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LOAD FREQUENCY CONTROL OF HYBRID POWER SYSTEM USING INTELLIGENT CONTROLLERS

Ramanpreet Kaur[1], Dr. Surya Prakash[2]

PG student (ME), EIED Department, Thapar University, Patiala

EIED Department, Thapar University Patiala (India)

Abstract

In this paper the model of hybrid power system is developed. It comprises two thermal power generation system with Photovoltaic generation system (PV), wind turbine, fuel cell, aqua electrolyzer and battery storage system. To maintain the preferred frequency and power exchange with the neighboring system in the hybrid power system is the objective of Automatic Generation Control (AGC). The deviation in the frequency from the desired value is due to the change in the load and any mismatch. This requires a quick and precise controller to keep the frequency at desired value. This paper deals with the Artificial Intelligence technique called Fuzzy PI and Neuro- Fuzzy approach. The advantage of Neuro-fuzzy approach is that it can deal with non-linearities in the meantime and it is quicker than other conventional controllers. The output of intelligent controller is having better response and it is faster than other controllers.

I. INTRODUCTION

The installation of renewable energy sources is increasing to provide the required demand. In general the renewable energy sources installed near the consumers and load enters the renewable sources include wind energy, PV and battery energy storage system. To meet the required demand of power, renewable energy resources system interconnected with the concentric system called the hybrid power system that provides continue and battery quality of service to the consumers. It is mostly depend on the controller used in the system for the frequency control. The change in the load element and the continue variation in the wind power results 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 frequency deviation, which have to be taken into consideration in the LFC scheme. Expanding interest for electrical energy, constrained measure of non-renewable energy sources, and expanding worries to ecological things required for a quick improvement in the field of RESs. Some most recent reviews which are clarify the effects of battery energy storage (BES), capacitive energy (CE), SMES, wind turbine (WT) and photovoltaic (PV) control generation the dynamic execution of the AGC system. L.Mengyan et al. [1] have explained the reviews on tie line control with a considerable control of wind power. A robust controller has been composed containing SMES for adjustment of tie-line control variation in the interconnected system with wind farms [2]. Moreover, a utilization of small rating CE units was used for the change of AGC execution of a multi-unit

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multi-region control system containing GRCs [3]. Afterward, R. Oba et al. [4] have explored the impact of RESs, for example, PV in the three-area interconnected system to minimize the disturbances with the help of PID controller. An AGC scheme for hybrid system associated MW class PV power generating system is proposed in [5] while a control conspires for the photovoltaic-diesel single-stage independent power system is depicted in [6]. Artificial intelligence that accomplishes skill in taking care of the issues by achieving information about particular assignments is called learning based or intelligent system. AI was initially proposed by E. A. Feigenbaum et al. in the mid 1970s [7]. AI constitute intelligent strategy based techniques in which it deals with information or rule based system calculation, which utilizes the information and interface methodology to tackle issues that are sufficiently difficult for human. Fundamental points of interest of AI systems are:

- It is long-term and predictable
- It can be effectively exchanged or corrected

Scientists have great attention about the adaptive neuro fuzzy interference system because it deals with nonlinearities and does not require exact numerical modeling of the system [8]. ANFIS controller has the potential to give an enhanced execution even to a system with wide parameter varieties [9]. The ANFIS controller has advantages of robust, basic, simple to be changed, usable for multi information. Utilization of ANFIS control rather than PI conventional controller can be a powerful app roach to explain the issue of variation in the system parameters

II. SYSTEM MODEL

In this model interconnected power system is considered to develop the HNF controller. It comprises two thermal system and five renewable energy sources. The DG system under review comprises of energy assets, for example, WTG, FC, AE, PV and BESS. The dynamic performance of a control system within the sight of wind power generation may be not quite the same as conventional power plants. The output powers of such sources are relying upon climate conditions seasons and land area. At the point when wind power is under control system, extra imbalance is there when the definite wind power changes from its determined value because of wind speed varieties. Thus, planning traditional generators units to take after load may be influenced by wind control. Since wind power is a discontinuous source which varies from the conventional plants, the output power control of wind turbine is a difficult task. When demand is more than the existing wind power, the problem of stability may occur. Thus, coordination among stability and controllability of dynamic power in wind turbines has to be characterized. Some output of wind power generator is used by AE for production of hydrogen, which is utilized as a part of FC for power generation. The BESS is utilized for load leveling in power system.

