

Intelligent Automatic Generation Control of Two Area Interconnected Power System using Hybrid Neuro Fuzzy Controller

Sathans and A. Swarup

Abstract—This paper presents the development and application of an adaptive neuro fuzzy inference system (ANFIS) based intelligent hybrid neuro fuzzy controller for automatic generation control (AGC) of two-area interconnected thermal power system with reheat non linearity. The dynamic response of the system has been studied for 1% step load perturbation in area-1. The performance of the proposed neuro fuzzy controller is compared against conventional proportional-integral (PI) controller, state feedback linear quadratic regulator (LQR) controller and fuzzy gain scheduled proportional-integral (FGSPI) controller. Comparative analysis demonstrates that the proposed intelligent neuro fuzzy controller is the most effective of all in improving the transients of frequency and tie-line power deviations against small step load disturbances. Simulations have been performed using Matlab®.

Keywords—Automatic generation control, ANFIS, LQR, Hybrid neuro fuzzy controller

I. INTRODUCTION

IN an interconnected power system, automatic generation control (AGC) is one of the most important issues. In the event of sudden load perturbation in any area, the deviation of frequencies of all the areas and also of the tie line powers occurs, which has to be corrected to ensure generation and distribution of good quality electric power. This is achieved by AGC, the main objective of which is to keep the system frequency and the inter area tie-line power as near to the scheduled values as possible through suitable control action. Over the past decades, the issue of AGC has been dealt with extensively [1]-[2] and many researchers [3] have applied different control strategies, such as classical control, optimal state feedback control, variable structure control and robust control etc. to the AGC problem in order to achieve improved performance. All of these strategies have proved to be insufficient due to the inherently nonlinear nature and unpredictable operating conditions of power system. The advent of intelligent control techniques has solved this problem to a great extent. Several researchers [4]-[12] have effectively applied these techniques to AGC problem.

Neuro-fuzzy systems, for example, have emerged from the fusion of artificial neural networks (ANN) and fuzzy inference systems (FIS) and form a popular framework for solving real

world control problems. There are several approaches to integrate ANN and FIS and very often the choice depends on the application. One such important integration is the pioneering Adaptive Neuro-Fuzzy Inference System (ANFIS) [13], which is presently available in MatLab. In this study an ANFIS based intelligent hybrid neuro fuzzy controller is proposed as the supplementary controller for AGC of two-area interconnected thermal power system with reheat non linearity. A comparison of the proposed controller is made with the conventional PI controller, state feedback LQR controller and fuzzy gain scheduled proportional-integral (FGSPI) controller, to show the relative goodness of the proposed control strategy. The settling times, overshoots and undershoots of the power and frequency deviations are taken as the performance indices. Comparative analysis shows that the proposed intelligent hybrid neuro fuzzy controller is the most effective of all in improving the transients of frequency and tie-line power deviations against small step load disturbances.

II. CONFIGURATION OF TWO-AREA POWER SYSTEM

Fig. 1 shows the configuration of two-area interconnected power system.

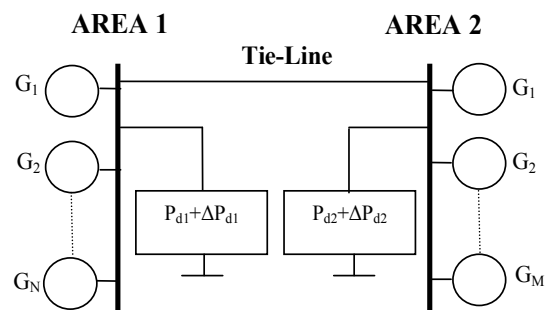


Fig. 1 Configuration of an uncontrolled two-area power system

III. PLANT MODEL DESCRIPTION

The two-area interconnected power system is taken as a test system in this study, which consists of reheat turbine type thermal unit in each area. The model of the system under consideration is as shown in Fig. 2, where symbols have their usual meanings. The conventional AGC scheme has two control loops: The primary control loop, which controls the frequency by self-regulating feature of the governor, however, frequency error is not fully eliminated; and the supplementary control loop, which has a controller that can eliminate the

Sathans is with the department of Electrical Engineering, National Institute of Technology, Kurukshetra, 136119, India (phone: 91-1744-233390; fax: 91-1744-238050; e-mail: sathans.suhag@gmail.com).

