Load Frequency Control of Hybrid Power System with LQR based Controller

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Abstract

In an integrated electrical system, there is a frequency deviation of each region due to some small unexpected load changes in an area as well as continuous power changes along the tie line. The most important thing for controlling the load frequency (LFC) is to maintain the actual frequency and output power preferred in the electrical system and to control the alteration in tie line power among the interconnected areas. Thus, the LFC system primarily includes a control system suitable for the power system, which can bring all fields and power frequencies in the tie line back to their desired point value after switching loads. In the present work, LFC integrated power systems with distributed power have been developed. Because of the renewable energy resources it can take to get enough energy. Hence, it is possible to include renewable energy sources because of the power efficiency but higher frequency variability in the hybrid system. Two zones taken in each region have wind turbines, photovoltaic (PV) generation systems, fuel cells, battery storage systems and thermal power generation systems with aqua electrolyser. LFC requires fast and accurate controllers to maintain frequency at your preferred rate. This paper is related to the Artificial Intelligence Technique (Fuzzy PI and Neuro-Fuzzy Approach) and LQR based controller for LFC. The LQR was then performed on a hybrid Power system which proved to be the best controller. The performance of three controllers is compared to the custom parameter that maximum overshoot, settling time and maximum undershoot.

Keywords
ACE (Area Control Error), ANFIS (Adaptive neuro-fuzzy inference system), FLC (Fuzzy logic controller), LFC (Load frequency control), LQE (Linear quadratic regulator), PI (Proportional Integral)
Abbreviations: AGC, Automatic Generation Control ;BESS, battery energy storage Station; CE, capacitive energy; PV,photovoltaic ; WT, wind turbine.

1. INTRODUCTION

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 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 manage 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 varies 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. Feigen baum 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 modelling [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.

2. 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 adjust 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 evaluate the performance of three controllers in terms of settling time, overshoot and undershoot.

3. MODELING OF SYSTEMS

In this paper 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 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 employed to the optimum controllers for the Load frequency control. In this paper 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.

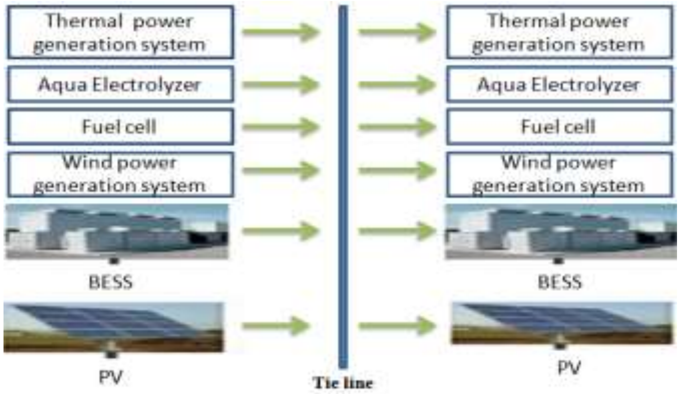

Fig. 1. Layout of the hybrid power system

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.

3.1 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.

3.1.1 Turbine 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.

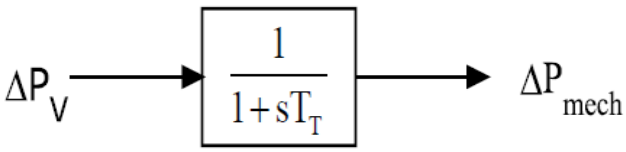

Fig. 2. Transfer function of turbine

Where, T_T is time constant for the turbine model

3.1.2 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

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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:

$$W_{kin} = W_{kin}^0 \left(\frac{f}{f^0}\right)^2 \quad (1)$$

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 constant.

$$B = \frac{\partial P_D}{\partial f} \quad (2)$$

Write the power balance equation

$$\Delta P_T = \Delta P_D + \frac{d(W_{kin})}{dt} + B\,\Delta f \quad (3)$$

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

By neglecting Δf, the kinetic energy is written as

$$= W_{kin}^0 \left[1 + \frac{2\,\Delta f}{f^0} + \left(\frac{\Delta f}{f^0}\right)^2\right] \approx W_{kin}^0 \left[1 + \frac{2\,\Delta f}{f^0}\right] \quad (4)$$

$$\Delta P_T - \Delta P_D = \frac{2W_{kin}^0}{f^0} \frac{d}{dt} (\Delta f) + B\,\Delta f \quad (5)$$

At specified frequency, the stored kinetic energy is

$W_{kin} = H \times P_r$

Now by dividing equation by P_r

$$\Delta P_T - \Delta P_D = 2\,H \frac{d}{dt} (\Delta f) + B\,\Delta f \quad (6)$$