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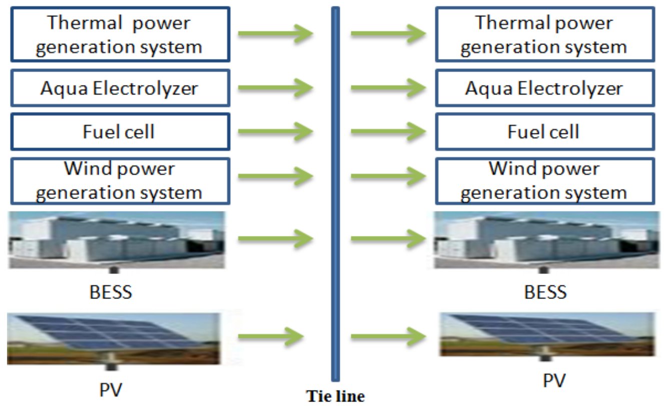

Fig 1: Layout of the hybrid system

Wind power turbine

Wind speed is responsible for the wind turbine power. It varies with time. The wind turbine mechanical power output is varies with cube of the wind speed. The wind turbine power is given by

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

(1)

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

Wind turbine system has various nonlinearities. The output power varies when the wind turbine is canceled out the frequency fluctuations by using the pitch controller. Restrictions of deviation in the output power decide the set point of pitch angle. The non linearity introduces in the system by the pitch system which adjust the pitch angle in accordance with the wind speed. The wind turbine transfer function is given by:

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

(2) Aqua Electrolyzer

For the hydrogen production some part of the wind turbine generator is used by the aqua electrolyzer which is fed to the fuel cell for power generation. The aqua electrolyzer transfer function is expressed as:

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

(3) Fuel cell

The fuel cell converts the chemical energy (hydrogen) into electrical energy through the combination of the gaseous hydrogen and air without combustion. It is considered the main resource in the hybrid power system because of various advantages like greater efficiency and less pollution. FC generator has non linearity and model of higher order. The fuel cell transfer function for low frequency analysis is expressed as:

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

(4) Battery energy storage system

The BESS is providing extra power damping to the power system swings for improving the both dynamic and transient stability. The wind turbine power is continuously varying and small time power variations cause large problems in the operation of power system. There is solution for use of energy storage systems.

The BESS has good technical characteristics thus it can store huge amount of wind power. The BESS transfer function is expressed as:

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

(5) Photovoltaic power generation system

The electric circuit of the PV consists of parallel resistor, diode, photocurrent and a series resistor as shown in figure 2. The PV array behavior is based on the PV module model with $N_S \times N_P$ modules is given by equation shown below:

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

(6)

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)

PV array has unique operating point and has linear voltage-current characteristics under the specific temperature conditions.

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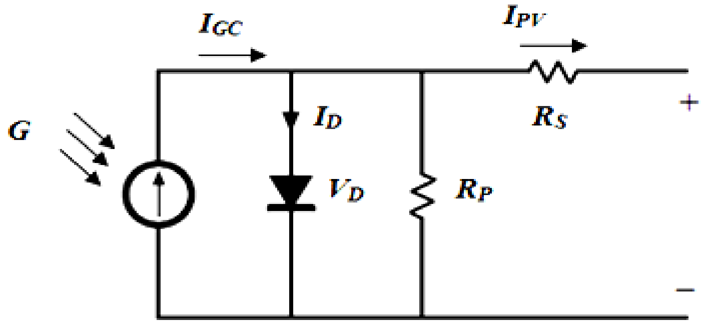

Fig 2: Electric circuit of PV module.

