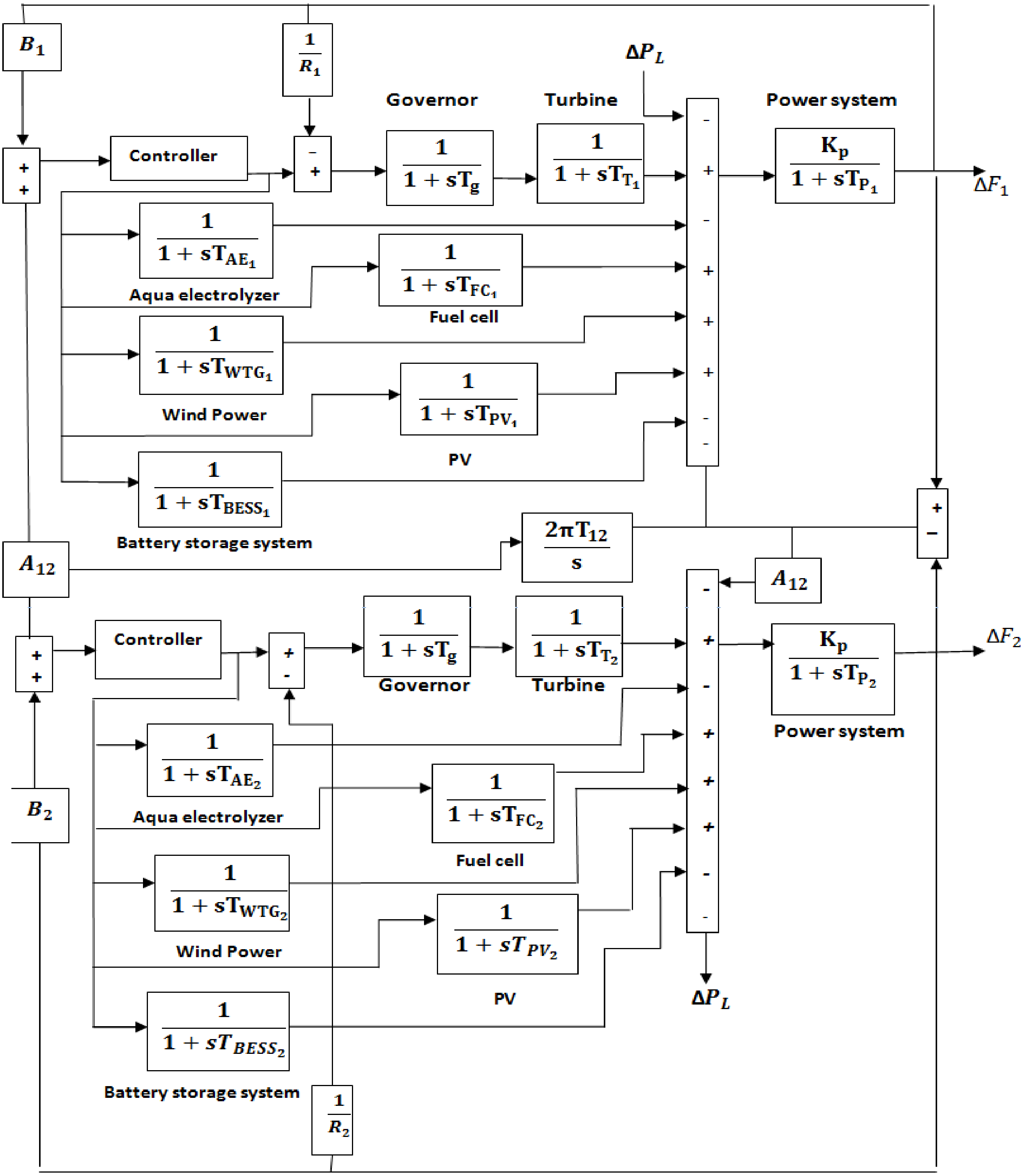

Figure 5: Block diagram of hybrid power system.

Nomenclature

T_g = Time constant for the governor

T_{T_1}, T_{T_2} = Time constant for the turbine

T_{P_1}, T_{P_2} = Time constant for the power system

T_{AE_1}, T_{AE_2} = Time constant for the aqua elecrolyzer

T_{FC_1}, T_{FC_2} = Time constant for the fuel cell

T_{PV_1}, T_{PV_2} = Time constant for PV

T_{BESS_1}, T_{BESS_2} = Time constant for battery energy storage system

T_{WTG_1}, T_{WTG_2} = Time constant for the wind turbine generator

B_1, B_2 = Frequency biasing parameters

R_1, R_2 = Speed regulation parameter for the governor

$\Delta F1$, $\Delta F2$ = Frequency variation in the hybrid system

T12 = Coefficient for synchronizing

CHAPTER 3

CONTROL METHODOLOGY

3.1 Automatic controller

The U_i control signal is generated by the LFC which keeps the frequency and tie line power constant. The U_i control signal U_i is

$$U_i = -k_i \int_0^T (ACE_i) = -k_i \int_0^T (\Delta P_{tiei} + B_i \Delta F_i)\, dt. \tag{3.1}$$

Take the derivative of equation:

$$U_i = -k_i(ACE_i) = -k_i(\Delta P_{Tiei} + B_i \Delta F_i) \tag{3.2}$$

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. Fuzzy logic controller is anticipated for solving the load frequency problem in [10]-[13].

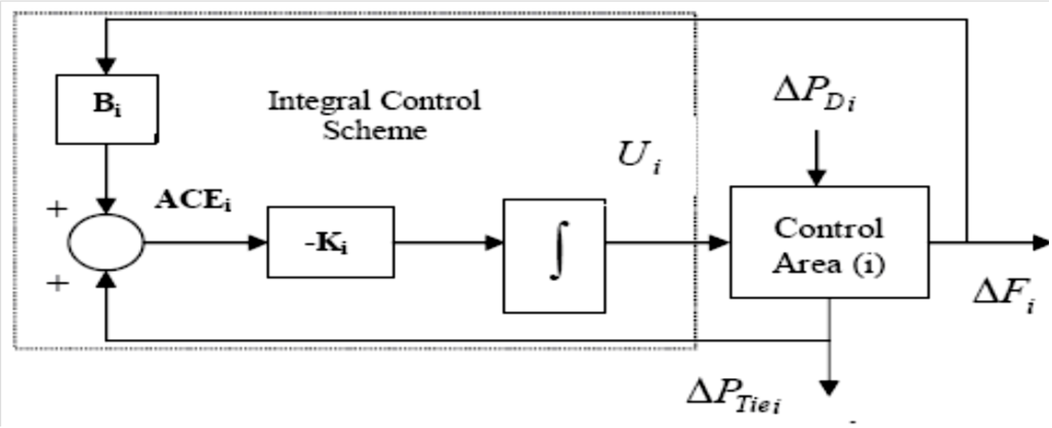

Figure 6: Conventional PI controller

3.2 Fuzzy logic controller

In present time, the FLC is extensively received attentions in a variety of applications of power system [14]. 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.The problem of LFC consists of the sudden load variation or a variation in input wind generation that continuously perturb the operation of the system. For this reason, the deviation frequency should be regulated.

3.2.1 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.

3.2.2 Knowledge Base

The necessary a part of the fuzzy could be a knowledge base that consists of IF-THEN rules. 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.

3.2.3 De-Fuzzification

The purpose of De-fuzzification is to altering the output fuzzy variable into a crisp value, because of this, it is used for controlling process. Crisp value is necessary in practical power system applications for controlling action. The block diagram of FLC is shown in figure 5. 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 (7, 8) and Table-1 for the comparison of FLC with the proposed controller.

