ANFIS based Neuro-Fuzzy Controller in LFC of Wind-Micro Hydro-Diesel Hybrid Power System

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ABSTRACT
This paper presents the design and analysis of Neuro-Fuzzy controller based on Adaptive Neuro-Fuzzy Inference System (ANFIS) architecture for Load frequency control of an isolated wind-micro hydro-diesel hybrid power system, to regulate the frequency deviation and power deviations. Due to the sudden load changes and intermittent wind power, large frequency fluctuation problem can occur. This newly developed control strategy combines the advantage of neural networks and fuzzy inference system and has simple structure that is easy to implement. So, in order to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to control the system. Simulations of the proposed ANFIS based Neuro-Fuzzy controller in an isolated wind-micro hydro-diesel hybrid power system with different load disturbances are performed. Also, a conventional proportional Integral (PI) controller and a fuzzy logic (FL) controller were designed separately to control the same hybrid power system for the performance comparison. The performance of the proposed controller is verified from simulations and comparisons. Simulation results show that the performance of the proposed ANFIS based Neuro-Fuzzy Controller damps out the frequency deviation and attains the steady state value with less settling time. The proposed ANFIS based Neuro-Fuzzy controller provides best control performance over a wide range of operating conditions.

General Terms
Frequency fluctuation, damping, controller design.

Keywords
Load Frequency Control, Wind micro hydro diesel Hybrid power system, conventional PI controller, Fuzzy logic controller, Neuro-Fuzzy controller, Adaptive Neuro-Fuzzy Inference System .

1. INTRODUCTION
Nowadays, electricity generation is very important because of its increasing necessity and enhanced environmental awareness such as reducing pollutant emissions. The dynamic behaviour of the system depends on disturbances and on changes in the operating point. The quality of generated electricity in power system is dependent on the system output, which has to be of constant frequency and must maintain the scheduled power and voltage. Therefore, load frequency control, LFC, is very important in order to supply reliable electric power with good quality for power systems.

The wind- micro hydro –diesel system is one of the hybrid systems utilizing more than one energy source. For the increasing demand of electricity due to developments at a faster rate, it is becoming difficult to meet the increasing demand of electricity only with conventional sources. In most remote and isolated areas, electric power is often supplied to the local community by diesel generators. However, diesel generators cause significant impacts on the environment. [2]. Due to the environmental and economic impacts of a diesel generator, interest in alternative cost-efficient and pollution-free energy generation has grown enormously. Currently, wind is the fastest growing and most widely utilized renewable energy technology in power systems. Wind power is economically attractive when the wind speed of the proposed site is considerable for electrical generation and electric energy is not easily available from the grid [1].

Wind power is intermittent due to worst case weather conditions, so wind power generation is variable and unpredictable. Wind power is not fully controllable and their availability depends on daily and seasonal patterns [3]. As a result, conventional energy sources such as diesel generators are used in conjunction with renewable energy for reliable operation. The hybrid wind power with diesel generation has been suggested by [2] and [3] to handle the problem above. To meet the increasing load demand for an isolated community, expansion of these hybrid power systems is required. One possible option available is to add a micro hydro generating unit in parallel, where water streams are abundantly available. The resulting wind-micro hydro-diesel hybrid power system must provide good quality service to the consumer load, which depends mostly on the type and action of the generation controller. The unsteady nature of wind and frequent change in load demands may cause large and severe oscillation of power. The fluctuation of output power of such renewable sources may cause a serious problem of frequency and voltage fluctuation of the grid [2]. An effective controller for stabilizing frequency oscillations and maintaining the system frequency within acceptable range is significantly required. Therefore, a control system is required to detect the load changes and its mechanical power production and stabilize the system frequency[4]. The supplementary controller of the diesel generating unit, called the Load Frequency Controller, may satisfy these requirements. The load frequency control (LFC) maintains the frequency deviation from its nominal value to within specified bounds and dynamic performance of the system[7],[8],[9] . The function of the load frequency controller is to eliminate a mismatch created either by the small real power load change or due to a change in input wind power.

The Load Frequency control (LFC) or Automatic Generation Control (AGC) has been one of the most important subjects concerning power system engineers in the last decades. Research studies were conducted for Load Frequency control of Thermal and Hydro power system with conventional and intelligent controllers [6],[11]-[14]. Load Frequency controller was designed with conventional PI controller for wind- diesel hybrid system [5] and for wind-diesel- hydro hybrid power system[16].[17]. LFC using Fuzzy logic controller with optimization techniques for wind –diesel hybrid system was presented in [15]. LFC using ANFIS based controllers for thermal and Hydrothermal systems are presented in [20] and [21] respectively. In the proposed paper, adaptive Neuro-Fuzzy Inference System based Neuro-Fuzzy controller is designed for Load Frequency Control of wind-micro hydro-diesel hybrid power system.

