AGC OF DIVERSE SOURCE DEREGULATED POWER SYSTEM USING

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Abstract: *This article proposes an adaptive controller in a deregulated power system for generation related ancillary services. In an interconnected power system, due to the intense participation of Gencos, the frequency and tie-line responses become aggressive in nature, which in turn affects the ancillary services in the power system like AGC. The ANFIS controller is designed here using MATLAB – Simulink for a five area control structure, in order to retain the balance between the generation and demand and also the steady state error of the proposed control area. The test system constructed with Thermal-hydro-Gas power generations and the performance of the controller is evaluated by applying large load disturbances and sudden perturbations with nonlinearities like Generation Rate Constraint (GRC) and Backlash. The simulated results show that the proposed control strategy provides better performance for this large interconnected power system in a deregulated environment.*

Keywords: *AGC, GRC, Deregulated system, Multisource power generation.*

1. INTRODUCTION

Nowadays, the power system possessed with large interconnected areas to handle the power requirements. An unexpected change in load, originates the fluctuations in the areas of the interconnected system which in turn resulted in deviation in frequency and tie-line power. The AGC is responsible for tracking the system performance and for providing the quality of power to the consumers. The electric power industry being revolutionized and offer the consumers to buy the power of their choice in the open market. The deregulated power system unbundled the entities of electrical utilities into generation companies (Gencos), transmission companies (Transcos) and distribution companies (Discos). The independent system operator (ISO) is taking care of all the power exchanges between the utilities and also controls the ancillary services in the system.

This article proposes an ANFIS controller for AGC with nonlinearities and disturbances for uneven number of Gencos and Discos, the attention has been paid on trajectory sensitivity of the five area deregulated structure. To validate the performance of the proposed controller, a study has been carried out for three test cases. The simulation for the five area control model is proceeded with poolco based transaction, bilateral transaction and contract violation test cases. The area control error (EQ.1) is responsible for accomplishing the assignment of AGC [9].

$$ACE = \sum_j \left(\Delta P_{tieij} + b_i \Delta f_i \right) \qquad (1)$$

Over the decades, the lot of researchers has been concentrated on AGC in a large scale power system. The integral of ACE is taken as control signal in an industry [12]. The frequency and tie line error reaches zero steady state while using ACE as control signal [16]. The conventional LFC schemes have been modified [23-25] and the dynamic response of the system improved by considering the effects of dynamics on contract [1, 21-22]. The AGC becomes a challenging one for a future power environment [17-18]. The reliability of the power system has been ensured only by advanced economic, efficient,

enhanced control scheme [20, 27-28]. The slower response of the governor is not capable for diminishing the deviations [1]. Conventional controller provides more frequency deviation and takes more for computation [10&14]. Fixed gain controller less effective for a wide range of operating condition [5-7]. Self adjusting gain based adaptive controller should be designed to track the operating conditions [2, 4& 14]. Few of them proposed FACTS devices [15]. Some of them have been tried for ANN for AGC [2, 4, 8 & 26] for learning reinforcement [13] fuzzy [10]. Recently ANFIS proposed for hydro thermal control system [11, 19].

From the literatures, it is clear that most of them concentrated on interconnected and few of them focused on deregulated system and less concentration is made on adaptive controllers. The ANFIS controller which is adaptive in nature is proposed here with hydro thermal gas power generations in a deregulated power system for AGC in consideration with nonlinearities for large load variations and various test cases.

2. Problem Formulation

This article proposes a controller for AGC in a deregulated system. The problem is to maintain the steady state error of the frequency and tie line deviations (i.e., ACE=0). The participation of each Discos with several Gencos are illustrated by Disco Participation Matrix (DPM). The [Eq. 2] shows the DPM for the power system of nth area. The column and the rows depict the Discos and Gencos of the system. The total load power contracted by a Disco with a Genco is shown in each entry of the DPM [24].The sum of total entries in a column corresponds to one

DISCO be equal to one (i.e.) $\sum_{j=1}^{n} cpf_{ij} = 1$

$$DPM = \begin{pmatrix} cpf_{11} & cpf_{12} & \cdots & cpf_{1n} \\ cpf_{21} & cpf_{22} & \cdots & cpf_{2n} \\ \vdots & \vdots & & \vdots \\ cpf_{n1} & cpf_{n2} & \cdots & cpf_{nn} \end{pmatrix} \quad (2)$$

$$AGPM = \begin{pmatrix} AGPM_{11} & .. & AGPM_{1N} \\ : & : & : \\ AGPM_{N1} & .. & AGPM_{NN} \end{pmatrix} \quad (3)$$

Where,

$$AGPM_{ij} = \begin{pmatrix} gpf_{(si+1)(zj+1)} & .. & gpf_{(si+1)(zj+mj)} \\ : & : & : \\ gpf_{(si+ni)(zj+1)} & .. & gpf_{(si+ni)(zj+mj)} \end{pmatrix}$$

For i,j=1,2,....N, and $\quad s_i = \sum_{k=1}^{i-1} n_i$; $\quad z_j = \sum_{k=1}^{j-1} m_j \quad ; s_1 = z_1 = 0$

Where, n_i and m_j are the number of GENCOs and DISCOs in area i and the generation participation factor (gpf_{ij}) shows the possible contracts between Genco and Disco. The power exchange between Gencos and various Discos is described through Augmented Generation Participation Matrix (AGPM) [Eq. 3]. The entries in a each column shows unity for AGPM.

