International Journal of Electrical and Power Engineering 1 (5): 486-492, 2007
ISSN: 1990-7958

NERC's Based Market Structure for Frequency Related Ancillary Services

A. Peer Fathima, S.M. Shabna Fathima and M. Abdullah Khan
Department of Electrical and Electronics Engineering,
BSA Crescent Engineering College, Vandalur, Chennai-600048, India

Abstract: In this study, a new market structure is designed for frequency related ancillary services namely load following and frequency regulation. This structure is also in compliance with NERC (North American Electric Reliability Council) control performance standards and reduces the wear and tear of generating unit's equipment. Three-area test system is used to illustrate the proposed methodologies. The model is simulated using Matlab Simulink tool box for three area system and results are obtained . The performance of the structure is investigated using ramp with random load disturbance. In addition to load disturbance, the contract violation issue is also analyzed. Two sets of case study results are reported. The first case study analyses the performance of the conventional controller with high control parameter and the second case study simulates the design of fuzzy tuned controller. The effectiveness of the above two cases for an interconnected power system is compared. The simulation results show that the fuzzy tuned market structure is better in reducing wear and tear of the generating unit's equipments and how the generation can be shared among the Genco's with and without contract violation.

Key words: Load frequency control, NERC control performance standards, ancillary services, load following, frequency regulation, contract violation, fuzzy logic

INTRODUCTION

One of the objectives of the AGC is to maintain the system frequency at nominal value. The concept of AGC in vertically integrated power system is discussed by Elgerd (1982) and Jaleeli *et al.* (1992). An exhaustive bibiliography on the AGC on powersystem and recent philosophies are discussed by Ibraheem *et al.* (2005). For many years electric utilities have used successfully a simple decentralized control structure in their automatic generation control scheme.

In this study, we formulate the three-area dynamics model following the ideas presented by Christie and Bose (1986), Kumar *et al.* (1996, 1997) and Vaibhav *et al.* (2001). Specifically we focus in reducing wear and tear caused by the conventional controller and the designed controller is also in compliance with NERC standards (Dulpichet and Ali, 2002; Ali, 2005).

Different market structures for frequency regulation are proposed in the literature. Frequency control practices in various countries are discussed in. Feasibility of a bilateral market for loadfollowing service between supplier and customer is discussed by Emila *et al.* (2001). Fuzzy logic controller design and operational performance of AGC system of Eskom's is described by Chown and Hartman (1998). Fuzzy logic controller is used to tune the gain of the conventional controller (Dulpichet and Ali, 2002). The rules for the fuzzy logic controller are such that it is in compliance with NERC standards and also reduce wear and tear of the generating unit's equipments. The research work on NERC is contained on NERC (2002), Maojun *et al.* (2000) and George (2001).

With restructuring of the power industry new participants have emerged to compete in the generation business and to provide ancillary services such as regulation and load following Eric and Brendam (1996). To succeed in this competition the new market structure has to reduce operating and maintenance costs associated with generating unit's maneuvering.

In this study, three area dynamic model is designed to reduce unnecessary wear and tear of the equipment and it is also in compliance with NERC standards with and without contract violation.

NERC STANDARDS

For equitable operation of the interconnected power system, control areas have to comply with the North American Electric Reliability Council (NERC) control performance standards CPS1 and CPS2, which were adopted in February 1997.

Corresponding Author: A. Peer Fathima, Department of Electrical and Electronics Engineering,
BSA Crescent Engineering College, Vandalur, Chennai-600048, India

CPS1: The CPS1 standard replaces A1 criterion. Instead of requiring ACE to cross zero at least once every ten minutes, CPS1 takes a more reasonable approach based upon statistical theory. First, an expression is identified which represents, quantitatively, a control area's contribution to the reliability objective of the interconnected system to which it belongs. This expression, called the Compliance Factor (CF), is comprised of two components, frequency deviation and ACE.

Whenever, a control area has a nonzero ACE and there is a frequency deviation at the same time, a nonzero CF is formed that could be either positive or negative depending upon the signs of ACE and frequency deviation at the moment. A positive CF means the control area is acting as a burden to the interconnected power system for that particular time. On the other hand, a negative CF indicates that the area is helping the Interconnection. For each individual clock-minute, a CF value is calculated using the clock-minute average of frequency error and clock-minute average of ACE divided by its bias. At the end of each month, the overall average for the past twelve months is used to derive the control area's percentage CPS1 compliance.

