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ANFIS controller based frequency linked availability based tariff mechanism for a restructured power system

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Abstract: This paper proposes the frequency linked availability based tariff (ABT) mechanism along with ANFIS controller for extenuating the issues in load frequency control (LFC) for a four area deregulated/restructured power system. To scrutinize the effective performance of the proposed approach, the dynamic performance of the system is analyzed with single and bilateral contract considering the value of the marginal cost higher and lesser than the Unscheduled interchange (UI). For this analysis, UI rate chart from the Central Electricity Regulation Commission (CERC) is used. The simulation results confirm that the ANFIS controller performance is comparatively better than proportional controller in two different contract cases.

1. Introduction

Load frequency control (LFC) is one of the prominent issues in a deregulated power system operation and control for maintaining secure electric power to the consumers. Major objectives of the LFC in a restructured power system is (i) to maintain the expected power output and the nominal frequency must be in specified limits. (ii) to maintain the exchange of net power between control areas within its pre specified values [1-3].

In a competitive power market several market players like Generation companies (GENCO) distribution companies (DISCO), transmission companies (TRANSCO) and independent system operator (ISO) came into existence and main power transactions are carried out by these entities [3,5,9]. In this environment, DISCOs in one control area may undergo contract with GENCOs with its own control area or other areas. [5-7]. For secure and reliable operation of the entire system, ISO provide certain ancillary services [4]. Load following and LFC and are treated as the ancillary services for maintaining the frequency and prolonging the power system reliability and security.

The dynamic responses of the power system network are improved with the help of some control strategies such as fuzzy logic, AI based neural network, ant colony algorithm, genetic algorithm, particle swam optimization algorithm are applied for controlling the output of the system [7,8,9]. These methodologies continuously tracking the fluctuations in the load and vary the governor setting points as soon as possible to move the system back to the normal stable operation [10-13].

The Indian power sector consists of a large combination of various types of power generations like thermal, hydro, nuclear and renewable power generations like solar, wind and tidal etc. Fossil fuel based thermal plants are donating the major part of the total power production. Entire Indian power system network are subdivided in to five interconnected regional grid systems.

Before 2002, the regional grids are operating in a dissatisfactory manner. During peak hours frequency may violate drastically from the prescribed limits. Conventional tariff systems were not able to controlling the frequency violations caused by the regional grids. To overcome this situation, the frequency linked three part ABT based system is implemented in all the regional grids. It overcome the basic issues by providing incentives to the GENCOs for the production of excess power in the peak hours for meeting the excessive load demand and curtailed the power production during the off peak hours. And also it penalises heavily to the load centres for over drawls and pulling down the frequency from its nominal levels [14-18].

The present work proposes an ANFIS controller based ABT system for extenuating the various LFC issues in a restructured power sector. A conventional multi area hydro-thermal restructured power system incorporating frequency linked ABT blocks with ANFIS controller is developed by using MATLAB/Simulink. The developed scheme is tested in the regional grid Indian system system under two different contract scenarios.

2. Availability Based Tariff (ABT)

In 2002, a new tariff structure ABT is introduced in Indian power system. It replaces the conventional monolithic charge structure into a rational three-part tariff structure [17-21]. First part of the ABT is called the constant portion, which is connected to the available generating units, the second portion is the variable part, connected with the energy charge for schedule interchanges and the third portion is called frequency dependent part which is connected with unscheduled interchange. The UI behaves as a tool for controlling grid frequency and encourages the system to regain back to its normal frequency [20-23]. The three major components of ABT are discussed below.

2.1 fixed charge or capacity charge

The major parts of fixed charge are the interest and depreciation of the loan, maintenance cost, insurance, taxes etc. The total cost to be paid to the producing company during the year for the fixed cost will depend on mean availability of the unit in the same particular year.

2.2 Variable charge or energy charge

This charge comprises of the fuel cost or variable cost of the plant for the scheduled power generation. Energy charges or variable charges are payable by every consumer based on the scheduled energy and it is irrespective to the actual power generation.

2.3. Un scheduled interchange

If the system may violate the scheduled power exchange, the third portion of ABT came into picture. If frequency is higher than 50Hz, then the UI price is low and vice versa. In case of excess drawl, beneficiary unit or company has to remunerate the penalty as per the UI rate. As per CERC, UI rate chart are given in Fig.2. The deviation from the scheduled value is termed as UI pricing scheme in ABT [24-26].

3. Basic scheme for ABT based LFC

A framework for a ABT based frequency linked scheme for a single area LFC system is given in Fig. 1[16]. In this scheme, the primary control loop mechanisms with Free Governor Mode of Operation (FGMO) is used for suppressing the area frequency oscillations within few seconds and the control loop in secondary side (LFC or AGC) is also try to move back the system frequency to its nominal value within five to ten minutes. Due to the lack of generation, successful application of a system level control procedure is not to be possible in the current Indian power system. In this paper, the UI pricing method of ABT is treated as a system level control mechanism. and generating stations are expected to work based on UI price signal in real-time. Feedback signal using in this method is called Generation Control Error (GCE) which is the deviation between incremental cost generating unit due to the variable load and cost for the UI at a particular period [19-20].

