Automatic Generation Control in De-centralized Electricity Market using Adaptive Neuro-Fuzzy Inference System (ANFIS)

[1]Durga Hari Kiran B, *Student Member, IEEE,* [2]P S Bhargav and [3]Sailaja Kumari M, *Member, IEEE*
National Institute of Technology Warangal
Department of Electrical Engineering, Warangal, India.
[1]bdurgaharikiran@yahoo.co.uk, [2]bhargava3939@gmail.com, [3]sailaja@nitw.ac.in

Abstract— **This paper proposes Automatic Generation Control (AGC) in Decentralized Electricity market using a Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS controller facilitates simulation of various types of transactions that occur in decentralized electricity market. In this paper only bi-lateral transactions are considered between Gencos in different areas. The ANFIS controller provides faster response compared to PI controller to regain system stability. The proposed ANFIS controller is tested on New England 39 bus System and 75 bus Indian power system. The system reaches a stable state with minimum % overshoot and minimum settling time using ANFIS controller. A comparison between centralized AGC (AGC) and de-centralized AGC (DAGC) schemes with ANFIS and PI controllers is presented.**

Keywords— Load Frequency Control, Automatic Generation Control, ANFIS, Decentralized Electricity market.

I. INTRODUCTION

Reliable operation and quality are the major concerns for power system since the beginning of decentralization. The Order no. 888 of Federal Energy Regulatory Commission (FERC) has initiated open access in Electricity markets. Frequency Regulation is one such essential part of de-centralised power system which maintains frequency at nominal value with the help of Load Frequency Control (LFC).

LFC is used as AGC scheme to maintain nominal frequency and minimal unscheduled interchanges. The basic AGC scheme is explained in [1]. AGC has evolved as a system service in De-centralised power system. Here, Genco's look at AGC as a translatable service in a interconnected grid. Different type of controllers like PI, fuzzy etc., are proposed in [2], [3] for AGC. A multi-objective AGC control in interconnected grid using NSGA-II is presented in [4]. A Differential Evolution based LFC is proposed in [5] in multi-source power system consisting of thermal, gas and hydro power systems. A hybrid bacteria foraging optimization algorithm and particle swarm optimization is proposed in [6] for AGC in linear and non-linear power system. The concept of AGC under bi-lateral contracts and disco participation is proposed in [7].

In this paper AGC with ANFIS controller in de-centralised power system is proposed under bi-lateral transactions. The controller designed here reduces the Area control error significantly in less time when compared with PI controller under similar environment.

The paper is organized as follows: Section-I presents introduction and literature survey. Section-II deals with problem identification and ANFIS controller design. Section-III provides outcomes of the work and discussions. Finally, Section-IV provides contributions of the work with concluding remarks.

II. PROBLEM IDENTIFICATION AND ANFIS CONTROLLER DESIGN

In de-centralized power system each Genco has its own bi-lateral and pool-co contracts with other Gencos. It is essential for the system operator to maintain the frequency at nominal value. But, due to de-centralization, the system operator is no more able to control the Gencos. So, balancing the frequency deviations under different type of transactions has become an issue for the system operator. Many researchers have attempted this problem with PI, fuzzy logic and other type of controllers. But, still there is a need of faster controller for balancing the system frequency deviations.

The proposed ANFIS controller is a hybrid technique consisting of fuzzy Interface system (FIS) with fuzzy rules formed by back propagation algorithm. FIS utilizes fuzzy-Sugeno model. In designing of ANFIS controller, area control error and its derivate are taken as inputs and the area frequency deviations or Tie-line flows are obtained as output. MATLAB SIMULINK is used to design the de-centralized power system and ANFIS edit is used to implement ANFIS controller. The architecture of ANFIS controller is given in fig.1.