CPS1 assesses the impact of ACE on frequency over a 12-month period. To calculate CPS1 ,one minute average information is used for the latest 12 months.
One minute average of the compliance factor is:

$$CF_1=[(ACEi/-10B)_1*(\Delta F/\varepsilon_1^2)_1] \quad (1)$$

The accumulated compliance factor is:

$$CF_{ac}=AVG_{12month}[CF1] \quad (2)$$

The control performance standard CPS1 is:

$$CPS1=(2-CF_{ac})*100 \text{ in } \% \quad (3)$$

Where,
ΔF : Interconnectionfrequencyerror
ε_1 : Targeted frequency bound for CPS1
B_i : Frequency bias of the ith control area

To comply with NERC, CPS1 should not be less than 100%.

CPS2: The second performance standard, CPS2 limits the magnitude of the short term ACE values. It requires the 10 min averages of control area's ACE are greater than L_{10}.. This standard is very similar to the A2 criterion. The difference is that CPS2 uses a statistically derived 10 min average L_{10} the depends upon the Interconnection'sε_{10} where as A2 depends on empirical formula L_d based on control area load characteristics. The equations are given:

$$AVG_{10Minute}(ACE_I) \le L_{10} \quad (4)$$

$$L_{10}=1.65\varepsilon_{10}v\,[(-10B_i)\,(-10B_S)] \quad (5)$$

Where,
B_S : Summation of frequency bias setting.
ε_{10} : Targeted frequency bound of CPS2.

To comply with this standard, each control area must have its compliance no less an 90%. A compliance percentage is calculated from the following equation.

$$CPS2 = [1\text{-}Violations_{Month}/(\text{Total period-avnavailed period})] * 100 \quad (6)$$

Where, violations $_{months}$ are a count of the number of periods that the clock-10 min average of ACE are greater than L_{10} in one month.

Relationship between CPS1 and CPS2: CPS1 is met, CPS2 is automatically satisfied if ACE of each control area are independent random variable and the averages of these random variables are zero.

FUZZY LOGIC CONTROLLER

Controller design: In this study, fuzzy logic rules are designed to manipulate the conventional load frequency controller to achieve two objectives:

- To reduce wear and tear of the unit equipment.
- Comply with NERC's control performance standards. CPS1 and CPS2.

In the fuzzy rule based load frequency control the structure of secondary loop is modified as shown in Fig. 1. The fuzzy logic system will lower the gain (K_I) of integral controller when the value of either input rises. On the other hand, control parameter will be increased when the value of either input falls. This algorithm will reduce wear and tear of generating unit equipment since the governor set point or raise/lower signal (ΔP_c) generated from the integral controller is modified with much lower frequency while the control area has high compliance.

Input and output membership functions: The fuzzy logic system is developed based on Mamdani's method. The input to the fuzzy logic system are:

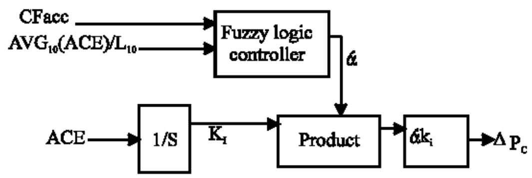

Fig. 1: Secondary loop of fuzzy tuned controller

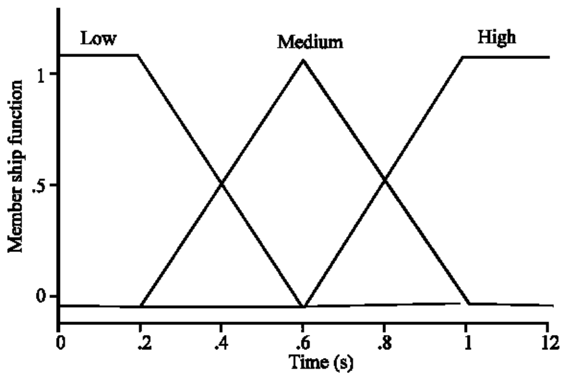

Fig. 2: Input variable Cf_{ac}

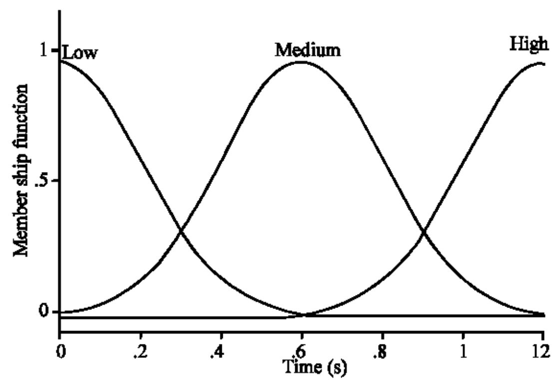

Fig. 3: Input variable ACE

- Accumulated average Compliance Factor(CF_{ac}).
- Ten minute average of ACE divided by L_{10} (AVG_{10}[ACE]/ L_{10}].

The output of the fuzzy system is the fuzzy gain (α) which is used to tune the control parameter (K_I) of the integral controller. The input and output membership functions for the fuzzy system are as given in following Fig 2-4.

Figure 2 and 3 describe (CF_{ac}) and (AVG_{10} [ACE]/ L_{10}]. Figure 4 describe the fuzzy gain (α).

Fuzzy rule design: All control areas normally comply with CPS1, but some of them cannot manage to comply with CPS2 although their compliances with CPS1 are very high. Usually the control parameters of the load frequency

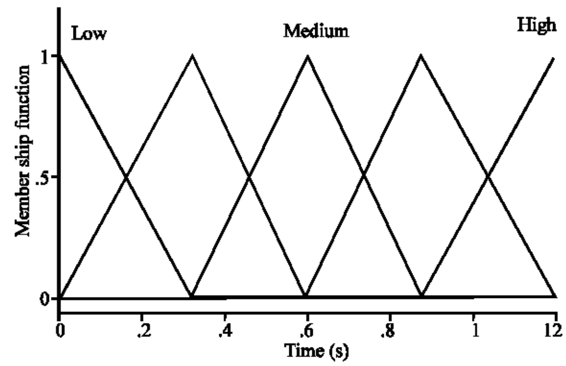

Fig. 4: Output variable(α)

Table 1: Rule table for fuzzy tuned controller

AVG(ACE)/L10			
CFac	Low	Medium	High
Low			
Low	Very low	Low	Medium
Medium	Low	Medium	High
High	Very high	Very high	Very high

control are fixed and may be tuned once a year. As a result, the values of the control parameters can be higher than necessary, control area has very high compliance, but they incur much wear and tear on their equipments. In addition the value of control parameter can be sometimes very low, when there are rapidly large load changes in loads ,which cause high average of ACE and lead to violation of CPS2 (Table 1).

Fuzzy logic rules for the proposed LFC are designed to automatically tune the gain parameter to be in a good range, which does not cause unnecessary wear and tear.

SYSTEM STUDY

Three-area test system shown in Fig. 5 is used for simulation. Let Genco1, Genco2, Disco1 are in area 1, Genco3, Genco4, Disco2 are in area 2 and Genco5 and Disco3 are in area 3. Disco1 demands 30Mw/hr ramp and superimposed on 1Mw random load disturbance. The structure is designed based on the frequency related ancillary services namely load following and regulation services. Bilateral providers Genco1 and Genco3 provide load following services. Pool providers Genco2 and Genco4 provide regulation services. Genco5 provides both Load following and regulation services.

Load following services: Load following is the use of online generation equipment to track intra and inter hour changes in customer loads (Table 2).

The cell (i,j) in table shows the percentage of load requirement from disco(j) supplied from Genco (I).