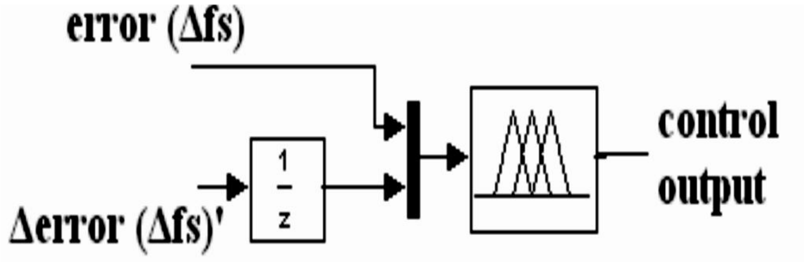

Figure 7: Block diagram of fuzzy logic controller

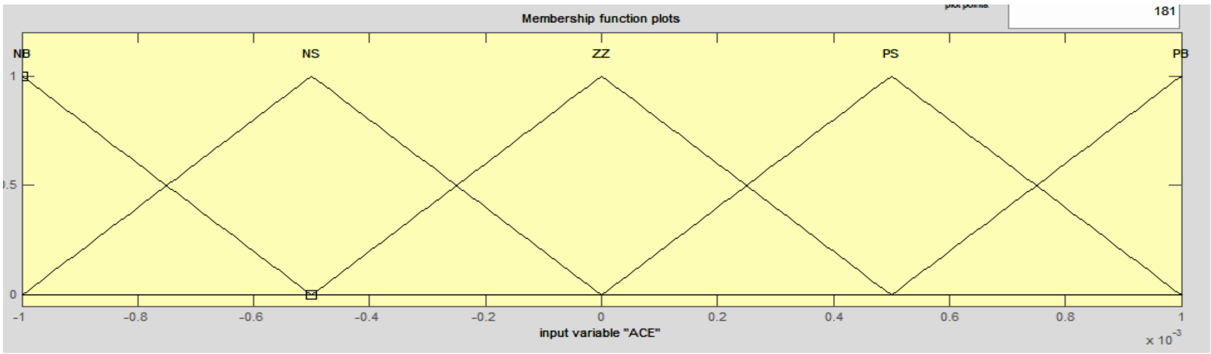

Figure 8: Membership function of input ACE

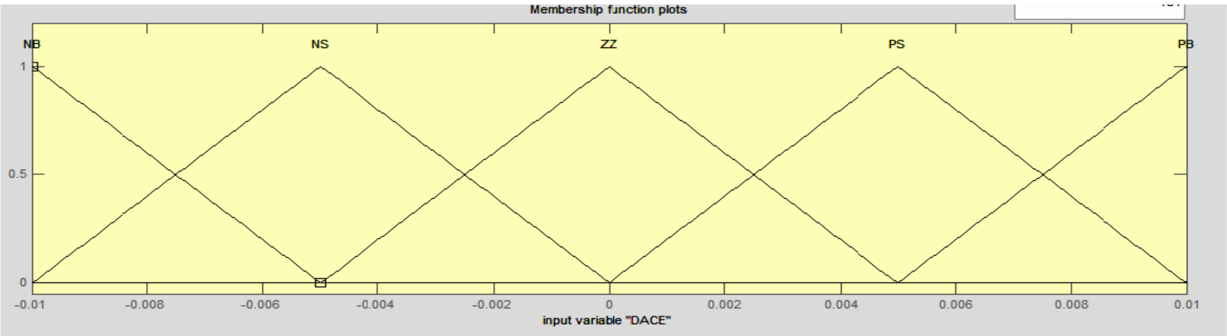

Figure 9: Membership functions of input DACE

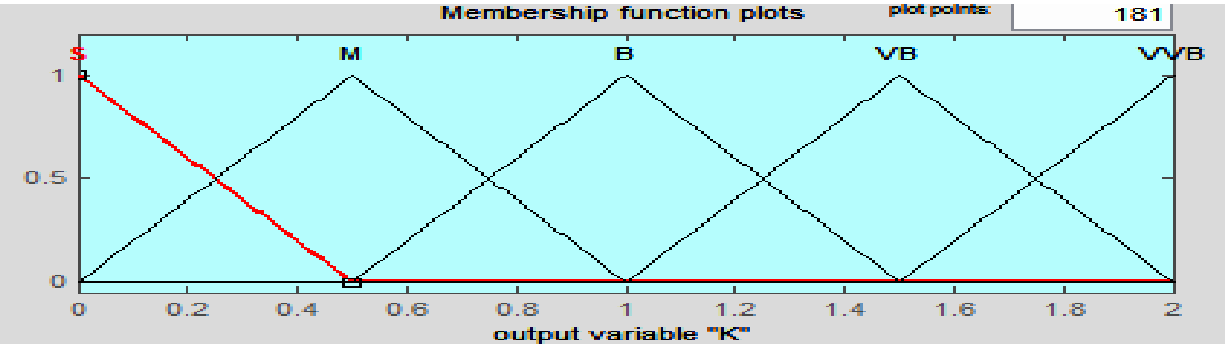

Figure10: Membership functions for output K

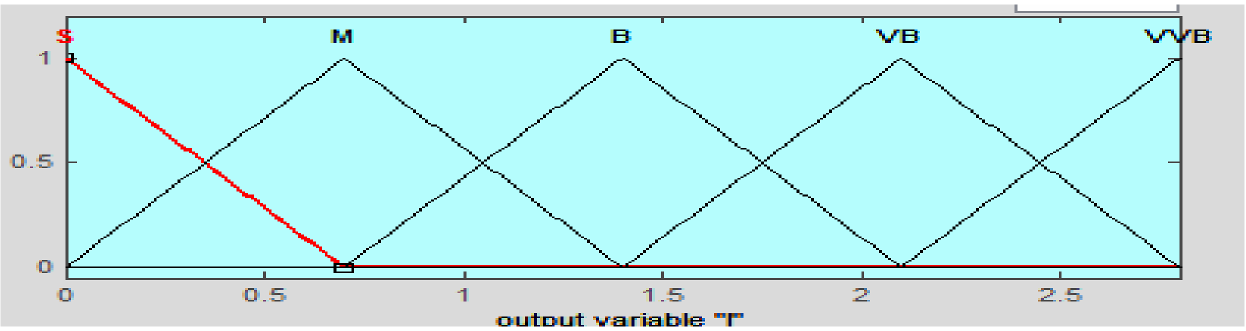

Figure11: Membership functions for output I

TABLE 1: Fuzzy logic rule base consisting five membership functions

ACE/DACE	**NB**	**NS**	**ZZ**	**PS**	**PB**
NB	**S**	**S**	**M**	**M**	**B**
NS	**S**	**M**	**M**	**B**	**VB**
ZZ	**M**	**M**	**B**	**VB**	**VB**
PS	**M**	**B**	**VB**	**VB**	**VVB**
PB	**B**	**VB**	**VB**	**VVB**	**VVB**

3.3 ANFIS based Neuro-fuzzy controller

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. A ANFIS is fuzzy Sugeno models place in the configuration of adaptive system to persuade the learning and modification [15]. 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.

Rule 1: if (x is A1) and (y is B1) then (f1 = p1x + q1y + r1)

Rule 2: if (x is A2) and (y is B2) then (f2 = p2x + q2y + r2)

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.

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 Figure 13.

.

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:

$$O_i^1=\mu_{Ai}(x) = 1/\left[1 + \left|\frac{x-c_i}{a_i}\right|^{2bi}\right] \qquad \text{For i = 1, 2} \qquad (3.1)$$

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.

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:

$$O_i^2= \mu_{Ai}(x) . \mu_{Bi}(y) \qquad \text{For i=1, 2} \qquad (3.2)$$

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

$$O_i^3= \overline{w_\iota} = \frac{w_i}{w_1+w_2} \qquad \text{For i=1, 2} \qquad (3.3)$$

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

$$O_i^4 = \overline{w_\iota} f_i = \overline{w_\iota}(p_i x+q_i y+r_i) \qquad \text{For i=1, 2} \qquad (3.4)$$

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

$$O_i^5=\sum_i \overline{w_\iota} f_i=\frac{\sum_i w_i f_i}{\sum_i f_i} \qquad (3.5)$$

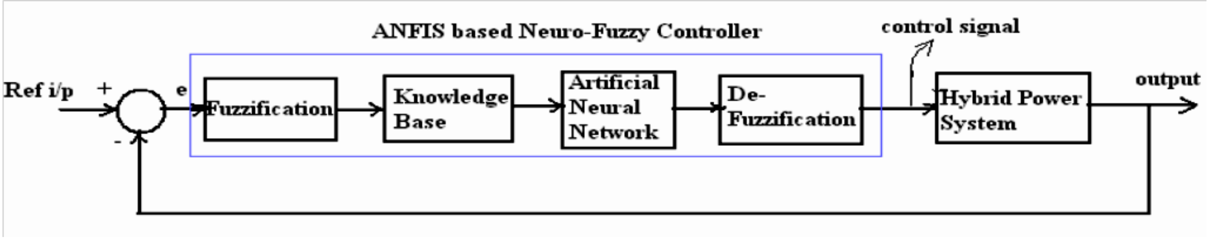

Figure 12: Block diagram of Neuro fuzzy controller

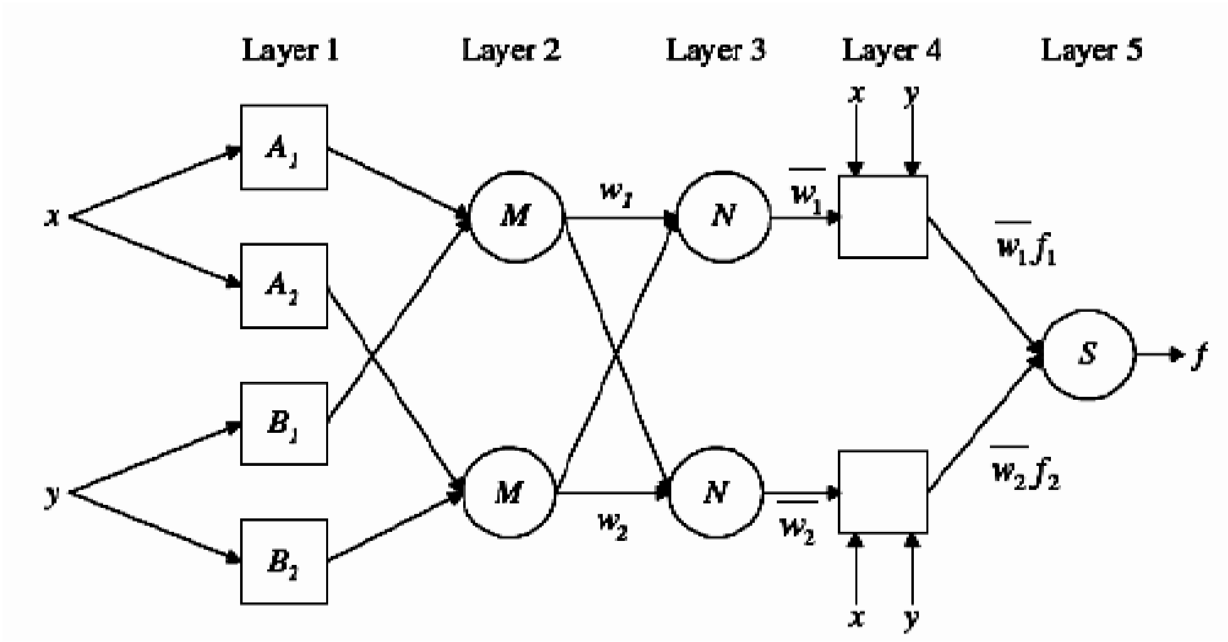

Figure 13: ANFIS architecture

3.3.1 Steps for the designing of Neuro-Fuzzy Controller

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.

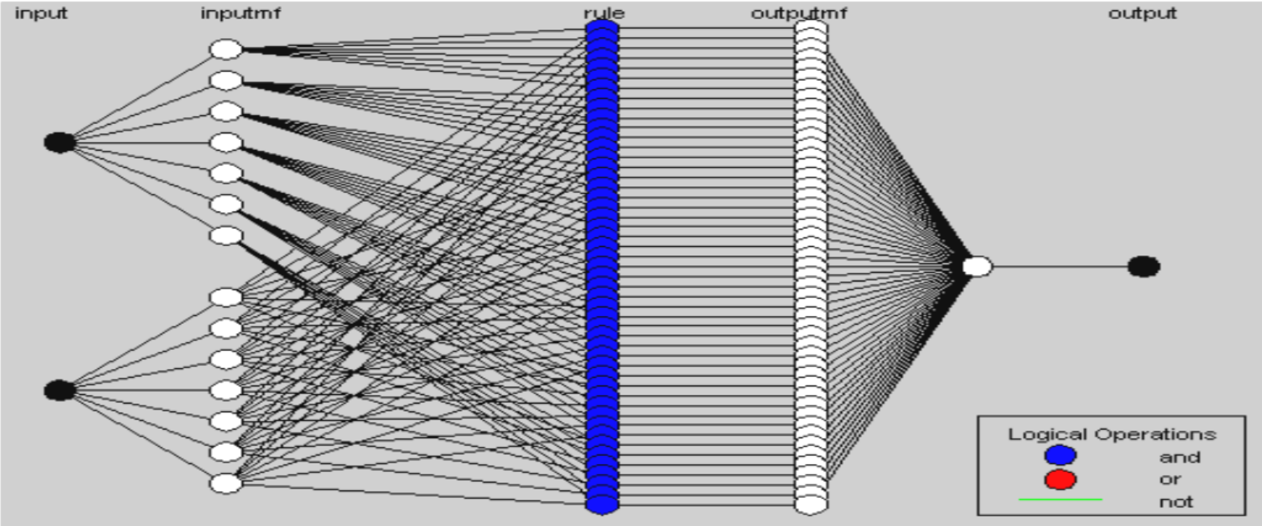

Figure14: ANFIS structure for the designed Neuro- Fuzzy controller**.**

3.4 Linea Quadratic Regulator

This is the strategy utilized for designing of controlled power grid with the change of magnitude of the performance index of variables of system. Throughout the section, discussion of optimal controllers with quadratic performance index for the linear systems, this is often conjointly called linear quadratic regulator. The objective of the planning of this regulator is to resolve a law of control u*(x, t) that is able to convert that system as of the initial position to final position with the change of magnitude of the performance index. The quadratic performance index is used here as the linear performance index and its principle is minimum energy criterion.

The plant as discussed is taken into consideration:

X (t) =Ax (t) + B u (t)

The main function is to find the vector **K** which is used for the controlling purpose:

U (t) = -K (t)*x (t)

This decreases the quadratic performance index value **J** in the form:

$$J=\int_{to}^{tf}(x'Qx\ +\ u'\,Ru)dt \qquad (3.6)$$

Where **R** is the real symmetric matrix and Q is the non-negative semi definite matrix. **Q** is the definite positive matrix when all its primary minors are positive. The preference of **Q** and **R** allocate the comparative weighting of the each control inputs and each state variable. For getting the result, the Langrange multipliers is used the n vector from the unconstrained equation

$$[x, \lambda, \mu, t]=[x^2 Qx + u^2 Ru]+\lambda'[Ax + Bu - x']$$

Place the partial derivative equal to zero to find the optimal values.

$$\frac{\partial L}{\partial \lambda} = AX^* + \mathrm{B}u^* - x'^* = 0 \Rightarrow x'^* = AX^* + \mathrm{B}u^* \qquad (3.7)$$

$$\frac{\partial L}{\partial u} = 2\mathrm{R}u^* + \lambda'\mathrm{B} = 0 \Rightarrow u^* = -\frac{1}{2}R^{-1}\lambda'\mathrm{B} \qquad (3.8)$$

$$\frac{\partial L}{\partial x} = 2Qx'^* + \lambda' + A'\lambda = 0 \Rightarrow \lambda' = -2\mathrm{Q}x'^* - A'\lambda \qquad (3.9)$$

Assumption is taken that a symmetric, time varying positive definite matrix is present **p (t)**

$$\lambda = 2\ p(t)\ x(t) \qquad (3.10)$$

Substituting (3.10) in (3.8) w

$$U^*(t) = -\ R^{-1} B'\ p(t)\ x(t) \qquad (3.11)$$

Get the derivative of (3.10)

$$\lambda = 2(\ p\ x^* + p^*\ x) \qquad (3.12)$$

Finally equate (3.9) and (3.12)

$$p\ (t) = -\ p\ (t)\ A - A'\ p\ (t) - Q + p\ (t)\ B\ R^{-1} B' p\ (t) \qquad (3.13)$$

This equation is referred as the Riccati equation.