The PV transfer function is expressed as:

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

(7)

III. AUTOMATIC CONTROLLER

The control signal U_i is generated by the load frequency controller which maintains the frequency and tie line power. The control signal U_i is

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

(8)

By taking derivative of the equation:

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

(9)

The main advantage of using PI controller is that it minimizes the steady state error to zero. PI controller with preset gains has been considered at nominal working conditions, but over a large range of working conditions it fails to give the finest control performance. Fuzzy logic techniques has been projected for solving this problem in [10]-[13].

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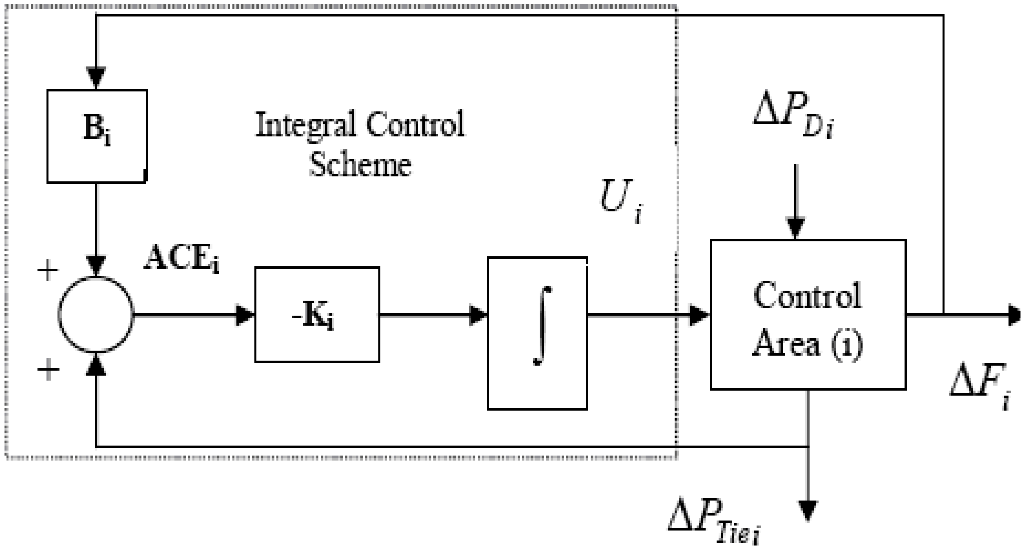