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

Equation (6) can also be written as

$$\Delta P_T - \Delta P_D = 2\,H \frac{d}{dt} \left(\frac{\Delta f}{f^0}\right) + B\,f^0 \left(\frac{\Delta f}{f^0}\right) \quad (7)$$

Laplace transform of equation (6) gives

$$\Delta P_T(s) - \Delta P_D(s) = \frac{2H}{f^0} s\Delta f(s) + B\,\Delta f(s) \quad (8)$$

$$\Longrightarrow \Delta f(s) = G_p(s)[\Delta P_T(s) - \Delta P_D(s)] \quad (9)$$

Where

$$G_p(s) = \frac{K_p}{1 + s\,T_p} \quad (10)$$

$$T_p = \frac{2\,H}{f^0 B} \quad (11)$$

$$K_p = \frac{1}{B} \quad (12)$$

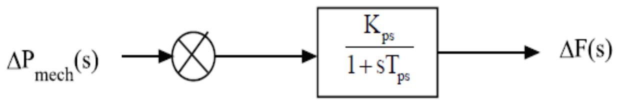

Fig. 3. Transfer function model of generator -load

3.1.3 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.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\,\Delta f \qquad (13)$$

$$\frac{\Delta P_v}{\Delta P_g} = \frac{1}{1+sT_g} \qquad (14)$$

3.1.4 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); 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

$$G_{WTG}\,(s) = \frac{K_{WTG}}{1+s\,T_{WTG}} \qquad (15)$$

3.1.5 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:

$$G_{AE}(s) = \frac{K_{AE}}{1+s\,T_{AE}} \qquad (16)$$

3.1.6 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:

$$\mathrm{G_{FC}(s)} = \frac{\mathrm{K_{FC}}}{1+\mathrm{s\,T_{FC}}} \qquad (17)$$

3.1.7 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:

$$G_{BESS}(s) = \frac{K_{BESS}}{1+s\,T_{BESS}} \qquad (18)$$

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3.1.8 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

$$I_A = N_P I_{SC} - N_P I_0 \, exp\left(\left[\frac{V_A + I_A R_S}{n N_S V_T}\right] - 1\right) \quad (19)$$

Where

I_0 = Diode saturation current (A)

R_S = Series Resistance (Ω)

I_A = PV Array output current (A)

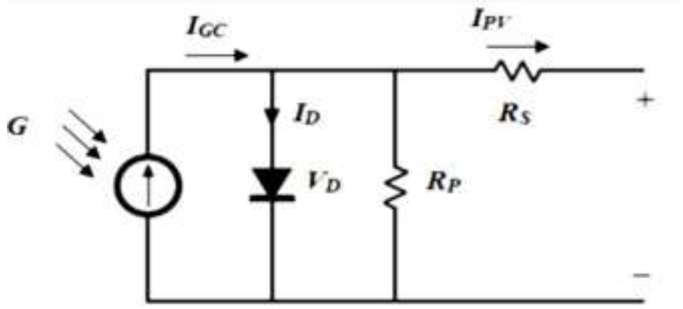
n = Diode ideal constant

I_{SC} = PV module short circuit current (A)

V_T = PV module thermal potential (V)

V_A = PV array terminal voltage (V)

$$G_{PV}(s) = \frac{K_{PV}}{1 + s\, T_{PV}} \quad (20)$$



3.1.9 Two area interconnected power system

The Tie- lines are used to interconnect two or more power systems. The flow of electrical energy between the two areas is caused by Tie lines. If the load in the area is diverted, the area receives power from another area using a Tie line. Therefore, load frequency control must also control Tie line power exchange errors. Tie line power error is an integral part of the frequency variation between the two regions. Power in the tie line can be expressed mathematically

$$P_{12}^0 = \frac{|V_1^0|\,|V_2^0|}{X} \sin(\delta_1^0 - \delta_2^0) \quad (21)$$

Where

δ_1^0 δ_2^0= power angles of equivalent machines

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

$$\Delta P_{12} = T_{12}\,(\Delta\delta_1 - \Delta\delta_2) \quad (22)$$

Where

The synchronizing coefficient is

$$T_{12} = \frac{|V_1^0|\,|V_2^0|}{X} \cos(\delta_1^0 - \delta_2^0) \quad (23)$$

Frequency deviation Δf is related to reference angle by

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

$$\Delta\delta = 2\pi \int \Delta f \, dt \quad (23)$$

$$\Delta P_{12} = 2\pi T_{12} \left(\int \Delta f_1 - \int \Delta f_2\right) \quad (24)$$