The ANFIS based Neuro-Fuzzy controller for a governor in diesel side and for a blade pitch control in wind side are designed individually for performance improvement of the Wind-micro hydro-diesel hybrid system. Simulations are performed for load frequency control in an isolated wind - micro hydro- diesel hybrid power system with different load disturbances by the proposed ANFIS based Neuro-Fuzzy controller and also with conventional PI and fuzzy logic controller for comparison. The proposed adative Neuro-Fuzzy Inference System trains the parameters of the Fuzzy logic controller and improves the system performance. Simulation results show the superior performance of the proposed Neuro- fuzzy controller in comparison with the conventional PI controller and fuzzy logic controller in terms of the settling time, overshoot against various load changes .

2. SYSTEM MODEL DESCRIPTION

The schematic block diagram of the isolated wind-micro hydro-diesel hybrid power system is shown in Fig-1. In the hybrid system considered, synchronous generator is connected on diesel-generator (DG) and induction generators connected on wind turbine and hydro turbine[10]. Moreover, the Blade pitch controller is installed in the wind side while the governor is equipped with the diesel side. In the wind-turbine generating unit, the ANFIS based Neuro-Fuzzy controller is designed as a supplement controller for the pitch control, which constantly maintains the wind power generation . For the diesel generating unit, the ANFIS based Neuro-Fuzzy controller is designed to improve the performance of governor. The proposed Neuro-Fuzzy controller uses the system frequency deviation of the power system as a feedback input on diesel side, so that it can offset the mismatch between generation and load demand by adjusting the speed changer position.

***Nomenclature*:**

ΔFs - deviations in system frequency
ΔF_T - speed of the wind-turbine induction generator.
ΔP_{GD} – deviation in diesel power generation
ΔP_{GW} - deviation in wind power generation
ΔP_{GH} - deviation in hydro power generation
ΔP_{IW} - deviation in input power
ΔP_{IH} - deviation in micro hydro power

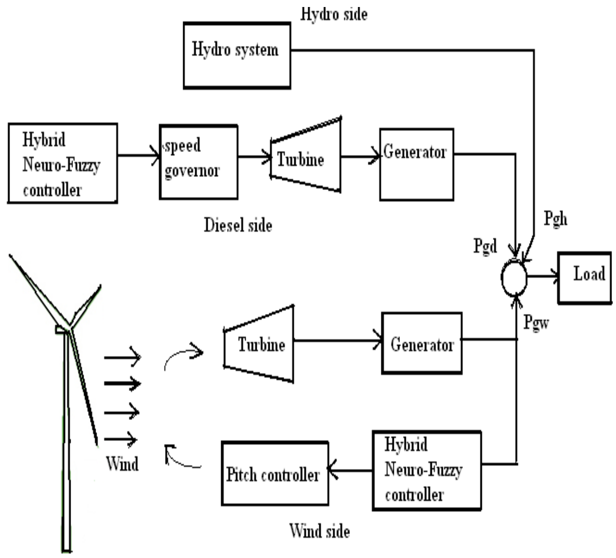

Figure-1: Configuration of isolated wind - micro hydro - diesel hybrid system

Table 1 : System parameters

Simulation Parameter
Rd=5.0;Kd=0.3333;Td1=1.0;Td2=2.0;Td3=0.025;Td4=3.0;Tw=4.0; Kig=0.9969;Kp=72.0;Tp=14.4; Ktp=0.003333;Kpc=0.08;Kp1=1.25;Tp1=0.6; Kp2=1.0;Tp2=0.041;Kp3=1.4;Tp3=1.0; Kgh=0.2;Th=1;

The transfer function block diagram of a wind- micro hydro-diesel hybrid power system with Neuro-Fuzzy controller used in this study is shown in Fig-2. The input power to the wind-power generating unit is not controllable in the sense of generation control, but a supplementary controller known as LFC can control the generation of the diesel unit and thereby of the system. The transfer function block diagram of this hybrid system includes the LFC and also the blade-pitch controller with ANFIS based Neuro-Fuzzy controller. The dynamics of the wind power generating unit is described by a first order system. The continuous time dynamic behavior of the load frequency control system is modeled by a set of state vector differential equations.

$$X' = AX + BU + \Gamma p \qquad (1)$$

where X, U and p are the state, control and disturbance vectors, respectively. A, *B* and Γ are real constant matrices, of the appropriate dimensions, associated with the above vectors.