Fig 3: conventional PI controller connected in i^{th} area

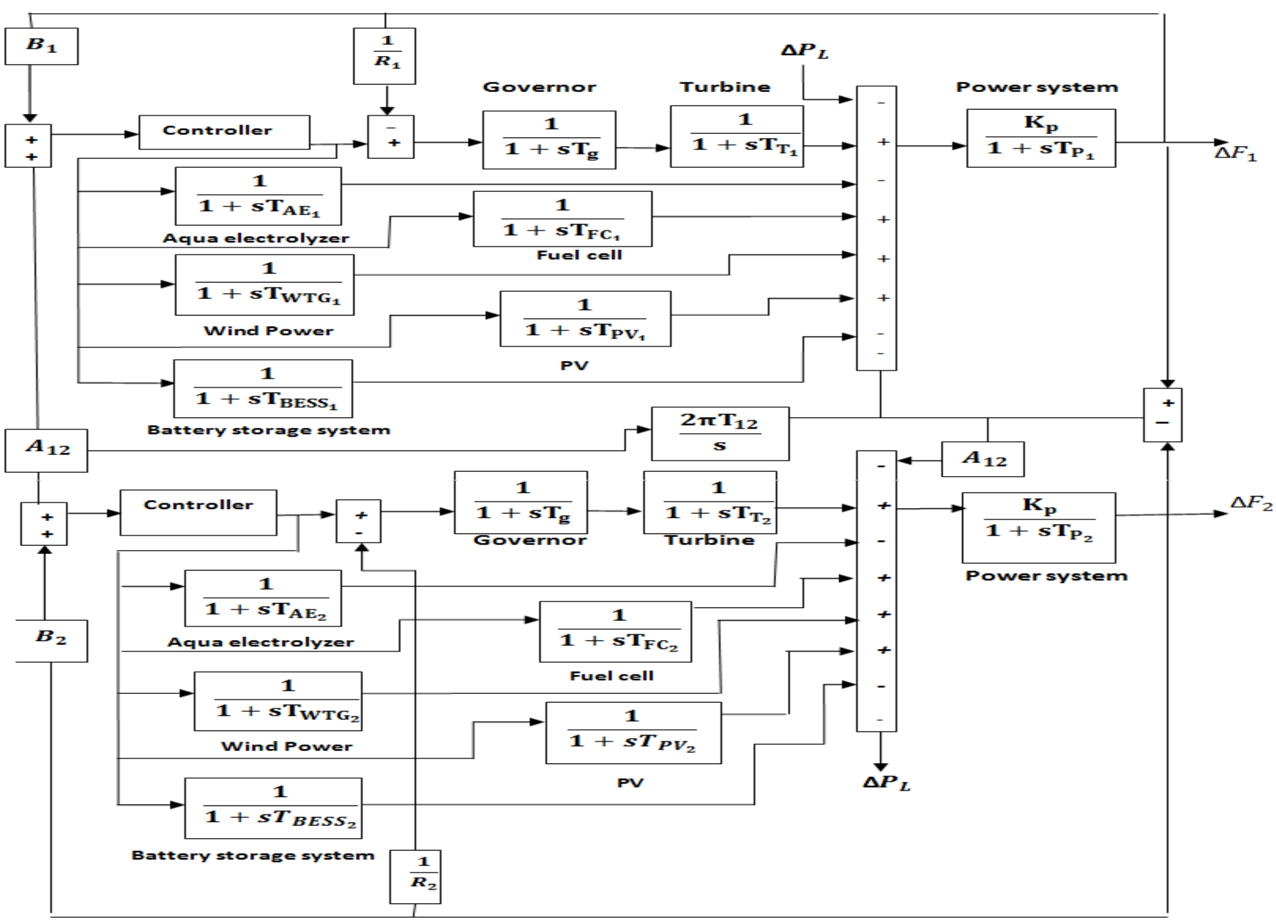

Fig 4: Block diagram of hybrid power system.

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IV. FUZZY LOGIC CONTROLLER

In recent times, the fuzzy logic based control has widely received attentions in a range of power systems applications [14]. FLCs are knowledge-based controllers generally derived 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 inference model. The LFC problem is composed of the unexpected small load variation or a variation in input wind power which always perturb the operation of a power system. For this reason, the frequency deviation must be controlled.

4.1 Fuzzification

Fuzzification is the procedure of converting real-valued variable to a fuzzy set variable. Fuzzy variables are based on nature of the power system wherever it is implementing.

4.2 Knowledge Base

The main part of the fuzzy is a knowledge base carrying of fuzzy IF-THEN rules. The rule base has a set of fuzzy rules. The data base consists of membership function of fuzzy subsets. A fuzzy rule may have fuzzy variables and fuzzy subsets described by membership function.

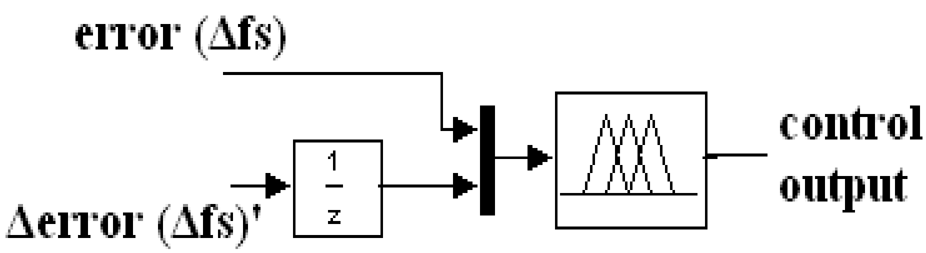

Fig 5: Block diagram of fuzzy logic controller

4.3 De-Fuzzification

The function of De-fuzzification is to transforming the fuzzy output variable to a crisp value; as a result it will be used for control operation. It is used because crisp value is required in practical applications for control action. The block diagram of fuzzy logic controller is shown by figure 5. The rules of Knowledge base are used to decide the fuzzy controller action. To determine the performance of controller is based on method of de-fuzzification , membership functions and knowledge base. The error signal for fuzzy logic controller is input variable (ΔFs) in diesel side for governor. For two input and two output rule base and membership functions with five linguistic variables (NB, NS, ZZ, PS, and PB) are shown in Fig-6 and Table-1 for the fuzzy logic controller for comparison with the proposed controller.