Compensators were normally accustomed assure all the specifications during a system.

However within the majority of the cases, the system desires to execute many additional specifications that don't seem to be straightforward to realize within the compensating system. As a substitute to the present there's the most use of best system. Testing and error system formulate it is tough in favor of designers to succeed in the specifications. This test and error process workings are suit to the system with one input and output. Nevertheless designed for a multi-input and output system, the error and test methodology is removed and altered with optimum methodology wherever the uncertainties in error abolish within the optimum methodology. It contains one performance index particularly integral square performance index. There reduction of the performance index is completed by the Lyapunov stability theorem to present in improved performance for a continuing system configuration. The R and Q matrix must be precisely chosen and if the response is inappropriate then the the other matrix of Q and

R is chosen. K is created by the programming automatically and the control system results are taken.

3.5 State space modeling of two area power system

Consider the ith area of the power system and derive the differential equation under normal operating condition in which the disturbances are negligible.

Differential equation of the governor

$$\Delta x'_{vi} = -\frac{1}{T_{gi}}\Delta x_{vi}(t) - \frac{1}{T_{gi}R_i}\Delta f_i(t) + \frac{1}{T_{gi}}\Delta p_{ci}(t) \tag{3.14}$$

For Turbine Generator:

$$\Delta p'_{gi} = -\frac{1}{T_{ti}}\Delta p_{gi}(t) + \frac{1}{T_{ti}}\Delta x_{vi}(t) \tag{3.15}$$

For Power System:

$$\Delta f'_i(t) = -\frac{D_i f_0}{2H_i}\Delta f_i(t) - \frac{f_0}{2H_i}(\Delta p_{tie,i} - \Delta p_{gi}) \tag{3.16}$$

Tie Line Power Equation:

$$\Delta p'_{tie,i}(t) = \Sigma T_{ij}(\Delta f_i - \Delta f_j)$$

$$\dot{X} = AX + BU$$

Developing the state space model we need the matrices A and B.

$$A = \begin{bmatrix} 0 & T_{12} & 0 & 0 & 0 & -T_{12} & 0 \\ -\frac{f_0}{2H_1} & -\frac{f_0 D_1}{2H_1} & \frac{f_0}{2H_1} & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 \\ 0 & -\frac{1}{T_{g1}R_1} & 0 & -\frac{1}{T_{g1}} & -\frac{1}{T_{g1}} & 0 & 0 \\ -\frac{f_0}{2H_2} & 0 & 0 & 0 & 0 & -\frac{f_0 D_2}{2H_2} & \frac{f_0}{2H_2} \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{g2}R_2} & -\frac{1}{T_{t2}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}; \quad B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{1}{T_{g1}} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{1}{T_{g2}} \end{bmatrix}$$

$$X=\begin{bmatrix}\Delta p_{tie}(t)\\ \Delta f_1(t)\\ \Delta p_{g1}(t)\\ \Delta x_{v1}(t)\\ \Delta f_2(t)\\ \Delta p_{g2}(t)\\ \Delta x_{v2}(t)\end{bmatrix};\ U=\begin{bmatrix}\Delta p_{c1}(t)\\ \Delta p_{c2}(t)\end{bmatrix}$$

Δx_{vi}= additive change in the position of the valve

Δp_{vi}= additive change in the generated power

Δx_{vi}= additive change in the position of the speed changer

Subscript ‘i’ represents the area

CHAPTER 4

SIMULATION AND RESULTS

4.1 Simulink model of hybrid power system

This simulink model consists of two identical interconnected hybrid power systems and in each area consists of one thermal power generation system with wind turbine, Photovoltaic generation system (PV), fuel cell, battery storage system and aqua electrolyzer. Fuzzy-PI , Neuro- Fuzzy approach and LQR is implemented in the simulink model for LFC.

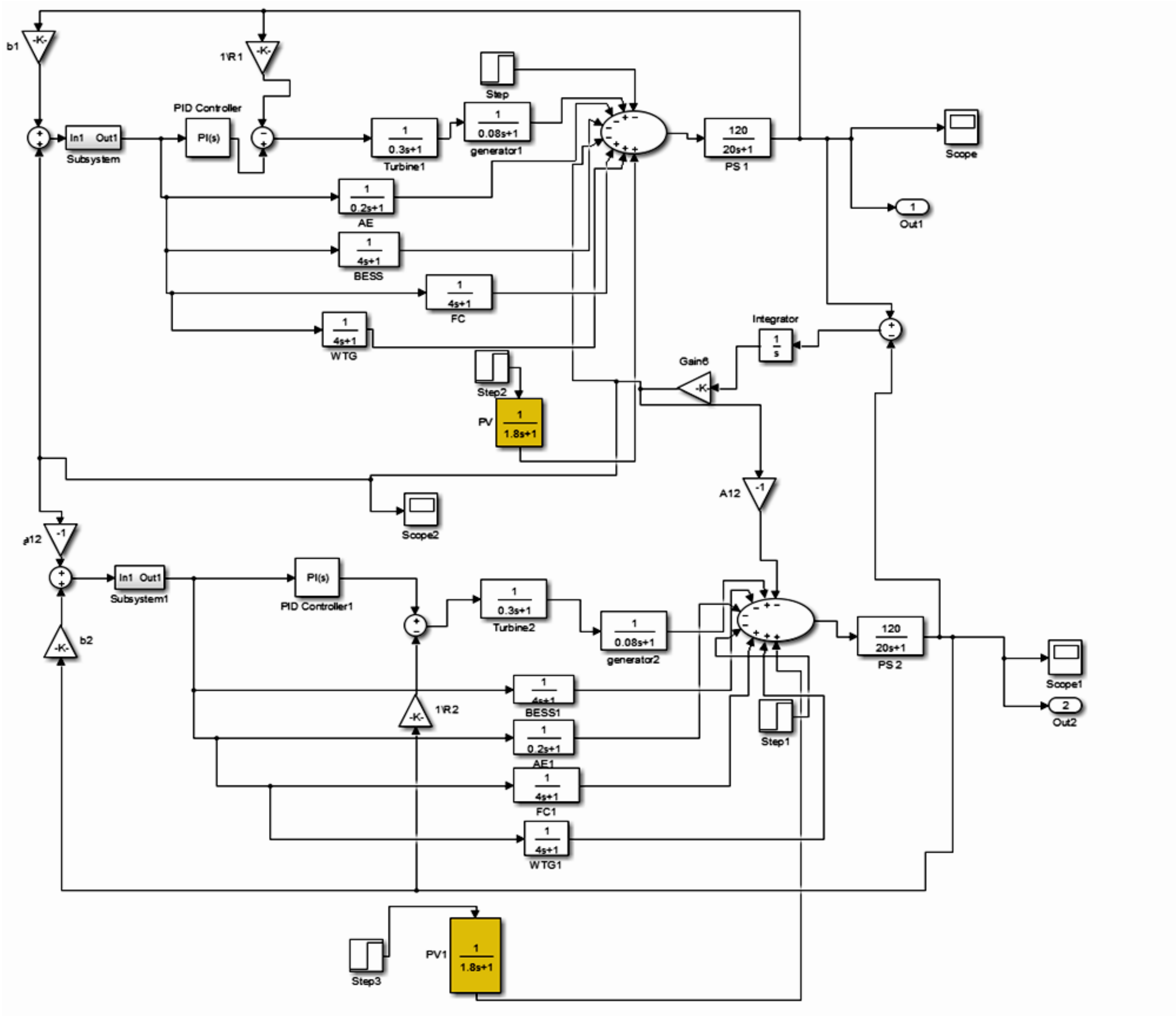

Figure 15: Simulink model of hybrid power system

Table 2: Magnitude of the parameters of the hybrid power system

Parameters of each area of hybrid power system	Magnitude of parameters
T_{T_1}, T_{T_2}	0.3s
T_g	0.08s
T_{P_1}, T_{P_2}	20s
K_p	120 Hz/p.u
T_{AE_1}, T_{AE_2}	0.2s
T_{FC_1}, T_{FC_2}	4s
T_{PV_1}, T_{PV_2}	1.8s
T_{BESS_1}, T_{BESS_2}	4s
T_{WTG_1}, T_{WTG_2}	4s
B_1, B_2	0.425 p.u. MW/Hz
R_1, R_2	2.4 Hz/p.u.
T12	0.0707 p.u

4.2 Frequency response of uncompensated system at 1% loading

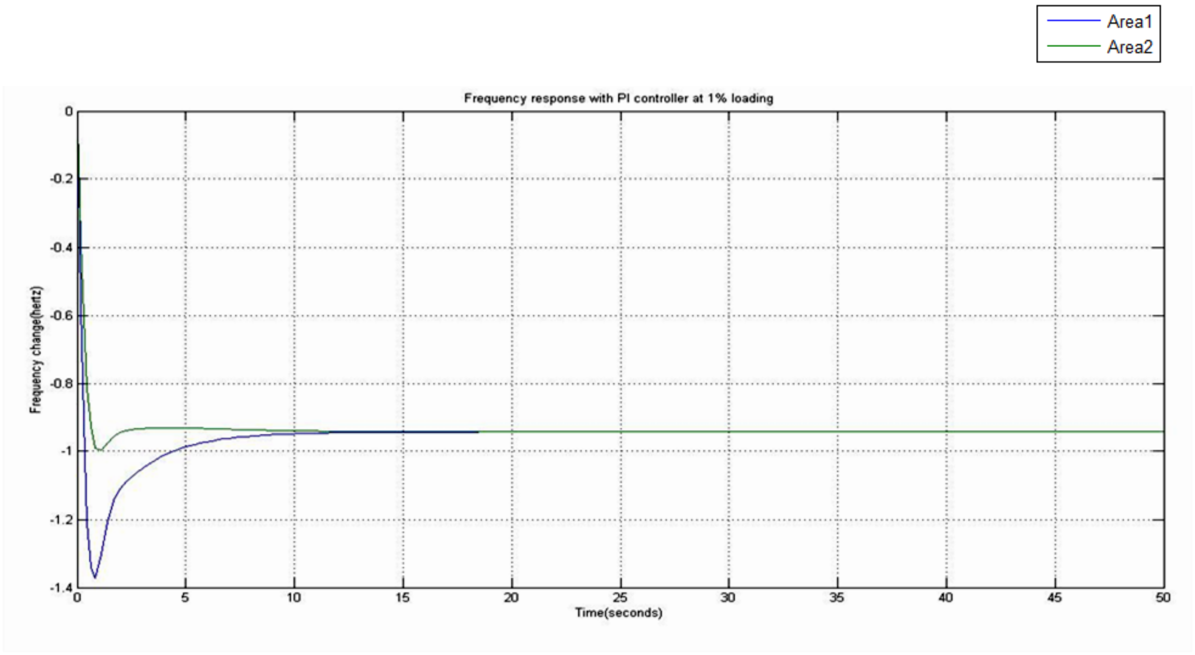

Figure16: Frequency response of uncompensated system.

