International Journal of Electrical and Power Engineering 3 (2): 112-118, 2009
ISSN: 1990-7958

# Fuzzy Logic Based Load Frequency Control of Hydro-Thermal System with Non-Linearities

[1]B. Anand and [2]A. Ebenezer Jeyakumar
[1]Department of Electrical Engineering, Hindusthan College of Engineering and Technology,
Coimbatore, 641032, India
[2]Sri Ramakrishna Engineering College, Coimbatore, 641022, India

**Abstract:** This study presents, a solution procedure using Fuzzy Logic Controller (FLC) to load frequency control of an interconnected hydro-thermal system. Thermal system comprises of governor dead band and generation rate constraint non-linearities and boiler dynamics. Hydro area incorporates both non-linearities. For conventional control strategies, proportional-integral controller is used. Integral square error technique is used to find optimum conventional controller gains. This controller does not provide adequate control performance with the consideration of non-linearities and boiler dynamics, when external disturbance occurs. The proposed FLC is used to control the dynamic performance of the two area system. Seven membership function is used to design the proposed controller. Time domain simulation is utilized to study the system performance. One percent step load disturbance is in given either area of the system. Finally, simulation results conclude that the proposed controller has better control performance than conventional PI controller.

**Key words:** Load frequency control, proportional-integral controller, integral square error, fuzzy logic controller

## INTRODUCTION

In recent years, major hike in power demand has been seen from the industrial and domestic side all around the world. To surpass this demand major changes have been made in power station to improve the efficiency and to increase the generating power. Load is actually a device that taps energy from the network. It varies from time to time due to uncertain demands of the consumers. When there is a change in load beyond the permissible value, the voltage and frequency get altered from the predetermined value, which is undesirable because all the electrical apparatus are designed to operate certain value. In this study, Automatic Generation Control (AGC) or Load Frequency Control (LFC) is an important issue in power system operation and control. In reality, a major power system is being divided into number of control areas or pools. Each control area is characterized by frequency and tie-line power. Naturally, all the control areas are coherent in nature.

To increase the reliable and uninterrupted power, there is a necessity to interconnect all the power systems. In this study, due attention is given to the interconnection of hydro-thermal system. Normally, thermal system consumes base load and hydro system for peak load, due to easiness in control. These two systems are interconnected through tie-lines. These tie-lines are utilized for contractual energy exchange between areas and provide inter-area support in case of abnormal conditions. India has the largest asset of more than 40,000 km of 400 kV ac lines in the world. Presently, most of the hydro electric power plants are situated in Southern, North Eastern and Himalayan region in the country. There are possibilities to generate more power from North Eastern and Himalayan region in future and a situation may arise for power engineers to have an interconnected hydroelectric power plants and hydrothermal power plants (Ibraheem and Ahmad, 2004).

For a multi area power system, the Area Control Error (ACE) comprises frequency deviation and tie-line power deviation. In order to track, the changes in the operating conditions and system parameters, proportional-integral controllers have been proposed (Swain, 2006). Although, the results of such controllers are acceptable, the tuning process for such controllers is complicated and usually requires perfect or explicit parameter values. These conventional controllers are based on the fixed gain irrespective of ACE. The dynamic performance of such controllers decrease in the presence of boiler dynamics and non-linearities such as Governor Dead Band (GDB) and Generation Rate Constraint (GRC).

---

**Corresponding Author:** B. Anand, No. 2, Arul Nagar, Near Krishna Hospitals, Palayamcottai, Tirunelveli, 627 002, Tamil Nadu, India

To overcome the difficulties, soft controller i.e., fuzzy logic controller is proposed. Fuzzy logic control has been found to be an effective alternative to conventional control technique. Although FLC allows incorporating knowledge centric to form a rule base which can be used to obtain appropriate control strategy. In this study a fuzzy logic based LFC for multi area power system considering generation rate constraint and governor dead band non-linearities and boiler dynamics is proposed.

The performance of the proposed FLC is compared with conventional PI controller when 1 step load disturbance is given in either area of the system.