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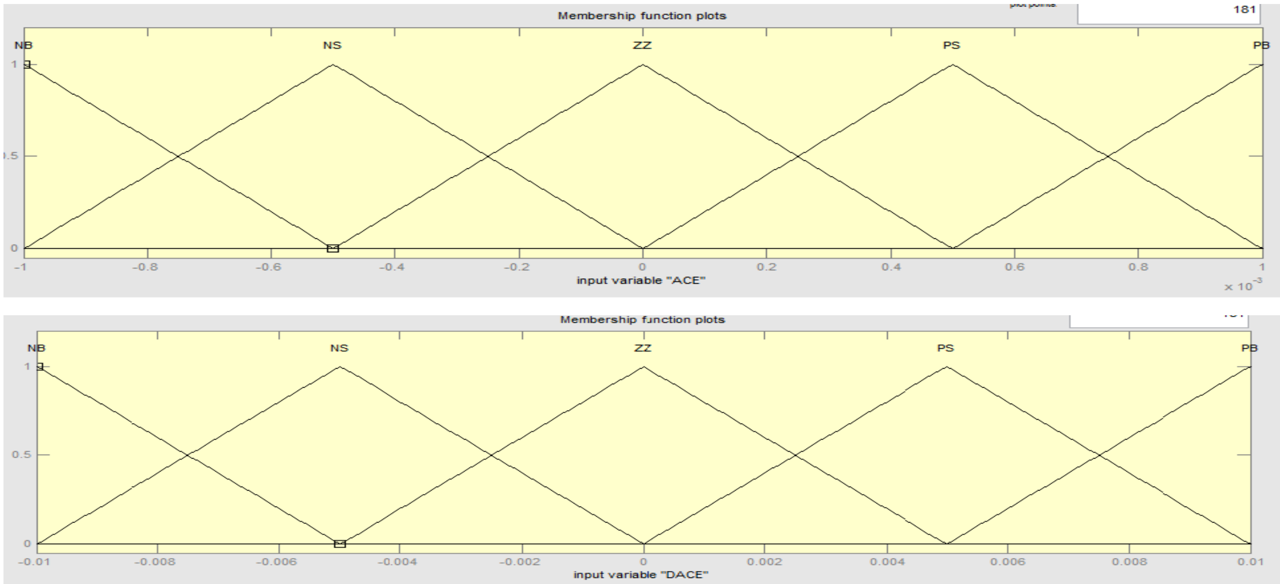

Fig 6: Membership functions of input and output variables

ACE/DACE	NB	NS	ZZ	PS	PB
NB	PB	PB	PB	PS	ZZ
NS	PB	PB	PS	ZZ	NS
ZZ	PB	PS	ZZ	NS	NB
PS	PS	ZZ	NS	NB	NB
PB	ZZ	NS	NB	NB	NB

TABLE 1: Rule base for fuzzy logic controller (with five membership functions)

V. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

ANFIS is a multi-layer versatile neural system based fuzzy inference system [15]. ANFIS algorithm is made up of fuzzy logic and neural systems with 5 layers to execute distinctive node functions to learn and tune parameters in a fuzzy interference system (FIS) structure utilizing hybrid learning mode. For the forward pass of learning, with constant premise parameters, estimation of least squared error approach is utilized to renew subsequent parameters and to pass the error to the backward pass. The resulting parameters are settled and the gradient descent strategy is used to update the subsequent parameters in the backward pass of learning. Subsequent and premise parameters will be recognized for membership function (MF) and FIS by repeating the forward and backward passes. Adaptive

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Neuro-Fuzzy Inference Systems are fuzzy Sugeno models put in the structure of adaptive frameworks to encourage learning and adjustment [15]. Such structure makes FLC more logical and less depending on expert information. Let us consider two-fuzzy rules to represent the ANFIS architecture based on a first order Sugeno model:

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 x and y are the inputs, Ai and Bi are the fuzzy sets, f_i are the outputs within the fuzzy region given by the fuzzy rule pi, qi and ri are the design parameters which are obtained during the training process.