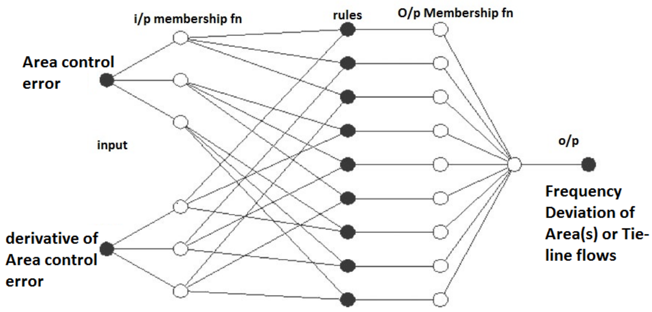

Fig. 1. architecture of ANFIS

III. CASE STUDY

In this paper a decentralised power system is assumed and the designed ANFIS controller is tested on 39 bus New

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England [8] test system and Indian 75 bus power system [9]. The Gencos in 39 bus and 75 bus system are divided into areas and the Gencos are considered to have bi-lateral contracts with other Gencos. The area information is given in Table I. The Data for Governor-Turbine model is taken from [10]. The system characteristics for 39 and 75 bus were given in Tables II and III respectively.

The main objective of LFC is to maintain the frequency of an area at nominal value under system disturbance condition. In de-centralized power system due to pool-co and bi-lateral transactions between Gencos of different areas frequency regulation becomes an issue. Power system needs a intelligent controller to respond quickly to maintain frequency at nominal values. This paper proposed a ANFIS controller and results are compared with the PI controller. The paper considers Bi-lateral transactions between areas.

TABLE I. GENCOS AREA INFORMATION

39 BUS SYSTEM		75 BUS SYSTEM
2 AREA	3 AREA	4 AREA
GENCO 30,31,32,33,34 DISCO 1,2,3	GENCO 31,32,39 DISCO 1,2	GENCO 1,2,3 DISCO 1,2,3
GENCO 35,36,37,38,39 DISCO 4,5,6	GENCO 30,37 DISCO 3	GENCO 4,5,6,7,8 DISCO 4,5,6
-	GENCO 33,34,35,36,38 DISCO 4,5,6	GENCO 9,10 DISCO 7,8,9
-	-	GENCO 11,12,13,14,15 DISCO 10,11,12

TABLE II. 39 BUS SYSTEM CHARACTERISTICS

39 BUS SYSTEM			
2 AREA		3 AREA	
GENCO 30,31,32,33,34 DISCO 1,2,3	AREA RATING 400 MW	GENCO 31,32,39 DISCO 1,2	AREA RATING 300 MW
GENCO 35,36,37,38,39 DISCO 4,5,6	AREA RATING 500 MW	GENCO 30,37 DISCO 3	AREA RATING 100 MW
-		GENCO 33,34,35,36,38 DISCO 4,5,6	AREA RATING 500 MW

TABLE III. 75 BUS SYSTEM CHARACTERISTICS

75 BUS SYSTEM	
4 AREA	
GENCO 1,2,3 DISCO 1,2,3	AREA RATING 460 MW
GENCO 4,5,6,7,8 DISCO 4,5,6	AREA RATING 994 MW
GENCO 9,10 DISCO 7,8,9	AREA RATING 400 MW
GENCO 11,12,13,14,15 DISCO 10,11,12	AREA RATING 4470 MW

A. 39 bus New England system

39 bus New England system consists of 10 Gencos and 6 discoms, those are considered to be in two different areas, Area 1 and Area 2. Simulink model for 39 bus system is given in fig. 2. A disturbance of 0.1 p.u. MW is considered in Area 2 and the frequency responses f_1, f_2 are shown in fig. 3 for centralised system with PI controller. In fig.4 the system with PI controller in decentralised system is shown. Fig. 5 shows the tie-line flows in 39 bus system in de-centralised system.