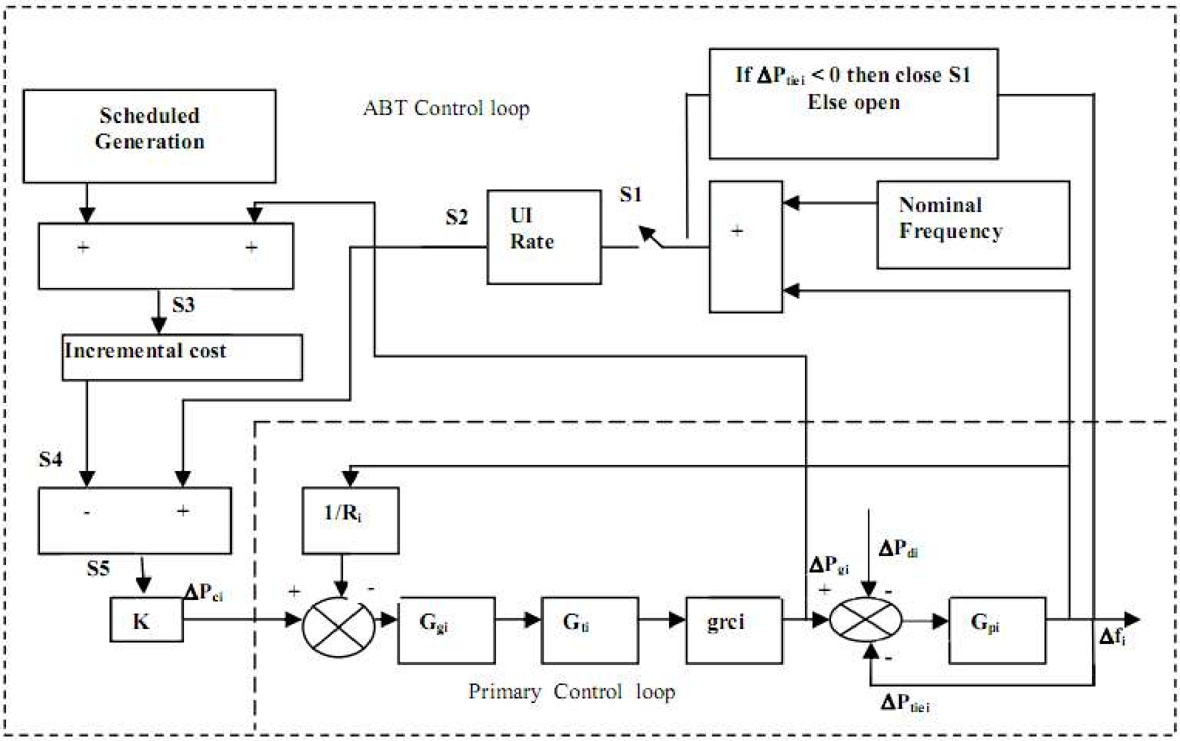

Figure 1. Basic structure of ABT based frequency control scheme.

The concept of ABT based frequency control loop is given in Fig.2. Here each Generating unit monitoring the UI cost ρ and it is compared with the marginal price γ. The error or deviation signal is derived, from the change in present UI cost and its marginal price. The deviation signal, is called as GCE which is given as input to the controller. Because of ABT, the amount received by generating units for UI value are different from the amount to be paid for Schedule Interchange (SI). For all the cases the generating units will earn the profit.

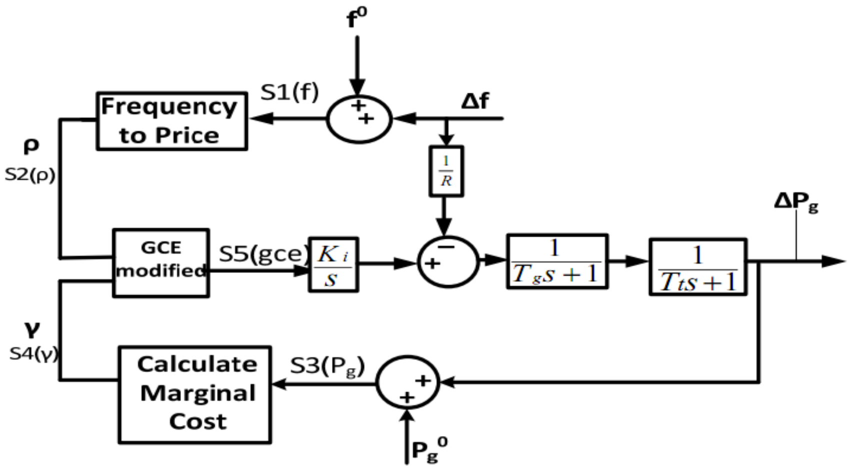

Figure 2. ABT based load frequency control scheme.

4. System modeling

The schematic representation of a four area restructured power system with ABT based frequency control loop system is given in Fig. 4. It consists of four different control areas consisting GENCO and DISCO of one in each area. GENCO having Hydro plant is considered in area-1 and thermal GENCOs are considered in other three areas. In a restructured power system GENCOs can contract with DISCOs in the same or other area. This type of contract is termed as "Bilateral contract" and it is implemented through Independent System Operator (ISO) [3,4]. Various schemes of contract are explained in Distribution type Participation Matrix - (DPM) given as follows.

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & \cdots & cpf_{1n} \\ cpf_{21} & cpf_{22} & \cdots & cpf_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ cpf_{31} & cpf_{32} & \cdots & cpf_{nm} \end{bmatrix} \quad (1)$$

The total number of columns and rows in a DPM shows the number of DISCOs and GENCOs respectively and each factor in the DPM is represented as contract participation factor (*cpf*), which represents the fraction of total power contracted between DISCOs and GENCOs [4-6]. The addition of all the values in a column must be equal to one. ie.,

$$\sum_{i=1}^{nGENCO} cpf_{ij} = 1; \qquad \text{for } j = 1,2,..nDISCO \quad (2)$$

It is assumed that all generating units in each individual area are generating power at scheduled value and frequency of the grid frequency is considered as 50Hz. If a sudden load disturbance occurs in any area, the area frequency and tie-line power exchange must be altered, which indicates in the supply frequency deviation Δf.

$$S_1(f) = \Delta f + f^0 \quad (3)$$

If $S_1(f)$ related to the frequency signal and $S_2(\rho)$ mentioned in (INR/MWh) corresponds the UI price signal are the input signals for calculating the UI rate issued by CERC in the year of 2015 [25].

If $S_1(f) > 50.2$ Hz

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$$S_2(\rho) = 0 \text{ Rs/MWhr} \tag{4}$$

If $50.0Hz < S_1(f) \le 50.2Hz$

$$S_2(\rho) = 8250 * (S_1(f)) \text{ Rs/MWhr} \tag{5}$$

If $49.8Hz < S_1(f) \le 50.0Hz$

$$S_2(\rho) = 1650 + 14250 * (50 - S_1(f)) \text{Rs/MWhr} \tag{6}$$

If $49.48Hz < S_1(f) \le 49.8Hz$

$$S_2(\rho) = 4500 + 14062.5 * (49.8 - S_1(f)) \text{Rs/MWhr} \tag{7}$$

If $S_1(f) \le 49.48.2 \text{ Hz}$

$$S_2(\rho) = 9000 \text{ Rs/MWhr} \tag{8}$$

In addition, with this, the incremental cost of the thermal units and hydro units are expressed as

$$S_4(\gamma) = a_i + b_i P_{Gi} \text{ (Rs/MWhr)} \tag{9}$$

Where a and b are called as incremental cost co-efficient and P_{Gi} is power output of hydro GENCO in ith area.