A. Swarup is with the department of Electrical Engineering, National Institute of Technology, Kurukshetra, 136119, India (phone: 91-1744-233375; fax: 91-1744-238050; e-mail: akhilesh.swarup@gmail.com).

frequency error with the help of conventional integral control action. The main objective of the supplementary control is to restore balance between each control area load and generation after a load perturbation so that the system frequency and the tie-line power flows are maintained at their scheduled values. So the control task is to minimize the system frequency deviation Δf_1 in area 1, Δf_2 in area 2 and the deviation in the

tie-line power flow ΔP_{tie} between the two areas under the load disturbances ΔP_{d1} and ΔP_{d2} in the two areas. This is achieved conventionally with the help of integral control action. The supplementary controller of the i^{th} area with integral gain K_i is therefore, made to act on ACE_i , given by (1), which is an input signal to the controller.

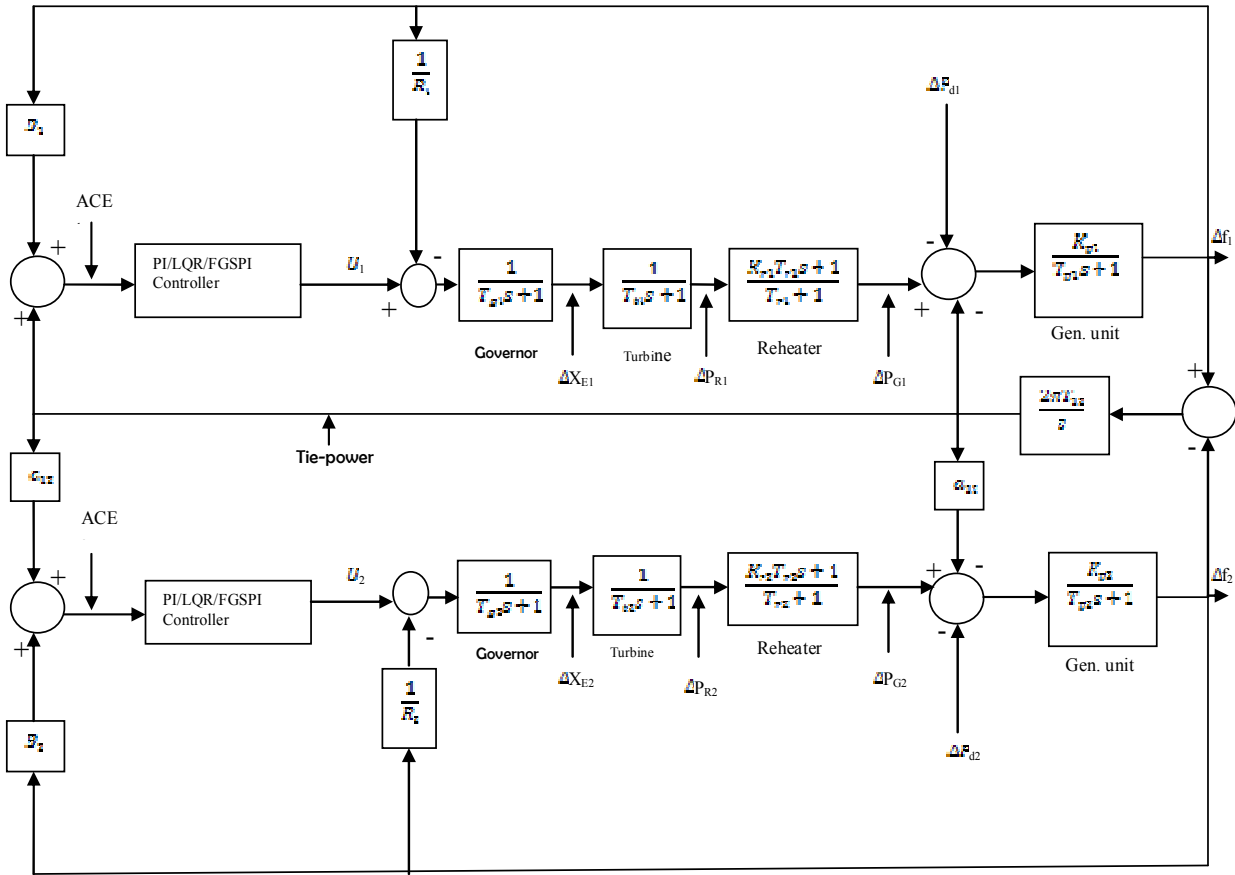


Fig. 2 Transfer function model of two-area reheat power system

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

where ACE_i is the area control error of the i^{th} area
 Δf_i = frequency error of i^{th} area
 $\Delta P_{tie,ij}$ = tie-line power flow error between i^{th} and j^{th} area
 B_i = frequency bias coefficient of i^{th} area