Table 2 : Load following contracts

I/j	Disco-1	Disco-2	Disco-3
Genco-1	50%	20%	40%
Genco-2	-	-	-
Genco-3	30%	80%	-
Genco-4	-	-	-
Genco-5	20%	-	60%

Table 3: Regulation contracts

	ACE (area1)	ACE (area2)	ACE(area3)
Genco-1	-	-	-
Genco-2	100%	-	-
Genco-3	-		-
Genco-4	-	100%	-
Genco	-	-	100%

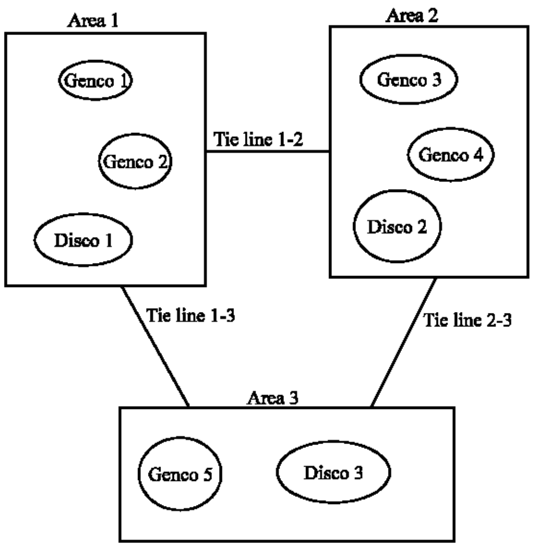

Fig. 5: Three area interconnected power system

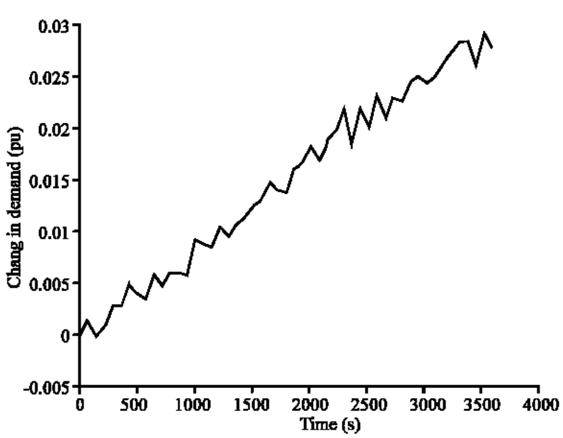

Fig. 6: Ramp with random disturbance

Regulation services: Regulation is the use of online generating units that are equipped with AGC and that can change output quickly to track the moment to moment fluctuation in customer loads and to correct unintended fluctuations in generation (Table 3).

RESULTS AND DISCUSSION

Performance of genco's for load following and regulation services: Disco1 demands 0.03 puMw ramp with 0.001 puMw random disturbance as shown in Fig. 6. The response of various Genco's are obtained for the given disturbance.

Figure 7a and b show the plot of generation responses from Genco1 and Genco3 providing load following services. Figure 7c and d show the plot of generation responses from Genco2 and Genco 4 providing regulation services. Figure 7e show output response of Genco5, which provides both regulation and load following services.

Satisfaction of NERC-CPS standards and reduction of wearandtear of generating units equipment: In this study, performance of the structure is analyzed for Conventional controller andfuzzy tuned controller.

Reduction of wear andtear: In this study, the performance of the conventional controller and the fuzzy tuned controller are assessed for the new market structure. The input to the fuzzy logic controller.

(1 min avg of CF_{ac} and 10 min avg of ACE/L_{10}) are obtained from the average of CFac and ACE. The speed changer signals for the above two controllers are compared in Fig. 8a and b [X-axis time in secs, Y-axs output of the speed charge in pu.Mw].

The Table 4 is based on the Fig. 8a and b NERC standard CPS1 is 200% whenever frequency is on schedule or ACE is zero. If ACE is aggravating the frequency error, CPS1 will become less than 200%. According to standards the minimum acceptable score of CPS1 is 100%. The table can also be formulated for the other genco's in the similar manner.

The Table 4, Fig. 8a and b show that the number of peaks, peak overshoot and peak undershoot is more in conventional controller compared to fuzzy tuned controller. This gives the conclusion that fuzzy tuned controller reduces wear and tear of the generating unit's equipment.

Satisfaction of CPS1: The accumulated Compliance Factor (CF_{ac}) and CPS1 is calculated using Eq. 1-3, based on the assumption that one year average of CF_{ac} is approximately equal to 1 h average of $CF_{ac.}$ From the results. we observe that CPS1 is greater than 100%. Hence, it comply with NERC standard CPS1.