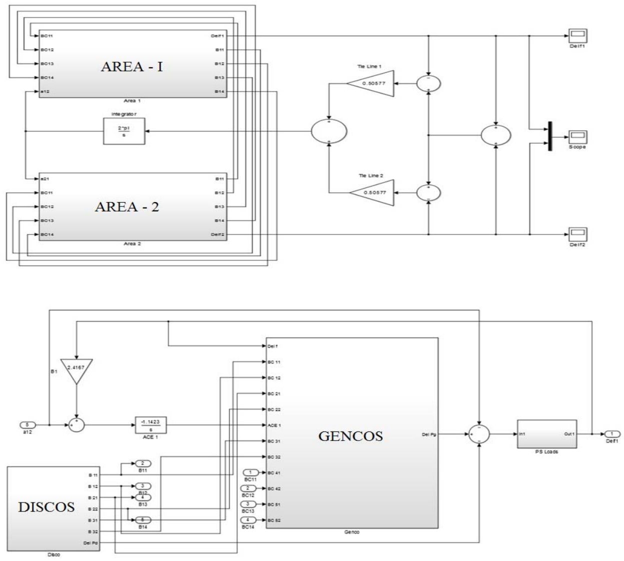

Fig. 2. Simulink model for two area 39 bus system

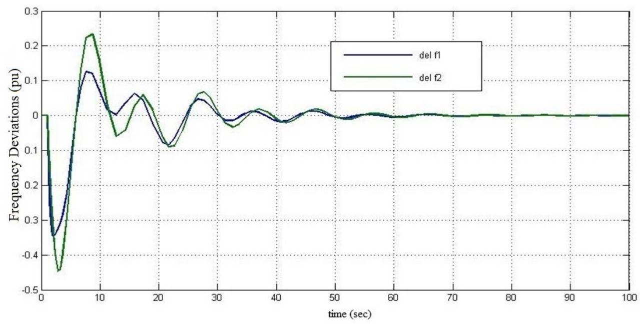

Fig. 3. Frequency response of two area 39 bus system with PI controller in centralised model

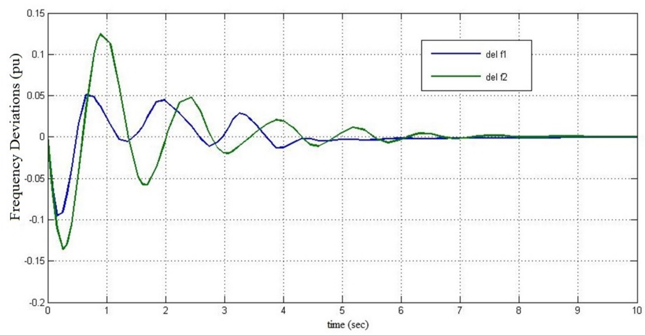

Fig. 4. Frequency response of two area 39 bus system with PI controller in de-centralised model

From fig.3 and fig.4 it is evident that the decentralized system with PI controller, settles down within 10secs., whereas the centralized model takes about 80 secs.

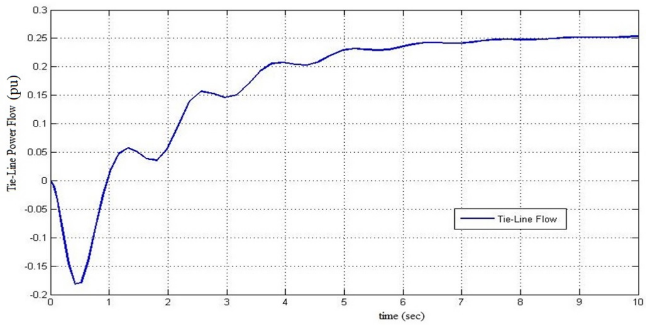

Fig. 5. Tie-line flows of two area 39 bus system with PI controller in de-centralised model.

Fig.5 shows the tie-line power flows of 39 bus system. The frequency deviation in centralised AGC and de-centralised AGC are compared in fig.6 over a time span of 5 secs. It is evident from the figure that the Decentralized AGC out performs the centralized AGC with minimum overshoot and settling times.

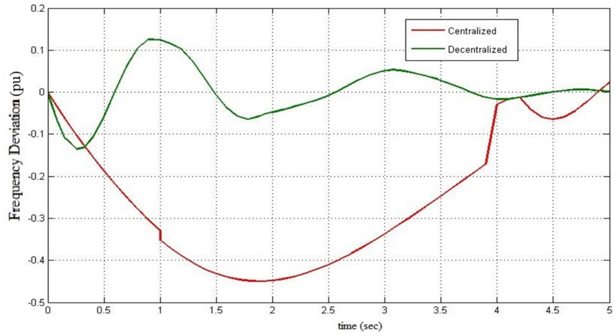

Fig. 6. Centralised AGC vs Decentralised AGC in area-2 for two area 39 bus system with PI controller