## TWO AREA HYDRO-THERMAL SYSTEM

The block diagram model of two area interconnected hydro-thermal power system with non-linearities and boiler dynamics is shown in Fig. 1. The thermal area is incorporated with GRC, GDB and boiler dynamics. The hydro area is incorporated with GRC and GDB. The nominal parameters of the system are given in Appendix 1. Matlab version 7.3 has been used to study the dynamic performance such as frequency deviation in area1 and 2 (del $F_1$ and del $F_2$), tie-line power deviation (del $P_{tie}$) and area control error in area1 and 2 ($ACE_1$ and $ACE_2$) for 1% step load disturbance in either area of the system. The literature (Nanda *et al*., 2006) have shown that hydro area takes more settling time than thermal area. For this analysis, load disturbance is given in hydro area.

**Governor dead band:** Governor dead band is defined as the total magnitude of a sustained speed change within which there is no resulting change in valve position. The backlash non-linearity tends to produce a continuous sinusoidal oscillation with a natural period of about 2s (Tripathy *et al.*, 1992). The speed governor dead band has significant effect on the dynamic performance of load frequency control mechanism. In this study, describing function approach is used to incorporate the governor dead band non-linearity. The hysteresis types of non-linearities are expresses as:

$$y = F(x, \dot{x}) \text{ rather than as } y = F(x) \tag{1}$$

To solve the non-linear problem, it is necessary to make the basic assumption that the variable x, appearing in the Eq. 1 is sufficiently close to a sinusoidal Eq. 2 that is:

$$x \approx A \sin \omega_0 t \tag{2}$$

where:

A = Amplitude of oscillation.
$\omega_0$ = Frequency of oscillation.

$$\omega_0 = 2\pi f_0 = \pi \tag{3}$$

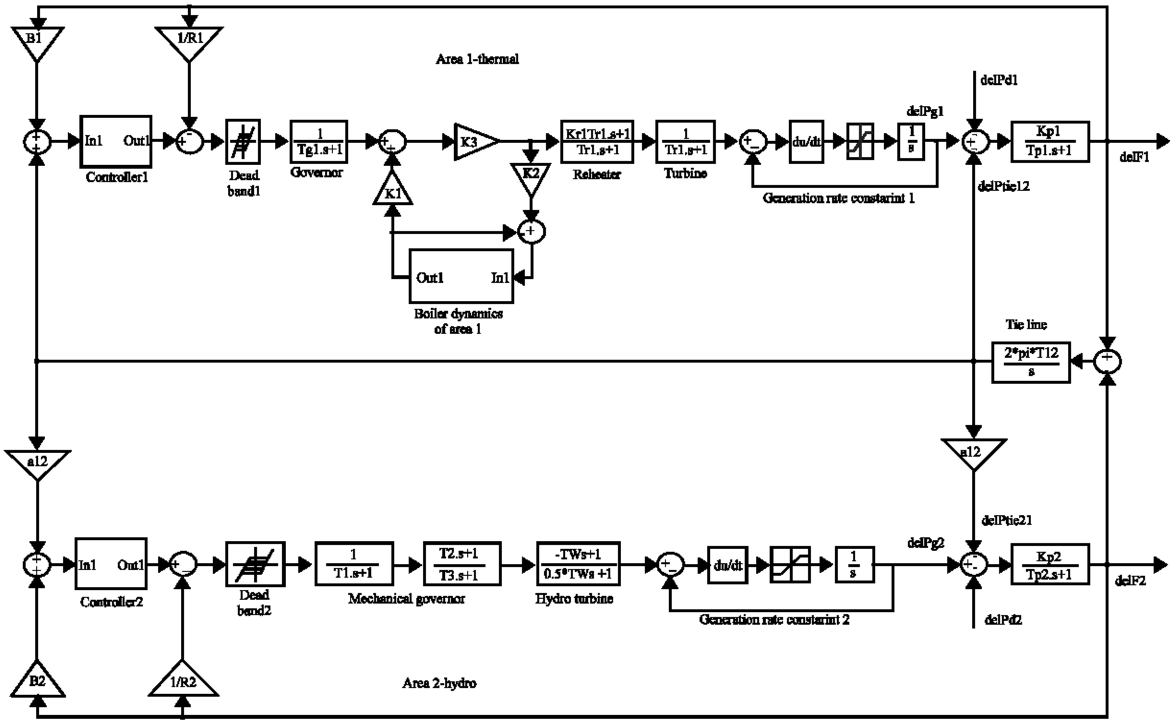

Fig. 1: Two area interconnected hydro-thermal system

As the variable function is complex and periodic function of time, it can be developed in a Fourier series as (Tripathy *et al*., 1992):

