International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 02, Issue – 10, October – 2017, PP – 27-36

Scaling Factor Tuning of Fuzzy Logic Controller for Load Frequency Control Using Particle Swarm Optimization Technique

Pawan Kumar[1], Kusumlata Agarwal[2] and Avdhesh Sharma[3]
[1]Pawan Kumar is Masters in Engineeringin power system from MBM Engg. College,
JNV University Jodhpur, India
[2]Kusumlata Agarwal is currently pursuing PhD program in power system in MBM Engg. College,
JNV University Jodhpur, India
[3]Avdhesh Sharma is HOD andProfessor in Electrical Engineering Department, M.B.M Engg. College,
JNV University Jodhpur, India

Abstract: In this paper scaling factors of fuzzy logic controller are tuned using particle swarm optimization (PSO) technique which is investigated for two-area automatic generation control (AGC) system. The conventional controllers for load frequency control are designed at nominal operating conditions and do not provide optimal performance on other operation conditions. Hence, traditional tie line bias controllers like PI controllers are modified using fuzzy logic controller. But it is difficult to tune the scaling factor of fuzzy logic controller. So particle swarm optimization technique is applied to tune the scaling factor of fuzzy logic controller in order to keep system tie line power and area frequencies at their desired values.

Keywords: Area control error (ACE), Area frequency response characteristic (AFRC), Automatic generation control (AGC), Fuzzy logic controller (FLC), Genetic algorithm (GA), Integral control, Load frequency control (LFC), Particle swarm optimization (PSO).

1. INRODUCTION

When load in the system increases; turbine speed drops before the governor adjusts the input. As the change in speed decreases, the error signal becomes smaller and the position of governor valves gets near to the required position to maintain constant speed. However the constant speed will not be at set point and there will be an offset. An integrator is generally added to overcome this problem, which will automatically adjust the generation and restore the area frequency to its nominal value, this is known as automatic generation control (AGC). In interconnected power system there are many control areas, which are connected with the tie lines and each of which performs its self automatic generation control with an objective of maintaining the area control error (ACE) close to zero using complete tie line bias control action. Each control area has responsibility for load frequency control effectively alonwith to set the tie line power at predecided schedule. Complete tie line bias control works effectively provided tie line bias control characteristic matches its own area governor drooping characteristic.

Many number of control strategies exist to achieve better performance. One of the controllers suited for this purpose is integral controller which can help to limit the steady state deviation. Fuzzy set theory was introduced by Zadeh in 1965, provides an effective method of dealing with the problem of knowledge representation in an uncertain environment [1]. Fuzzy logic has the advantage of modeling complex, nonlinear problems linguistically rather than mathematically and using natural language processing [2]. The use of fuzzy logic requires the knowledge of a human expert to create an algorithm that mimics his/her expertise and thinking. Nowadays, the use of fuzzy control systems in real-life application is increasing day by day. Most of the systems that require computer aided system are using the fuzzy decision support systems [4]. The performance of the fuzzy system found better than other conventional methods [13, 16]. The improvement of the fuzzy system is depends on the how it represents and processes the imprecise information. In the fuzzy system, number of rules is increasing exponentially with an increasing number of variables. Then define the rule set and membership function for achieving system's good performance is more difficult for experts [3, 5]. In the fuzzy logic, a search space problem is defined by a rule set and membership functions.

Further the fuzzy logic system can be improved by using advance optimization methods like Genetic algorithm (GA) and Particle swarm optimization (PSO). Here PSO is used to tune the fuzzy controller for two areas thermal system [12]. GA can be used to obtain the global optimum of scaling factor for FLC but PSO based FLC provide better dynamic responses compared to the conventional ones. An approach of using PSO to optimize fuzzy controllers was also proposed in reference [10].

In this paper scaling factors of fuzzy logic controller are tuned using particle swarm optimization (PSO) technique which is investigated for two-area automatic generation control (AGC) system.

2. LOAD FREQUENCY CONTROL IN TWO AREA SYSTEM

Power system frequency regulation or load frequency control (LFC) is a major function of automatic generation control which has been one of the important control problems in power system design and operation. Normal frequency deviation beyond certain limits may directly impact on power system operation as well as system reliability. The large frequency deviation can damage equipments, affect load performance which cause the transmission lines to be overloaded and can interfere with system protection schemes and ultimately to an unstable condition. Two primary objectives of a power system load frequency control is to maintain frequency and power interchanges with neighbouring control areas at the pre decided schedule [5].

Power flow over the line is from system 1 to system 2 is given by

$$P_{12} = \frac{|V_1||V_2|}{X}\sin(\delta_1 - \delta_2) \qquad \text{... (1)}$$

Where, $|V_1|$ and $|V_2|$are voltage magnitudes at ends 1 and 2, δ_1 and δ_2 are phase angles of voltages V_1 and V_2 respectively and X is reactance of tie line.