The scheduled contracted power exchange is given [3]:

$\Delta P_{tie12}^{scheduled} =$ (Demand of Discos in area2 from Gencos In area1) - (Demand of Discos in area1 from Gencos in area2)

$d_i = \Delta P_{loc,i} + \Delta P_{di}$ \hfill (4)

Where,

$\Delta P_{loc,i} = \sum_{j=1}^{mi} \Delta P_{Lj-i} ; \ \Delta P_{d,i} = \sum_{j=1}^{mj} \Delta P_{ULj-i}$

$\eta_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} T_{ij} \Delta f_j,$ \hfill (5)

$\xi_i = \Delta P_{tie,ik,sch} \sum_{\substack{k=1 \\ k \neq i}}^{mj} \Delta P_{tie,ik,sch},$ \hfill (6)

$\Delta P_{tie,ik,sch} =$
$\qquad \sum_{t=1}^{mk} apf_{(si+j)(zk+t)} \Delta P_{Lt-k}$

$\sum_{j=1}^{ni} - \sum_{t=1}^{nk} \sum_{j=1}^{mi} apf_{(sk+t)(zi+j)} \Delta P_{Lj-l}$ \hfill (7)

$\Delta P_{tie,i,error} = \Delta P_{tie,i-actual} - \xi_i$ \hfill (8)

$\rho_i = [\rho_{1i} \dots \rho_{ki} \dots \rho_{nii}]^T$

$; \rho_{ki} = \sum_{j=1}^{N} [\sum_{t=1}^{mj} gpf_{(si+k)(zj+t)} \Delta P_{Lt-j}]^T$ \hfill (9)

$\Delta P_{m,k-i} = P_{ki} + apf_{ki} \sum_{j=1}^{mj} \Delta P_{ULj-i}$ \hfill (10)

Where, k=1,2.....n_i and $\Delta Pm,ki$ is the desired total power generation of a GENCO k in area i, moreover should track the demand of the DISCOs in contract with it in the steady state.

3. Test System

The problem is defined for AGC of deregulated system. A five area control structure with un uniform distribution of Discos and Gencos are considered as shown in Fig. 1. The Table 1 shows the

plant and control parameters used for modelling the control structure in a deregulated system.

The Governor Dead band resulted in the total quantity of a sustained speed change such that there is no resulting change. The characteristic of the speed governor is a nonlinear one and it has to be linearised.

The limiter for the governor dead band is 0.06% [26]. There will be an apparent steady state speed regulation (R) raise in governor dead band. The back lash, a linkage between the camshaft and piston resulted in governor dead band.
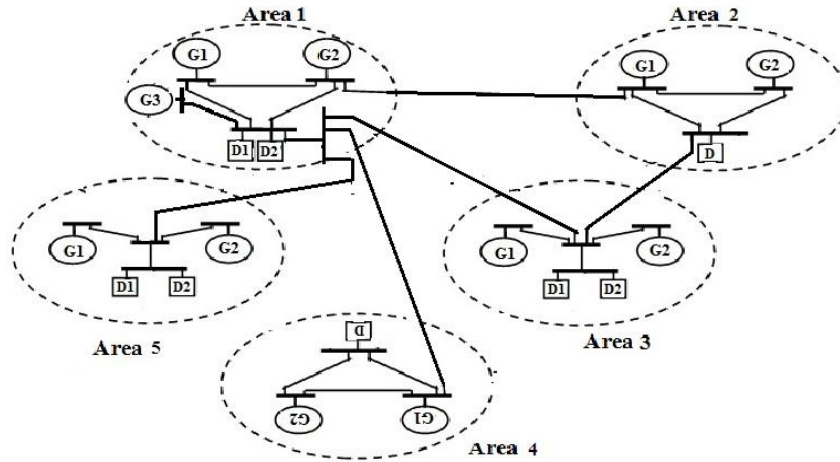

Fig.1. Structure of five control area restructured power system.