Taking Laplace transform of the above equation

$$\Delta P_{12}(s) = \frac{2\pi T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (25)$$

3.1.10 Area control error

The linear combination of tie line power and frequency errors gives Area control errors. ACE describes the deviation between the generation and load of two fields. The purpose of load frequency control is to reduce the frequency error in both Areas and the tie-line power priority error, which is not a trivial task due to load fluctuations. The frequency error must be kept at zero, and the steady state error in the frequency of the power system is that the tie line power error results in an error in tie line power, which is 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:

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

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

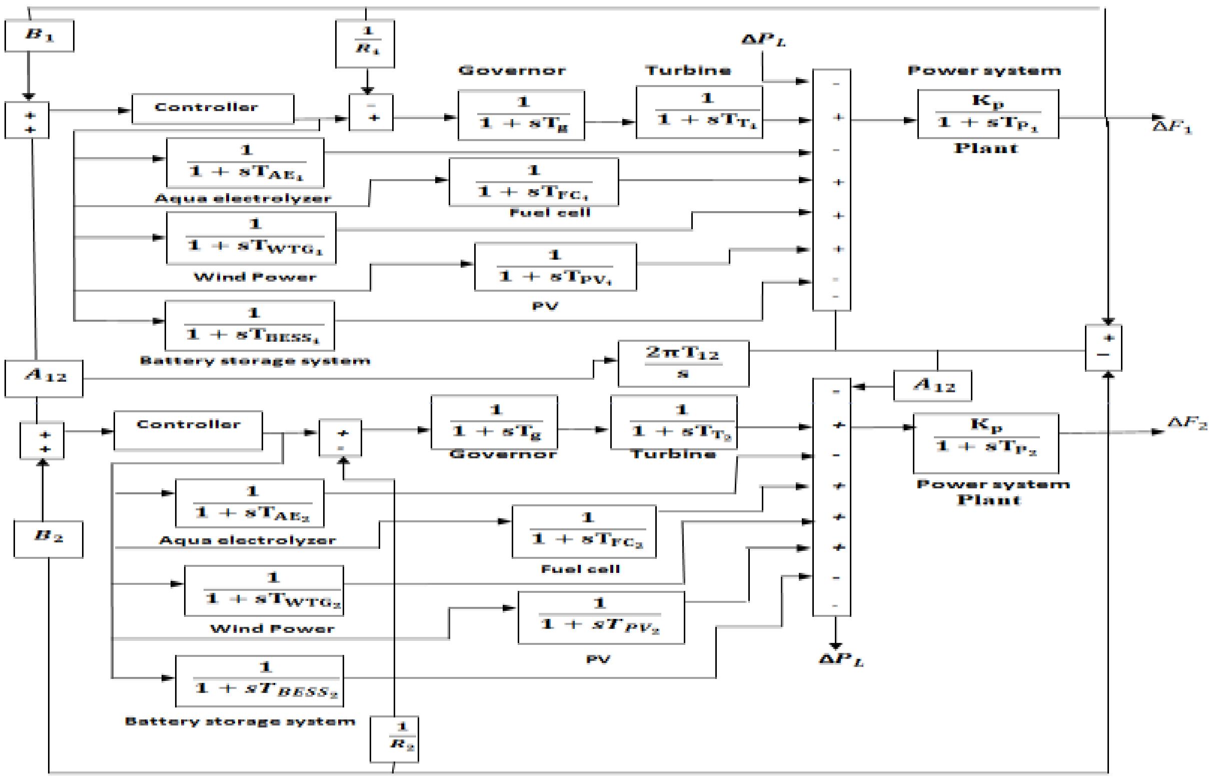


Fig. 5. Block diagram of hybrid power system

4. CONTROL METHODOLOGY

4.1 Automatic controller

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

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

Take the derivative of equation:

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

The main application PI controller is to keep the error to zero at steady state. PI controllers with pre-defined gains are measured under negligible conditions under working conditions. It cannot provide optimal control performance over an infinite range of working conditions. [10]-[13] Fuzzy logic controllers are estimated to solve the load frequency problem.

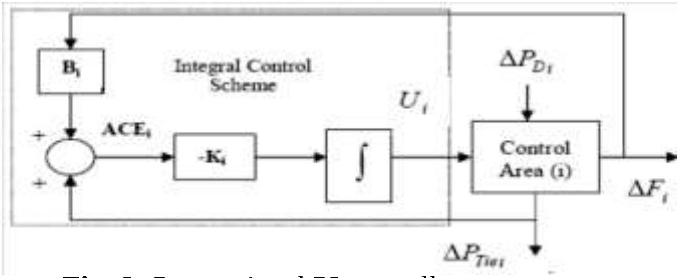


Fig. 6. Conventional PI controller

4.2 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.