For small deviations in angles δ_1 and δ_2, the change in power transfer ΔP_{12} is given by

$$\Delta P_{12} = \left[\frac{|V_1||V_2|}{X}\cos(\delta_1 - \delta_2)\right](\Delta\delta_1 - \Delta\delta_2) \qquad \text{... (2)}$$

The synchronizing coefficient (T_{12}) of tie line is defined as

$$T_{12} = \frac{|V_1||V_2|}{X}\cos(\delta_1 - \delta_2) \qquad \text{... (3)}$$

Finally ΔP_{12} is represented as

$$\Delta P_{12} = \frac{2\pi . T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \qquad \text{... (4)}$$

Implementation of above tie line equastions in model [6] is shown below in figure 1.

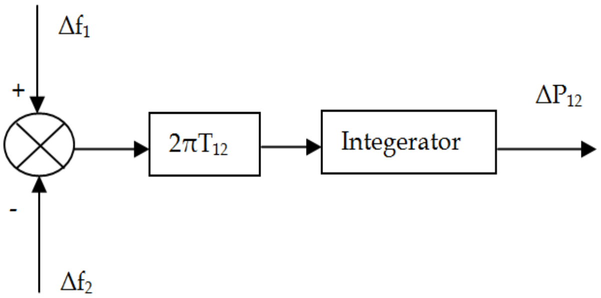

Figure 1: Representation of tie-line

The control signals are proportional to the change in frequency as well as change in tie line power. A suitable linear combination of frequency and tie line power changes for respected area is known as the area control error. Actually ACE is the difference between scheduled and actual electrical generation within a control area on the power grid, taking frequency bias into account. The area control errors for a two area system are given as

$$ACE_1 = \Delta P_{12} + B_1\,\Delta f_1 \qquad \text{... (5)}$$
$$ACE_2 = \Delta P_{21} + B_2\,\Delta f_2 \qquad \text{... (6)}$$

Where,

ACE_1 = Area control error of system 1

ACE_2 = Area control error of system 2

ΔP_{12} = Change in power transferred from 1 to 2

Also $\Delta P_{21} = -\Delta P_{12}$

B_1 and B_2 are constants which represent the frequency bias and can be determined from the size of the system. Generally it is standardized equal to area frequency response characteristic (B= D+1/R) [16].

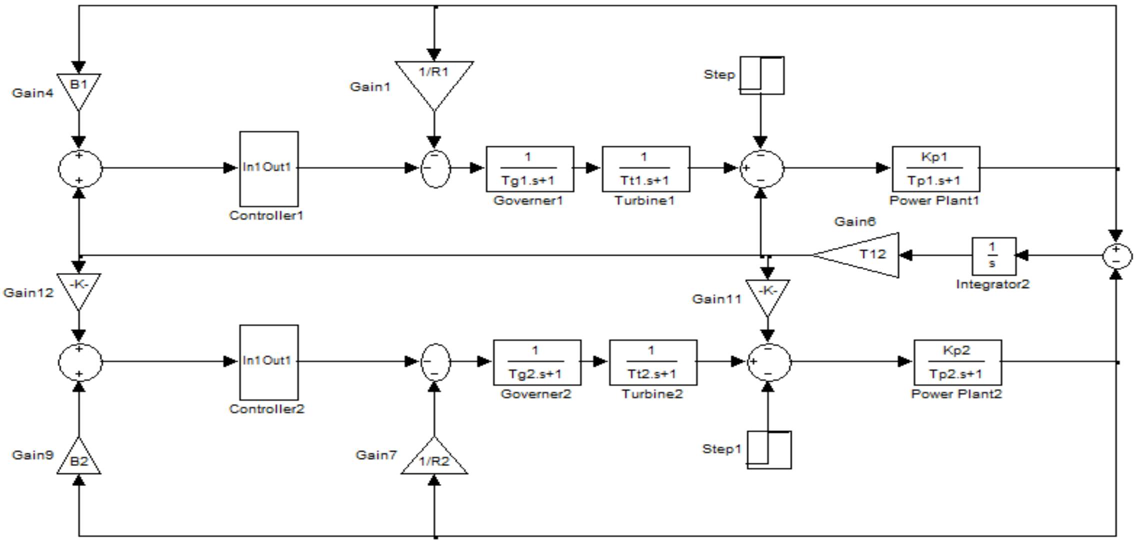

Figure 2: Model of automatic generation control for two area thermal System

3. PID CONTROLLER

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, and then choosing P, I, and D based on the dynamic model parameters. The PID controller encapsulates three of controller structures in a single package. The parallel form of a PID controller is given as:

$$C(S) = K_P + K_I / S + K_D S \qquad \ldots (7)$$

Where, K_P - Proportional Gain, K_I - Integral Gain and K_D- Derivative gain.
Performance of PID controller is not better as given in table 2, 3 and 4, so it can be further improved by fuzzy logic controller.