IV. THE CONVENTIONAL PROPORTIONAL-INTEGRAL (PI) CONTROLLER

The block diagram representation of the conventional PI controller is as shown in Fig. 3 [6]. The control signal u_i is formulated as:

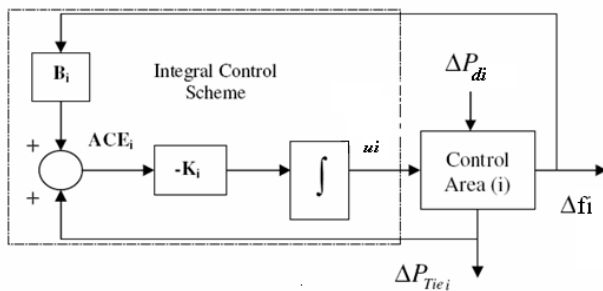


Fig. 3 Conventional PI controller installed on i^{th} area

$$u_i = -K_i \int_0^T (ACE_i) dt = -K_i \int_0^T (\Delta P_{tie,i} + B_i \Delta f_i) dt \quad (2)$$

Differentiating (2) yields

$$\dot{u}_i = -K_i (ACE_i) = -K_i (\Delta P_{tie,i} + B_i \Delta f_i) \quad (3)$$

where K_i is the gain of integral controller of i^{th} area

A. Optimization of the Integral gain K_i , and frequency bias factors B_i

In this study, we have considered $B_1=B_2=B$ and $K_{i1}=K_{i2}=K_i$. We need to optimize B and K_i values, in order to obtain good dynamic response of the AGC system. In this study B and K_i values are optimized using the integral squared error (ISE) technique by minimizing the quadratic performance index (PI) given by (4) for 0.01 p.u. step load change in area-1. The performance index curves, plotted for various values of B , are shown in Fig. 4.

$$PI = \int_0^T (\Delta P_{tie}^2 + w_1 \Delta f_1^2 + w_2 \Delta f_2^2) dt \quad (4)$$

where, w_1 and w_2 are the weight factors both of which are chosen as 0.25 for the system considered. It is observed from Fig. 4 that the optimal value of $K_i = 0.35$ and $B=0.8$ which occurs at a minimum value of $PI = 0.0009154$.