4.2.1 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.

4.2.2 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.

4.2.3 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 7. 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 (8, 9, 10 & 11) and Table-1 for the comparison of FLC with the proposed controller.

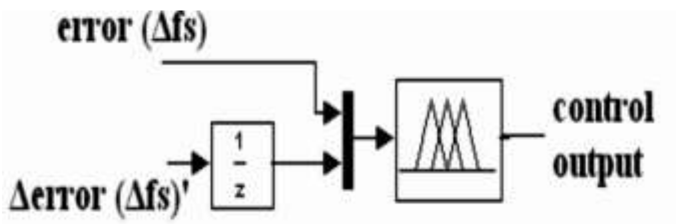


Fig. 7. Block diagram of fuzzy logic controller

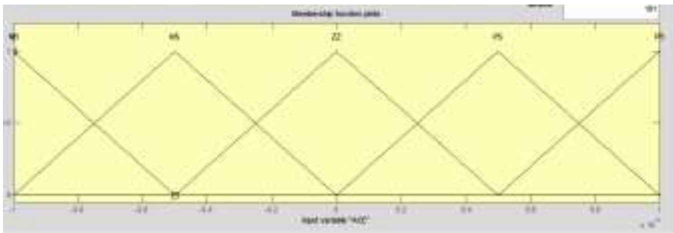


Fig. 8. Membership function of input ACE

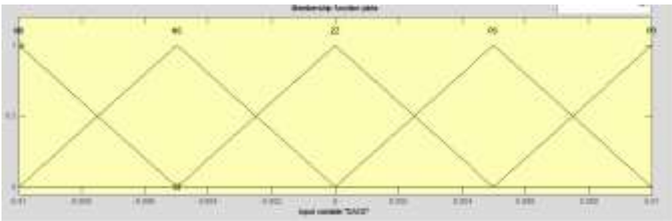


Fig. 9. Membership functions of input DACE

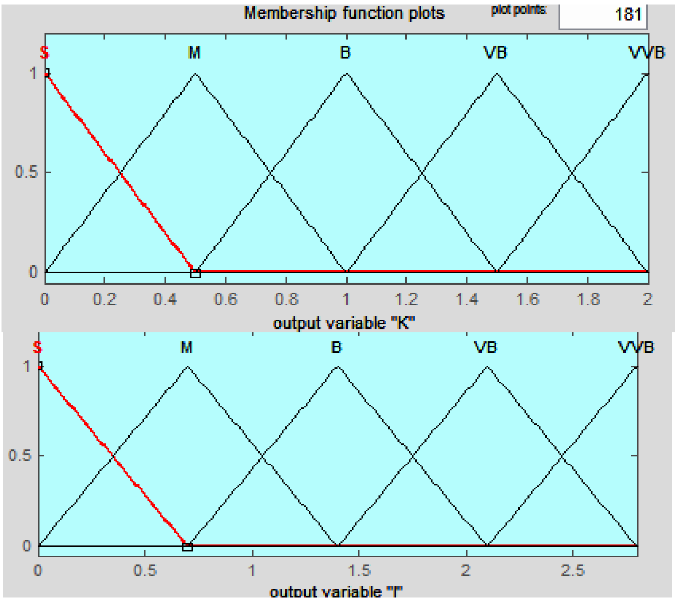


Fig. 11. Membership functions for output I

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

4.3 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.

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.

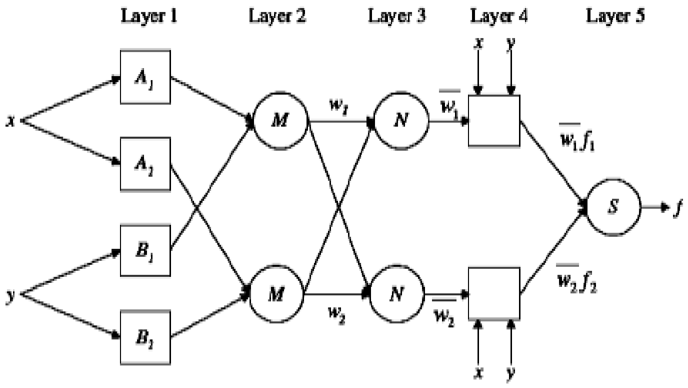


Fig. 13. ANFIS architecture

4.3.1 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.