$$F(x,\dot{x}) = F^0 + N_1 x + \frac{N_2}{\omega_0}\dot{x} + ....... \quad (4)$$

As the backlash non-linearity is symmetrical about the origin, $F^0$ is zero. For the analysis, in this study, backlash non-linearity of about 0.05% for thermal system is considered. From the Eq. 4 simplification, neglect higher order, the Fourier co-efficients are derived as $N_1 = 0.8$ and $N_2 = -0.2$. By substituting the $N_1$ and $N_2$ values in Eq. 4, the transfer function model of governor dead band non-linearity is expressed as:

$$F(x,\dot{x}) = 0.8x - \frac{0.2}{\pi}\dot{x} \quad (5)$$

For hydro system, the deadband non-linearity is about 0.02% is considered, in this study.

**Generation rate constraint:** In practice, there exits a minimum and maximum limit on the rate of change in the generating power ($\Delta P_G$). Figure 2 shows the Generation Rate Constraint (GRC).

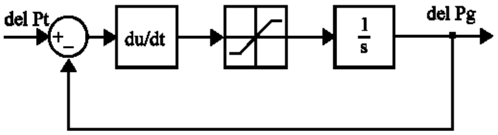

Fig. 2: Generation rate constraint

Due to adiabatic expansion, sudden power decrease would draw out excessive steam from boiler system to cause steam condensation. The steam valve of high pressure turbine acts as a control valve associated with LFC. The boiler can afford to keep its steam pressure to be constant for a while and thus, it is possible to increase generation power up to certain limit of normal power during the first few seconds. After the generation has reached this upper bound the power increases of the turbine should be restricted by GRC (Kundur, 1994).

The literature has shown that the dynamic responses of the system with the presence of GRC have larger overshoots and longer settling times, compared to the system without GRC (Lu *et al*., 1995). Furthermore, if the parameters of the controller are not chosen properly, the system may become unstable. A generation rate constraint of 0.0017 p.u. MW $\sec^{-1}$ is considered here for thermal system, i.e.,

$$\Delta \dot{P}_g \le 0.1\,\text{p.u.MW}\,\text{min}^{-1} = 0.0017\,\text{p.u.MW}\,\text{sec}^{-1} \quad (6)$$

The typical value of permissible rate of generation for hydro system is much higher than thermal system. In this present study, GRC of 4.5% $\sec^{-1}$ for rising generation and 6% $\sec^{-1}$ for lowering generation is considered.

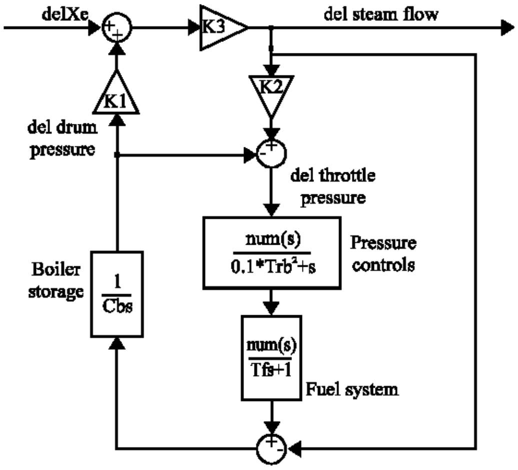

Fig. 3: Boiler dynamics

**Boiler dynamics:** Boiler is a device for producing steam under pressure. Figure 3 shows the model to represent the boiler dynamics. Basically, this model is drum type boiler. An oil/gas fired boiler system has been considered in this study, because such boilers respond to load demand changes more quickly than coal fired units (Chen *et al*., 2008). Drum type boiler is otherwise known as recirculation boilers which rely on natural or forced circulation of drum liquid to absorb energy from the hot furnace walls, called water walls for generating steam.

The boiler receives feed water which has been preheated in the economizer and provides saturated steam outflow. Recirculation boiler make use of a drum to separate steam flow from the recirculation water so that it can proceed to the super heater as a heatable vapour, hence, recirculation boiler are referred to as drum type boiler.

For boiler control strategies or modes of operation, there are four methods available, namely, boiler leading, turbine leading, coordinated boiler turbine control and sliding pressure control, here, boiler leading or turbine following mode of control is considered. With this operation, the MW demand signal is applied to combustion controls. Steam flow and MW output closely follow steam production in the boiler (Kundur, 1994).