Similarly, IC in the case of hydro GENCO is expressed as

$$S_4(\gamma) = c_i + d_i P_{Gi} \text{ (Rs/MWhr)} \tag{10}$$

Where c and d are called as co-efficient of incremental cost and P_{Gi} is called power output of ith GENCO

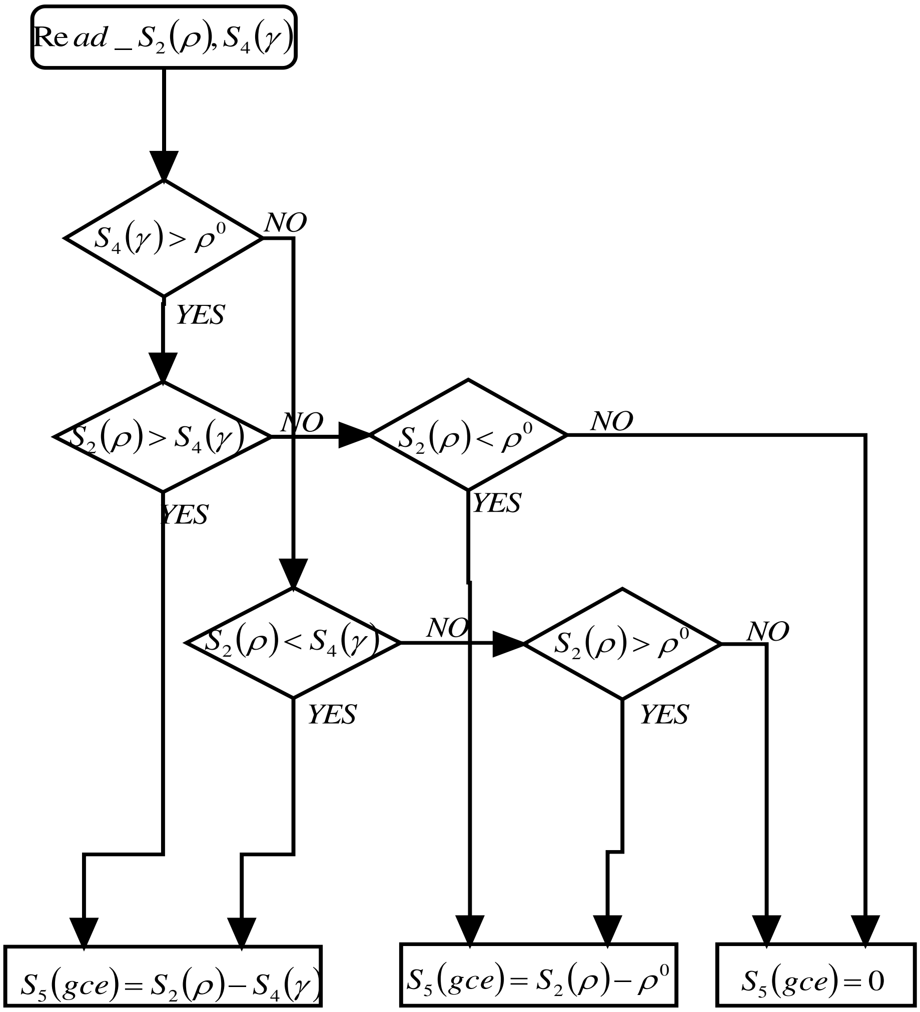


Figure 3. Flow chart for calculating GCE

The UI based price signal S2 (ρ) is now comparing with the other factor incremental cost based signal S4 (γ) and produce the generation control error (GCE) signal. UI price at 50.0Hz is denoted as ρ^0 and it is calculated from the UI chart issued by CERC, India. Modified GCE control scheme flow chart is shown in Fig.3 [16]. The control scheme ensures that whenever a sudden variation in the load demand occurs each generating unit responds to change their generation based on the error signals received from GCE block for smoothening the frequency. To reduce the Generation Control Error (GCE) of generating units after a sudden load disturbance, ANFIS controller is used for minimizing the area frequency oscillations and tie-line power oscillations for enhancing the stability of the system. Detailed analysis of ANFIS controller is discussed below.

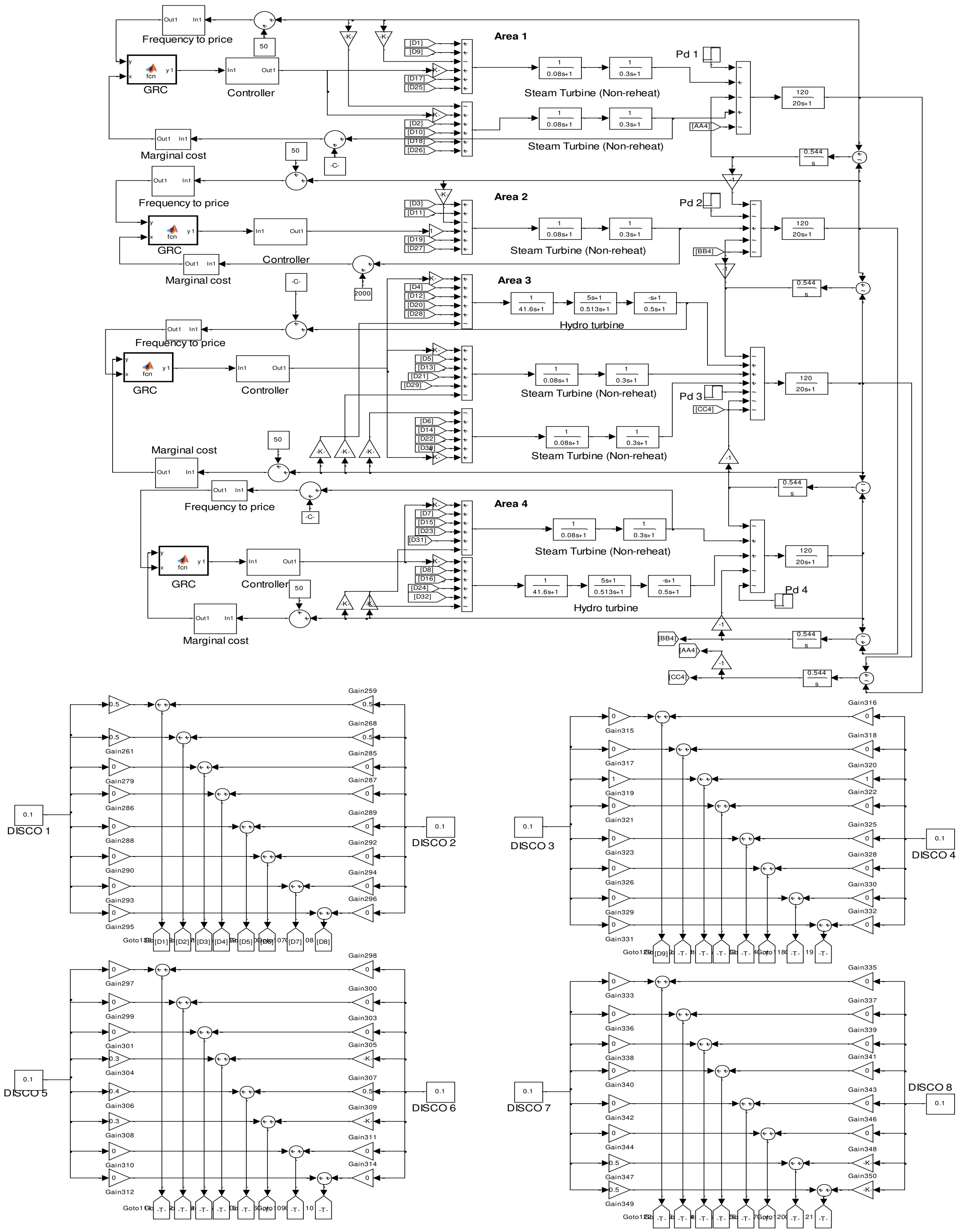


Figure 4. Simulated model of four area restructured power system with ABT mechanism

5. Concept of suggested ANFIS controller

ANFIS controller is the combination of artificial neural network (ANN) and fuzzy logic based adaptive type network having zero synaptic weight. Fig.5 shows the ANFIS structure including outputs and inputs. The concept is taken from the references [12-13].