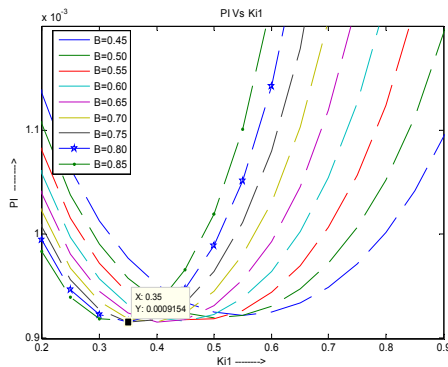


Fig. 4 The optimal integral gain K_i and the frequency bias factor B

V. STATE FEEDBACK LQR CONTROLLER

The two-area interconnected power system, shown in Fig. 2, can be modeled as a multi-variable state space model as in (5) [6].

$$\dot{x} = Ax(t) + Bu(t) + Ld(t) \quad (5)$$

where A is system matrix, B is input distribution matrix, L is disturbance distribution matrix, $x(t)$ is state vector, $u(t)$ is control vector and $d(t)$ is disturbance vector.

$$x(t) = [\Delta f_1, \Delta P_{G1}, \Delta P_{R1}, \Delta X_{E1}, \Delta P_{tie}, \Delta f_2, \Delta P_{G2}, \Delta P_{R2}, \Delta X_{E2}]^T;$$

$$u(t) = [u_1, u_2]^T; \quad d(t) = [\Delta P_{d1}, \Delta P_{d2}]^T$$

where Δ denotes the deviation from the nominal values and u_1 and u_2 are the controller outputs in Fig. 2. The system output, which depends on ACE_i , is written as:

$$y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix} = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} = Cx(t) \quad (6)$$

where C is the output matrix.

As proposed in [14] and [15], the integrals of ACE_i are also considered as states thus adding two new states to the state model given by (5) and (6), which will drive the ACE_i to zero at steady state. Defining these states as vector $q(t)$, yields a new state model given by (7) and (8):

$$\dot{x}_a = A_a x_a(t) + B_a u(t) + L_a d(t) \quad (7)$$

$$y_a(t) = C_a x_a(t) \quad (8)$$

Where

$$x_a(t) = \begin{bmatrix} x(t) \\ q(t) \end{bmatrix}; \quad y_a(t) = \begin{bmatrix} y(t) \\ q(t) \end{bmatrix}; \quad x_a(0) = \begin{bmatrix} x(0) \\ q(0) \end{bmatrix}$$

$$A_a = \begin{bmatrix} A & 0 \\ C & 0 \end{bmatrix}; \quad B_a = \begin{bmatrix} B \\ 0 \end{bmatrix}; \quad L_a = \begin{bmatrix} L \\ 0 \end{bmatrix}; \quad C_a = \begin{bmatrix} C & 0 \\ 0 & I \end{bmatrix}$$

The control vector u is obtained by means of feeding back all the states through a constant feedback gain matrix K .

$$u = -Kx_a(t) \quad (9)$$

The gain matrix K is determined by minimizing the quadratic performance index given by (10).

$$J = \int_0^{\infty} (X_a^T Q X_a + u^T R u) dt \quad (10)$$

where Q and R are 11×11 and 2×2 symmetric positive definite matrices, respectively, which are identified from the quadratic performance index. Then using the matrices A_a , B_a , Q and R , the optimal values of feedback gain matrix K are computed by solving the algebraic matrix Riccati equation using the LQR built-in function in Matlab®.

VI. THE FUZZY GAIN SCHEDULED PROPORTIONAL-INTEGRAL CONTROLLER

Fuzzy gain scheduling is considered to be the most promising alternative combining fuzzy logic with conventional controllers. The approach means that the values of the controller parameters are gathered to a fuzzy rule base with the operation conditions where they are valid. During the control, the fuzzy gain scheduler gives appropriate values for the controller parameters. Here a fuzzy gain scheduled proportional-integral (FGSPI) control scheme is implemented for the system considered. In this study, the gain scheduling is done based on the frequency deviation step response of the