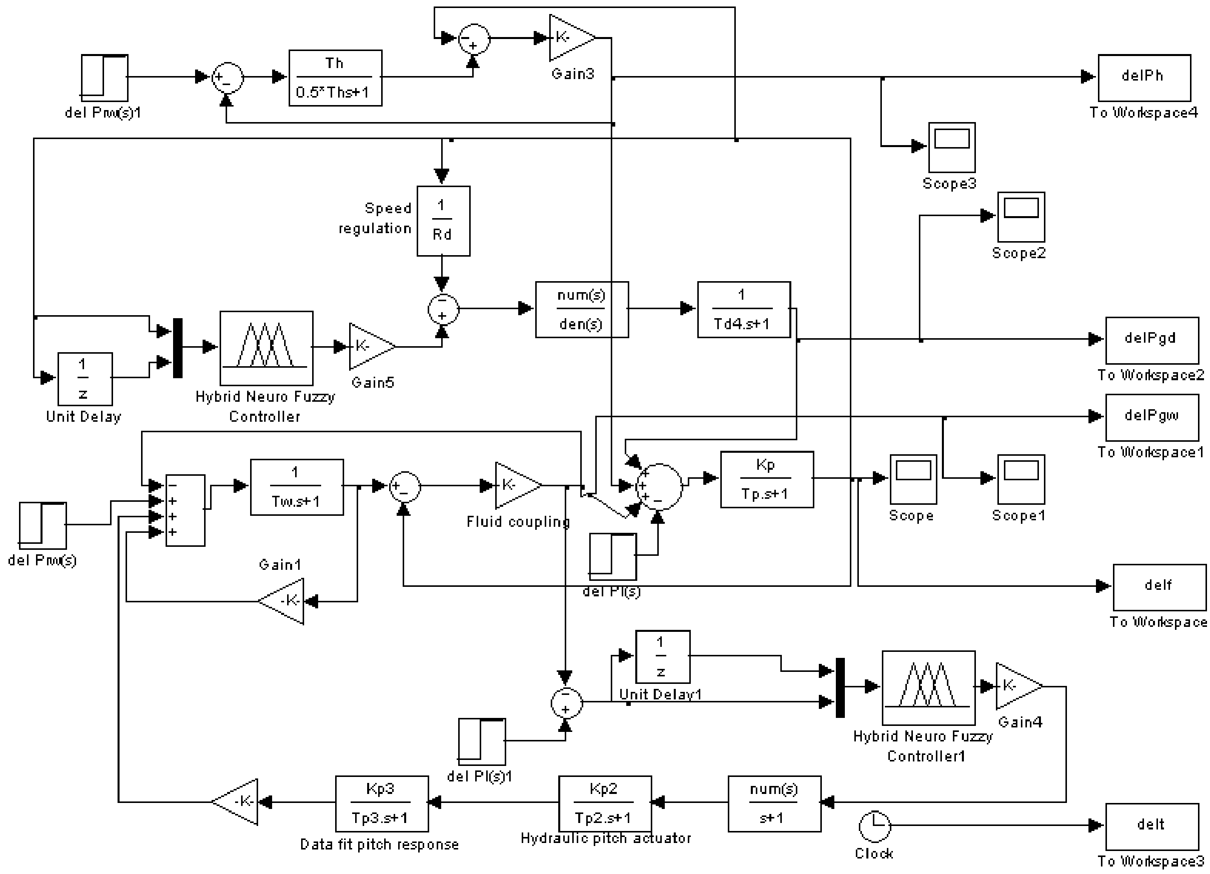

Figure-2: Simulink model of wind -micro hydro- diesel hybrid system with ANFIS based Neuro-Fuzzy controller

3. CONVENTIONAL PI CONTROLLER

Among the various types of load-frequency control, the PI controller is most widely applied to speed-governor systems for LFC schemes[17]. One advantage of the PI controller is that it reduces the steady-state error to zero. Fig-3 shows the block diagram of conventional PI controller.

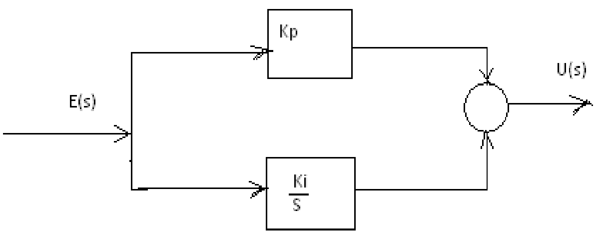

Figure-3: Block diagram of conventional PI controller

Mathematically it is represented as

$$U(s) = KpE(s) + Ki\int E(s) \_\_\_\_\_\_\_\_\_(2)$$

However, since the conventional PI controller with fixed gains has been designed at nominal operating conditions, it fails to provide the best control performance over a wide range of operating conditions and exhibits poor dynamic performance. To solve this problem, Fuzzy Logic techniques have been proposed in [6],[11]-[14]. System operating conditions are monitored and used as inputs to a fuzzy system whose output signal controls the inputs to governor for increasing or decreasing the generation for maintaining the system frequency.

4. FUZZY LOGIC CONTROLLER

Recently, the fuzzy logic based control has extensively received attentions in various power systems applications [18]. FLCs are knowledge-based controllers usually derived from a knowledge acquisition process or automatically synthesized from self-organizing control architectures. A fuzzy system knowledge base consists of fuzzy IF-THEN rules and membership functions characterizing the fuzzy sets. The Fuzzy Logic Controller considered here for comparison is based on Mamdani inference model. The LFC problem considered here is composed of the sudden small load perturbations or a change in input wind power which continuously disturb the normal operation of a power system. Hence, the deviations of frequency must be controlled.

4.1 Fuzzification

Fuzzification is the process of transforming real-valued variable into a fuzzy set variable. Fuzzy variables depend on nature of the system where it is implemented.