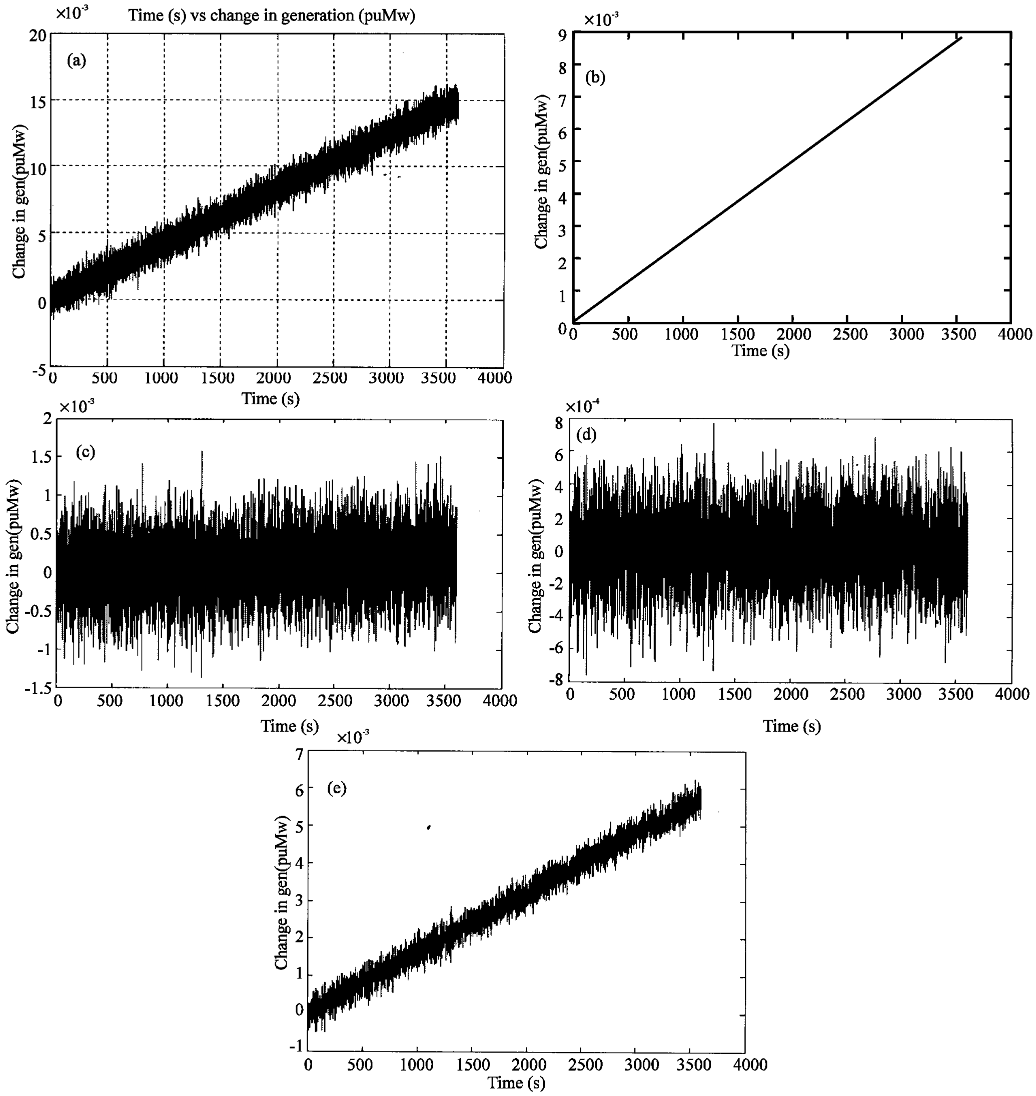

Fig. 7: (a) Response of genco1, (b) Response of genco2, © Response of genco3, (d) Response of genco4, (e) Response of genco5