Table 1.Power system plant and control parameters

Area 1			Area 2		Area 3		Area 4		Area 5	
Thermal-Hydro-Gas			Hydro-Thermal		Thermal-Hydro		Hydro-Thermal		Thermal-Gas	
GENCO 1	GENCO 2	GENCO 3	GENCO 1	GENCO 2	GENCO 1	GENCO 2	GENCO 1	GENCO 2	GENCO 1	GENCO 2
Thermal	Hydro	Gas	Thermal	Hydro	Thermal	Gas	Thermal	Hydro	Thermal	Gas
T_g=0.06s	T_g=0.2s	T_g=0.049 s	T_1=0.06s	T_g=0.2s	T_g=0.06s	T_1=0.049s	T_1=0.06 s	T_g=0.2s	T_g=0.06 s	T_1=0.049 s
T_t=0.3s	T_t=0.55s	T_t=0.2s	T_3=10.2s	T_t=28.149s	T_t=10.2s	T_3=1.1s	T_3=10.2 s	T_t=28.149 s	T_t=10.2 s	T_3=1.1s
R=0.3333Hz/p.u. MW	K_r =0.3113	K_r =0.5	T_2=0.3s	R=.29633Hz/p.u.MW	K_r =0.33	T_2=0.2s	T_2=0.3s	R=.29633Hz/p.u.MW	K_r =0.33	T_2=0.2s
T_r=10.2s	T_r=10.6 s	T_r=1.1s	T_w =1s	K_g=1	T_r=10s	T_w =1.5s	T_w =1s	K_g=1	T_r=10s	T_w =1.5s
	R=0.32Hz/p.u.MW	R=.33Hz/p.u.MW	R=0.32Hz/p.u.MW	K_t=1	R=0.2899Hz/p.u.MW	R=0.3077Hz/p.u.MW	R=0.32Hz/p.u.MW	K_t=1	R=0.2899Hz/p.u.MW	R=0.3077Hz/p.u.MW
K_g=1	K_g=1	K_g=1	K_g=1		K_g=1	K_g=1	K_g=1		K_g=1	K_g=1
K_t=1	K_t=1	K_t=1	K_t=1		K_t=1	K_t=1	K_t=1		K_t=1	K_t=1
K_p=20 Hz/ p.u. MW T_p=120s B=0.532p.u. MW/Hz Prated=2000 MW (Nominal Load) P°= 1000 MW f=60Hz			K_p=20 Hz/ p.u. MW T_p=120s B=0.495p.u. MW/Hz Prated=2000 MW (NominalLoad) Po= 1000 MW f=60Hz		K_p=20 Hz/ p.u. MW T_p=120s B=0.542 p.u.MW/Hz Prated=2000 MW (Nominal Load) Po= 1000 MW f=60Hz		K_p=20 Hz/ p.u. MW T_p=120s B=0.495p.u. MW/Hz Prated=2000 MW (NominalLoad) Po= 1000 MW f=60Hz		K_p=20 Hz/ p.u. MW T_p=120s B=0.542 p.u.MW/Hz Prated=2000 MW (Nominal Load) Po= 1000 MW f=60Hz	
T12=T13=T23= T14-T15=0.543 p.u/Hz										

This backlash is the reason for continuous sinusoidal oscillations in the natural period of about 2secs. The structure for i[th] area in the presence of nonlinearities is shown in Fig.2.
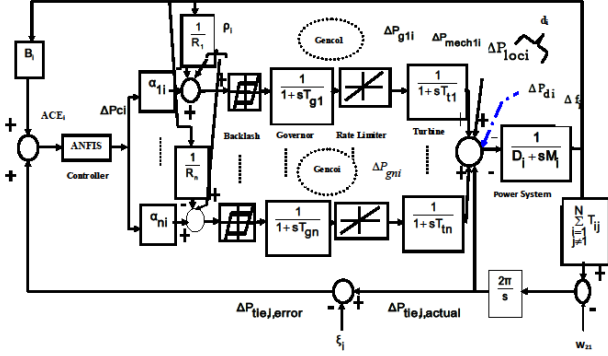

Fig.2.The ith area Control structure of a deregulated system with GRC and Backlash

4. Adaptive Neuro Fuzzy Inference System

The neuro fuzzy approach is considered for an AGC, since it is an adaptive network without any synaptic weights, although it has the node such as adaptive and non-adaptive nodes. The classical feed forward topology of ANN easily transforms this into an adaptive network. It is similar as that of the adaptive network simulator, Takagi–Sugeno's fuzzy controllers and it is comparably the same functionality like Fuzzy Inference System (FIS) (Gayadhar Panda, Sidhartha Panda & Cemal Ardil, 2009). For the given set of input/output, the ANFIS regulates the non-linear and linear parameters using back propagation gradient descent and least squares methods.

The architecture of ANFIS for 2-input, type-3 with 9 rules is shown in Fig. 3. The input space is divided into 9 fuzzy subspaces since, three membership functions are associated with each input and they are governed by fuzzy if-then rules.