4.3 Frequency response of three controllers at different loading.

Case 1 Frequency response at 1% loading with three controllers

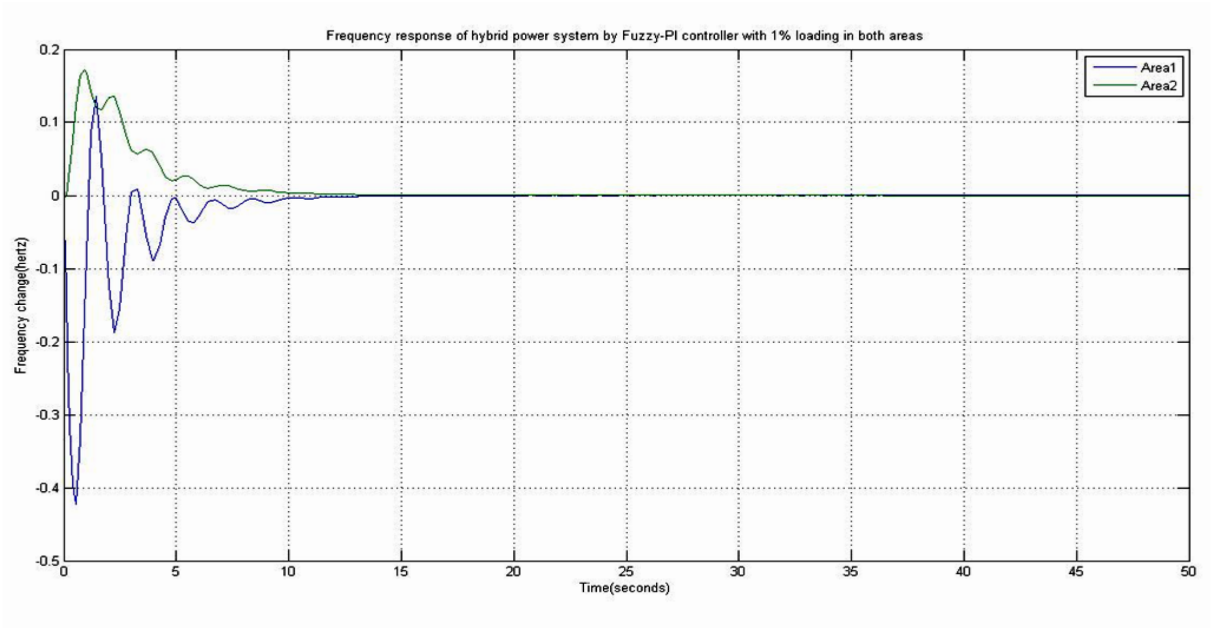

Figure 17: Frequency response of hybrid power system at 1% loading with Fuzzy-PI controller

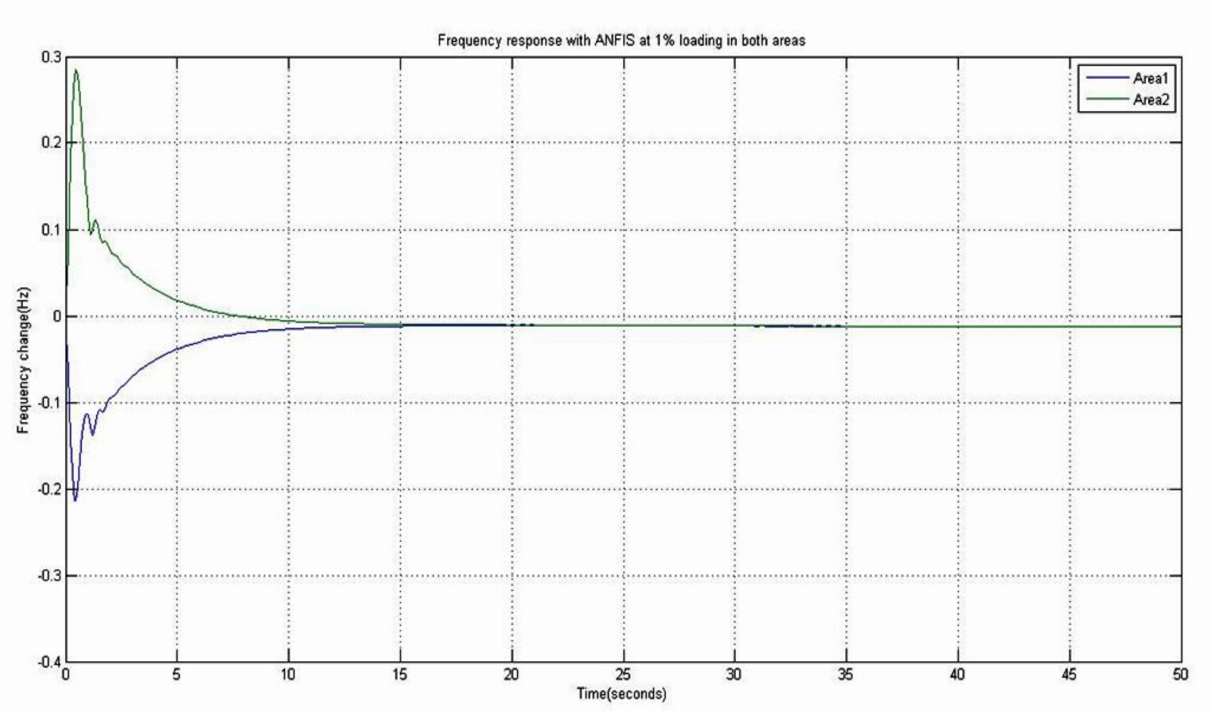

Figure18: Frequency response by ANFIS with 1% loading in both areas

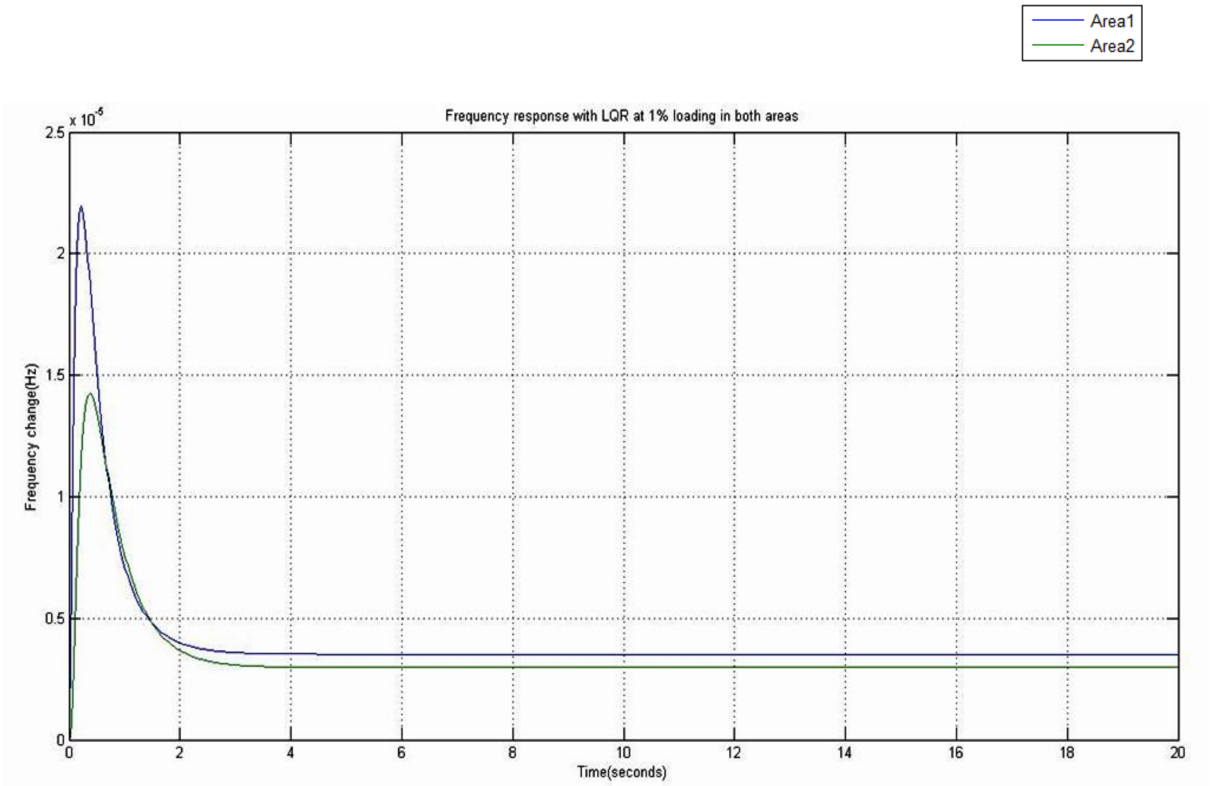

Figure 19: Frequency response with LQR at 1% loading in both areas.

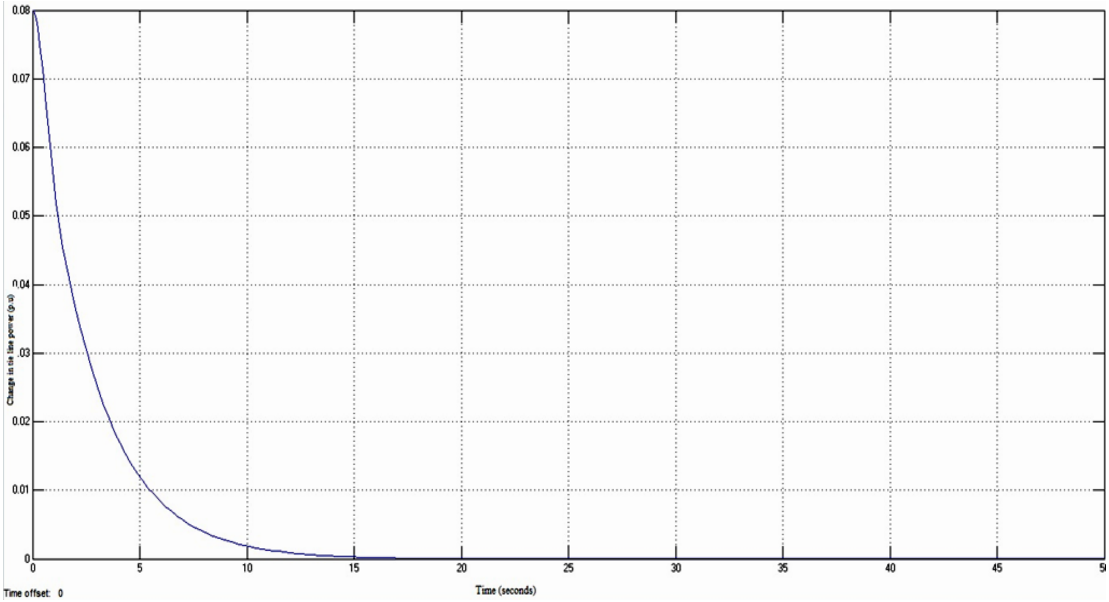

Figure 20: Change in tie line power (p.u) with Fuzzy-PI controller.