In five layers, the first and the fourth layers have adaptive nodes on the other hand, the second, third and fifth layers have fixed nodes. The adaptive nodes are linked with their respective parameters and get updated with next iteration but the fixed nodes are without any parameters. The two rules of ANFIS architecture is shown in Fig.

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 i1 = μAi (*x*) , For i=1,2

(10)

O i1 = μB*i*-2 (*y*) , For i=3,4

(11)

x and y is the inputs to node I , A is a linguistic label (small, big, negative big) and μAi (x), μBi-2 (y) can be any fuzzy membership function.

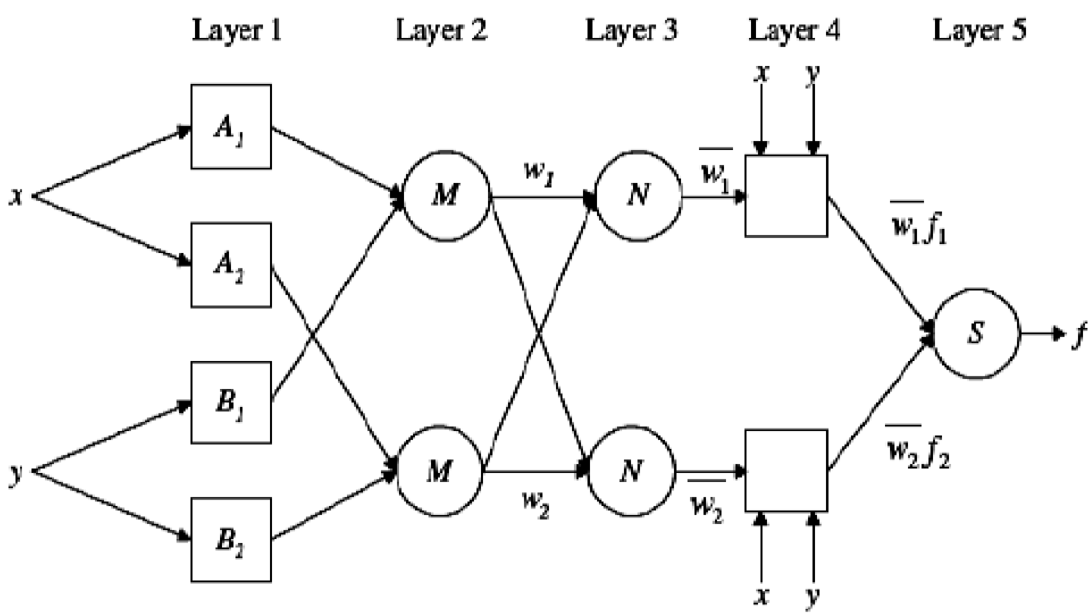

Fig: 7 ANFIS architecture

Layer 2: **Rule layer**: A fixed node labeled M whose output is the product of all the incoming signals, the outputs of this layer can be represented as:

O i2 = *wi* = *μ*A*i* (*x*) *μ*Bi (*y*) ***i*=1,2**

(10)

Layer 3: **Normalization layer** : A circle node labeled N is also a fixed node.

O i3 = _*wi* = *wi* / (*w*1 + *w*2) ***i*=1,2**

(6)

Layer 4: **Defuzzification layer**: An adaptive node with a node .The each node output is simply the product of a first order polynomial the normalized firing strength.

O i4 = _*wi fi* = *wi* (p*ix* + q*iy* + r*i*) ***i*=1,2**

(7)

Layer 5: **Summation neuron** a fixed node which calculates the whole output by summing up of all incoming signals.