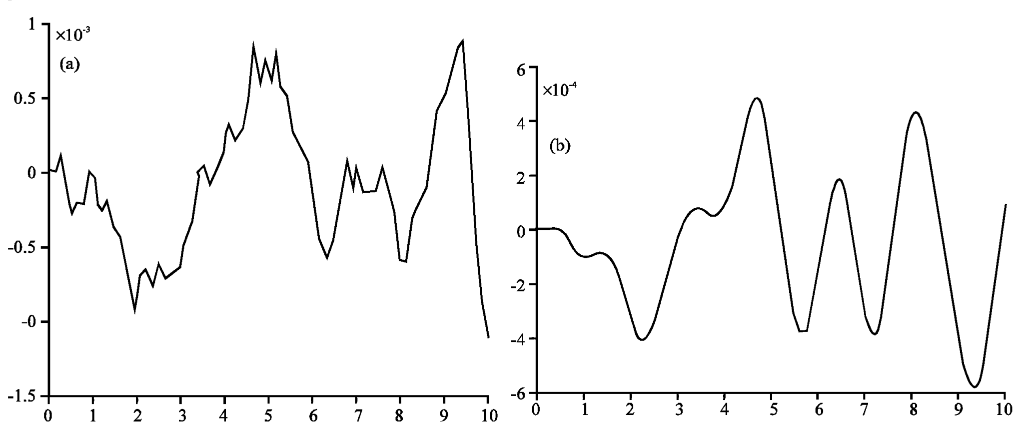

Fig. 8: (a) Speed changer response of genco 5 with Integral controller, (b) Speed changer response of genco 5 with fuzzy tuned controller

Table 4: The number of peaks, peak overshoot and peak

Parameters	Integral controller	Fuzzy controller
No of peaks	15	7
Peakovershoot (pu.Mw)	0.0008	0.0005
Peakundershoot (pu.Mw)	0.0012	0.00059

Table 5: The fuzzy tuned controller satisfies

ACE/ Time(Min)	ACE-1 Area1	ACE-2 Area2	ACE-3 Area3
0-10	-0.00011	-0.000067	-0.000047
10-20	-0.00012	-0.00008	-0.000051
20-30	-0.00014	-0.000072	-0.000042
30-40	-0.00013	-0.000076	-0.000047
40-50	-0.00013	-0.000079	-0.000049
50-60	-0.00012	-0.000079	-0.000051

(10 min average of ACE) L_{10} =0.0068 (calculated)

Table 6: The governer responces

Parameters	Integral controller	Fuzzy controller
No of peaks	15	5
Peakovershoot (pu.Mw)	0.0009	0.00045
Peakundershoot (pu.Mw)	0.0008	0.00059

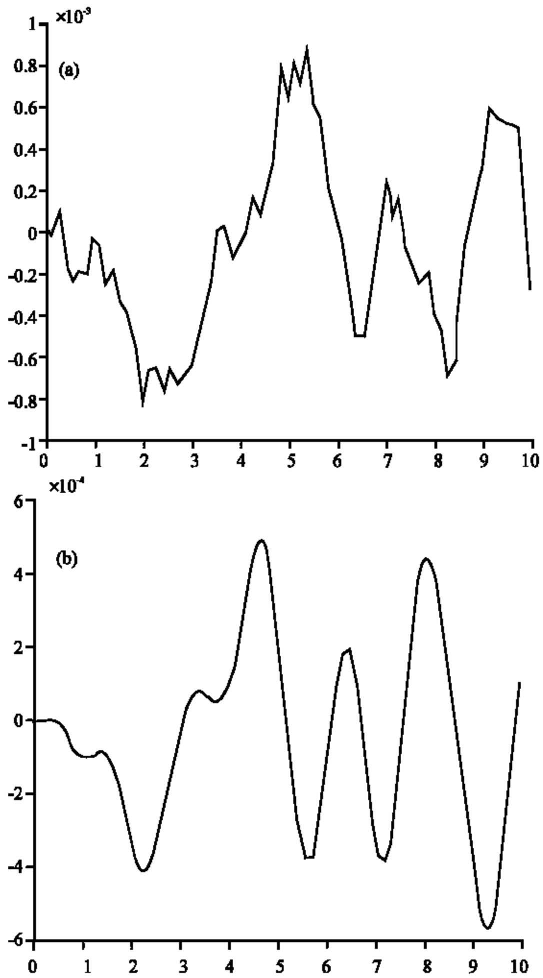

Fig. 9: (a)Speed changer response of genco 5 with Integral controller, (b)Speed changer response of genco 5 with fuzzy tuned controller

Satisfaction of CPS2: The value of L_{10} is calculated using Eq. 6. The 10 min average of ACE is also compared with L_{10} in Table 5 which show that the fuzzy tuned controller satisfies NERC standard CPS2.