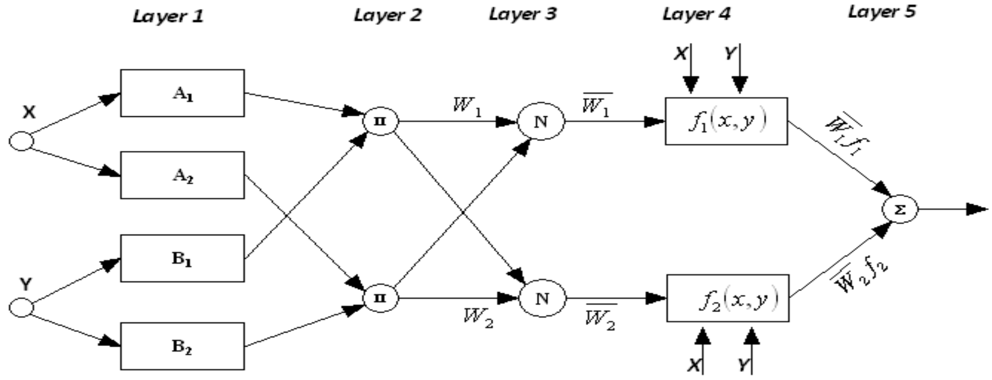


Figure 5. ANFIS structure.

It is assumed that the FIS with Takagi - Sugeno's controller having inputs x and y and an output z is considered here [27].

6. Simulated responses - Results and discussions

The suggested four area deregulated system model with ABT based ANFIS control scheme is shown in Fig.4. The parameter values of the test system are obtained from the regional Indian system which is shown in Appendix A. simulation procedures are performed under deregulated environment having three possible contract scenarios which are explained below

Case 1 – single contract

In this contract case, DISCOs in one area is contract with the same area GENCOs. Disturbance is created in all four areas. The values are assumed as $\Delta P_{L1}=\Delta P_{L2}=\Delta P_{L3}=\Delta P_{L4}$=0.1pu and analysed using DPM (11):

$$DPM=\begin{bmatrix}0.5&0.5&0.0&0.0&0.0&0.0&0.0&0.0\\0.5&0.5&0.0&0.0&0.0&0.0&0.0&0.0\\0.0&0.0&1.0&1.0&0.0&0.0&0.0&0.0\\0.0&0.0&0.0&0.0&0.3&0.25&0.0&0.0\\0.0&0.0&0.0&0.0&0.4&0.5&0.0&0.0\\0.0&0.0&0.0&0.0&0.3&0.25&0.0&0.0\\0.0&0.0&0.0&0.0&0.0&0.0&0.5&0.6\\0.0&0.0&0.0&0.0&0.0&0.0&0.5&0.4\end{bmatrix} \quad (11)$$

Power output ($\Delta P_{GENCO-i}$) of GENCO in each area is obtained by

$$\Delta P_{GENCO-1}=(0.5\times 0.1)+(0.5\times 0.1)+(0\times 0.1)+(0\times 0.1)+(0)+(0)+(0)+(0)=0.1\,\text{pu MW}$$

Similarly, $\Delta P_{GENCO-2}$= 0.1 pu MW, $\Delta P_{GENCO-3}$= 0.2 pu MW, $\Delta P_{GENCO-4}$= 0.055 pu MW, $\Delta P_{GENCO-5}$= 0.09 pu MW, $\Delta P_{GENCO-6}$= 0.055 pu MW, $\Delta P_{GENCO-7}$= 0.011 pu MW, $\Delta P_{GENCO-8}$= 0.09 pu MW are calculated [3].

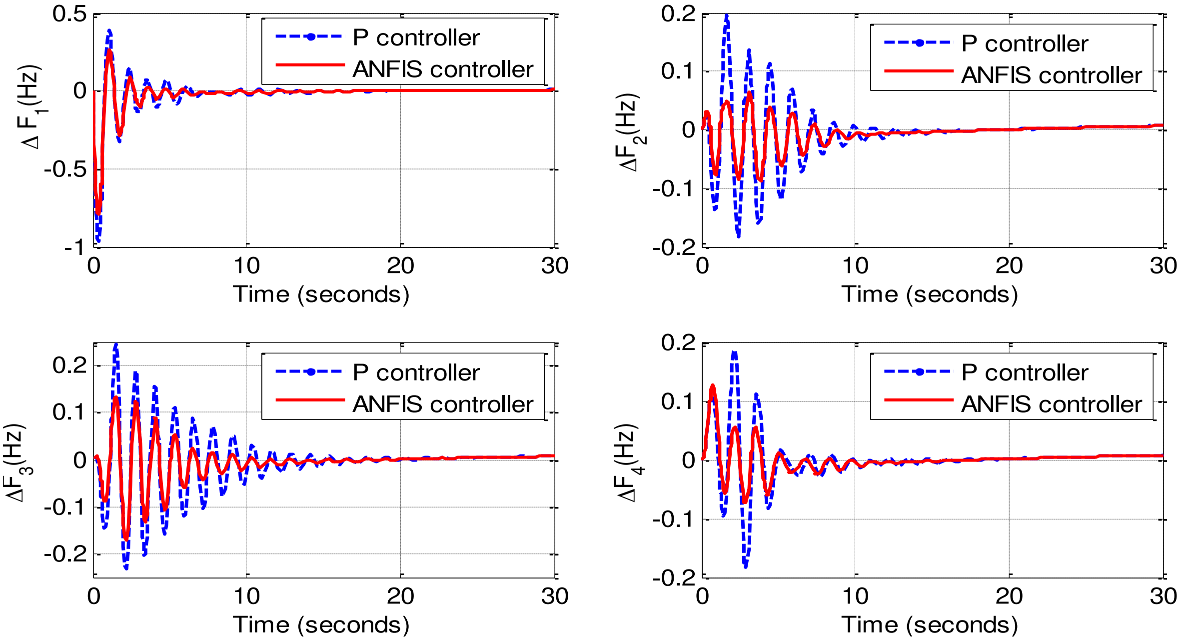
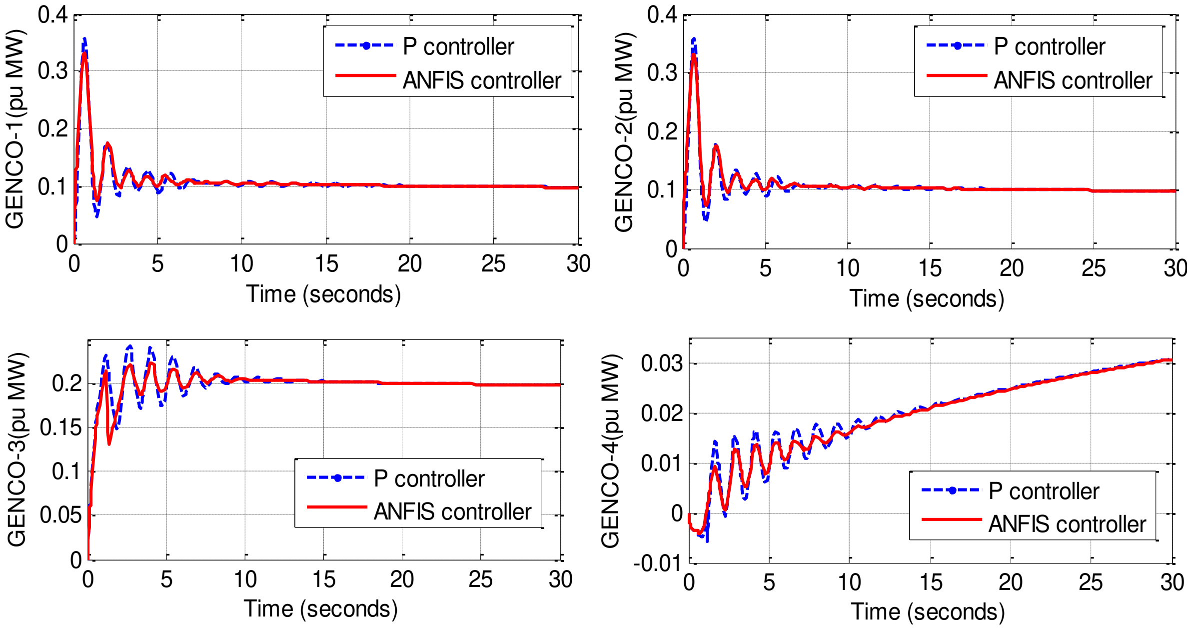