The fuzzy reasoning is expressed in Fig. 4 which is if x is A1 and y is B1, then Z1 = p1x + q1y + r1. The premise part of a rule defines a fuzzy subspace, while the consequent part specifies the output within this fuzzy subspace. The functions of each node in a layer are described below:

The *Layer* 1 is the input layer. The external crisp signals are passed to the next layer. *Layer* 2 is the fuzzification layer; the crisp signals are fuzzified based on Gaussian membership function which is given by

$$O_i^1 = \mu_{A_i}(x) = 1/\left[1 + \left|\frac{x - c_i}{a_i}\right|^{2b_i}\right] \tag{11}$$

In other words, $o^1{}_i$ is the membership function of A_i and it indicates the degree to which the given x satisfies the measure A_i. Where, x, A_i are the input and linguistic associated with this node function for i[th] node, respectively. *Layer* 3 is the rule layer. The firing strength of each fuzzified neuron is calculated in this layer corresponds to a Sugeno-type fuzzy rule.

$$O_i^2 = \mu_{A_i}(x).\mu_{B_i}(y) \tag{12}$$

In an ANFIS, the conjunction of the rule antecedents is evaluated by the operator product. *Layer* 4 is the normalisation layer. The normalised firing strength of each neuron from the layer 3 is calculated through the ratio of the firing strength of a given rule to the sum of firing strengths of all rules.

$$O_i^3 = \overline{w_i} = \frac{w_i}{w_1 + w_2} \tag{13}$$

Layer 5 is the defuzzification layer. Each neuron in this layer is connected to the respective normalisation neuron, and also receives initial inputs, *x* and *y*. The weighted average defuzzification method is used here for processing the output as per the rules defined.

$$O_i^4 = \overline{w_i}f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{14}$$

$p_i, q_i \& r_i$ are the parameter set in the layer referred as consequent parameters. *Layer* 6 is represented by a single summation neuron. The sum of the outputs of all the neurons from the defuzzification layer gives the ANFIS output, z (ΔPc). Where, $\overline{w_i}$ output of the layer,

$$O_i^5 = \sum w_i f_i \frac{\sum_i w_i f_i}{\sum_i f_i} \tag{15}$$

The basic learning rule is the back propagation gradient descendent, which calculates error signals (the derivative of the squared error with respect to each node's output) recursively from the output layer backward to the input nodes.
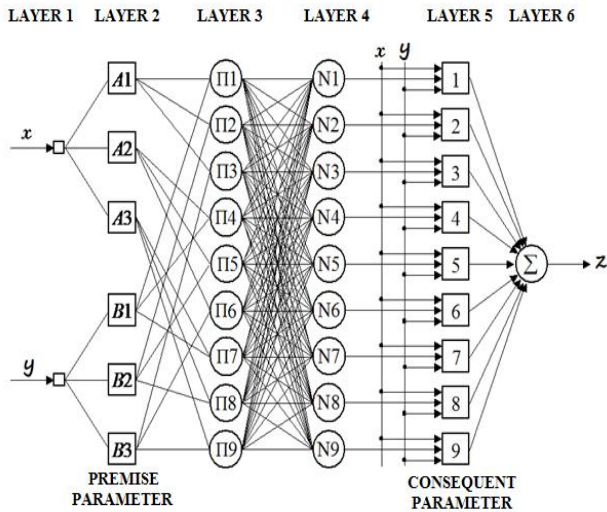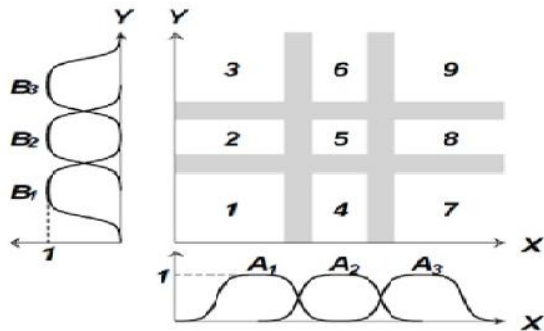

Fig. 3 Architecture of ANFIS controller

Fig. 4 Fuzzy reasoning of ANFIS controller

This learning rule is exactly the same as the back propagation learning rule used in the common feed forward neural networks.

$$f = \overline{w_i} f_1 + \overline{w_i} f_2 = (\overline{w_1} x) p_1 + (\overline{w_1} y) q_1 + (\overline{w_1}) r_1 + (\overline{w_2} x) p_2 + (\overline{w_1} y) q_2 + (\overline{w_1}) r_2 \tag{16}$$

The hybrid learning algorithm combines the gradient descent and the least-squares method for an optimal parameter search by equation (4.6). The Multi Layer Perceptron (MLP) model is employed for AGC of deregulated system, the back-propagation technique

is implemented here so as to reduce the minimum square error between the actual output and the objective of each pattern in the training. The network weights are updated in a recursive algorithm starting from the output layer and working backward to the first hidden layer. The learning process of ANFIS system acquires the semantic properties of the essential fuzzy system into account.

4.1   ANFIS controller design

The Sugeno-type Fuzzy Inference System (FIS) controller is used for realizing the ANFIS controller. The inputs considered here are the ACE and derivative of the ACE. Through the fuzzy membership function, the output (ΔPc) for the AGC is derived. The ANFIS-Editor is used for realizing the system and for putting into practice.