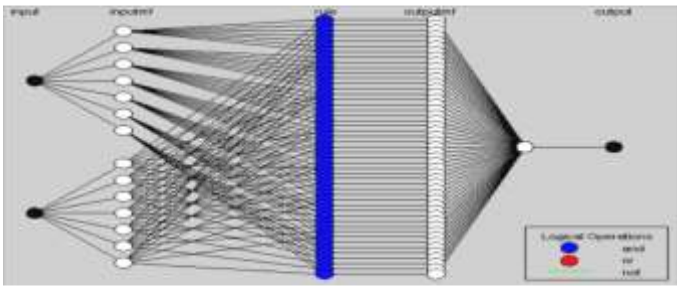


Fig. 14. ANFIS structure for the designed Neuro- Fuzzy controller

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4.4 Linear Quadratic Regulators

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:

$$J = \int_{to}^{tf} (x' Qx + u' Ru)\, dt \qquad (26)$$

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

$$\boldsymbol{x}, \boldsymbol{\lambda}, \boldsymbol{\mu}, \mathbf{t} = \left[\mathbf{x^2Qx} + \mathbf{u^2Ru}\right] + \boldsymbol{\lambda}' \left[\mathbf{Ax} + \mathbf{Bu} - \mathbf{x}'\right]$$

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

$$\frac{\partial L}{\partial \lambda} = AX^* + Bu^* - x'^* = 0 \Rightarrow x'^* = AX^* + Bu^* \qquad (27)$$

$$\frac{\partial L}{\partial \mathbf{u}} = 2Ru^* + \boldsymbol{\lambda}'B = 0 \Longrightarrow u^* = -\frac{1}{2} R^{-1}\boldsymbol{\lambda}'B \qquad (28)$$

$$\frac{\partial L}{\partial \mathbf{x}} = 2Qx'^* + \boldsymbol{\lambda}' + A\boldsymbol{\lambda}' = 0 \Rightarrow \boldsymbol{\lambda}' = -2Qx'^* - A\boldsymbol{\lambda}' \qquad (29)$$

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

$$\lambda' = 2\, p(t)\, x(t) \qquad (30)$$

substitute (equation 30) into (equation 28)

$$u^* = -R^{-1}Bp(t)x(t) \qquad (31)$$

Get the derivative of equ (30)

$$\lambda = 2\,(\mathrm{px}^* + \mathrm{p}^*\mathrm{x}) \qquad (32)$$

Finally equate equation (29) & equation (32)

$$p(t) = -p(t)A - A'p(t) - Q + p(t)BR^{-1}B'p(t) \qquad (33)$$

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 favour 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.

5. SIMULATIONRESULTS AND DISCUSSION

5.1 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.s follows

Consider the Hybrid Power System with these parameters

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}	0.3 s
T_g	0.08 s
T_{p_1}, T_{p_2}	20 s
K_p	120 Hz/p.u
T_{AE_1}, T_{AE_2}	0.2 s
T_{FC_1}, T_{FC_2}	4 s
T_{PV_1}, T_{PV_2}	1.8 s
T_{BESS_1}, T_{BESS_2}	4 s
T_{WTG_1}, T_{WTG_2}	4 s
B_1, B_2	0.425 p.u. MW/Hz
R_1, R_2	2.4 Hz/p.u.
T_{12}	0.0707 p.u.

Where

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

T_g = Time constant for the governor

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

T_{12}= Coefficient for synchronizing

5.2 Frequency response of three controllers at different loading.

5.2.1 Case 1: Frequency response at 1% loading with three controllers

The simulation results are shown in figure (15-19) and the table-3 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.

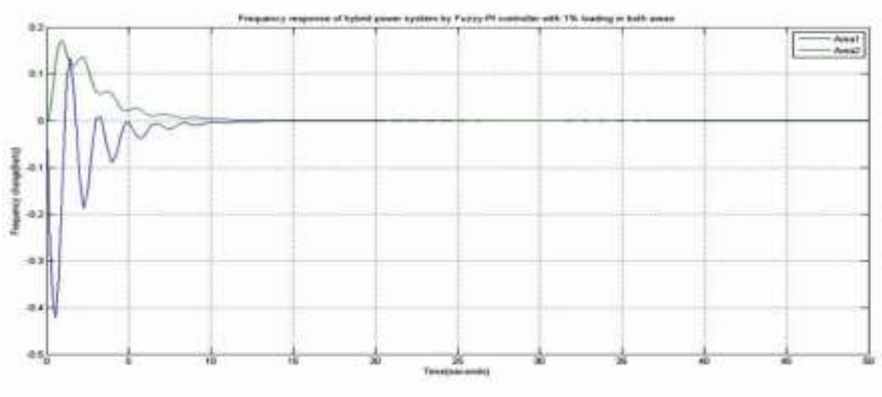

Fig. 15. Frequency response of hybrid power system at 1% loading with Fuzzy-PI controller