4.2 Knowledge Base

The heart of the fuzzy system is a knowledge base consisting of fuzzy IF-THEN rules. The rule base consists of a set of fuzzy rules. The data base contains the membership function of fuzzy subsets. A fuzzy rule may contain fuzzy variables and fuzzy subsets characterized by membership function.

4.3 De-Fuzzification

The purpose of De-fuzzification is to convert the output fuzzy variable to a crisp value, So that it can be used for control purpose. It is employed because crisp control action is required in practical applications. Fig-4 shows the block diagram of Fuzzy logic controller designed for comparison.

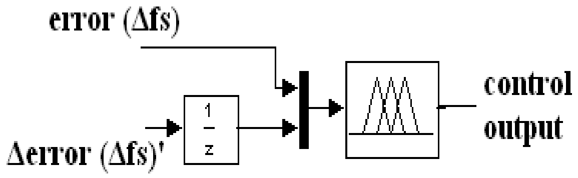

Figure-4: Block diagram of Fuzzy logic controller

The heuristic rules of the knowledge base are used to determine the fuzzy controller action. The membership functions, knowledge base and method of de-fuzzification essentially determine the controller performance. The input variable (ΔFs) in diesel side for governor is used as error signal for fuzzy logic controller. The membership functions with 7 linguistic variables (NL,NM,NS,Z,PS,PM,PL) for two input and one output variable and rule base are shown in Fig-5 and Table-2 for the designed fuzzy logic controller for comparison with the proposed controller.

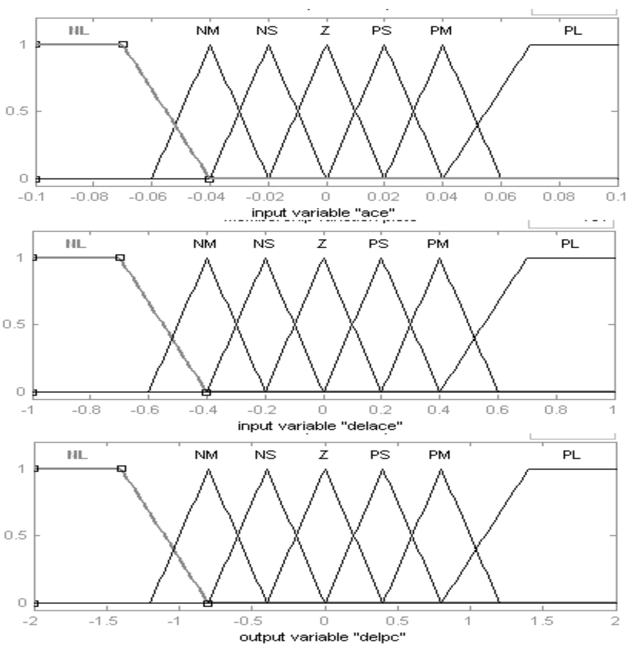

Figure-5 Membership functions of input and output variable

Table-2 Rule base (with 7 membership functions)

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PM	PM	PS	Z
NM	PL	PM	PM	PM	PS	Z	PS
NS	PM	PM	PS	PS	Z	NS	NM
Z	PL	PM	PS	Z	NS	NM	NL
PS	PM	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NL
PL	Z	NS	NM	NM	NL	NL	NL

5. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM(ANFIS)

ANFIS is a multi-layer adaptive neural network-based fuzzy inference system[19]. ANFIS algorithm is composed of fuzzy logic and neural networks with 5 layers to implement different node functions to learn and tune parameters in a fuzzy inference system (FIS) structure using a hybrid learning mode. In the forward pass of learning, with fixed premise parameters, the least squared error estimate approach is employed to update the consequent parameters and to pass the errors to the backward pass. In the backward pass of learning, the consequent parameters are fixed and the gradient descent method is applied to update the premise parameters. Premise and consequent parameters will be identified for membership function (MF) and FIS by repeating the forward and backward passes. Adaptive Neuro-Fuzzy Inference Systems are fuzzy Sugeno models put in the framework of adaptive systems to facilitate learning and adaptation [19]. Such framework makes FLC more systematic and less relying on expert knowledge. To present the ANFIS architecture, let us consider two-fuzzy rules 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, fi are the outputs within the fuzzy region specified by the fuzzy rule, pi, qi and ri are the design parameters that are determined during the training process.

Out of the five layers, the first and the fourth layers consist of adaptive nodes while the second, third and fifth layers consist of fixed nodes. The adaptive nodes are associated with their respective parameters, get duly updated with each subsequent iteration while the fixed nodes are devoid of any parameters. The ANFIS architecture to implement these two rules is shown in Fig. 6.

Layer 1: fuzzification layer Every node I in the layer 1 is an adaptive node. The outputs of layer 1 are the fuzzy membership grade of the inputs, which are given by:

$$O\, i^1 = \mu A i\, (x)\ , \text{ For } i=1,2 \qquad (3)$$
$$O\, i^1 = \mu B i\text{-}2\, (y)\ , \text{ For } i=3,4 \qquad (4)$$

where x and y is the inputs to node i, where A is a linguistic label (small, large) and where $\mu Ai\ (x)$, $\mu Bi\text{-}2\ (y)$ can adopt any fuzzy membership function.