Boiler following controller tends to be fairly response to AGC signals, on the order of 3% $\min^{-1}$ for a 30%

excursion particularly if fueled by oil or gas. The AGC signal usually drives the speed-load set point adjusts on the speed-governor control action which in turn, causes turbine valve movement. The boiler control senses the changes in stem pressure to adjust flows of air, fuel etc.

## CONVENTIONAL PI CONTROLLER

To achieve better dynamic performance and to provide accuracy, Proportional Integral (PI) controller is adopted. The main idea of implementing PI controller is to actuate the load reference point until the frequency deviation becomes zero. Integral controller provides zero steady state frequency deviation and proportional controller reduce the overshoot. The load frequency controller is based upon tie line bias control where each area tends to reduce the Area Control Error (ACE) to zero.

Literature survey shows that many utilities such as frequency control and voltage control use PI controller to achieve improved dynamic performance. The task of load frequency controller is to generate a control signal (u) that maintains dynamic parameter at predetermined values. The control signals can be written as:

$$u_1 = -K_p \cdot ACE_1 - K_i \int ACE_1 dt \qquad (7)$$

$$u_2 = -K_p \cdot ACE_2 - K_i \int ACE_2 dt \qquad (8)$$

where, $K_p$ and $K_i$ are proportional and integral gains, respectively. For conventional PI controller, the gain $K_p$ and $K_i$ has been optimized using Integral Square Error (ISE) criterion. For ISE technique, the objective function used is,

$$J = \int_0^t (\Delta F_1^2 + \Delta F_2^2 + \Delta P_{tie}^2) dt \qquad (9)$$

Where:

$\Delta F$ = Change in frequency.

$\Delta p_{tie}$ = Change in tie line power.

Using ISE technique, the objective function Eq. 9 for LFC, the tuning values of optimum proportional-integral controller gains are found to be $K_p$= 0.3 and $K_i$ = 0.12. Figure 4 shows the performance index curve, which is used to find optimum conventional controller gain values. By adopting the above PI gain, the two area hydro-thermal system is simulated with 1 step load disturbance in hydro area. The dynamic parameters such as frequency deviation in area 1 and 2 and tie line power deviation are not properly settling down even with the consideration of PI controller. From the simulation results, it is found that the tie-line power deviation has high frequency oscillation around the set point. So, it is necessary to develop an alternate controller, which is capable of handling area frequency deviation and tie-line power deviation.

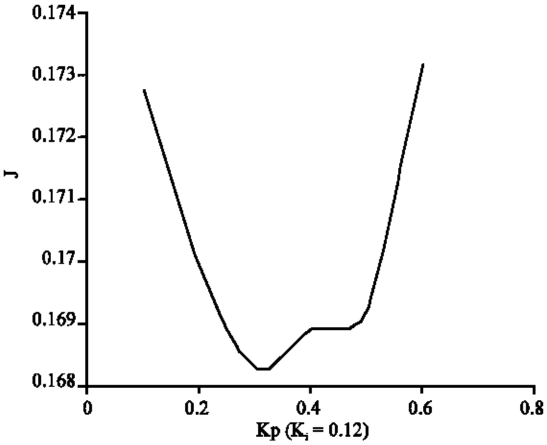

Fig. 4: Performances index curve (J)

## FUZZY LOGIC CONTROLLER

The method of fuzzification has found increasing applications in power systems. The applications of fuzzy sets signify a major enhancement of power systems analysis by avoiding heuristic assumptions in practical cases. This is because fuzzy sets could be deployed properly to represent power system uncertainties. The advantage of using fuzzy logic is that the controller is based on heuristic and therefore, able to incorporate human intuition and experience.

The concept of fuzzy logic was developed by Zadeh (1965), which widely exists in engineering problems. His process approach emphasized modeling uncertainties that arise commonly in human thought processes. The first fuzzy controller was developed (Mamdani and Pappis 1977) was steam engine controller and later fuzzy traffic lights. The design of FLC can be normally divided into three areas namely allocation of area of inputs, determination of rules and defuzzifying of output into a real value. In this study the proposed fuzzy controller takes the input as ACE and $\dot{ACE}$, which is given by:

$$ACE_i = F_i B_i + \Delta P_{tie} \qquad (10)$$

where, $B_i$ is frequency bias constant, taken as:

$$1/K_{pt} + 1/R_i \qquad (11)$$

Table 1: Fuzzy control rules

| | ACE | | | | | | |
|---|---|---|---|---|---|---|---|
| ACĖ | NB | NM | NS | ZO | PS | PM | PB |
| NB | PB | PB | PB | PB | PM | PM | PS |
| NM | PB | PM | PM | PM | PS | PS | PS |
| NS | PM | PM | PS | PS | PS | PS | ZO |
| ZO | NS | NS | NS | ZO | PS | PS | PS |
| PS | ZO | NS | NS | NS | NS | NM | NM |
| PM | NS | NS | NM | NM | NM | NB | NB |
| PB | NS | NM | NB | NB | NB | NB | NB |