4. FUZZY LOGIC SYSTEM

An objective of fuzzy logic is to make computers think like human being. Fuzzy logic is deals with the vagueness intrinsic to human like thinking and natural language. Using fuzzy logic algorithms can enable machines to understand and respond to vague human concepts such as large, small, hot, cold etc. It is also provides a relatively simple approach to reach definite goal from imprecise information [9].

4.1 FUZZY LOGIC SYSTEM

Fuzzy logic controller (FLC) is used for automatic generation control (AGC) in a two area system is given below in form of block diagram.

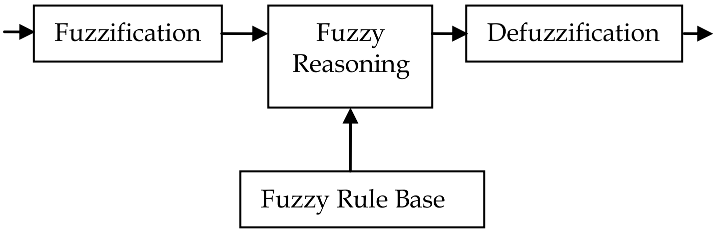

Figure 3: Structure of fuzzy logic controller [14]

Fuzzy Logic Controller consists of four main parts: Fuzzification, knowledge base, decision-making logic and defuzzification.

(i) The Fuzzification:

(a) It measures the values of input variables.

(b) Performs a scale mapping that transforms the values of input variables into universe of discourse.

(c) Convert input into suitable linguistic values.

(ii) The Knowledge Base:

The knowledg consists of data base and linguistic control rule base:

(a) The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in fuzzy logic controller.

(b) The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules.

(iii) The Decision Making Logic:

The Decision Making Logic has the capability of simulating system like human decision making. It takes decision on as rules applied according to problem.

(iv) Defuzzification:

(a) Similar to fuzzification it converts the range of values of input variables into corresponding universe of discourse.

(b) Defuzzification yields a non-fuzzy and control action from an inferred fuzzy control action [7].

Rule base for fuzzy logic:

Error and cumulative error are two inputs of fuzzy logic controller and output is found comparing these inputs. In this work of fuzzy logic controller is designed which is based on 49 rules. As seven membership functions in error input and seven membership functions in cumulative error input, so total 7*7=49 rules. These fuzzy logic rules are in "if and then" format. These rules can be placed in form of table as given in table 1 [15].

Table 1: Fuzzy logic controller rule base:

Comulative error

Error

ce e	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PM	PM	Z	NS	NS
Z	PB	PM	PM	Z	NS	NM	NB
PS	PM	PM	NS	NS	NM	NB	NB
PM	PS	PS	NS	NM	NB	NM	NB
PB	NS	NS	NM	NM	NM	NM	NB

Fuzzy set:

In fuzzy logic system different membership functions (e.g. triangular, Gaussian, S-shaped) can be used for input and output variable. Triangular membership functions with equal shape (conventional fuzzy set) and unequal set (tuned fuzzy set) [11] for input and output action are used in this work. Range of fuzzy logic controller input error is taken from -0.8 to +0.8 (as shown in figure 5 and figure 6), cumulative error is -1.5 to +1.5 and output control action is taken from -0.015 to +0.015 for both conventional and tuned FLC. Where the range of fuzzy logic controller input error, cumulative error and output control action is taken from -1 to 1 for PSO based FLC. Scaling factors Ta(1), Ta(2) and Ta(3) given in figure 4 are optimized using PSO for fast response.