The design steps for ANFIS controller in MATLAB Simulink is as follows:
1. Sketch the Simulink model with fuzzy controller and simulate it with the specified rule base.
2. Collect the training data while simulating the model.
3. The two inputs, i.e., ACE and d(ACE)/dt and the output signal, ΔPc provides the training data.
4. Use anfisedit to generate the ANFIS.fis file.
5. Stack the training data composed in Step 3 and create the FIS with Gaussian membership function.
6. Train the collected data with generated FIS up to a particular number of epochs.
7. Save the FIS. This FIS file is the artificial neural and fuzzy enhanced ANFIS file.

5. Simulation Results And Discussion

The simulation has been carried out for AGC in a deregulated power system for multi source power generation. The five area control structure is considered here with nonlinearities to validate the proposed controller, ANFIS. The study has been made for three test cases, namely Poolco Transactions, Bilateral Transactions and for the worst case, Contract violations [3]. The ANFIS controller provides a zero steady state error with minimum settling time, overshoot and undershoot. The GENCO power deviation for the test cases is presented in Table 2.

5.1 Test Case 1 Poolco Transactions

For this case, the Discos are restricted in buying power from the other Gencos except their control

areas. The power exchange between the Discos and available Gencos are being simulated based on the following AGPM. The results thus obtained for this case is tabulated in Table 3 and Table 4.The frequency and tie-line power response for this scenario for the five area is shown in figures 5 to 8 in red colour.

$$AGPM = \begin{pmatrix} 0 & 0 & 0.3 & 0 & 0.1 & 0.2 & 0 & 0.3 \\ 0.5 & 0 & 0 & 0.2 & 0 & 0.1 & 0.1 & 0 \\ 0 & 0.3 & 0 & 0 & 0.25 & 0.1 & 0 & 0 \\ 0.25 & 0.2 & 0.4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.3 & 0.1 & 0.25 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.2 & 0.2 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.35 & 0.15 & 0 & 0 & 0 \\ 0 & 0.3 & 0 & 0 & 0 & 0.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.2 & 0 & 0 \\ 0.25 & 0 & 0 & 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.3 & 0.7 \end{pmatrix}$$

Table 2.Actual power generated (pu)

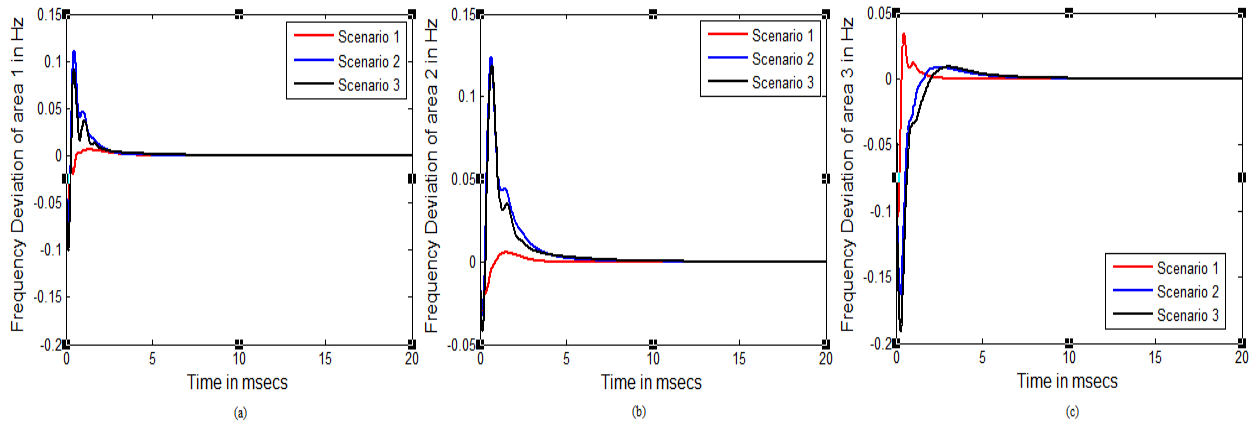| Area	Genco	Scenario		
		1	2	3
1	1	0.1	0.09	0.107
	2	0.04	0.085	0.097
	3	0.075	0.09	0.11
2	1	0.042	0.065	0.075
	2	0.09	0.085	0.1
3	1	0.05	0.09	0.105
	2	0.06	0.06	0.068
4	1	0.125	0.05	0.07
	2	0.058	0.02	0.03
5	1	0.11	0.1	0.11
	2	0.045	0.065	0.0825