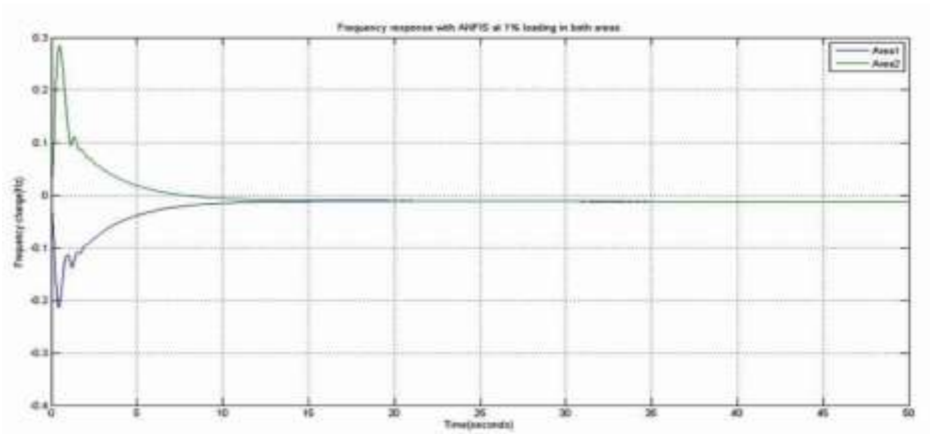

Fig. 16. Frequency response by ANFIS with 1% loading in both areas

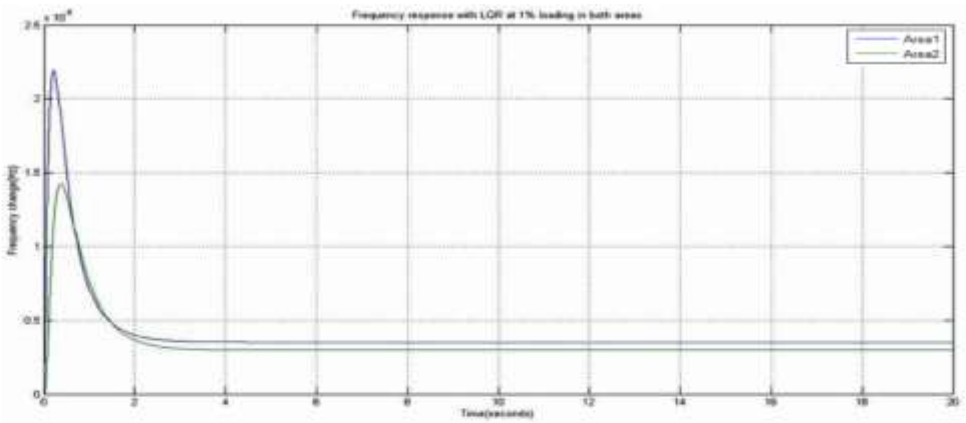

Fig. 17. Frequency response with LQR at 1% loading in both areas

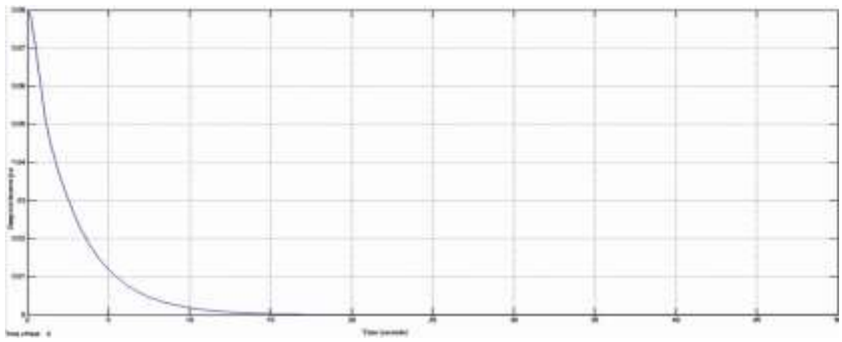

Fig. 18. Change in tie line power (p.u) with Fuzzy-PI controller

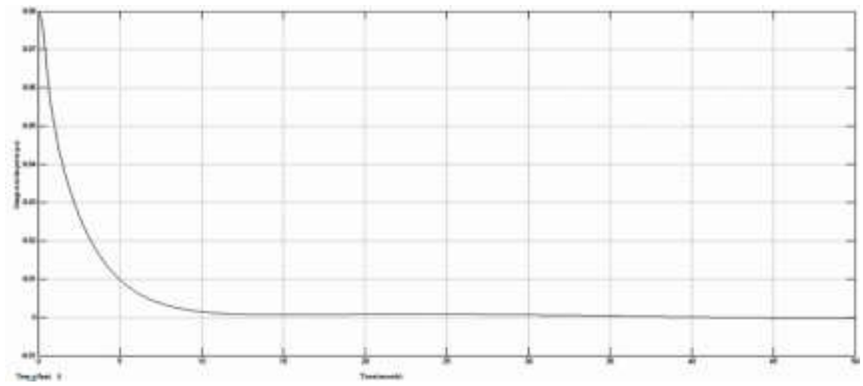

Fig. 19. Change in tie line power (p.u) with ANFIS

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

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

5.2.2 Case 2: Frequency response of hybrid power system at 2% loading with three controllers

The Simulation results shows in figure (20-22) and the table-4 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