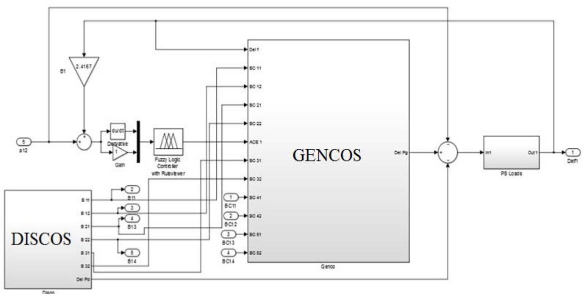

Fig. 7. Simulink model for two area 39 bus system with ANFIS controller in de-centralised model

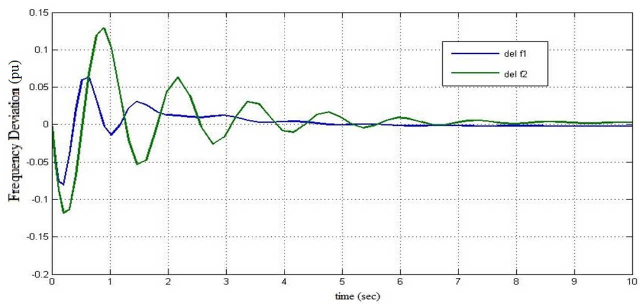

Fig. 8. Frequency response of two area 39 bus system with ANFIS controller in de-centralised model

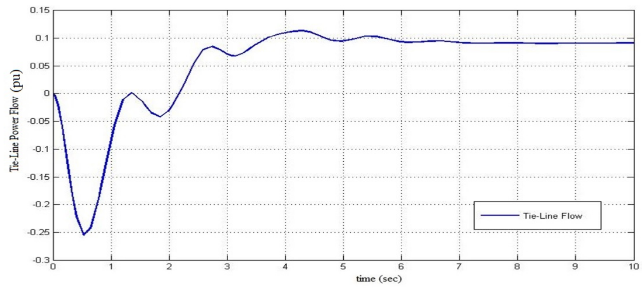

Fig. 9. Tie-line flows of two area 39 bus system with ANFIS controller in de-centralised model.

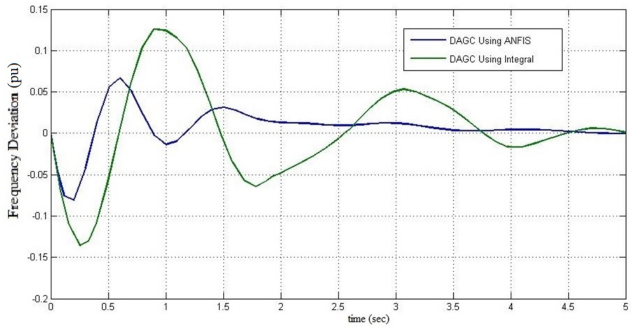

Fig. 10. Frequency deviation of area-2 in two area 39 bus system with PI and ANFIS controller in de-centralised model

Fig. 7 shows the simulink model of two area 39 bus system with ANFIS controller. Fig. 8 shows the frequency deviations with ANFIS controller. From figures 5 and 9 it can be concluded that, even the tie-line flow deviations are small with ANFIS controller compared to PI controller in de-centralised model. Fig. 10 gives the frequency deviation comparison of area-2 with PI and ANFIS controller in de-centralised system.