system for different values of K_i (shown as K in Fig 5). As can be seen from Fig. 5, a higher value of K_i results in reduction of maximum deviation of the system frequency but the system oscillates for longer times, whereas lower value of K_i yields relatively higher maximum frequency deviation at the beginning but provides effective damping in the later cycles. This necessitates a variable K_i , therefore, higher values of K_i are scheduled at the initial stage and then changed gradually depending on the system frequency changes. In this study, we use fuzzy rule-based scheme for gain scheduling of PI controllers according to ACE and rate of change of ACE. For the FGSPI controller, the Mamdani fuzzy inference mechanism was used with five triangular membership functions for each of the three linguistic variables (ACE_i , $d(ACE_i)/dt$, K_i) with suitable choice of intervals of the membership functions (-0.1 to 0.1 for ACE_i); (-0.03 to 0.03 for $d(ACE_i)/dt$); and (0.001 to 1 for K_i), where ACE_i and $d(ACE_i)/dt$ act as the inputs of the controller and K_i is the output of the controller. Defuzzification has been performed using bisector of area method. The appropriate fuzzy rules, developed in our study for the FGSPI controller, are given in Table I, where, NB, NS, Z, PS, PB represent negative big, negative small, zero, positive small, and positive big respectively.

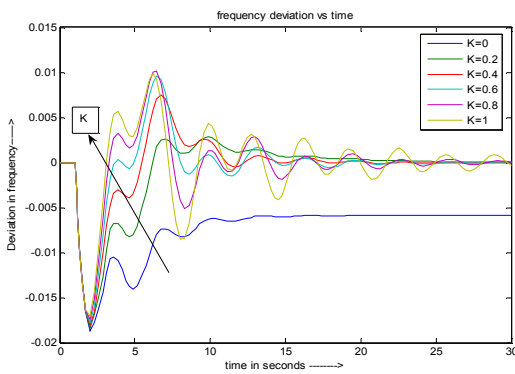


Fig. 5 Frequency deviation step response

VII. THE PROPOSED HYBRID NEURO-FUZZY CONTROLLER

In this work we propose to use an adaptive network based inference system (ANFIS) in order to generate fuzzy membership functions and control rules for the hybrid neuro-fuzzy controller. A fuzzy gain scheduled proportional integral controller is used to provide the required training data. The controller design process consists of generating input-output

data pairs to identify the control variables range and initial fuzzy memberships, and then to tune or adapt them using an ANFIS network structure. The controller inputs are the area control error (ACE) and the rate of change of ACE ($d(ACE)/dt$) and the output is the control signal.

A. Algorithmic Steps to design hybrid neuro-fuzzy controller:

1. Draw the Simulink model of the power system under consideration with FGSPI controller and simulate it with the given rule base.
2. Collect the training data while simulating with FGSPI controller. The two inputs, i.e., ACE and $d(ACE)/dt$ and the output signal of the controller give the training data. The training data contains as much information as possible about the plant behavior for different load perturbations
3. Use anfisedit to create the .fis file.
4. Load the training data collected in Step 2 and generate the FIS with suitable (like gaussian/gbell etc.) membership functions.
5. Train generated FIS with the collected data up to a certain no. of Epochs.

In this study, ANFIS is trained with back propagation algorithm, using 100 epochs and an initial step size of 10^{-3} , which was the best step, found that gives acceptable error convergence.

VIII. SIMULATION RESULTS AND ANALYSIS

The objective of the simulations was to test the different control algorithms proposed in this study for AGC of two-area interconnected power systems with reheat nonlinearity. Simulations were performed using Matlab@Simulink. The parameters of the power system simulated are given in appendix A. The step load disturbance of 0.01 p.u. is applied in area-1 for all the controllers and the frequency oscillations and tie-line power flows are investigated. System dynamic performances, in terms of the deviations of frequencies of each area and tie-line power flows, are shown in Figs. 7 through 9. It can be noticed from these figures that the hybrid neuro-fuzzy controller is very effective in damping the frequency and tie-line power oscillations and reduces the settling time, overshoot and undershoot as compared to other controllers.