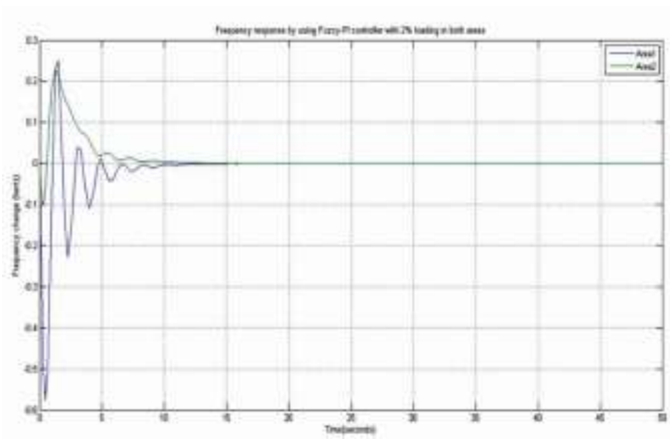

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Fig. 20. Frequency response of hybrid power system with Fuzzy- PI at 2% loading

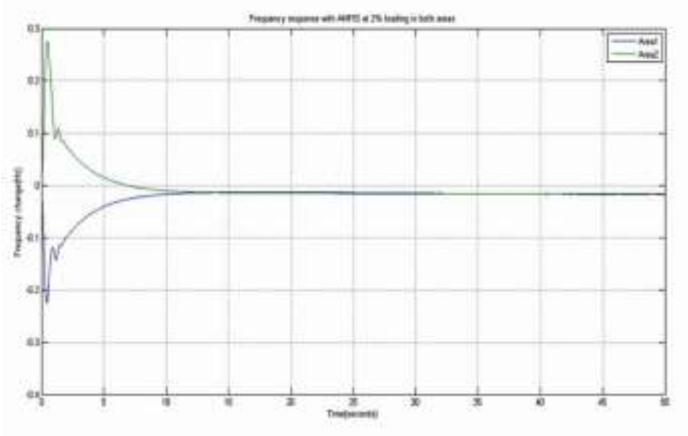

Fig. 21. Frequency response by ANFIS with 2% loading in both areas

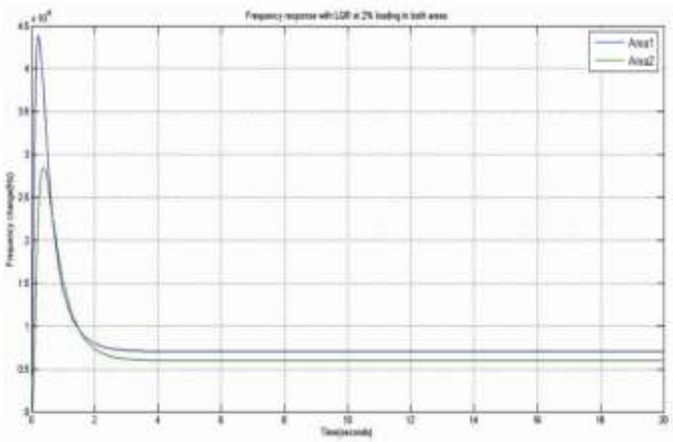

Fig. 22. Frequency response with LQR at 2%loading in both areas

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

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

5.2.3 Case3: Frequency response of hybrid power system at 3% loading

The simulation results are shown in figure (23-25) and table-5 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.