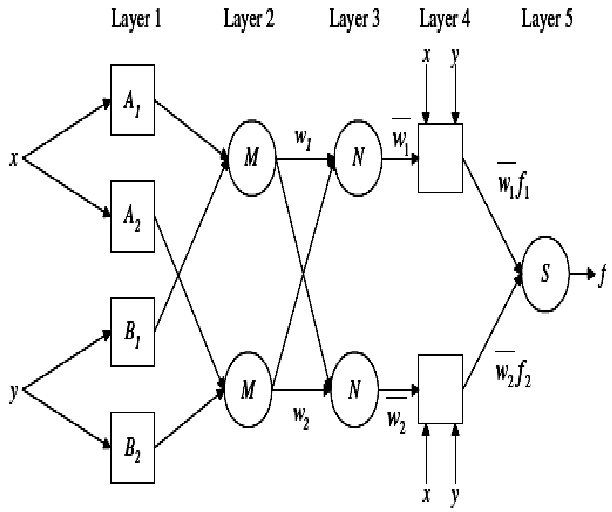

Figure-6. ANFIS architecture

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:

$$O\ i^2 = wi = \mu Ai\ (x)\ \mu Bi\ (y)\ i=1,2 \qquad (5)$$

Layer 3: normalization layer are also fixed node is a circle node labeled N.

$$O\ i^3 = \_wi = wi\ /\ (w1 + w2)\ i=1,2 \qquad (6)$$

Layer 4: defuzzification layer an adaptive node with a node The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial.

$$O\ i^4 = \_wi\ fi = wi\ (pix + qiy + ri)\ i=1,2 \qquad (7)$$

Layer5: summation neuron a fixed node which computes the overall output as the summation of all incoming signals.

$$O\ i^5 = \Sigma\ \_wi\ fi = \Sigma i{=}1\ wi\ fi\ /\ (w1 + w2) \qquad (8)$$

6. NEURO-FUZZY CONTROLLER

The development of the control strategy to control the frequency deviation of the wind-micro hydro-diesel hybrid power system using the concepts of ANFIS control scheme is presented here.. The neuro-fuzzy method combines the advantages of neural networks and fuzzy theory to design a model that uses a fuzzy theory to represent knowledge in an interpretable manner and the learning ability of a neural network to optimize its parameters . The proposed controller integrates fuzzy logic algorithm with a structure of artificial neural network (ANN) five-layer in order to reap the benefits of both methods .ANFIS is a specific approach in neuro-fuzzy development which was first introduced by Jang [19]. To start with, we design the controller using the ANFIS scheme. The model considered here is based on Takagi-Sugeno Fuzzy inference model. The block diagram of the proposed ANFIS based Neuro-Fuzzy controller for wind-micro hydro-diesel hybrid power system consists of 4 parts, viz., fuzzification, knowledge base, neural network and the de-fuzzification blocks, shown in Fig-7.

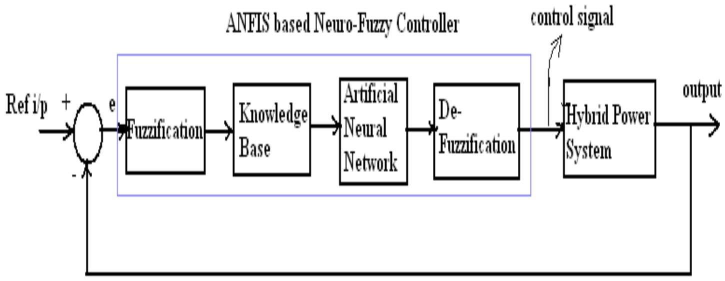

Figure-7 Block diagram of ANFIS based Neuro-Fuzzy Controller

ANFIS uses a hybrid learning algorithm to identify consequent parameters of Sugeno type fuzzy inference systems. It applies a combination of the least squares method and back propagation gradient descent method for training fuzzy inference system membership function parameters to emulate a given training data set. The fuzzy inference system under consideration has two inputs. In the proposed paper, inputs to the ANFIS considered are error(ΔFs) and change in error(ΔFs)' whereas the output is the corresponding signal to the governor. Steps to design the Neuro-Fuzzy Controller are as given below:

1. Draw the Simulink model with FLC (Takagi-Sugeno inference model) and simulate it with 7 membership functions for the two inputs(error(ΔFs) and change in error(ΔFs)') and with the given rule base.
2. Collect the training data while simulating with FLC to design the Neuro-Fuzzy controller.
3. The two inputs, i.e., error(ΔFs) and change in error(ΔFs)' and the output signal gives the training data.
4. Use 'anfisedit' to create the Neuro-Fuzzy FIS file.
5. Load the training data collected in Step.1 and load the Neuro-Fuzzy FIS file.
6.Choose the hybrid learning algorithm.
6. Train the collected data with generated FIS up to a particular no. of Epochs.