O i5 = Σ _*wi fi* = Σ*i=1 wi fi* / (*w*1 + *w*2)

(8)

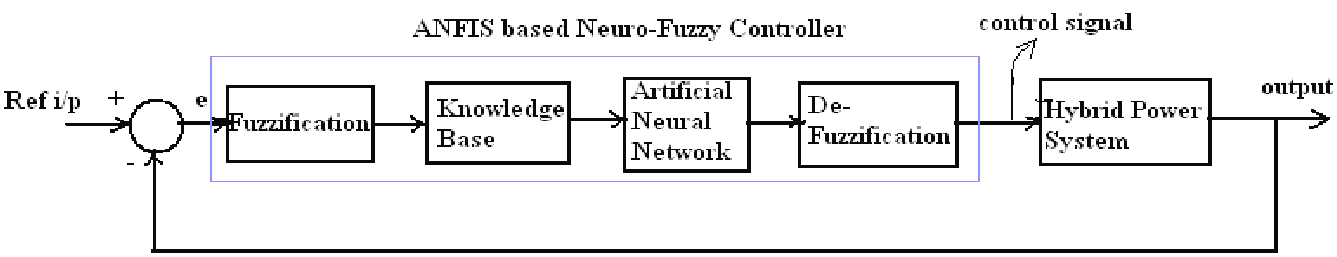

Fig 8: Block diagram of Neuro fuzzy controller

Steps to design the Neuro-Fuzzy Controller

1. Make the Simulink model with Fuzzy logic controller (Takagi-Sugeno model) and simulate the model for the two inputs with seven membership functions (error in frequency and rate of change in frequency error) and the rule base.
2. Gather the training data during simulation with FLC to propose the Neuro-Fuzzy controller.
3. The two data inputs, that is frequency change and rate of change of frequency error and output signal gives the training data.
4. Utilize "anfisedit" to make the Neuro-Fuzzy FIS file.
5. Load the data gathered in Step.1 and load the Neuro-Fuzzy FIS file.
6. Select the hybrid learning algorithm.
7. Train the gathered data with produced FIS up to a specific no. of Epochs.

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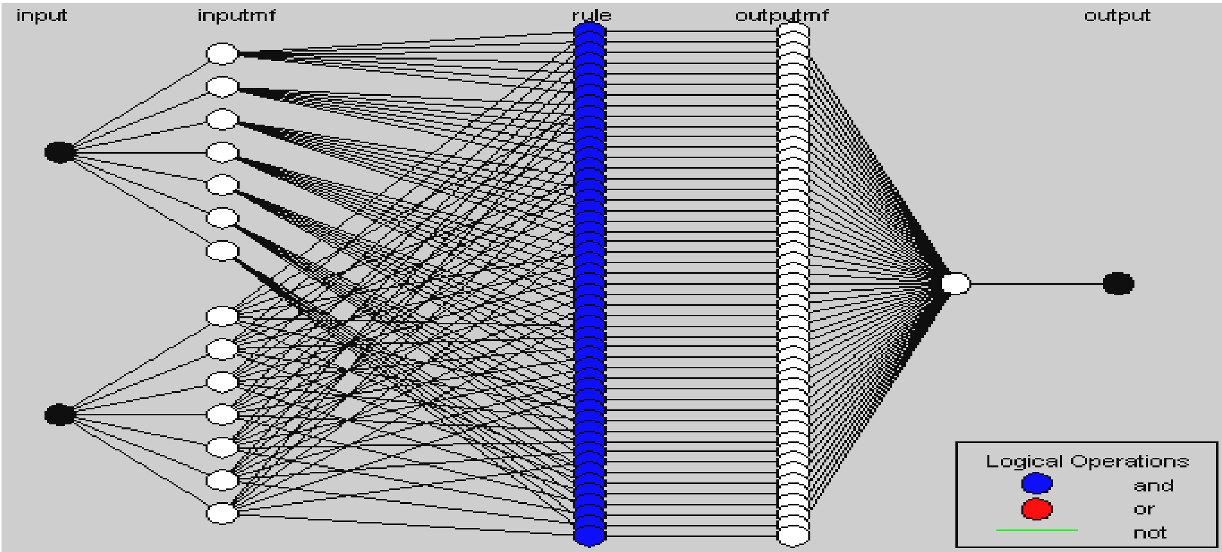