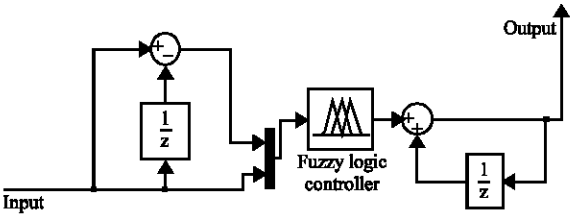

Fig. 5: Fuzzy logic controller

The block diagram of fuzzy logic controller is shown in Fig. 5 (Nanda and Mangla, 2004). Membership Functions (MF) specifies the degree to which a given input belongs to set. Here, seven membership function have been used to explore best dynamic performance namely,

- Negative Big (NB).
- Negative Medium (NM).
- Negative Small (NS).
- Zero (ZO).
- Positive Small (PS).
- Positive Medium (PM).
- Positive Big (PB).

Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. These rules help us to describe the control action in quantitative terms and have been obtained by examining the output response to corresponding inputs to the fuzzy controller. Rules are given in Table 1. The rules are interpreted as follows:

If ACE is PB and ACĖ is PS then output is NM

The mathematical procedure of converting fuzzy values into crisp values is known as defuzzification. A number of defuzzification methods are reported in literature. In this present study, centre of area method is adopted.

The fuzzy controller is designed with seven linguistic variables and triangular membership functions.

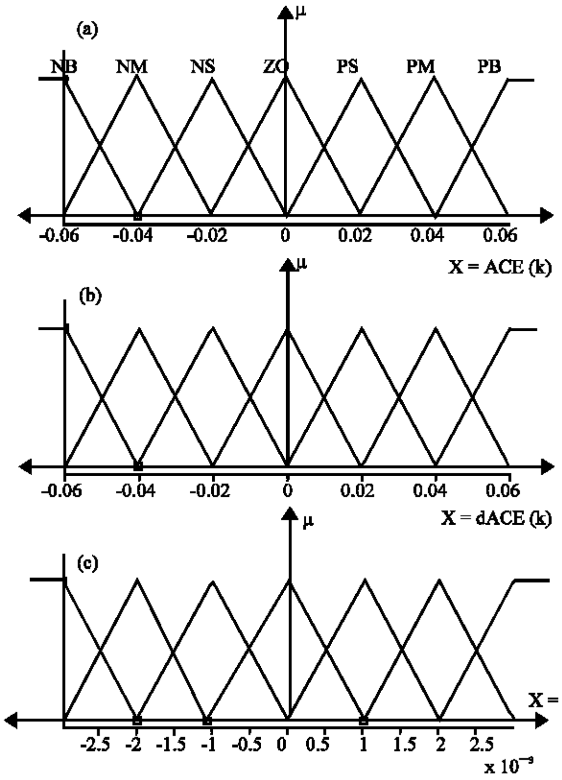

Fig. 6: Triangular membership fuctions a: input avriable ACE; b: input variable (ACĖ); c: output variable

Figure 6a and b shows the input variables ACE and ACĖ, respectively. Figure 6c shows the output variable.

## RESULTS AND DISCUSSION

Simulations were performed using conventional PI and fuzzy logic controllers applied to a two area interconnected hydro-thermal system considering non-linearities and boiler dynamics. Two performance criteria such as settling time and overshoots were considered in the simulation for the system dynamic parameter, frequency deviation in both the area and tie-line power deviations. The system is simulated with 1 step load disturbance in hydro area (Nanda *et al.*, 2006) have concluded that for the same perturbation, hydro area takes more settling time than in thermal area.

Frequency deviation in area 1 and 2 with conventional PI and FLC are shown in Fig. 7a and b, respectively also tie-line power deviation is shown in Fig 7c.