Figure 6. Frequency deviation responses of all the control areas under unilateral contract scenario



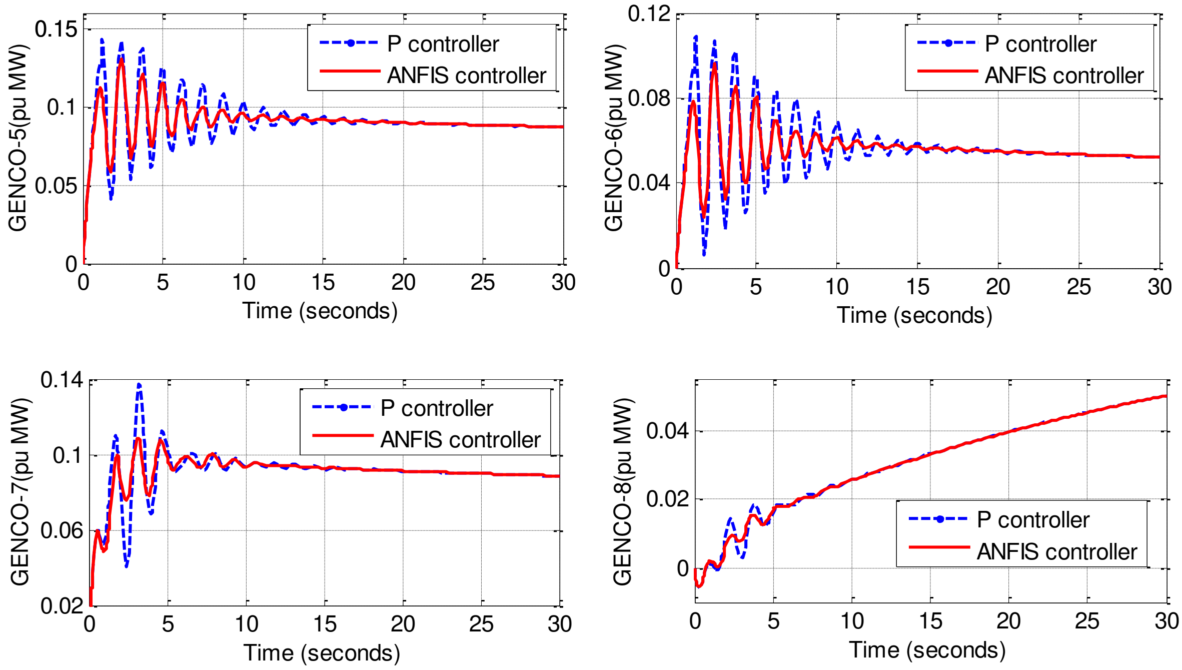


Figure 7. Power output deviations of all the control area of the system under single contract scheme

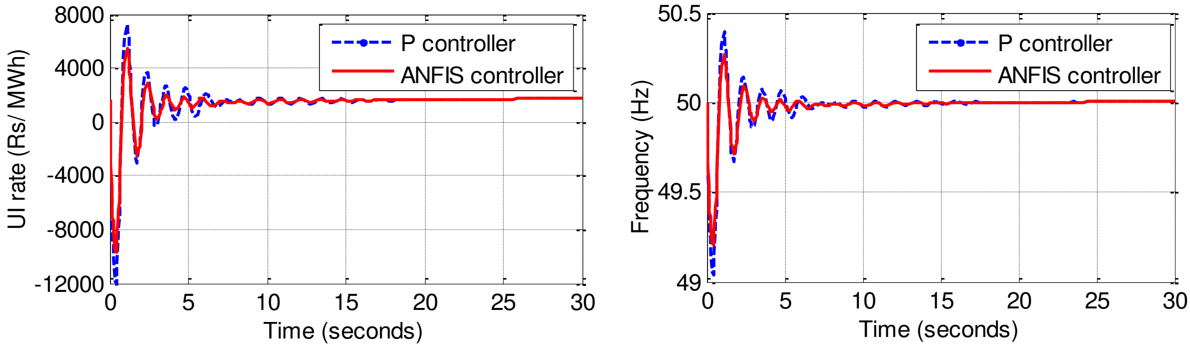


Figure 8. UI rate and frequency of area-1 under unilateral contract scenario

Table 1. Frequency deviation of all the areas with controllers under unilateral contract

	P controller			ANFIS controller		
	POS	PUS	Ts	POS	PUS	Ts
Frequency deviation (pu Hz)						
ΔF_1	0.437	-0.917	7	0.301	-0.732	5.4
ΔF_2	0.200	-0.195	14	0.075	-0.896	11
ΔF_3	0.254	-0.233	16	0.128	-0.188	12
ΔF_4	0.183	-0.185	12	0.132	-0.171	11