Fig-9: ANFIS structure for the designed Neuro- Fuzzy controller

VI. SIMULATION AND RESULTS

Simulation was performed by utilizing the proposed ANFIS based Neuro-Fuzzy controller , Fuzzy Logic controller (Mamdani model) and the regular PI controller to the hybrid power system incorporating the renewable energy sources . All the execution criteria for example, settling time, overshoot and zero steady state error are considered to get limited for all the cases. Change in frequency with different load settings or step load variation to get the ideal execution of hybrid power sytem. The same framework parameters given in Table 2 were utilized for the above three controllers for the comparison. simulation is done for 1 % ,2%, 3%,4% and 5% step increment in the load power (ΔPL=0.01 p.u. ,0.02 p.u.,0.03 p.u.,0.04 p.u. furthermore, 0.05 p.u.) at t = 0s . The overshoot and setting time of proposed ANFIS based Neuro-Fuzzy controller is lower than those of Fuzzy logic controller and regular PI controller.

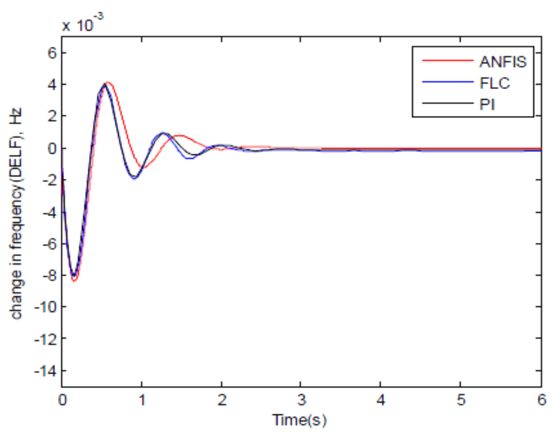

Fig 10: ΔF in hybrid power system for load change 2%

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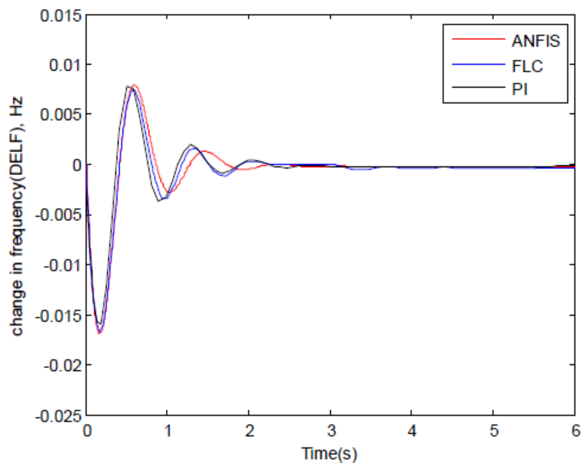

Fig 11: ΔF in hybrid power system for load change 4%

Change in load (p.u.)	Frequency Change		
	NFC	FLC	PI
0.01	2.0108	2.0508	2.1824
0.02	1.7844	2.1158	2.1789
0.03	1.7441	3.0695	2.1824
0.04	1.7265	3.0560	2.1816
0.05	1.7166	3.0646	2.1766

VIII. CONCLUSION

The Neuro-Fuzzy controller is intended for Load frequency control of a hybrid power system to direct the frequency deviation and power deviations, by using Adaptive Neuro-Fuzzy Inference System (ANFIS). Comparison of results of the proposed paper shows that the system reaction of the Load Frequency Control with the use of ANFIS based Neuro-Fuzzy controller has a very shorter settling time. The outcomes acquired by utilizing ANFIS based Neuro-Fuzzy controller proposed in this paper beat than those of regular PI controller and the fuzzy logic controller by the hybrid learning algorithm. It has been demonstrated that the proposed controller is successful and gives noteworthy change in system execution by combing the advantages of Fuzzy logic and neural systems. The proposed controller keeps the system more stable and reliable for sudden load changes and demonstrates its dominance.

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