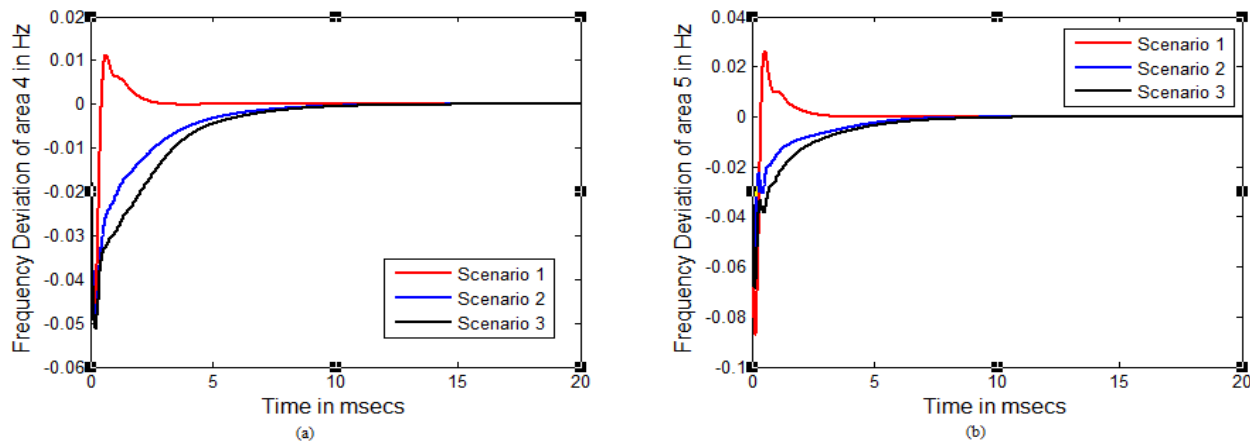Fig. 5 Frequency deviation (a) area 1 (b) area 2 (c) area 3
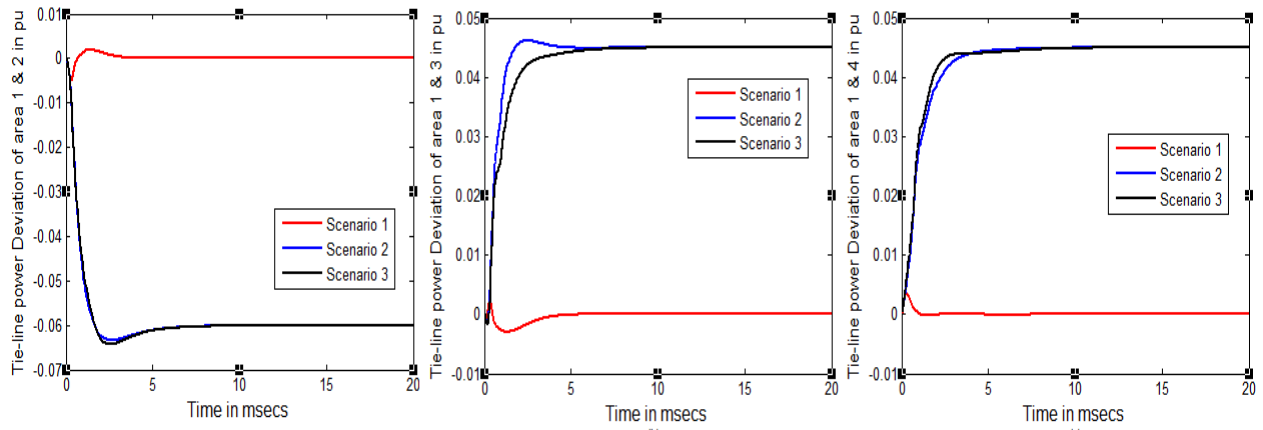

Fig. 6 Frequency deviation (a) area 4 (b) area 5

Fig. 7 Tie line power deviation between (a) area 1& 2 (b) area 1& 3 (c) area 1 & 4
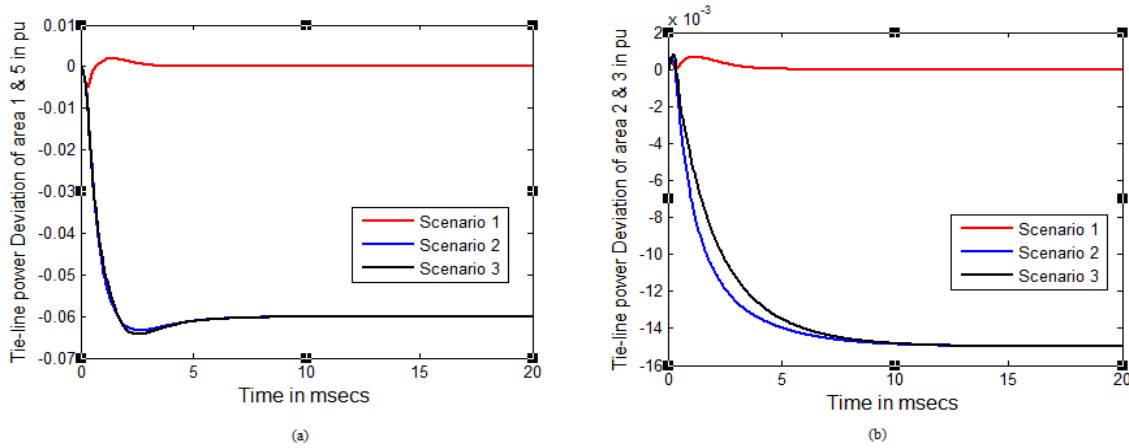