Contract violation: Disco violates a contract by demanding more power than that specified in the contract. This excess power is not contracted out to any genco. This uncontracted power must be supplied by the gencos in the same area as the disco. It must be reflected as local load of the area but not as the contract demand. Consider the study again with a modification that disco1 demands 40Mw ramp and 1Mw random disturbance. This excess power is reflected in the generation of genco1 and genco2 in area1.

From the governor responses (Fig. 9a and b and Table 6) we conclude that fuzzy tuned controller is better in reducing wear and tear with contract violation also.

In Fig 9a and b X-axis is Time in secs, Y-axis is output of the speed changer in pu.Mw.

CONCLUSION

We have proposed a new market for both load following and frequency regulation ancillary services in the deregulated power system. The output responses of the Genco's shows that how the generation can be shared among them based on their contracts. The performance of the structure is investigated for conventional and fuzzy tuned controller with ramp plus random load disturbances. Simulated results show that the fuzzy tuned load frequency controller is better in reducing unnecessary wear and tear of the generating unit's equipment and in compliance with NERC standards CPS1 and CPS2. The contract violation issue is analysed. From the speed changer responses the fuzzy tuned controller is better in reducing wear and tear with contract violation also.

During contract violation an intelligent meter will be needed at the disco end, which must be capable of talking to the network, accepting transaction over the network and allocating the extra disco load among the transactions in effect. Also disco who created contract violation can expect to pay more for their frequency related services. The establishment of standards for the communication of contract data, as well as measurements (load demand and generation data) among many participating entities and of standard control algorithms seems almost mandatory for the frequency related services.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to the Management, Correspondent, Principal and Head of the Department/EEE of BSA Crescent engineering college, Chennai, India for encouragement and support given throughout this research.

REFERENCES

Ali Feliachi, 2005. On the control of re-structured electric power system. Int. J. Control, Automation Sys., 3: 363-375.

Chown, G.A. and R.C. Hartman, 1998. Design and experience with a fuzzy logic controller for AGC. IEEE. Trans. Power Sys., 13: 965-970.

Christie, R. And A. Bose, 1996. Load frequency control issue in power system operation after deregulation. IEEE. Trans. Power Sys., 11: 1191-1200.

Dulpichet Rerkpreedapong and Ali Feliachi, 2002. Fuzzy based load frequency control in compliance with NERC'S standards. IEEE. Trans. Power Sys., pp: 1154-1159.

Elgerd, O.I., 1982. Electric Energy Systems Theory: An Introduction. McGraw Hill, New York.

Emila Nobile, A. Bose and K. Tomosovic, 2001. Feasibility of a Bilateral, Market for Load following IEEE. Trans. Power Sys., 16: 782-787.

Eric Hirst and B, Kirby, 1996. Ancillary services etails: Regulation, load following and generator response. Tech. Rep., ORNL/CON-433.Oak Ridge National Laboratory. Oak Ridge, TN.

Gross, G., 2001. Teongwoole Analysis of LFC performance assessment criteria. IEEE Transaction Power System.

Ibraheem, Prabhat Kumar and D.P. Kothari, 2005. Recent philosophies of automatic generation control strategies in power systems. IEEE. Trans. Power Sys., 20: 346-358.

Jaleeli, N., D.N. Ewart and L.H. Fink, 1992. Understanding automatic generation control. IEEE. Trans. Power Sys., 7: 1106-1122.

Kumar, J., Kah-Hoe Ng and Gerald Sheble, 1997. AGC simulator for price based operation, Part I: A Model. IEEE. Trans. Power Sys., 12: 527-532.

Kumar, J., Kah-Hoe Ng and Gerald Sheble, 1997. AGC simulator for price based operation, Part II: Case Study Results. IEEE. Trans. Power Sys., 12: 533-538.

Maojun Mike Yao, Raymond R.Shoults and Randy Kelm, 2002. AGC logicBased on NERC's new control performance standard and disturbance control standard. IEEE. Trans. Power Sys., pp: 15.

NERC, 2002. Training Document CPS Overview.

Vaibhav Donde, M.A. Pai and Ian. A. Hiskens, 2001. Simulation and optimization in an agc system after deregulation. IEEE. Trans. Power Sys., pp: 16.