Fig-8 shows the ANFIS structure for the designed Neuro-Fuzzy controller.

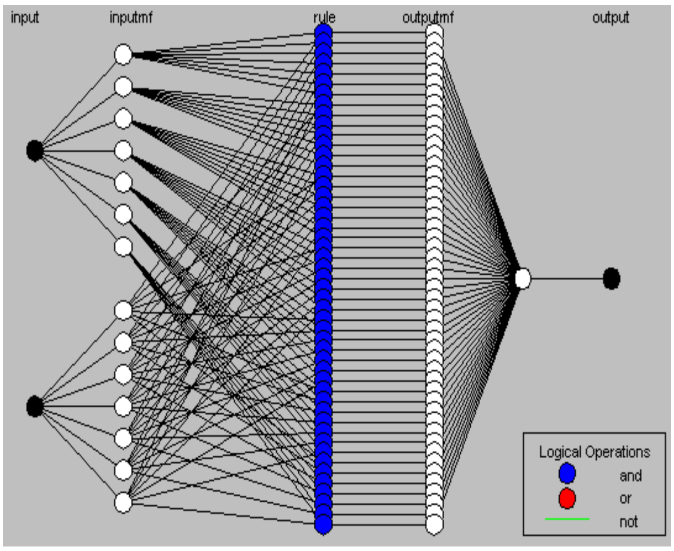

Figure-8. ANFIS model structure for LFC of wind-micro hydro-diesel hybrid power system

7. SIMULATION AND ANALYSIS

Simulations were performed using the proposed ANFIS based Neuro-Fuzzy controller , Fuzzy Logic controller (FLC-Mamdani model) and the conventional PI controller to the wind-micro hydro-diesel hybrid power system. All the performance criteria's such as settling time, overshoot and zero steady state are considered to get minimized for all the cases such as change in frequency, change in wind power, change in diesel power and change in hydro power during various load disturbances to get the optimum performance of the wind- micro hydro-diesel hybrid power system. The same system parameters given in Tables 1 were used for the above three controllers for comparison.

Simulation is carried out for 1 % ,2%, 3%,4% and 5% step increase in the power load (ΔPL=0.01 p.u. ,0.02 p.u.,0.03 p.u.,0.04 p.u. and 0.05 p.u.) at t = 0s . The overshoot and setting time of proposed ANFIS based Neuro-Fuzzy controller are lower than those of Fuzzy logic controller and conventional PI controller. The change in frequency of the system, change in wind power generation, change in diesel power generation and change in hydro power generation for 0.02 p.u. step load change is shown in Fig-9(a),9(b),9(c) and 9(d) respectively. And the change in frequency of the system, change in wind power generation, change in diesel power generation and change in hydro power generation for 0.04 p.u. step load change is shown in Fig-10(a),10(b),10(c) and 10(d).

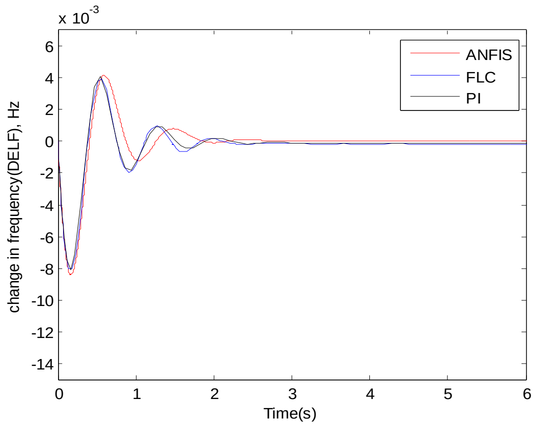

Fig-9(a) : Frequency deviation of the hybrid system for the step load change of 2%(0.02p.u.)

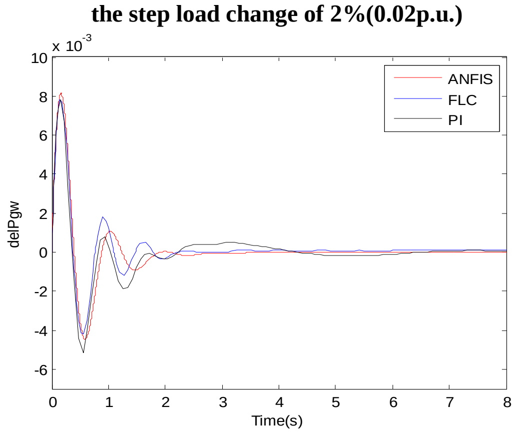

Fig-9(b) Change in wind power generation for the step load change of 2%(0.02p.u.)