Fig. 8 Tie line power deviation between (a) area 1 & 5 (b) area 2 & 3

5.2   Test Case 2 Poolco and bilateral based transactions

The Discos are allowed for transactions with any GENCOs within the area or other areas in the control structure. The contract of this scenario has been listed in the following AGPM. The simulated values are presented in Table 3 and Table 4. The simulated results for this scenario are shown in figures 5 to 8 in blue colour.

$$AGPM = \begin{pmatrix} 0 & 0 & 0.3 & 0 & 0.1 & 0.2 & 0 & 0.3 \\ 0.5 & 0 & 0 & 0.2 & 0 & 0.1 & 0.1 & 0 \\ 0 & 0.3 & 0 & 0 & 0.25 & 0.1 & 0 & 0 \\ 0.25 & 0.2 & 0.4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.25 & 0.1 & 0.25 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.2 & 0.2 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.35 & 0.15 & 0 & 0 & 0 \\ 0 & 0.25 & 0 & 0 & 0 & 0.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.2 & 0 & 0 \\ 0.25 & 0 & 0 & 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.3 & 0.7 \end{pmatrix}$$

5.3 Test Case 3 Contract violation

In this case, the Discos demands excess of power from the contracted Gencos than they prescribed in the agreement. This excess of power is located as an un-contracted demand. This case has been carried out for various demand condition. The main objective of the scenario is to evaluate the competence of the ANFIS controller for the unexpected load disturbances, uncertainties in the presence of nonlinearities. The Figures 5 to 8 shows the response characteristics for this case in black colour. The results shows that, the response reaches its steady state error with minimum overshoot and undershoot and also it takes less time for reaching the zero steady state.

The simulated results proves that the proposed controller is capable of providing better performance for the test cases considered and for a wide range of load perturbations.

6. CONCLUSIONS

For any real time grid in operation, the multi source generations are common. An ANFIS controller is proposed here for AGC problem in a five area deregulated system. The three test cases were considered for assessing the performance of controller. The performance measure shows the better results for the proposed controller. The simulated values and responses are presented which shows that the proposed system is capable of providing the zero steady state error. The proposed controller achieves reliability over tracking the frequency and tie line power deviations for a wide range of load disturbances and system uncertainties. The ANFIS controller proved its robust performance with reduced overshoot, undershoot and settling time with large load demands and uncertainities. The simulated results show that the ANFIS controller is a consistent controller to handle the real time deregulated system for any number of control areas in a deregulated environment.

A.1 APPENDIX

Table 3 Tie Line power deviation with respect to response characteristics

Area	Overshoots (pu)			Undershoot (pu)			Settling time (msecs)		
	Scenario			Scenario			Scenario		
	1	2	3	1	2	3	1	2	3
1-2	0.052	0.0266	0.048	-0.044	-0.019	-0.136	4	6	8
1-3	0.0037	0.1393	0.1092	-0.012	-0.006	-0.007	5	7	4
1-4	0.052	0.6619	0.0523	-0.044	-0.085	-0.156	6	8	9
1-5	0.0048	0.2393	0.112	-0.014	-0.007	-0.009	4	7	8
2-3	0.0053	0.691	0.232	-0.016	-0.006	-0.004	3	6	7

Table 4 Frequency Deviation with respect to Response Characteristics

Area	Overshoots (Hz)			Undershoot (Hz)			Settling time (msecs)			Computational time (secs)
	Scenario			Scenario			Scenario			
	1	2	3	1	2	3	1	2	3	
1	0.2386	0.1761	0.2146	-0.367	-0.394	-0.489	4	8	9	
2	0.1092	0.0556	0.0414	-0.07	-0.222	-0.131	4	9	8	
3	0.3671	0.2856	0.2489	-0.246	-0.328	-0.327	6	8	10	0.15
4	0.1204	0.1932	0.3656	-0.008	-0.309	-0.391	4	9	8	
5	0.0946	0.2969	0.4806	-0.004	-0.23	-0.367	6	8	10	

References

1. Abraham, R.J., Das, D. & Patra, A. (2011). Load following in a bilateral market with local controllers. International Journal Electrical Power and Energy Systems, 33(10), 1648–1657.

2. Ansarian, M., Shakouri, H., Nazarzadeh, G.J. & Sadeghzadeh, S.M. (2006). A novel neuro optimal approach for LFC decentralized design in multi-area power system. In Proceeding: Power and Energy Conference, 167–72.

3. Baghya Shree, S. & Kamaraj, N. (2016). Hybrid Neuro Fuzzy approach for automatic generation control in restructured power system. International Journal of Electrical Power and Energy Systems, 74, 274-285.

4. Baghya Shree, S & Kamaraj, N (2016). AGC in restructured power system using ANFIS controller. International Transactions on Electrical Energy Systems, 1-14.