TABLE IV. COMPARISON OF VARIOUS CONTROLLERS FOR 39 BUS SYSTEM

CONTROLLERS	PERCENTAGE OVERSHOOT (%)	SETTLING TIME (sec)
AGC Using Integral Controller	0.44	80
DAGC Using Integral Controller	0.14	9
DAGC Using ANFIS Controller	0.08	5

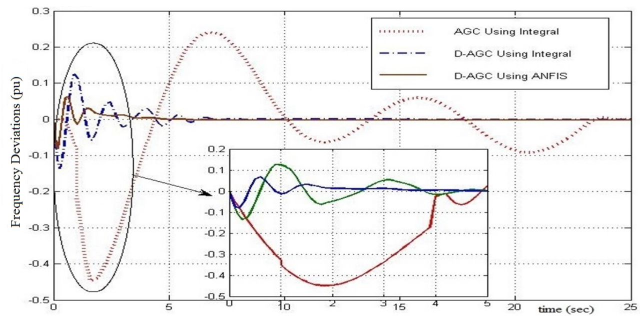

Fig. 11. Frequency deviation comparison of two area 39 bus system

Table IV and fig. 11 provide comparsion of PI and ANFIS controller in centralized and decentralized models. It is evident from the comparison that ANFIS controller in decentralized model significantly reduced the % overshoot and settling time.

In order to increase complexity in the system the 39 bus system is further studied as 3 area system. Results are given in figs. 12, 13 and 14. For the sake of comparison the no. of discos and Bi-lateral transactions between Gencos are kept same. Here a disturbance of 0.1p.u. is considered in Area-3.

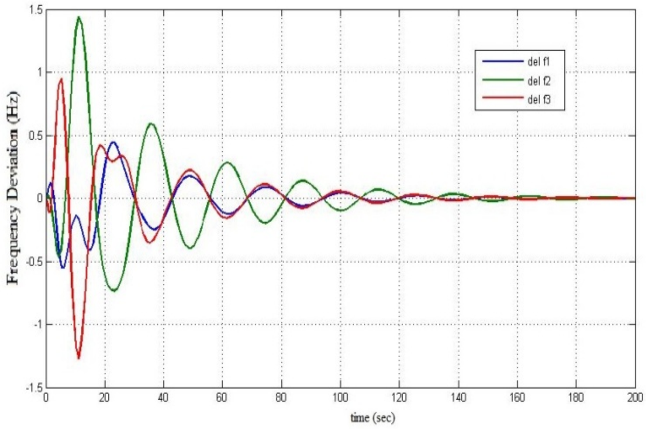

Fig. 12. Frequency response of three area 39 bus system with PI controller in centralised model

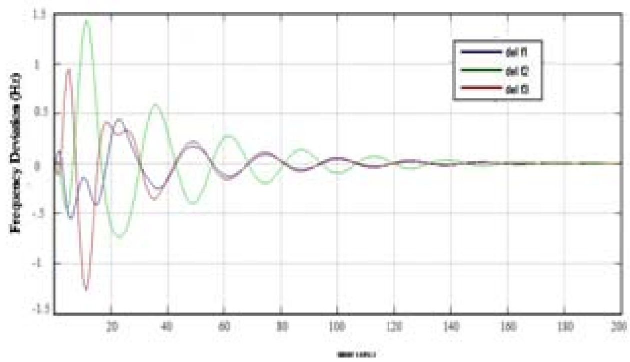

Fig. 13. Frequency response of three area 39 bus system with PI controller in de-centralised model

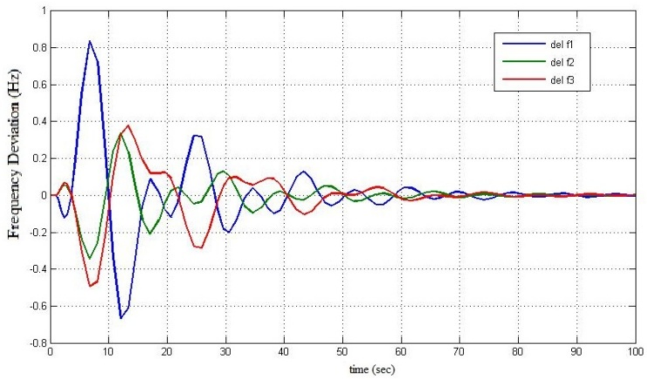

Fig. 14. Frequency response of three area 39 bus system with ANFIS controller in de-centralised model

From figs. 12, 13 and 14, it is evident that the ANFIS controller is fast acting and is reducing the area frequency deviations to minimum error in less time.