Table 2. GENCOs output deviations with controllers under unilateral contract

Controller	P controller			ANFIS controller		
	POS	PUS	Ts	POS	PUS	Ts
Power output deviation (pu MW)						
$GENCO_1$	0.371	0.038	11	0.328	0.081	8
$GENCO_2$	0.356	0.023	10	0.322	0.081	8
$GENCO_3$	0.282	0.021	12	0.225	0.125	9
$GENCO_4$	0.0162	-0.005	14	0.014	-0.002	10
$GENCO_5$	0.140	0.041	15	0.135	0.063	11
$GENCO_6$	0.108	0.009	16	0.104	0.031	12
$GENCO_7$	0.138	0.046	11	0.118	0.080	9
$GENCO_8$	0.018	0.00	8	0.014	-0.005	6

Frequency deviations and GENCOs power output deviations of the proposed ABT based multi area deregulated power system with Proportional and ANFIS controllers under unilateral contract are shown in Figs. 6 and 10. UI rate and frequency of area-1 under unilateral contract scenario is shown in Fig.8. Detailed time domain analysis based on the performance indices peak undershoot (PUS), peak overshoot (POS) and settling time (Ts) of frequencies and GENCOs output deviations for the Proportional and ANFIS controllers are given in Table 1 and 2. From all these results, it should be clear that ABT system with ANFIS controller reduces the frequency and GENCOs power output deviations better than the P controller.

Case 2- Bilateral contract

In bilateral contract case, system DISCOs are having the chance to collaborate with any one of the GENCOs in the same control area or other areas. The disturbance on DISCO is considered as $\Delta P_{L1} = \Delta P_{L2} = \Delta P_{L3} = \Delta P_{L4} = 0.1pu$ Corresponding DPM is given below

$$DPM = \begin{bmatrix} 0.2 & 0.3 & 0.1 & 0.1 & 0.1 & 0.1 & 0.0 & 0.0 \\ 0.4 & 0.3 & 0.1 & 0.2 & 0.1 & 0.1 & 0.0 & 0.0 \\ 0.1 & 0.1 & 0.3 & 0.2 & 0.0 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.2 & 0.2 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.2 & 0.2 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.2 & 0.2 & 0.2 & 0.1 \\ 0.0 & 0.0 & 0.1 & 0.1 & 0.1 & 0.0 & 0.2 & 0.3 \\ 0.0 & 0.0 & 0.1 & 0.1 & 0.1 & 0.1 & 0.3 & 0.3 \end{bmatrix} \quad (12)$$

During steady state, output of the GENCOs are obtained. The values are: $\Delta P_{GENCO-1}$ = 0.09 pu $\Delta P_{GENCO-2}$ = 0.12 pu MW, $\Delta P_{GENCO-3}$ = 0.1 pu MW, $\Delta P_{GENCO-4}$ = 0.1 pu MW, $\Delta P_{GENCO-5}$ = 0.1 pu MW, $\Delta P_{GENCO-6}$ = 0.11 pu MW, $\Delta P_{GENCO-7}$ = 0.08 pu MW, $\Delta P_{GENCO-8}$ = 0.1 pu MW.

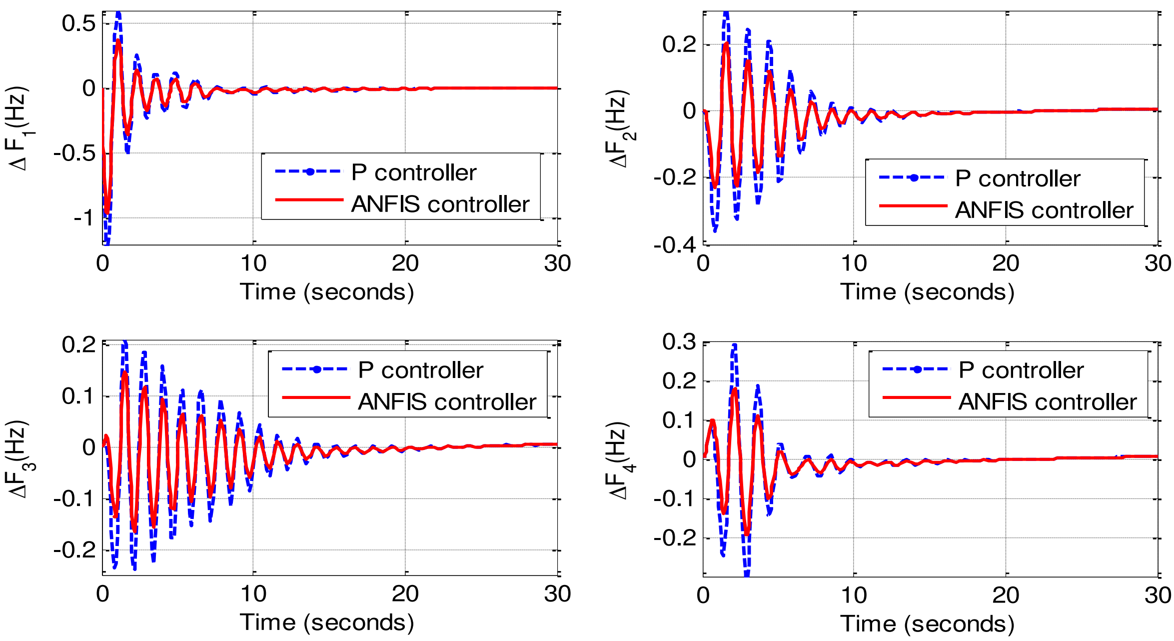
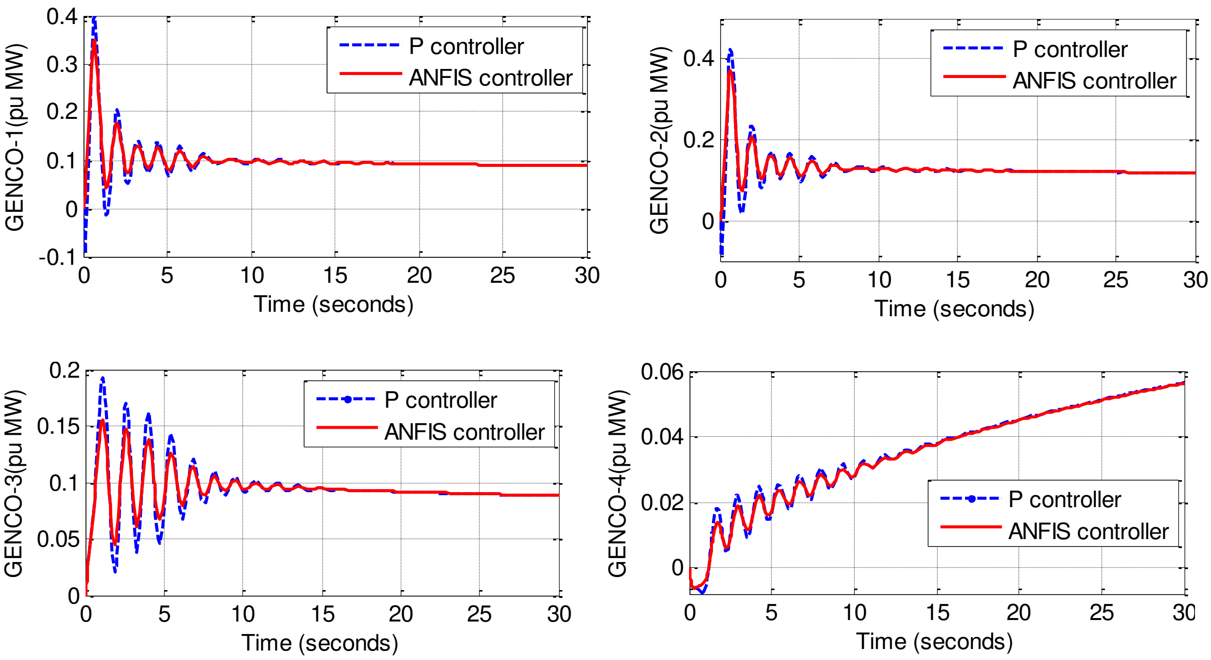