By examine these results, conventional PI controller does not provide good control performance also it takes more settling time to settle down the steady state error,

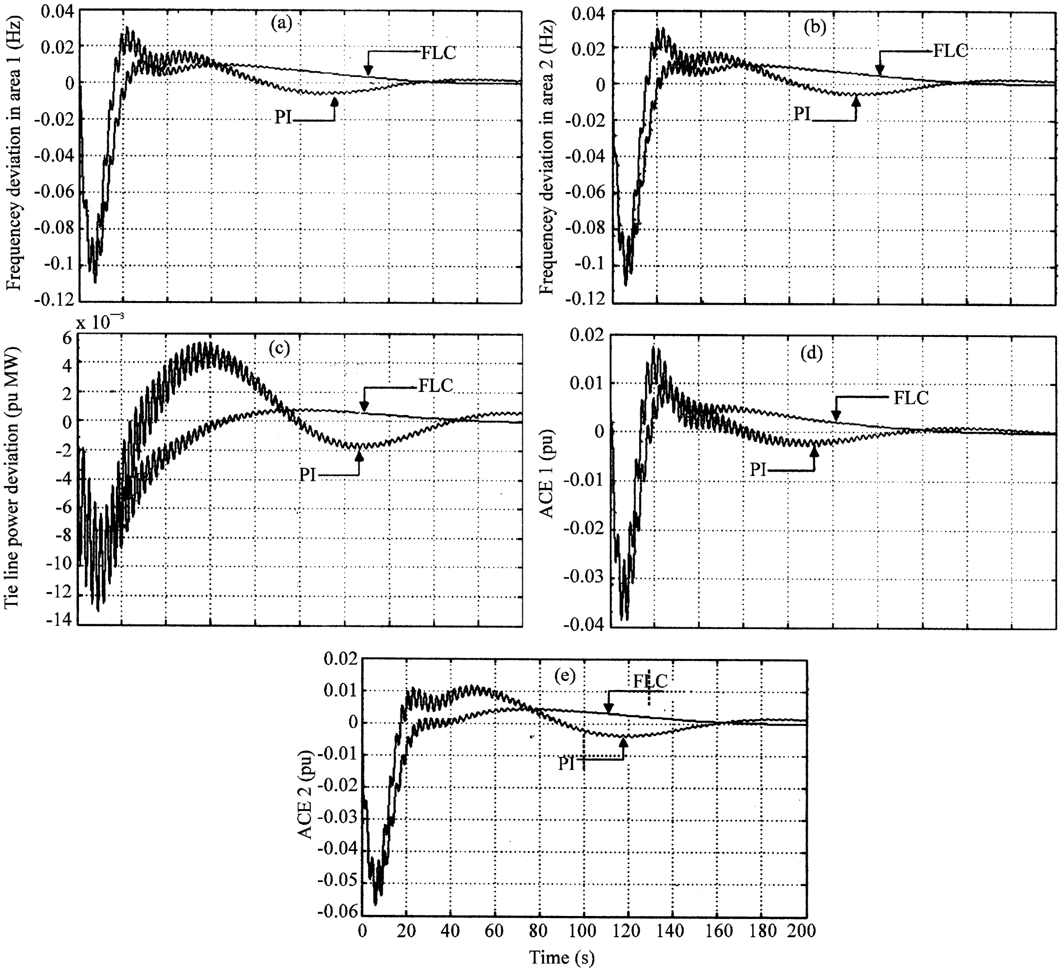

Fig. 7: A: frequencey deviation in area 1, b: frequencey deviation in area 2, c: Tie-line power deviation and d: area control error in area 1, e: Area control crror in area for both PI and fuzzy controller

due to the fixed value of PI gains irrespective of changing error. But fuzzy logic controller provides satisfactory control performance, over conventional PI controller. Referring Fig. 7c FLC gives very good performance whereas PI controller has high oscillation nearer to set point.

The simulation results of frequency deviations and tie-line power deviation with FLC advocates, the proposed controller is suitable for LFC schemes, which is also verified through proper settlement of area control error in area 1 and 2, as clearly shown in Fig. 7 d and e. The area control error is defined as, a quantity reflecting the deficiency or excess of power within a control area. Here, the ACE in area 1 and 2 are also properly controlled with FLC. From all responses obtained, it is evident that the operation of FLC is more satisfied than that of conventional PI controller.