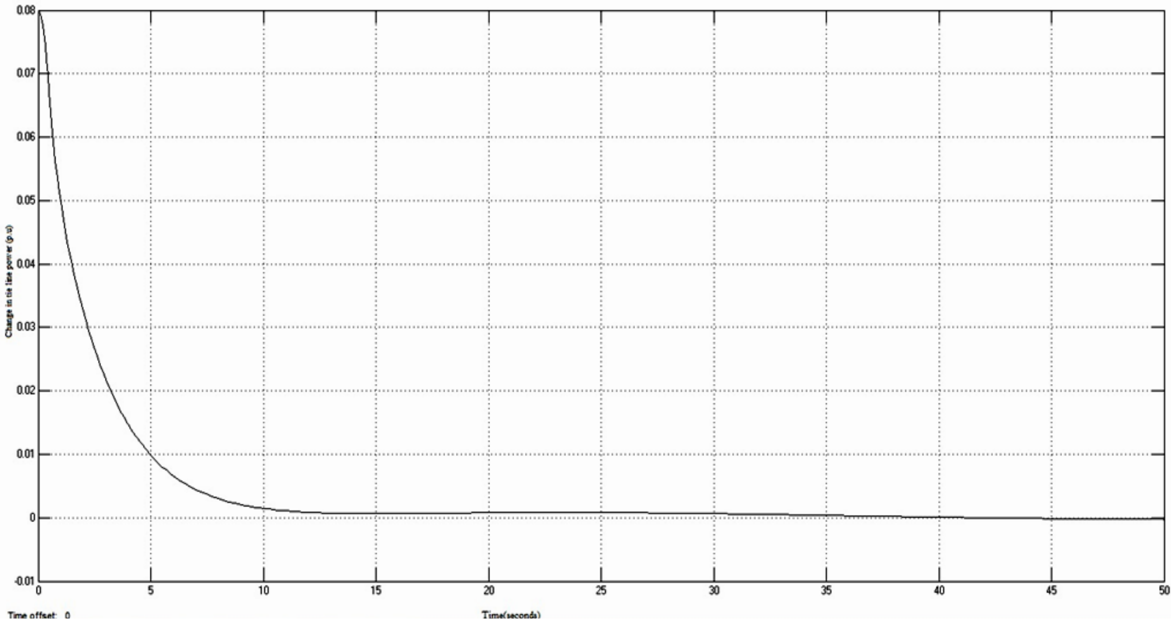

Figure 21: Change in tie line power (p.u) with ANFIS

Table 3: Comparison of parameters for three controllers at 1% loading

Controllers	Maximum overshoot (Hz)		Maximum undershoot (Hz)		Settling time (seconds)	
	Area1	Area2	Area1	Area2	Area1	Area2
Fuzzy-PI	-	0.17	-0.42	-	13	13
ANFIS	-	0.29	-0.19	-	11	11
LQR	2.2×10^{-5}	1.4×10^{-5}	-	-	3	3

Discussion

The simulation results are shown in figure (16-18) and the above tabular chart depicts the comparison of three controllers. ANFIS shows the better performance than the fuzzy-PI controller as the settling time is less than fuzzy-PI controller. However, LQR shows the best performance than the other two controllers because settling time and the overshoot is drastically reduced.

Case2 Frequency response of hybrid power system at 2% loading with three controllers

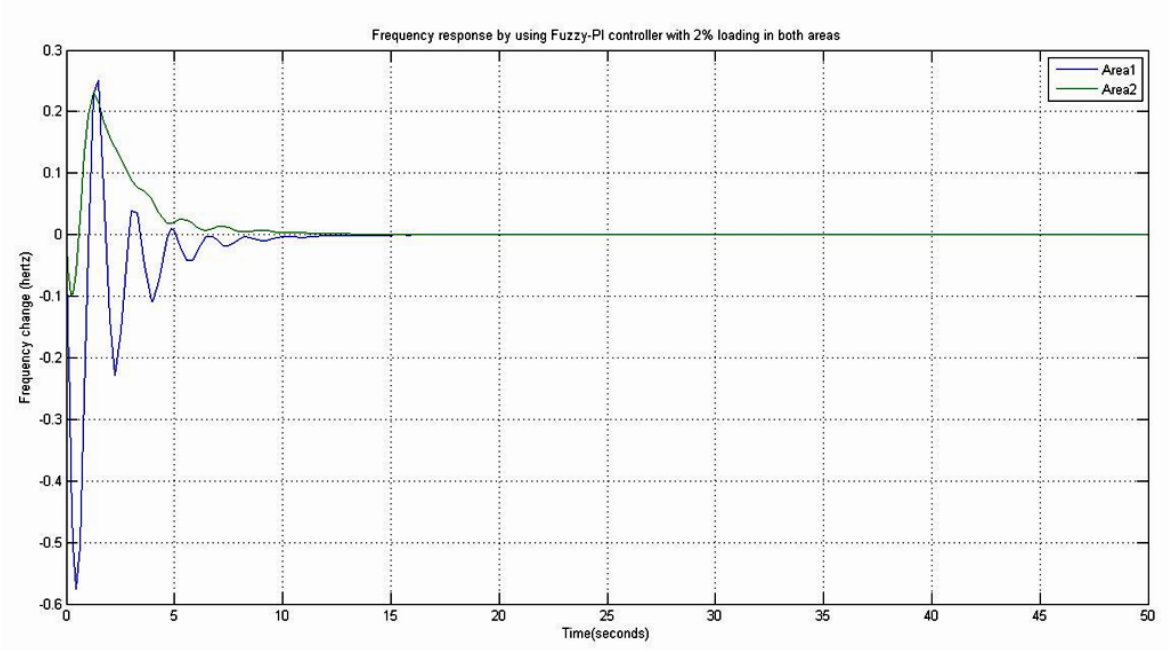

Figure 22: Frequency response of hybrid power system with Fuzzy- PI at 2% loading

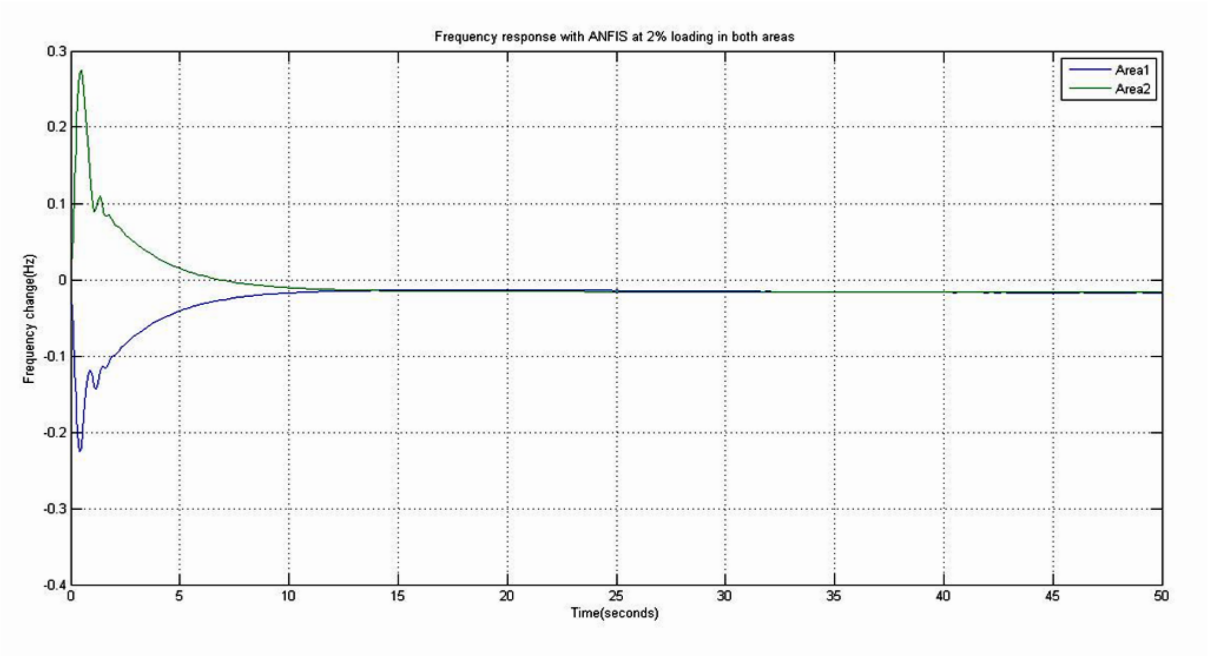

Figure23: Frequency response by ANFIS with 2% loading in both areas.

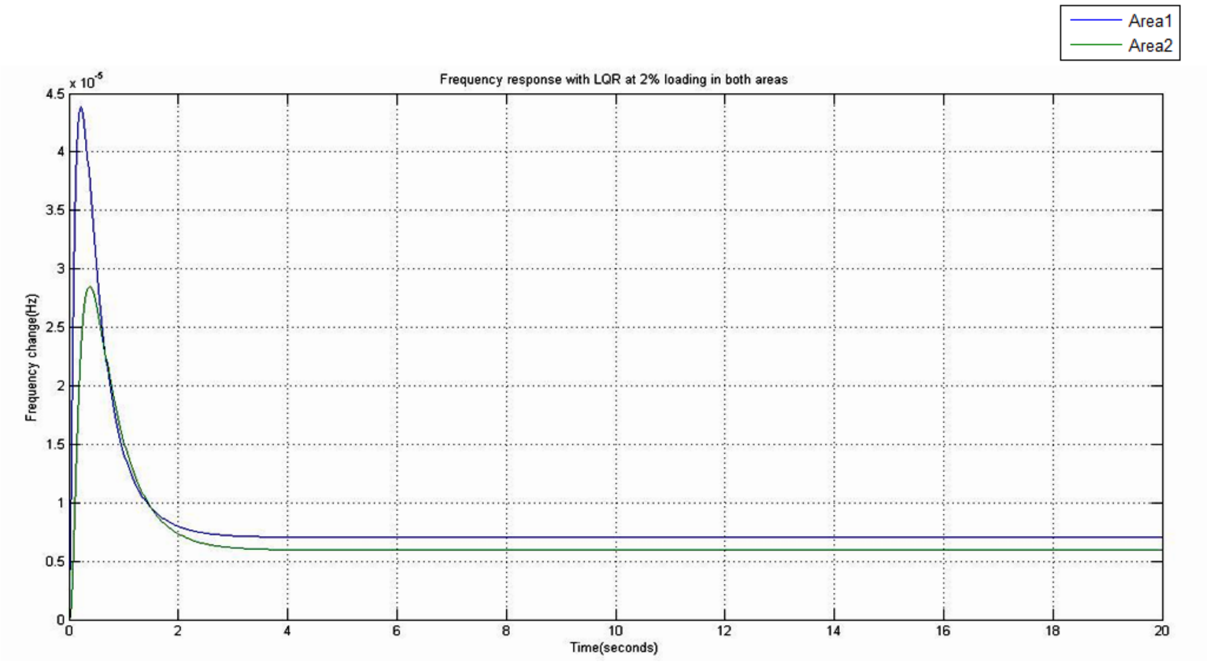

Figure 24: Frequency response with LQR at 2%loading in both areas

Table 4: Comparison of parameters for three controllers at 2% loading

Controllers	Maximum overshoot (Hz)		Maximum undershoot (Hz)		Settling time (seconds)	
	Area1	Area2	Area1	Area2	Area1	Area2
Fuzzy-PI	-	0.22	-0.58	-0.1	11	11
ANFIS	-	0.28	-0.22	-	10	10
LQR	4.3×10^{-5}	2.7×10^{-5}	-	-	2.5	2.5

Discussion

Simulation results in figure (22-24) and the above tabular chart illustrated the response of three controllers. ANFIS shows the better performance than the fuzzy-PI controller as the settling time is lesser than fuzzy-PI controller. But it can be concluded that LQR has best performance than the other two controllers as the settling time and the overshoot are reduced

Case 3 Frequency response of hybrid power system at 2% loading in area1 and 1% loading in area2

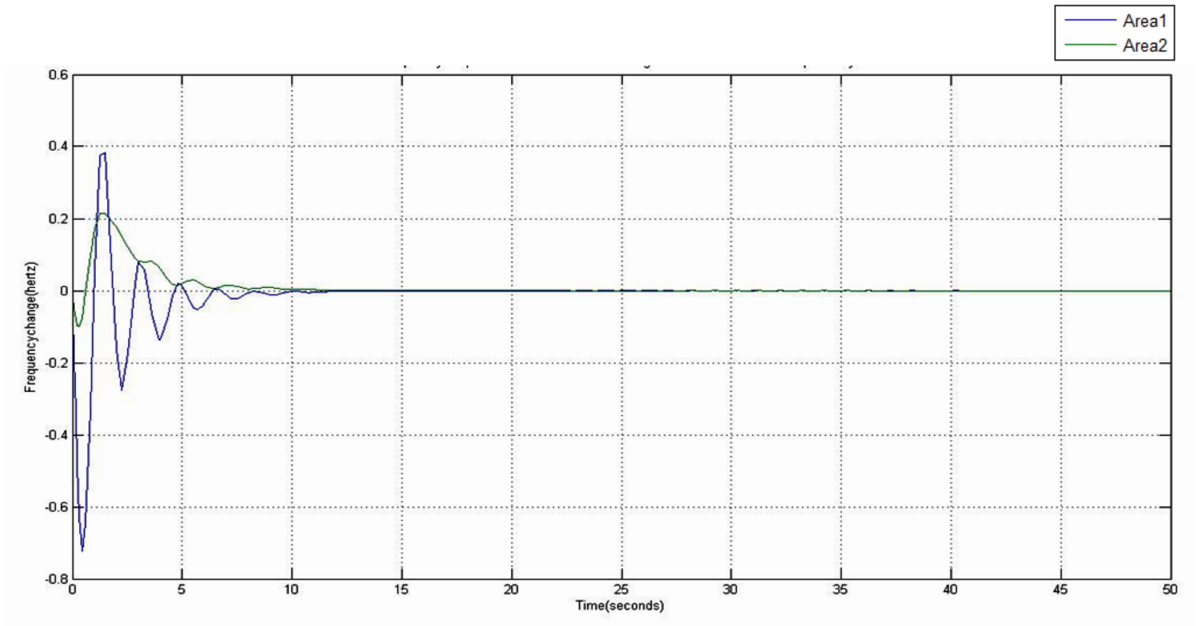

Figure 25: Frequency response of hybrid power system with Fuzzy -PI 2% and 1% loading in area1 and area2 respectively.