TABLE I
RULE BASE FOR FGSPI CONTROLLER

		ACE				
		NB	NS	Z	PS	PB
d/dt(ACE)	NB	PB	PB	PB	PS	Z
	NS	PB	PB	PS	Z	Z
	Z	PS	PS	Z	NS	NS
	PS	Z	Z	NS	NB	NB
	PB	Z	NS	NB	NB	NB

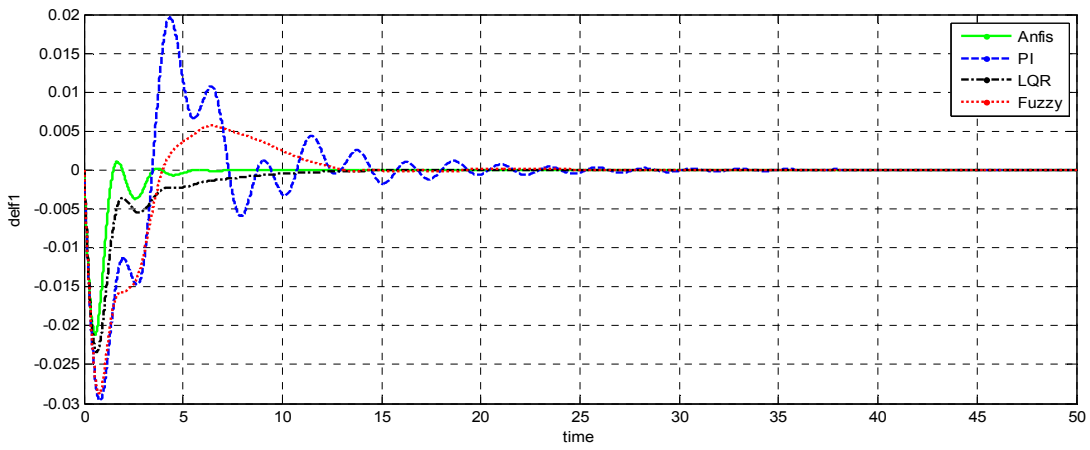


Fig. 7 Frequency deviation in area-1 (Δf_1) with different controllers

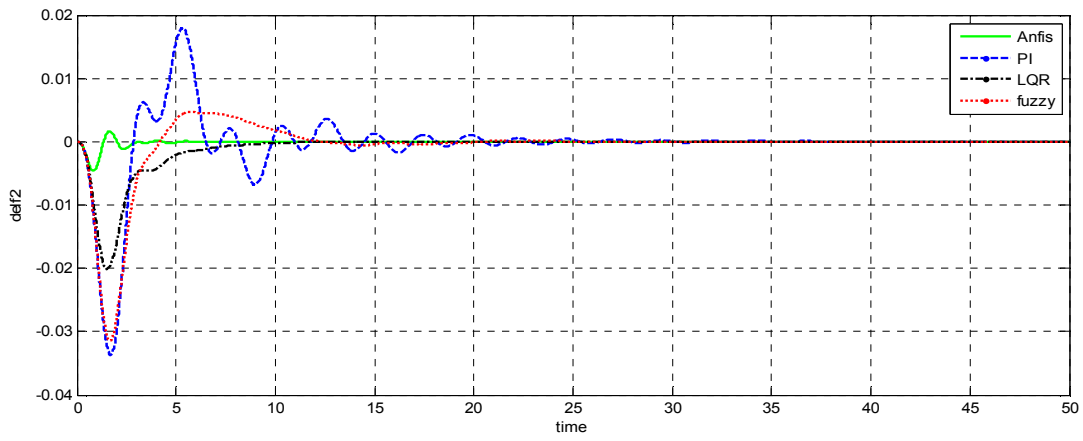


Fig. 8 Frequency deviation in area-2 (Δf_2) with different controllers

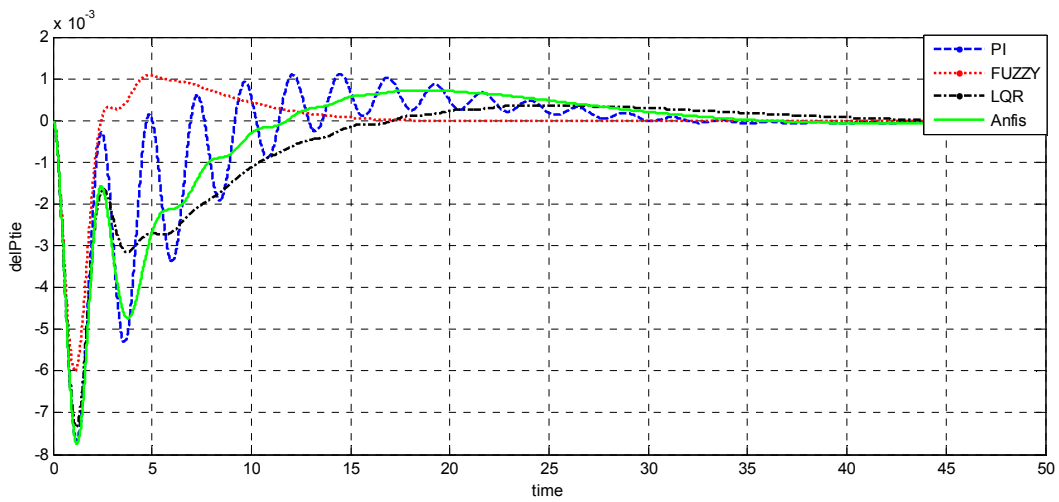


Fig. 9 Tie-line power deviation (ΔP_{tie}) with different controllers

IX. CONCLUSION

In this paper, the hybrid neuro-fuzzy controller, based on ANFIS architecture, is proposed for a two-area interconnected thermal power system with reheat nonlinearity in each area. The results have been compared against conventional PI controller, state feedback LQR controller and fuzzy gain scheduled proportional-integral (FGSPI) controller, developed and implemented on the same system. The results prove that the proposed hybrid neuro-fuzzy controller gives improved dynamic response as compared to all other controllers implemented in this study, in terms of damping of oscillations, overshoots, undershoots and settling times of the frequency and tie-line power deviations. The proposed intelligent controller is not only simple in design but also easy to implement. Moreover, the ability to adapt to disturbances makes the proposed intelligent controller more effective and it is expected that the controller will perform effectively under disturbances different from the ones applied during the training process.

Also the learning ability of ANFIS architecture can be used to generate mature fuzzy membership functions and fuzzy rules based on training data when human expert knowledge is not reliable.

X. APPENDIX

Two-area interconnected power system parameters

$$T_g = 0.08; B_1 = B_2 = 0.8; R_1 = R_2 = 2.4; T_{12} = 0.0707$$

$$T_p = 20; K_p = 120; T_i = 0.3; T_r = 10; K_r = 0.33; a_{12} = -1$$

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Sathans was born in Haryana, India, in 1970. He received the B. Tech. and M. Tech. degrees in Electrical Engineering from National Institute of Technology, Kurukshetra in 1992 and 1996 respectively. He is currently pursuing his research work towards his Ph. D. degree in the department of Electrical Engineering, National Institute of Technology, Kurukshetra. His research area is Intelligent Control. He is currently an Associate Professor at National Institute of Technology, Kurukshetra, India.

Akhilesh Swarup is a Professor in the department of Electrical Engineering at National Institute of Technology, Kurukshetra, India. He received the Ph. D. degree in Electrical Engineering from Indian Institute of Technology, Delhi. His research interests include Control Systems, Robust Control, Robotic Control and Intelligent Control. He is a senior member of IEEE.