Figure 9. Frequency deviation responses of all the control areas under bilateral contract scenario



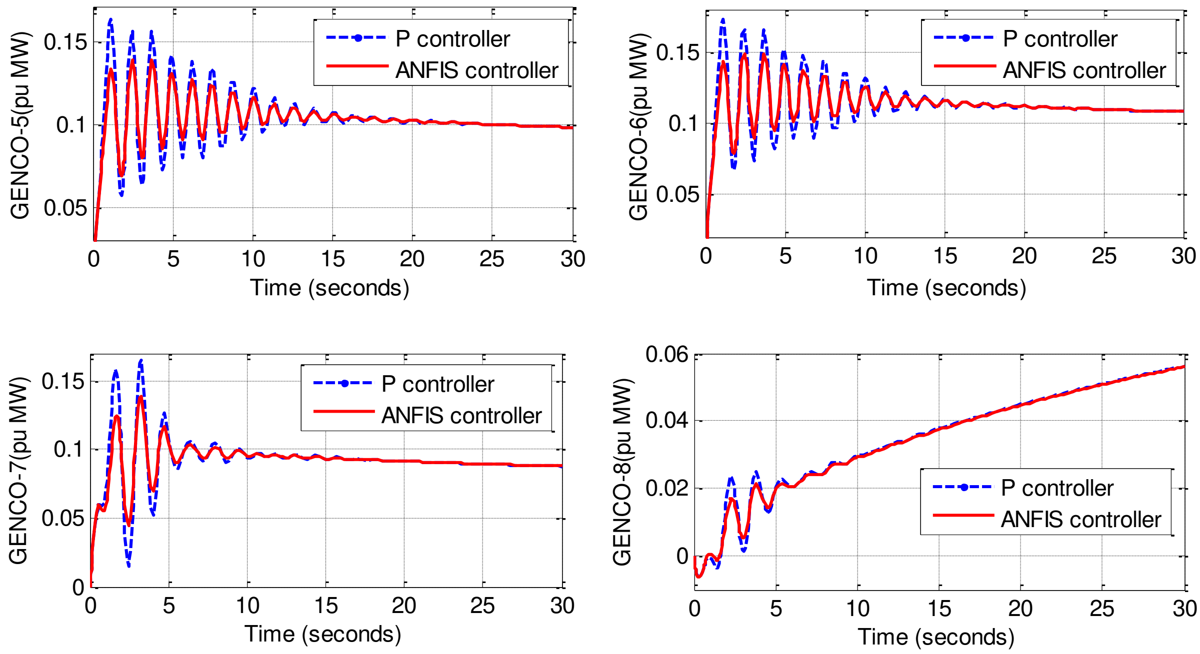


Figure 10. Power output deviations of all the control area of the system for bilateral contract scheme

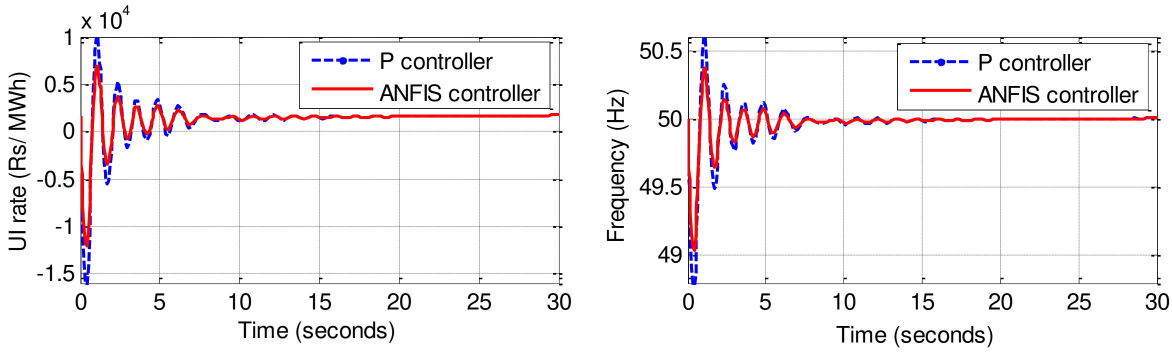


Figure 11. UI rate and frequency of area-1 under bilateral contract scenario

Table 3. Frequency deviation of all the areas with controllers under bilateral contract

	P controller			ANFIS controller		
	POS	PUS	Ts	POS	PUS	Ts
Frequency deviation (pu Hz)						
ΔF_1	0.521	-1.532	10	0.321	-0.978	9
ΔF_2	0.302	-0.376	12	0.201	-0.216	11
ΔF_3	0.205	-0.235	15	0.146	-0.145	14
ΔF_4	0.298	-0.300	12	0.188	-0.200	10

Table 4 Output power deviation of GENCOs with controllers under bilateral contract

Controller	P controller			ANFIS controller		
	POS	PUS	Ts	POS	PUS	Ts
Power output deviation (pu MW)						
$GENCO_1$	0.400	-0.082	8	0.352	0.012	7
$GENCO_2$	0.418	-0.071	7	0.386	0.001	6
$GENCO_3$	0.182	0.025	12	0.155	0.051	10
$GENCO_4$	0.035	-0.012	12	0.021	-0.008	11
$GENCO_5$	0.162	0.067	16	0.128	0.072	15
$GENCO_6$	0.179	0.075	15	0.151	0.078	14
$GENCO_7$	0.162	0.020	11	0.137	0.048	9
$GENCO_8$	0.023	-0.005	9	0.020	-0.003	8

Frequency deviations and GENCOs power output deviations of the proposed ABT based multi area deregulated power system with Proportional and ANFIS controllers under bilateral contract are shown in Figs. 9 and 10. UI rate and frequency of area-1 under bilateral contract scenario is shown in Fig.11. Detailed time domain analysis based on performance indices such as peak undershoot (PUS), peak overshoot (POS) and frequency settling time (Ts) and tie-line power variations for Proportional and ANFIS controllers are given in Table 3. Time domain analysis of each GENCOs are also given in Table 4. From all these results, it should be clear that ABT system with ANFIS controller reduces the frequency and GENCOs power output deviations than other controllers.