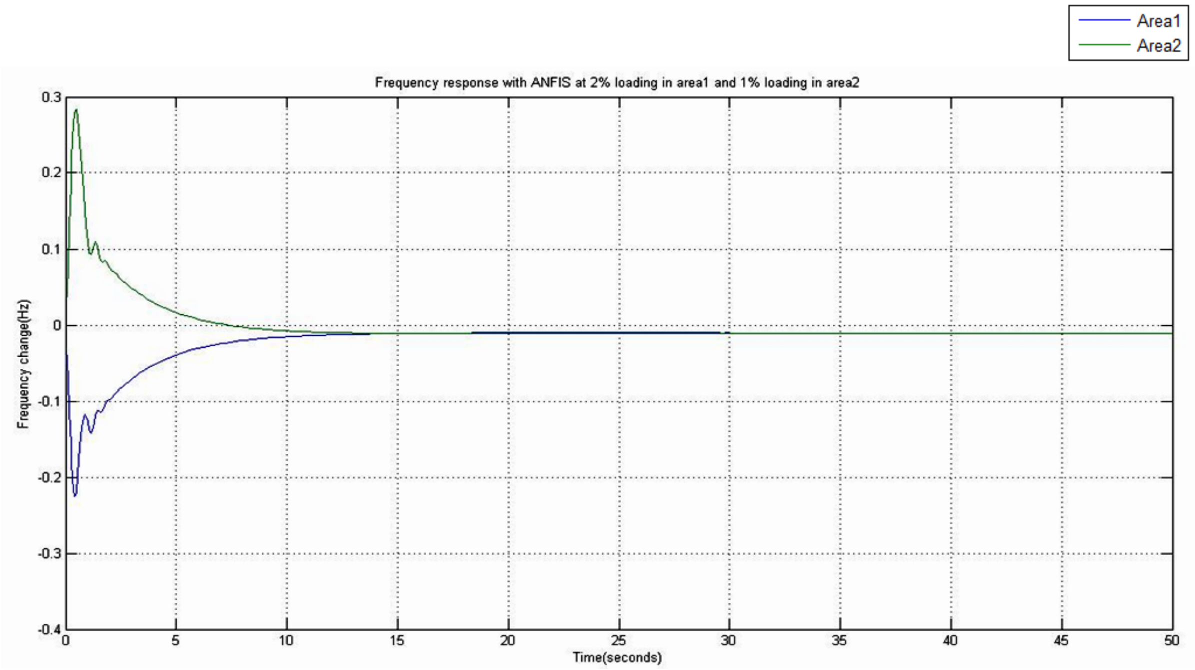

Figure26: Frequency response with ANFIS at given loading .

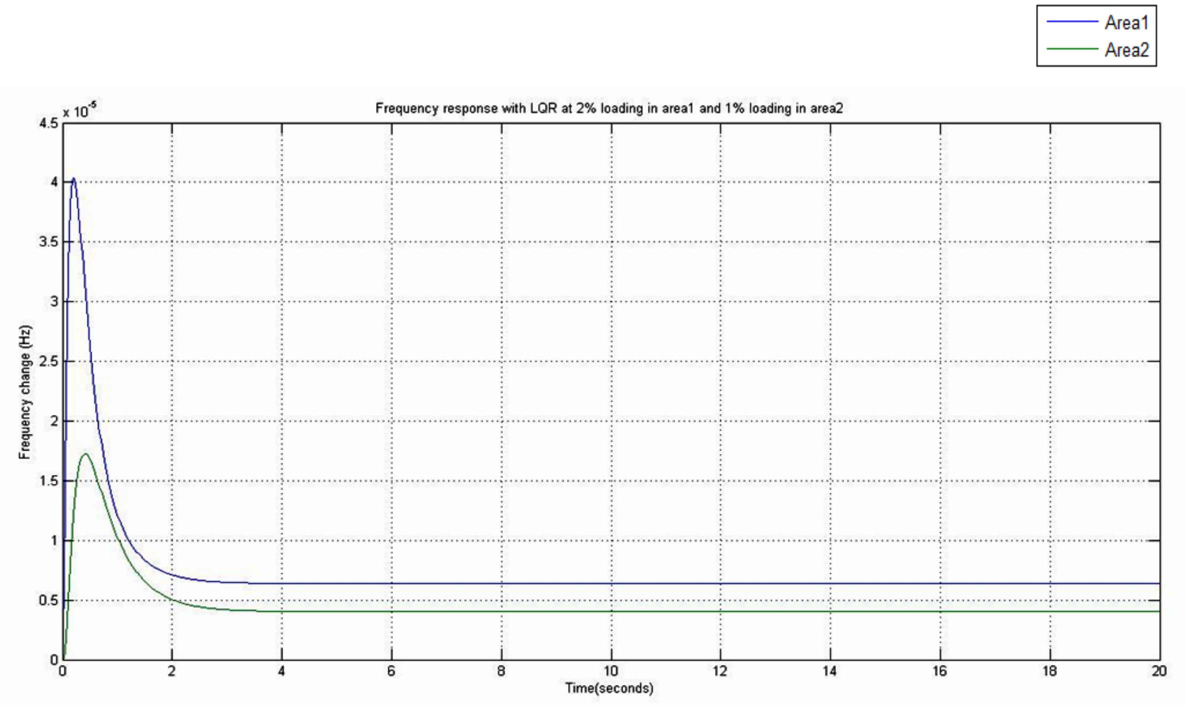

Figure 27: Frequency response with LQR at 2% loading in area1 and 1% loading in area2**.**

Table 5: Comparison of parameters for three controllers at 2% loading in area1 amd 1% loading in area2.

Controllers	Maximum overshoot (Hz)		Maximum undershoot (Hz)		Settling time (seconds)	
	Area1	Area2	Area1	Area2	Area1	Area2
Fuzzy-PI	-	0.22	-0.7	-0.12	10	10
ANFIS	-	0.28	-0.23	-	9	9
LQR	4.1×10^{-5}	1.7×10^{-5}	-	-	2.3	2.3

Discussion

From the above figure (25-27) and table-5, it can be concluded that the response of LQR is best than the other two controllers as the settling time and the overshoot are reduced. However, ANFIS is better than Fuzzy-PI controller.

Case4 Frequency response of hybrid power system at 3% loading

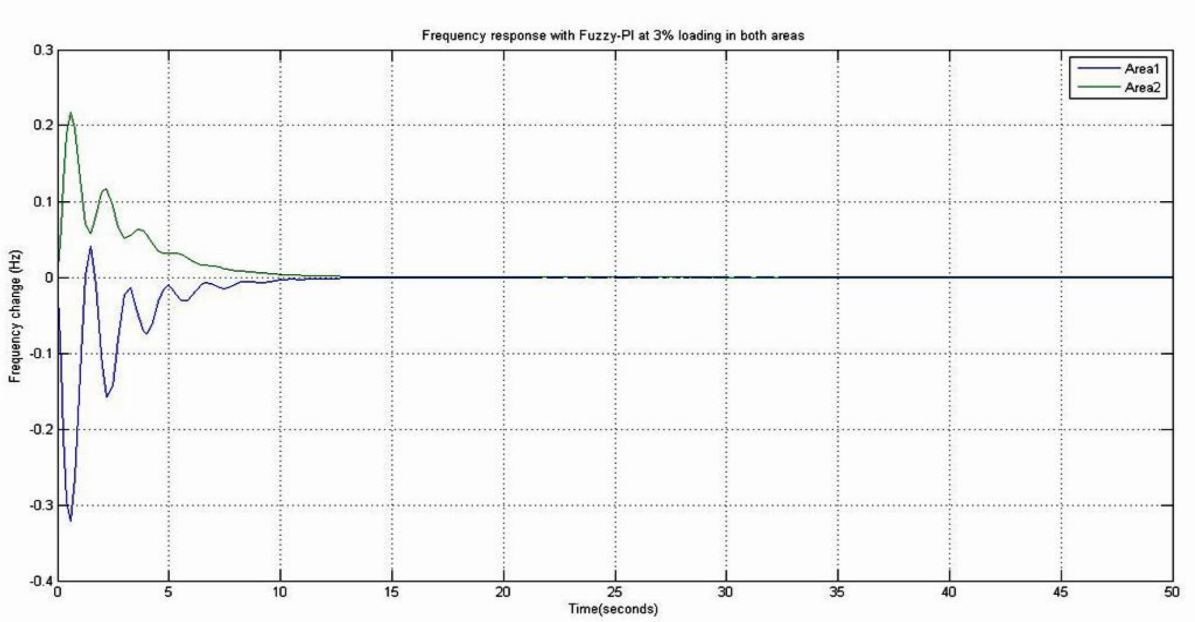

Figure28: Frequency response with Fuzzy-PI controller at 3% loading.