## CONCLUSION

In this study, fuzzy logic controller is proposed for load frequency control scheme of a two area interconnected hydro-thermal power system. The thermal system is incorporated with both non-linearities (GDB and GRC) and boiler dynamics. The hydro area includes both non-linearities. To design conventional PI controller gains, Integral Square Error (ISE) technique is used. Due to the fixed value of these gains the dynamic performance is not satisfactory. So an alternate controller i.e., fuzzy logic controller is proposed. Seven membership functions are utilized. The system is simulated by giving 1 sudden load perturbation in area 2. The dynamic parameters such as frequency deviations and tie-line power deviation are taken to validate the controller performance, which is also justified through area control error. The simulation results shows that FLC has better control performance over conventional PI controller even with the consideration of non-linearities and boiler dynamics. In conclusion, the proposed FLC is very simple and easy to implement since, it does not require the system parameters also it provides quality and reliable electric power supply.

Appendix 1: Nominal parameters

| System data | Boiler (oil fired) data |
|---|---|
| $T_{t1} = 0.3s$ | $K_1 = 0.85$ |
| $T_{g1} = 0.2s$ | $K_2 = 0.095$ |
| $K_{r1} = 0.333$ | $K_3 = 0.92$ |
| $T_{r1} = 10s$ | $C_b = 200$ |
| $K_{p1} = 120$ Hz pu$^{-1}$ MW | $T_d = 0$ |
| $T_{p1} = 20s$ | $T_f = 10$ |
| $T_{12} = 0.0707$ MW rad$^{-1}$ | $K_{ib} = 0.03$ |
| $R_1 = R_2 = 2.4$ Hz pu$^{-1}$ MW | $T_{ib} = 26$ |
| $K_{p2} = 80$ Hz pu$^{-1}$MW | $T_{rb} = 69$ |
| $T_{p2} = 13s$ | |
| $T_1 = 48.7s$ (hydro area) | |
| $T_2 = 0.513s$ (hydro area) | |
| $T_3 = 10s$ (hydro area) | |
| $T_w = 1s$ (hydro area) | |
| $f = 60$ Hz | |

## REFERENCES

Chen, C.S., Y.D. Lee, C.T. Hsu and C.T. Chen, 2008. Transient response of an incinerator plant by considering boiler model with dynamic steam variation. IEEE Trans. Power Syst., 23: 92-99. DOI:10.1109/TPWRS.2007.913211.INSPEC:TPWRS-00665-2005.

Ibraheem, P.K. and S. Ahmad, 2004. Dynamic performance enhancement of hydro-power system with asynchronous tie-lines. Institution of Engineers (India) J. EL, 85: 23-34.

Kundur, P., 1994. Power Systems Stability and Control. Tata McGraw-Hill Publishing Company, New Delhi, pp: 452-454. ISBN: 0-07-061133-5.

Lu, C.F., C.C. Liu and C.J. Wu, 1995. Effect of battery energy storage system on load frequency control considering governor deadband and generation rate constraint. IEEE Trans. Energy Conversion, 10: 555-561. INSPEC: 95WM 086-9EC.

Mamdani, E.H. and C.P. Pappis, 1977. A fuzzy logic controller for a traffic junction. IEEE. Trans. Syst. Man Cybernet., 7: 707-717. DOI: 10.1109/TSMC.1977.4309605.

Nanda, J. and A. Mangla, 2004. Automatic generation control of an interconnected hydro-thermal system using conventional integral and fuzzy logic controller. IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies (DPRT2004) April 2004 Hong Kong, pp: 372-377. PMID: 0-7803-8237-4/04/2004IEEE.

Nanda, J., A. Mangla and S. Suri, 2006. Some new findings on automatic generation control of an interconnected hydrothermal system with conventional controllers. IEEE Trans. Energy Conversion, 21: 187-194. DOI:10.1109/TEC.2005.853757.INSPEC:TEC-00170-2004.

Swain, A.K., 2006. A simple fuzzy controller for single area hydro power system considering generation rate constraints. Instit. Eng. (India) J. EL., 87: 12-17.

Tripathy, S.C., R. Balasubramanian and P.S.C. Nair, 1992. Effect of superconducting magnetic energy storage on automatic generation control considering governor deadband and boiler dynamics. IEEE. Trans. Power Syst., 7: 1266-1273. DOI: 0885-8950/92. INSPEC: 90 IC 588-4 PWRS.

Zadeh, L.A., 1965. Fuzzy sets. Int. J. Inform. Control, 8: 338-353.