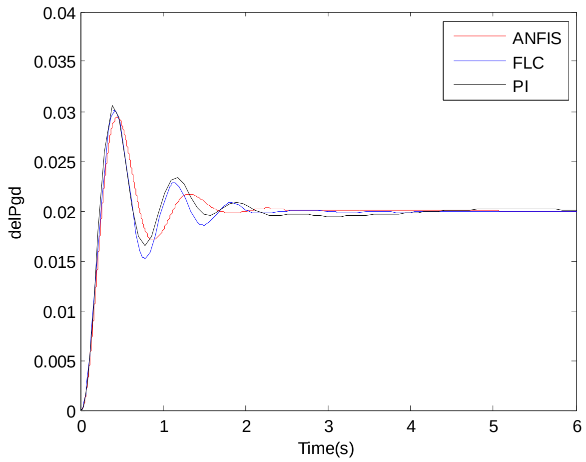

Fig-9(c) Change in diesel power generation for the step load change of 2%(0.02p.u.)

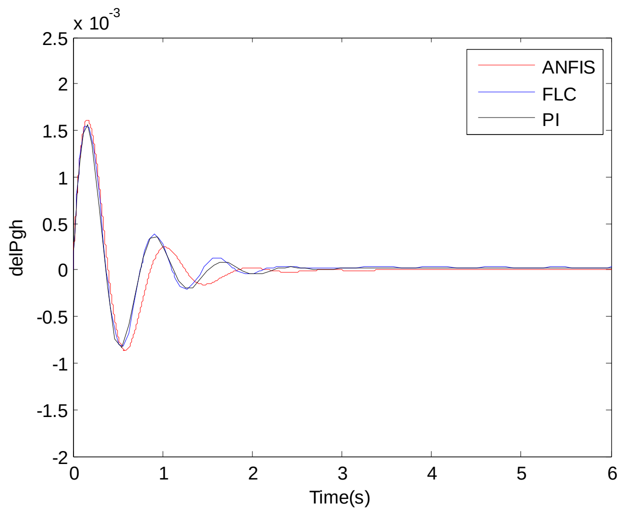

Fig-9(d) Change in hydro power generation for the step load change of 2%(0.02p.u.)

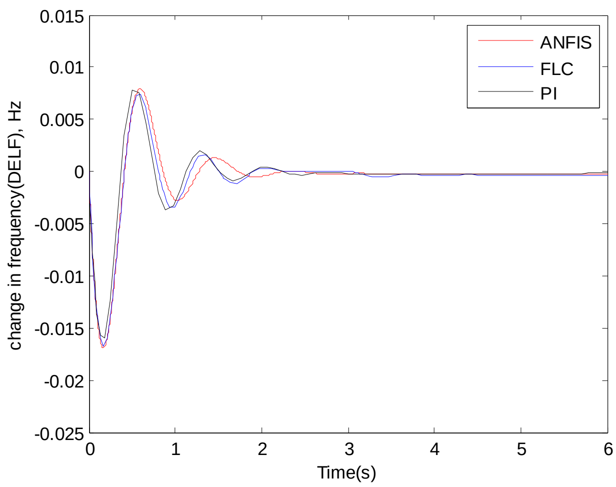

Fig-10(a) Change in frequency for the step load change of 4%(0.04p.u.)

Table-4: Settling time for deviations in frequency, wind , diesel and hydro power for various load disturbances

Load change (p.u.)	Change in frequency			Change in wind power			change in diesel power			change in hydro power		
	Proposed NFC	FLC	PI	Proposed NFC	FLC	PI	Proposed NFC	FLC	PI	Proposed NFC	FLC	PI
0.01	2.0108	2.0508	2.1824	2.1379	2.6802	5.4890	1.6971	1.9208	3.5387	1.9351	2.0442	2.1738
0.02	1.7844	2.1158	2.1789	2.4768	2.1509	5.4596	1.5938	1.9691	3.5366	1.7631	2.1046	2.1701
0.03	1.7441	3.0695	2.1824	2.4681	3.0778	5.4730	1.5676	2.0096	3.5382	1.7276	3.0307	2.1734
0.04	1.7265	3.0560	2.1816	2.4589	3.0667	5.4940	1.5556	2.0520	3.5357	1.7119	2.9750	2.1738
0.05	1.7166	3.0646	2.1799	2.4527	3.0688	5.4789	1.5488	2.0780	3.5395	1.9355	3.0068	2.1720

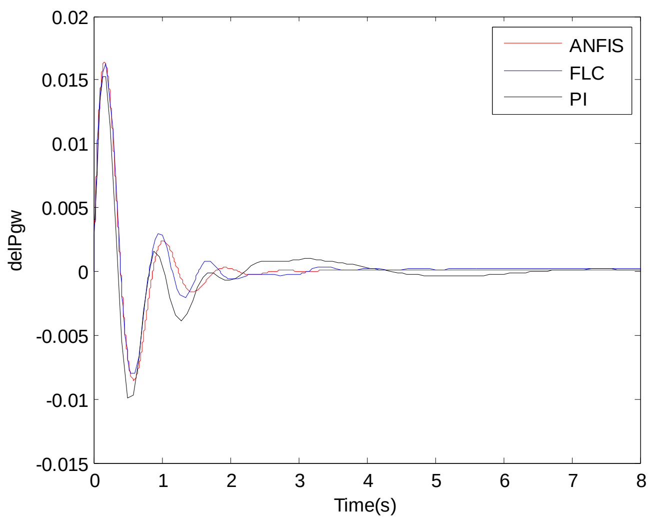

Fig-10(b) Change in wind power generation for the step load change of 4%(0.04p.u.)