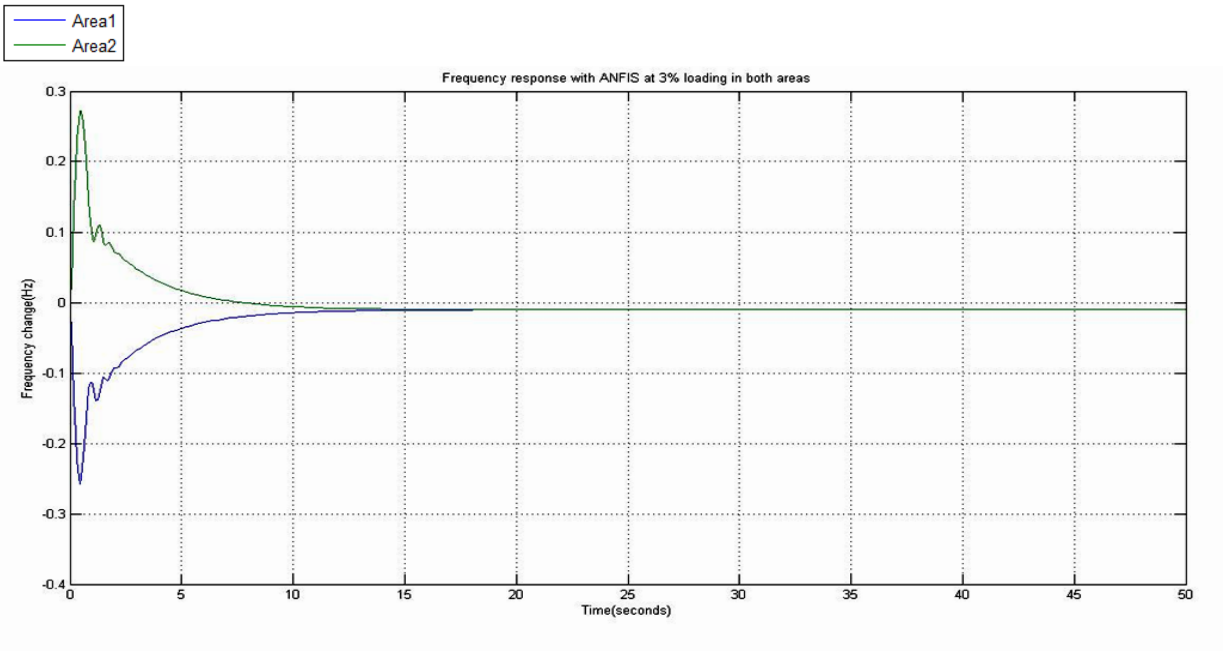

Figure29: Frequency response with ANFIS at 3% loading

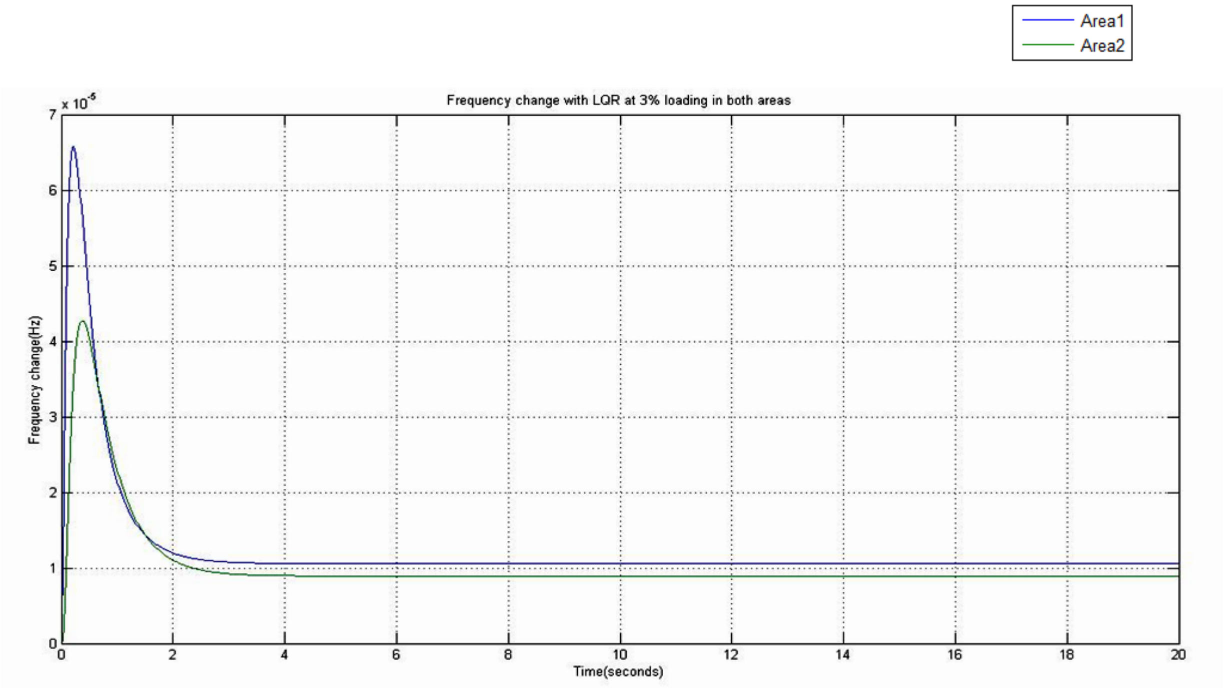

Figure 30: Frequency response with LQR at 3% loading in both areas.

Table 6: Comparison of parameters for three controllers at 3% loading

Controllers	Maximum overshoot (Hz)		Maximum undershoot (Hz)		Settling time (seconds)	
	Area1	Area2	Area1	Area2	Area1	Area2
Fuzzy-PI	-	0.21	-0.32	-	9	9
ANFIS	-	0.27	-0.25	-	8.5	8.5
LQR	6.5×10^{-5}	4.2×10^{-5}	-	-	2.2	2.2

Discussion

The simulation results are shown in figure (28-30) and table-6 depict the response of the three controllers. ANFIS shows the better performance than the fuzzy-PI controller as the settling time by ANFIS is lesser than fuzzy-PI controller. But LQR shows best response than the other two controllers as the overshoot and settling time by LQR is drastically reduced as the loading increases.

4.4 RESULTS

Af =

$$\begin{matrix}
-5 & 0 & 0 & 0 & 0 & 0 & -0.08 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -5 & 0 & 0 & 0 & 0 & 0.08 & 0 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.25 & 0 & 0 & 0 & -0.08 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -0.25 & 0 & 0 & 0.08 & 0 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -0.25 & 0 & -0.08 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -0.25 & 0.08 & 0 & -2.55 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 6 & -6 & 0 & 0 & 0 & 0 & 0 & 0 \\
8.2025 & 1.4080 & 33.8571 & 9.0460 & 33.8590 & 9.0646 & -49.3455 & -89.688 & 2.1720 & 20.4976 & 5.1140 & 33.8590 & 9.0646 & 2.8971 & 0.3482 \\
1.4208 & 8.1433 & 9.2704 & 33.8605 & 9.2710 & 33.8625 & 49.0112 & 2.1720 & -89.8263 & 4.7843 & 21.8094 & 9.2710 & 33.8625 & 0.3331 & 3.0155 \\
0 & 0 & 0 & 0 & 0 & 0 & -0.08 & -5.0460 & 0 & -3.333 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.08 & 0 & -5.4060 & 0 & -3.333 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -0.08 & -2.55 & 0 & 0 & 0 & -0.25 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.08 & 0 & -2.55 & 0 & 0 & 0 & -0.25 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.333 & 0 & 0 & 0 & -12.5 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.333 & 0 & 0 & 0 & -12.5
\end{matrix}$$

K=

$$\begin{matrix}
13.2025 & 1.4080 & 34.1071 & 9.0640 & 33.6090 & 9.0646 & -49.2655 & -89.6389 & 2.1720 & 20.4976 & 5.1140 & 33.6090 & 9.0646 & -9.6029 & 0.3482 \\
1.4208 & 13.1433 & 9.2704 & 34.1105 & 9.2710 & 33.6125 & 48.9312 & 2.1720 & -89.7763 & 4.7843 & 21.8094 & 9.2710 & 33.6125 & 0.3331 & -9.4845
\end{matrix}$$

p =

$$\begin{matrix}
0.9934 & -0.0035 & -0.0828 & -0.0350 & -0.0835 & -0.0350 & 0.0874 & -0.0198 & -0.0021 & -0.0345 & -0.0134 & -0.0835 & -0.0350 & -0.0074 & -0.0006 \\
-0.0035 & 0.9935 & -0.0352 & -0.0821 & -0.0352 & -0.0828 & -0.0857 & -0.0021 & -0.0197 & -0.0124 & -0.0363 & -0.0352 & -0.0828 & -0.0006 & -0.0075 \\
-0.0828 & -0.0352 & 16.3034 & -1.8624 & -3.6971 & -1.8625 & 2.7254 & -0.0512 & -0.0139 & -0.3205 & -0.1615 & -3.6971 & 1.8625 & -0.0123 & -0.0047 \\
-0.0350 & -0.0821 & -1.8624 & 16.3141 & -1.8625 & -3.6865 & -2.7008 & -0.0136 & -0.0512 & -0.1497 & -0.3404 & -1.8625 & -3.3865 & -0.0044 & -0.0128 \\
-0.0835 & -0.0352 & -3.6971 & -1.8625 & 16.3030 & -1.8626 & 2.7256 & -0.0504 & -0.0139 & -0.3199 & -0.1615 & -3.6970 & -1.8626 & -0.0115 & -0.0047 \\
-0.0350 & -0.0828 & -1.8625 & -3.6865 & -1.8626 & 16.3137 & -2.7009 & -0.0136 & -0.0512 & -0.3199 & -0.1615 & -3.6970 & -1.8626 & -0.0044 & -0.0120 \\
0.0874 & -0.0857 & 2.7254 & -2.7008 & 2.7256 & -2.7009 & 4.9295 & 0.0739 & -0.0734 & 0.3405 & -0.3597 & 2.7256 & -2.7009 & 0.0147 & -0.0152 \\
-0.0198 & -0.0021 & -0.0512 & -0.0136 & -0.0504 & -0.0136 & 4.9295 & 0.1345 & -0.0033 & -0.0307 & -0.0077 & -0.0504 & -0.0136 & 0.0144 & -0.0005 \\
-0.0021 & -0.0197 & -0.0139 & -0.0512 & -0.0139 & -0.0504 & -0.0734 & -0.0033 & 0.1347 & -0.0072 & -0.0327 & -0.00139 & -0.0504 & -0.0005 & -0.0142 \\
-0.0345 & -0.0124 & -0.3205 & -0.1497 & -0.3199 & -0.1497 & 0.3405 & -0.0307 & -0.0072 & 1.4807 & -0.0492 & -0.3199 & -0.1497 & 0.0803 & -0.0021 \\
-0.0134 & -0.0363 & -0.1615 & -0.3404 & -0.1615 & -0.3398 & -0.3597 & -0.0077 & -0.0327 & -0.0492 & 1.4669 & -0.1615 & -0.3398 & -0.0021 & 0.0797 \\
-0.0835 & -0.0352 & -3.6971 & -1.8625 & -3.6970 & -1.8626 & 2.7256 & -0.0504 & -0.0139 & -0.3199 & -0.1615 & 16.3030 & -1.8626 & -0.0115 & -0.0047 \\
-0.0350 & -0.0828 & -1.8625 & -3.6865 & -1.8626 & -3.6863 & -2.7009 & -0.0136 & -0.0504 & -0.1497 & -0.3398 & -1.8626 & 16.3137 & -0.0044 & -0.0120 \\
-0.0074 & -0.0006 & -0.0123 & -0.0044 & -0.0115 & -0.0044 & 0.0147 & 0.0144 & -0.0005 & 0.0803 & -0.0021 & -0.0115 & -0.0044 & 0.4089 & -0.0001 \\
-0.0006 & -0.0075 & -0.0047 & -0.0128 & -0.0047 & -0.0120 & -0.0152 & -0.0005 & 0.0142 & -0.0021 & 0.0797 & -0.0047 & -0.0120 & -0.0001 & 0.4088
\end{matrix}$$

4.5 Discussion

Simulation was executed by employing the proposed Fuzzy-PI, ANFIS based Neuro-Fuzzy controller and linear quadratic regulator to the hybrid power system integrating the renewable energy sources. All the implementation criteria for example settling time, maximum overshoot, and maximum undershoot are measured for all the cases. Frequency deviation was measured at different load settings to get the ideal performance of hybrid power system. The same outline parameters given in Table (3 to 6) were exploited for the three controllers for the comparison. Simulation was done for 1 % ,2% and 3% step increment in the load power (∆PL=0.01 p.u. ,0.02 p.u., furthermore 0.03 p.u . The overshoot, undershoot and setting time of projected LQR was lower than those of Fuzzy-PI controller and ANFIS based neuro fuzzy controller. The steady state error or frequency change in all controllers was in the acceptable range.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

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 LQR shows better performance in the frequency regulation as the non-linearities are increased in the hybrid system. The settling time and overshoot by LQR is very less as compared to the intelligent and conventional controllers. One important point it can be noticed that the settling time by LQR reduces with the load increase which cannot achieved by other two controllers. Therefore by means of LQR function, the steadiness of the supply frequency is acquired which has been demonstrated as the efficient regulator in this projected work.

5.2 Future scope

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.