7. Conclusion

This paper reveals that the frequency linked ABT mechanism with ANFIS controller can improve grid frequency and GENCOs power output deviations as compared to the existing manual UI based control structure. The ANFIS controller technique can effectively control all the GENCOs in each area and improves the performance of frequency. This helps in reducing the cost of unneeded exchange of power between generation companies and utilities. Time domain outputs shows that frequency linked ABT mechanism with ANFIS based controller provides better performance in view of performance indices such as undershoot, overshoot, settling time of frequency deviations and GENCO power deviations than conventional proportional controller.

8. References

[1] Christie R D and Bose A 1996 Load Frequency Control Issues in Power System Operations after Deregulation *IEEE Trans. on Power System*, **11**(3) pp 1191-1200

[2] Bekhouche N 2002 Automatic Generation Control Before After Deregulation *in Proc. of 34th South-eastern Symposium on System Theory UAH Huntsville, Alabama* pp 321-323

[3] Donde V, Pai M A, and Hiskens I A 2001 Simulation and Optimization in an AGC System after Deregulation *IEEE Trans. on Power System* **16** (3) pp 481–489

[4] Tyagi B and Srivastava S C 2005 A LQG Based Load Frequency Controller in A Competitive Electricity Environment *Int. J. of Emerging Electric Power Systems*, **2** (2) Article 1044.

[5] De Tuglie E and Torelli F 2006 Load Following Control Schemes for Deregulated Energy Markets *IEEE Trans. on Power System* **21**(4) pp 1691- 1698

[6] Bhatt P Roy R and Ghoshal S P 2010 Optimized Multi Area AGC Simulation in Restructured Power Systems *in Electrical Power and Energy Systems* **32** (4) pp 311-322

[7] Bhatt P, Roy. R, Ghoshal S P 2010 Load Frequency Control of Interconnected Restructured Power System Along with DFIG and Coordinated Operation of TCPS-SMES *in 11th Int. Conf. on Probabilistic Methods Applied to Power Systems (PMAPS 2010)* pp 131–136

[8] Tyagi B and Srivastava S C 2008 Automatic Generation Control Scheme Based on Dynamic Participation of Generators in Competitive Electricity Markets *in Proc. of 15th National Power System Conf. (NPSC -2008), IIT Mumbai, India* pp 195-200

[9] Fathima A P and Khan M A 2008 Design of a New Market Structure and Robust Controller for the Frequency Regulation Services in the Deregulated Power System *in Electric Power Components and Systems* **36**(8) pp 864–883

[10] Zhong J and Bhattacharya K 2003 Frequency Linked Pricing As An Instrument For Frequency Regulation In Deregulated Electricity Markets *in Proc. of IEEE Power Engineering Society Summer Meeting* pp 566-571

[11] Tyagi B and Srivastava S C 2006 A Decentralized Automatic Generation Control Scheme for Competitive Electricity Markets *IEEE Trans. on Power System* **21**(1) pp 312-320

[12] Pappachen A, Fathima A P 2016 Load frequency control in deregulated power system integrated with SMES–TCPS combination using ANFIS controller *Int. J. of Electric Power & Energy Systems* **82** pp 519-534

[13] Khuntia S R and Panda S 2012 Simulation study for automatic generation control of a multi-area power system by ANFIS approach *Applied Soft Computing* **12**(1) 333-341.

[14] Soonee S K Narasimhan S R and Pandey V 2006 Significance of Unscheduled Interchange Mechanism in Indian Electricity Supply Industry ICPSODR-2006 *Dept. of Electrical Engineering, ITBHU, India.*

[15] Tyagi B and Srivastava S C 2004 A Mathematical Framework for Frequency-Linked Availability-Based Tariff Mechanism in India *in Proc. of 13thNational Power Systems Conf. IIT Chennai India* **1** pp 516-521

[16] Chanana S and Kumar A 2010 A Price Based Automatic Generation Control Using Unscheduled Interchange Price Signals in Indian Electricity System *Int. J. of Engineering, Science and Technology* **2**(2) pp 23-30

[17] Chanana S and Kumar A 2008 Proposal for A Real-Time Market Based On Indian Experience of Frequency Linked Prices *in Proc. of IEEE Conf. on Global Sustainable Energy Infrastructure* pp 17-18

[18] Chanana S Some Important Aspects of Price Based Frequency Regulation and Pricing in Competitive Market *National Institute of Technology, Kurukshetra, PhD. Thesis, India*

[19] Pujara S M and Kotwal C D 2014 Optimized Integral Gain Controllers for Price Based Frequency Regulation of Single Area Multi-Unit Power System *Int. J. on Electrical Engineering and Informatics* **6**(2) pp 306-323

[20] Pujara S M and Kotwal C D 2014 Impact of UI rate on automatic generation controller of participating generators under frequency linked tariff system *J. of electrical engineering* **14**(4) pp 79-87
[21] Gupta S K, Kumar D and Ghose T 2010 Effect of automatic generation controller of participating generators under frequency linked Indian tariff system *Annual IEEE India Conf. (INDICON)*
[22] Parida S K 2010 Road Map to Develop Ancillary Services Model for Indian Electricity Scenario [online] http://www.pmintpc.com (accessed November 2010).
[23] Central Electricity Regulatory Commission 2010 Unscheduled Interchange Charges and Related Matters Regulation *CERC New Delhi, India.*
[24] Bhushan B 2005 ABC of ABT: A primer on availability tariff. Available online: http://www.nrldc.org/docs/abc_abt.pdf.
[25] Central Electricity Authority 2014 Load Generation Balance Report 2013-14 *CEA New Delhi, India*. Available online: http://cea.nic.in/god/gmd/lgbr_report.pdf
[26] Parida S K Singh S N and Srivastava S C 2009 An integrated approach for optimal frequency regulation service procurement *in India Energy Policy* **37**(8) pp 3020–3034
[27] Abhijith Pappachen and Peer Fathima A 2018 NERC's control performance standards based load frequency controller for a multi area deregulated power system with ANFIS approach *Ain Shams Engineering J.* **9**(4) pp 2399-2414