B. 75 bus Indian power system

Indian 75 bus power system is used for the study of AGC and DAGC. Study of the ANFIS controller in Indian market further shows its effectiveness. 75 bus system is divided into four control areas. PI and ANFIS controllers are tested while considering bi-lateral transactions. A change in load demand of 0.0503 p.u. and 0.0112 p.u. were considered in Area-2 and Area -4 respectively. The results are given in fig. 15 and 16. Fig 17 shows the comparison of frequency deviations for both PI and ANFIS controllers.

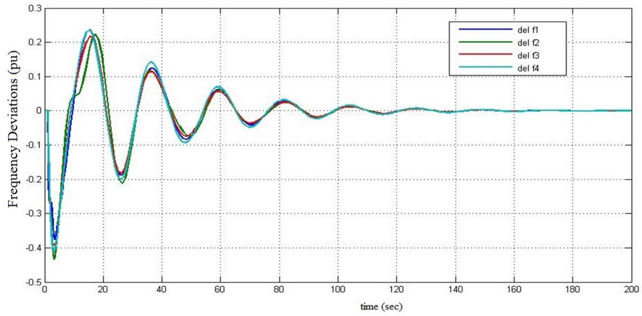

Fig. 15. Frequency response of four area 75 bus system with PI controller in de-centralised model

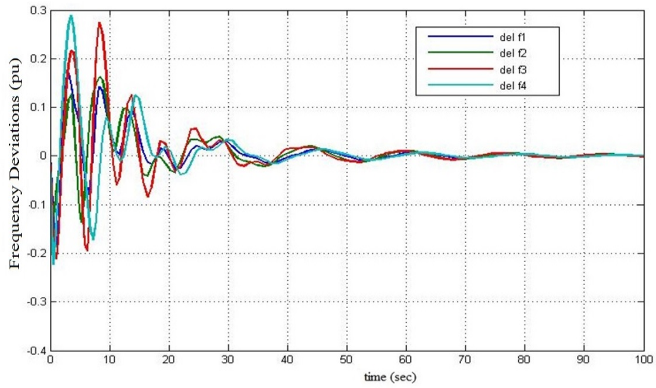

Fig. 16. Frequency response of four area 75 bus system with ANFIS controller in de-centralised model

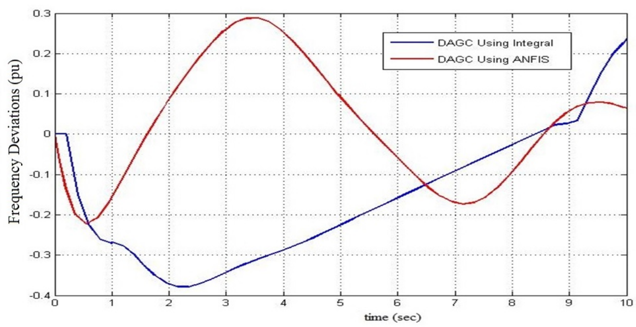

Fig. 17. Frequency deviation comparsion of area-4 in four area 75 bus system with PI and ANFIS controllers in de-centralised model

From fig. 17 it is evident that the ANFIS controller is fast acting and also smooth in reducing the frequency error in less time for the given transactions. The comparison for percentage overshoot and settling time for 75 bus system were given in Table V which shows that ANFIS controller gives minimum % overshoot in minimum time when compared with the PI controller.

TABLE V. COMPARISON OF VARIOUS CONTROLLERS FOR 75 BUS SYSTEM

CONTROLLERS	**PERCENTAGE OVERSHOOT (%)**	**SETTLING TIME (sec)**
DAGC Using Integral Controller	0.43	140
DAGC Using ANFIS Controller	0.21	60

IV. CONCLUSION

A decentralized AGC scheme using ANFIS controller is proposed in this paper under Bi-lateral transactions of Gencos. The ANFIS controller can reduce the frequency and tie line flow deviations to steady values with minimum % overshoot in minimum time. The proposed ANFIS controller is tested on a New England 39 bus System and Indian 75 bus power system. The proposed controller is compared with conventional PI controller to show its superiority. The proposed controller can be further, suitably designed in Energy as well as in Ancillary markets considering Pool-Co, Bi-Lateral and Hybrid transactions as a future scope.

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