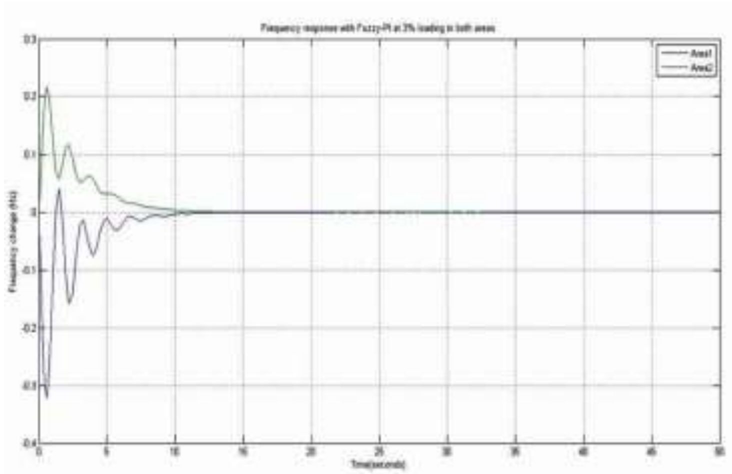

Fig. 23. Frequency response with Fuzzy-PI controller at 3% loading

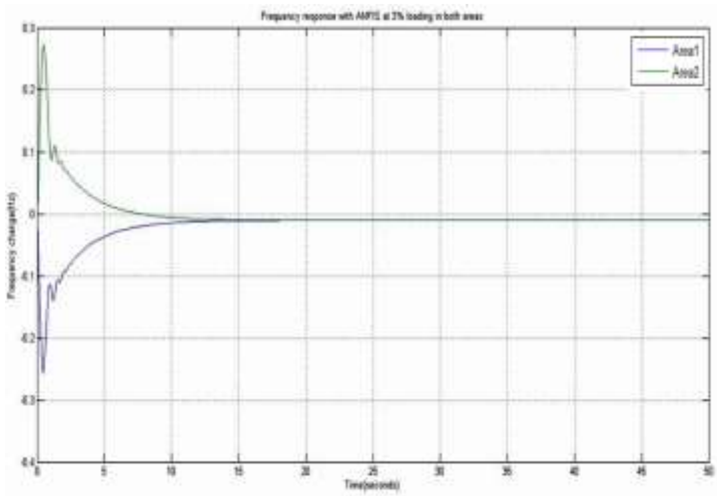

Fig. 24. Frequency response with ANFIS at 3% loading

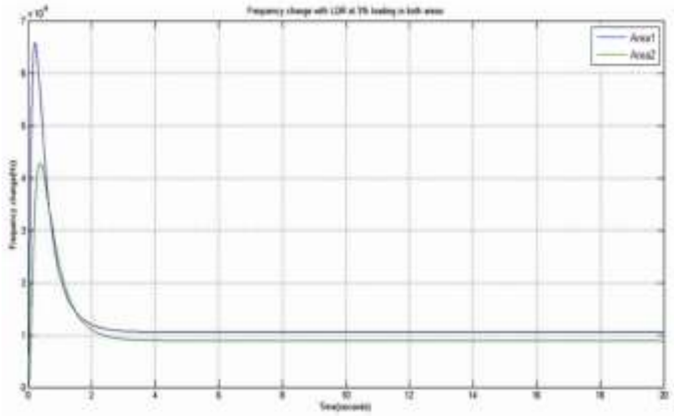

Fig. 25. Frequency response with LQR at 3% loading in both areas

Table 5: Comparison of parameters for three controllers at 3% loading

Controllers	Maximum Undershoot(Hz)		Maximum overshoot (Hz)		Settling time (seconds)	
	Area1	Area2	Area1	Area2	Area1	Area2
Fuzzy-PI	-0.32	-	-	0.22	9	9

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ANFIS	-0.25	-	-	0.28	8.5	8.5
LQR	-	-	6.5×10^{-5}	4.2×10^{-5}	2.2	2.2

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 5) were exploited for the three controllers for the comparison. Simulation was done for 1 % ,2% and 3% step increment in the load power (ΔPL=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.

6. 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 work

7. Future scope

1. In this proposed work, load fluctuations are essentially fixed and used. Consequently, in the future, this research work can be applied to dynamic load disturbances.

2. The parameters of the work of this project are used continuously throughout the operation. However, there are factor uncertainties here due to temperature changes, wear, atmospheric changes, and aging. Therefore, it is necessary to consider the deviation of factors in the design phase of the controller.

3. Load frequency control of hybrid power systems can be considered by using optimization techniques.

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