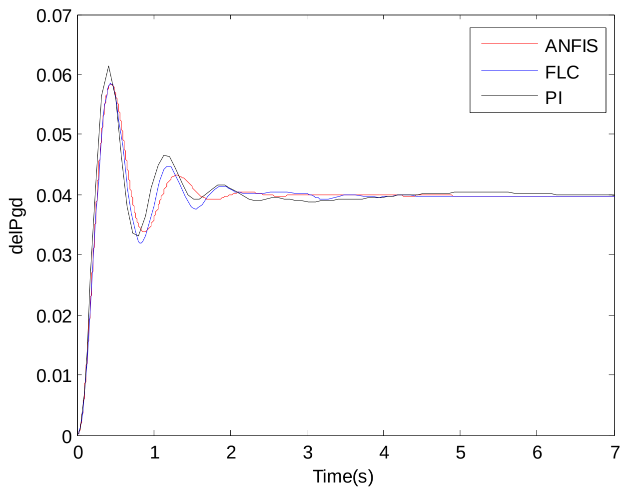

Fig-10(c) Change in diesel power generation for the step load change of 4%(0.04p.u.)

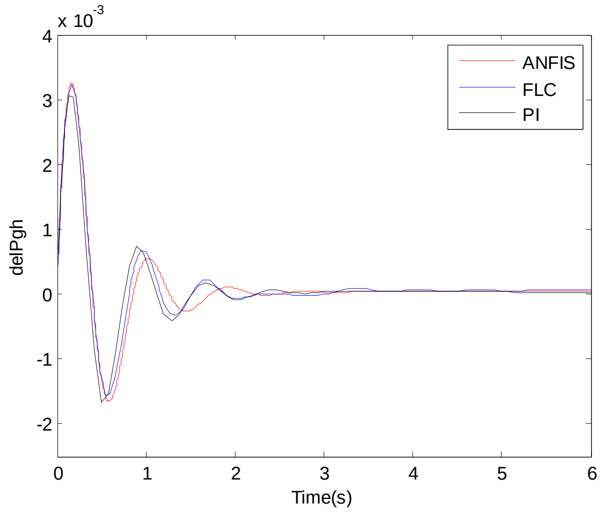

Fig-10(d) Change in hydro power generation for the step load change of 4%(0.04p.u.)

Mat lab 7.3-Simulink software is used for simulation. The overshoot and setting time of proposed ANFIS based Neuro-Fuzzy controller are lower than those of the Fuzzy logic controller(Mamdani model) and the conventional PI controller. From the simulation results , settling time for change in frequency, wind, diesel , hydro power generation for the proposed ANFIS based Neuro-Fuzzy controller, conventional PI controller and Fuzzy logic (Mamdani model) controller for a step load change of 1% , 2% ,3% ,4% and 5% are tabulated in Table -3 .

On analysing the performance from the Table-3, it is observed that the proposed ANFIS based Neuro-Fuzzy controller damps out the deviations with less settling time for various load disturbances(from 0.01 p.u. to 0.05 p.u.). The proposed ANFIS based Neuro-Fuzzy controller is reliable and maintains its response better than the fixed parameter PI controller and fuzzy logic controller, regardless of changes in load power variations.

It can be observed that the change in frequency, change in wind power generation and change in hydro power generation are maintained in the zero steady state value for various load disturbances with increase in diesel power generation . Thus deviations are damped out by LFC using proposed ANFIS based Neuro-Fuzzy controller and other two controllers by controlling the generation of the Diesel power generating unit and, thereby, of the Wind -micro hydro - diesel hybrid power system. Simulation results explicitly show that the performance of the proposed ANFIS based Neuro-Fuzzy controller is superior to the conventional PI controller and fuzzy logic controller in terms of overshoot, settling time against various load changes .

8. CONCLUSION

The Neuro-Fuzzy controller is designed for Load frequency control of an isolated wind-micro hydro-diesel hybrid power system, to regulate the frequency deviation and power deviations, based on Adaptive Neuro-Fuzzy Inference System (ANFIS) architecture . Performance comparison of the proposed paper indicates that the system response of the Load Frequency Control with the application of ANFIS based Neuro-Fuzzy controller has a quite shorter settling time.

The results obtained by using ANFIS based Neuro-Fuzzy controller proposed in this paper outperform than those of conventional PI controller and the fuzzy logic controller by its hybrid learning algorithm. The main advantage of designing the ANFIS based Neuro-Fuzzy controller is to control the frequency deviation and power deviation of the wind-micro hydro-diesel hybrid power system and to increase the dynamic Performance. It has been shown that the proposed controller is effective and provides significant improvement in system performance by combing the benefits of Fuzzy logic and Neural networks. The proposed controller maintains the system reliable for sudden load changes and proves it's superiority.

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