PUBLICATIONS

[1] Ramanpreet kaur and Surya Prakash, “Load frequency control of hybrid power system using intelligent controllers,” 7th International Conference on Recent Development in Engineering Science, Humanities and Management (ESHM-17), pp.227-289, June 2017.

REFERENCES

[1] L. Mengyan et al.,“Studies on the Tie-line Power Control with a Large Scale Wind Power,” International Conference on Electronics, Communications and Control, Ningbo, pp. 2302-2305, September 9- 11, 2011.

[2] I. Ngamroo, “Robust SMES Controller Design based on Inverse Additive Perturbation for Stabilization of Interconnected Power Systems with Wind Farms,” Energy Conversion and Management, Vol. 51, pp. 459-464, 2010.

[3] R. J. Abraham, D. Das and Amit Patra “Automatic Generation Control of an Interconnected Power System with Capacitive Energy Storage,” International Journal of Electrical and Electronics Engineering, Vol. 4, No. 5, pp. 351-357, 2010.

[4] R. Oba et al., “Suppression of Short Term Disturbances from Renewable Resources by Load Frequency Control Considering Different Characteristics of Power Plants,” IEEE Power Engineering Society General Meeting, Calgary, pp. 1-7, July 26-30, 2009.

[5] M. Datta, T. Senjyu, A. Yona and T. Funabashi, “Control of MWclass PV Generation to Reduce Frequency and Tie-line PowerFluctuations in Three Control Area Power System,” Proceedings of the 8th International Conference on Power Electronics, Korea, pp. 894-901, May/June 30-03, 2011.

[6] M. Rashed, A. Elmitwally and S. Kaddah, “New Control Approach for a PV-diesel Autonomous Power System,” Electrical Power Systems Research, pp. 1-8, 2007.

[7] E. A. Feigenbaum, B. G. Buchanan and J. Lederberg, “On generality and problem solving: A case study using the DENDRAL program,” Machine Intelligence 6, Edinburgh University Press, Edinburgh, pp. 165-190, 1971.

[8] J. W. Dixon, J. M. Contardo, and L. A. Moran, ”A Fuzzy controlled active front-end rectifier with current harmonic filtering characteristics and minimum sensing variable,” IEEE Transaction on Power Electronics, vol. 14, no. 4, pp. 724-729, July 1999.

[9] M. Rukonuzzaman, M. Nakaoka, “Fuzzy logic current controller for three-phase voltage source PWM-inverters”, Industry Application Conference, Vol. 2, pp. 1163 - 1169, 8-12 October 2000.

[10] B. Anand and A. Ebenezer Jeyakumar “Load Frequency Control with Fuzzy Logic Controller Considering Non-Linearities and Boiler Dynamics” ICGST-ACSE Journal, ISSN 1687-4811, Volume 8, Issue III, January 2009

[11] Ertugˇrul Cam, “Application of fuzzy logic for load frequency control of hydroelectrical power plants”, Energy Conversion and Management 48 (2007) 1281–1288.

[12] Yamashika, K., and Miyagi, H., “Multivariable self-Tuning Regulator for Load Frequency Control System with Interaction of Voltage on Load Demand”, IEEE Proceedings-D, Vol. 138, NO. 2, March 1999.

[13] Aldeen M., “A Fresh Approach to the LQR Problems with Application to Power Systems”, Proc. of Int. Power Engineering Conf., Singapore Vol. 1, 1993, Pp. 374 – 379.

[14] Pan, C. I., and Liaw L.M. “AN Adaptive Controller for Power System Load – Frequency Control”, IEEE on Power System. Vol. 4, No. 1, Feb. 1989, Pp 122 –128.

[15] Dyukanovic, M., et.al “Two-Area Load Frequency Control with Neural Networks,: Proc. 1993. North American Power Symposium, Pp. 161 – 169.

[16] Brich, A. P, et.al, “Neural Network Assisted Load Frequency Control”, 28th University Power Engineering Conf. Proc. Vol. 2, 1993, Pp. 518 – 521.

[17] Hsu, Y., and Cheng, C., “Load Frequency Control using Fuzzy Logic,” Int. Conf. on High Technology in the Power Industry, 1991, Pp. 32 – 38.

[18] Indulka, C. S., and Raj, B., “Application of Fuzzy Controller to Automatic Generation Control,” Electric Machines and Power Systems, Vol. 23, No. 2, Mar-Apr. 1995, pp. 209 –

[19]H. Yang, Z. Wei, and L. Chengzh, “Optimal design and technoeconomic analysis of a Hybrid solar-wind power generation system,” Applied Energy, vol. 86, pp. 163-169, Feb. 2009.

[20] S. Dihrab, and K. Sopian, “Electricity generation of hybrid PV/wind systems in Iraq,” Renewable Energy, vol. 35, pp. 1303-1307, Jun.2010.220.

[21] J.P. Reichling, and F.A. Kulacki, “Utility scale hybrid wind-solar thermal electrical generation: a case study for Minnesota,” Energy, vol. 33, pp.626-638, Apr. 2008.

[22] O. Ekren, B.Y. Ekren, and B. Ozerdem, “Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage – A case study” Applied Energy, vol.86, pp. 1043-1054, July-August 2009.

[23] S.K. Kim, J.H. Jeon, C.H. Cho, E.S. Kim, and J.B. Ahn, “Modeling and simulation of a grid-connected PV generation system for electromagnetic transient analysis, ”Solar Energy, vol.83, pp. 664- 678, May 2009.

[24] H.L Tsai, “Insolation-oriented model of photovoltaic module using Matlab/Simulink,” Solar Energy, vol. 84, pp. 1318-1326, July 2010.

[25] J.A. Gow, and C.D. Manning, “Development of a photovoltaic array model for use in power-electronics simulation studies,” IEEE Proceedings- Electric Power Applications, vol. 146, pp. 193-199, Mar. 1999.

[26] M.J. Khan, and M.T. Iqbal, “Dynamic modeling and simulation of a small wind fuel cell hybrid energy system,” Renewable Energy, vol. 30, pp. 421-439, Mar. 2005.

[27] T.S Bhatti, A.A.F. Al–Ademi and N.K. Bansal, “Load Frequency Control of Isolated Wind Diesel Hybrid Power System,” Energy Conver.Mgnt Vol. 38.No. 9. pp. 829-837,1997.

[28] Soundarrajan. A et al, “Intelligent controllers for Automatic Generation Control”, Proceedings of The International conference on Robotics, Vision, Information and signal processing, Malaysia, 2003, 307-311.

[29]. B. Anand and A. Ebenezer Jeyakumar “Load Frequency Control with Fuzzy Logic Controller Considering Non-Linearities and Boiler Dynamics” ICGST-ACSE Journal, ISSN 1687-4811, Volume 8, Issue III, January 2009.

[30] Ertug˘rul Cam, “Application of fuzzy logic for load frequency control of hydroelectrical power plants”, Energy Conversion and Management 48 (2007) 1281–1288 Load Frequency Control of Hybrid System Using Industrial Controller and 203 Implement Fuzzy Controller Practically Using PLC

[31] Ertugrul Cam ,IlhanKocaarslan, “Load frequency control in two area power systems using fuzzy logic controller”, Energy Conversion and Management 46 (2005) 233–243

[32] A. Soundarrajan, S. Sumathi, “Effect of Non-linearities in Fuzzy Based Load Frequency Control”, International Journal of Electronic Engineering Research Volume 1 Number 1 (2009) pp. 37–51.

[33] C. Chokpanyasuwan, S. Pothiya, S. Anantasate, W. Pattaraprakorn, and P. Bhasaputra ,”Robust Fuzzy logic-PID Controller for Wind-Diesel Power System using Particle Swarm Optimization”,GMSARN International Conference on Sustainable Development, Nov. 2008

[34] R. Dhanalakshmi, S. Palaniswami, “Load Frequency Control of Wind Diesel Hydro Hybrid Power System Using Conventional PI Controller”, European Journal of Scientific Research ,ISSN 1450-216X Vol.60 No.4 (2011), pp.630-641

[35] Bhatti T S, Al–Ademi A A F et al,”Load Frequency control of isolated wind-diesel-micro hydro hybrid power systems. Elsevier-Energy,. (1997), 22(5): 461-470.

[36] Gayadhar Panda, Sidhartha Panda and C. Ardil, “Hybrid Neuro Fuzzy Approach for Automatic Generation Control of Two–Area Interconnected Power System”, International Journal of Computational Intelligence, Vol. 5,No. 1, pp. 80-84, 2009.

[37] C.SrinivasaRao , “Adaptive Neuro-Fuzzy Based Inference System for Load Frequency Control ofHydrothermal System under Deregulated Environment” International Journal of Engineering Science and Technology Vol. 2(12), 2010, 6954-6962.

[38] Ertugrul Cam ,Ilhan Kocaarslan, “Load frequency control in two area power systems using fuzzy logic controller”, Energy Conversion and Management 46 (2005) 233–243

[39] A. Soundarrajan, S. Sumathi, “Effect of Non-linearities in Fuzzy Based Load Frequency Control”, International Journal of Electronic Engineering Research Volume 1 Number 1 (2009) pp. 37–51.

[40] Ross T J , “Fuzzy logic with Engineering Applications”, second edition, John wiley&sons Ltd. (2004)

[41] J.R. Jang, “ANFIS: Adaptive-network-Based Fuzzy Inference System”,IEEE Trans. On Systems, Man and Cybernetics, Vol. 23, No.3, May.1993, pp.665-685.

APPENDIX

The Matlab code for the LQR at 1% loading in both the areas for the hybrid power system

```
A =

[-5  0   0    0    0   0   -0.08   -2.55   0    0   0    0   0    0   0;

 0  -5   0    0    0   0    0.08     0   -2.55  0   0    0   0    0   0;

 0   0 -0.25  0    0   0   -0.08   -2.55   0    0   0    0   0    0   0;

 0   0   0  -0.25  0   0    0.08     0   -2.55  0   0    0   0    0   0;

 0   0   0    0 -0.25  0   -0.08   -2.55   0    0   0    0   0    0   0;

 0   0   0    0    0 -0.25  0.08     0  -2.55   0   0    0   0    0   0;

 0   0   0    0    0   0     0       6    -6    0   0    0   0    0   0;

-5   0 -0.25  0  0.25  0   -0.08   -0.05   0    0   0  0.25  0   12.5 0;

 0  -5   0 -0.25   0 0.25   0.08     0   -0.05  0   0    0  0.25   0  12.5;

 0   0   0    0    0   0   -0.08  -5.046   0 -3.333 0    0    0    0    0;

 0   0   0    0    0   0    0.08     0  -5.406  0 -3.333 0    0    0    0;

 0   0   0    0    0   0   -0.08 -2.55    0     0   0  -0.25  0    0    0;

 0   0   0    0    0   0    0.08    0    -2.55   0   0     0 -0.25  0    0;

 0   0   0    0    0   0     0      0     0  3.333  0     0   0  -12.5 0;

 0   0   0    0    0   0     0      0     0     0 3.333   0   0    0 -
12.5];

B =[0 0;

    0 0;

    0 0;

    0 0;

    0 0;

    0 0;
```

```
     0 0;

    -1 0;

    0 -1;

    0 0;

    0 0;

    0 0;

    0 0;

    0 0;

    0 0];

C = [0  0  0  0  0  0  0  6  0  0  0  0  0  0  0;

0 0 0 0 0 0 0 0 6 0 0 0 0 0 0];

D = [0 0;

0 0];

co = ctrb(A,B);

Controllability = rank(co);

q= [10 10 10 10 10 10 10 10 10 10 10 10 10 10 10];

Q= diag(q);

R=0.0015;

[K,p]=lqr2(A,B,Q,R);

Af=A-B*K;

PL= [0.01;0.01];

BPL =B*PL;

t = 0 : 0.02 : 20;

[y,x] = step(Af,BPL,C,D,1,t);

plot(t,x(:,1),t,x(:,15)),grid;

roots = eig(Af);
```