5. Beaufays, F., Magid, Y.A. & Widrow, B. (1994). Application of neural network to load frequency control in power system. IEEE Transactions on Neural Networks, 7 (1), 183–194.

6. Bevrani, H., Mitani, Y. & Tsuji K. (2004). Robust decentralized AGC in a restructured power system. Energy Conversion Management, 45, 2297–2312.

7. Bevrani, H., Mitani, Y., Tsuji, K. & Bevrani, H. (2005). Bilateral based robust load frequency control. Energy Conversion Management, 46(7–8), 1129–1146.

8. Bhatt, P., Roy, R. & Ghoshal S. (2010). Optimized multi area AGC simulation in restructured power systems. International Journal of Electrical Power and Energy Systems, 32(4), 311–322.

9. Chaturvedi, D.K., Satsangi, P.S. & Kalra, P.K.(1999). Load frequency control: a generalized neural network approach. International Journal of Electrical Power and Energy Systems, 21 (6), 405–415.

10. Elgerd, O.I. (1971). Electric Energy Systems Theory. McGraw-Hill, 315–389.

11. Ghoshal, S.P. & Goswami, S.K. (2003). Application of GA based optimal integral gains in fuzzy based active power- frequency control of non-reheat and reheat thermal generating systems. Electric Power Systems Research, 67(2), 79–88.

12. Hosseini, S.H. & Etemadi A.H. (2008). Adaptive neuro-fuzzy inference system based automatic generation control. Electric Power Systems Research, 78(7), 1230–1239.

13. Ibrabeem, PK. & Kothari, DP. (2005). Recent philosophies of automatic generation controlstrategies in power systems. IEEE Transactions on Power Systems, 20(1), 346–357.

14. Imthias Ahamed, T.P., Nagendra Rao, P.S. & Sastry, P.S. (2002). A reinforcement learning approach to automatic generation control. Electric Power Systems Research, 63 (1), 9–26.

15. Khuntia, S.R. & Panda, S. (2010). Comparative study of different controllers for automatic generation control of an interconnected hydro-thermal system with generation rate constraints. In Proceedings: Industrial Electronics, Control & Robotics (IECR) Conference, 243–246.

16. Menniti, D., Pinnarelli, A. & Scordino, N. (2004). Using a FACTS device controlled by a decentralized control law to damp the transient frequency deviation in a deregulated electric power system. Electric Power Systems Research, 72(3), 289–298.

17. Rakhshani, E. & Sadeh J. (2010). Practical viewpoints on load frequency control problem in a deregulated power system. Energy Conversion Management, 51(6), 1148–1156.

18. Ram, P. & Jha, A.N. (2010). Automatic generation control of interconnected hydrothermal system in deregulated environment considering generation rate constraints. In Proceedings: Industrial Electronics, Control & Robotics Conference, 148–159.

19. Ramey, D.G. & Skooglund, J.W. (1970). Detailed hydro governor representation for system stability studies. IEEE Transactions on Power Apparatus and Systems, 89 (1), 106–112.

20. Rao, C.S. (2010). Adaptive neuro-fuzzy based inference system for load frequency control of hydrothermal system under deregulated environment. International Journal of Engineering Science and Technology, 2(12), 6954–6962.

21. Rojas, I., Bernier, J.L., Rodriguez-Alvarez, R. & Prieto, Z. (2000). What are the main functional blocks involved in the design of adaptive neuro-fuzzy inference systems. In Proceedings: IEEE-INNS-ENNS Conference Neural Network, 551–556.

22. Shayeghi, H. & Shayanfar, HA. (2006). Decentralized robust AGC based on structured singular values. Journal of Electrical Engineering, 57, 305–317.

23. Shayeghi, H., Shayanfar, HA. & Jalili, A. (2009). Load frequency control strategies: a state of-the-art survey for the researcher. Energy Conversion Management, 50(2), 344–353.

24. Tan, W. (2009). Tuning of PID load frequency controller for power systems. Energy Conversion Management, 50(6), 1465–72.

25. Tan, W. (2010). Unified tuning of PID load frequency controller for power systems via IMC. IEEE Transactions on Power Systems, 25(1), 341–350.

26. Tan, W. (2011). Decentralized load frequency controller analysis and tuning for multi-area power systems. Energy Conversion Management, 52(5), 2015–2023.

27. Wu, Q.H., Hogg, B.W. Irwin, G.W. (1992). A neural network regulator for turbo generator. IEEE Transactions on Neural Networks, 3 (1), 95–100.

28. Yousef, M.Z., Jain, P.K. & Mohamed, E.A. (2003). A robust power system stabilizer configuration using artificial neural network based on linear optimal control. In Proceedings: Canadian Conference on Electrical and Computer Engineering, 569–573.

29. Zeynelgil, H.L., Demiroren, A. & Sengor, N.S. (2002). The application of ANN technique to automatic generation control for multi-area power system. International Journal of Electric Power and Energy Systems, 24 (5), 345–354.