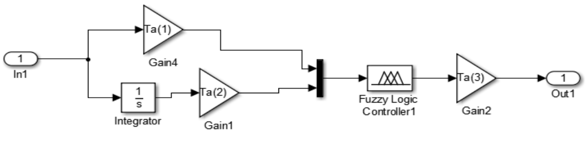

Figure 4: Fuzzy logic controller model

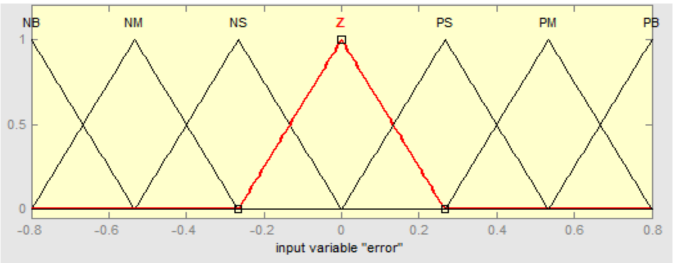

Figure 5: Error input using conventional membership functions

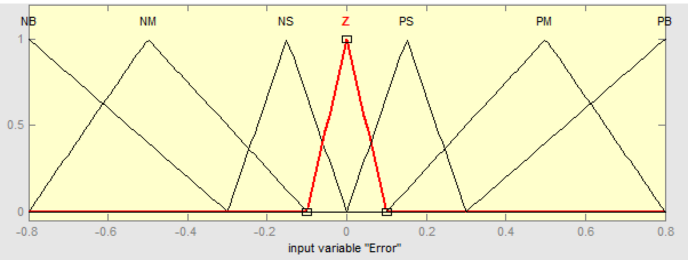

Figure 6: Error input using tuned membership functions

5. PSO ALGORITHMS

Last few years PSO algorithm is applied in many researches and applications and it is found that PSO is faster as compared to other optimization methods. Particles represented in PSO algorithm are potential solutions fly through problem space by following the current optimum particles swarm with a velocity component that decides flying direction and distance. Each particle obtains the best solution determined by objective function through iteration search. At each iterative, particles update themselves via two best values. One is individual best value named ‘pbest’, which keeps track of its coordinates associated with the best solution it has achieved so far in the problem space. The other one is global best value called ‘gbest’ that can be found in the whole population [8, 12]. Above explained process of PSO is given as flow chart in figure 7.

Present velocity is given as:

$$\begin{aligned} v_i^k &= w v_i^{k-1} + c_1 * rand_1 * (pbest_i - x_i^{k-1}) \\ &+ c_2 * rand_1 * (gbest_i - x_i^{k-1}) \end{aligned} \quad \text{... (8)}$$

$$w = w_{\max} - \frac{k}{iter_{\max}} * (w_{\max} - w_{\min}) \quad \text{... (9)}$$

Present position is given as:

$$x_i^k = x_i^{k-1} + v_i^{k-1} \quad \text{... (10)}$$

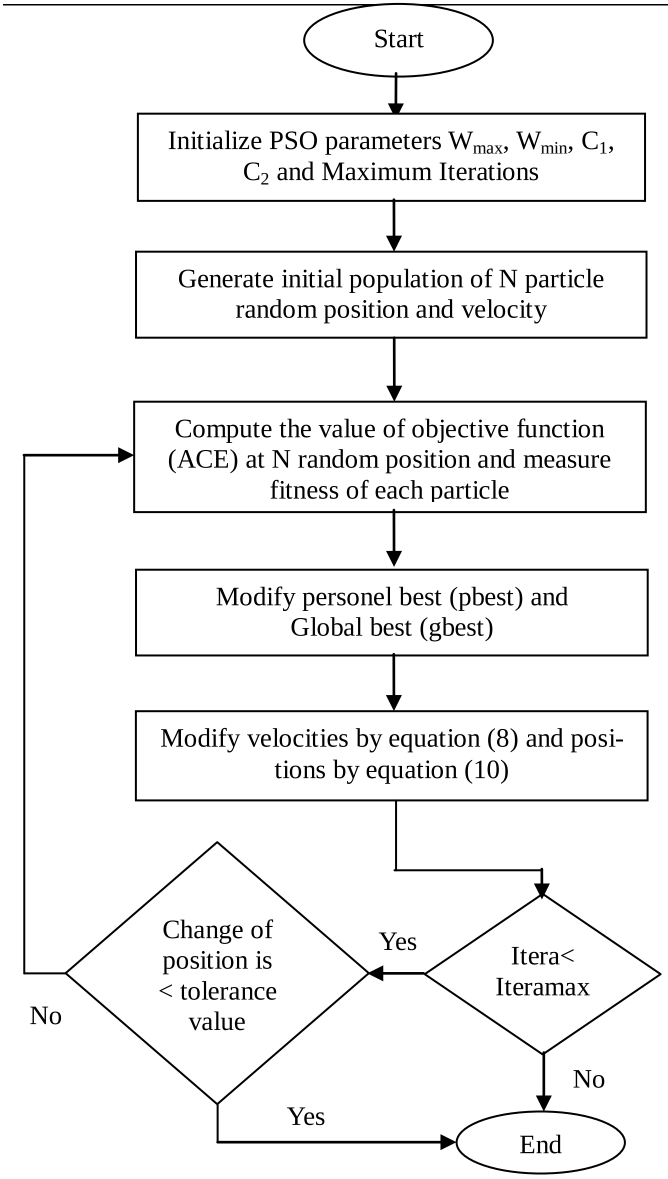

Figure 7: flow chart of PSO algorithm

In order to avoid falling into local optimum, a mutation operator on individual best value is introduced.

$$\sigma^2 = \frac{1}{m}\sum_{1}^{m}\left[\frac{f_i - f_{avg}}{f}\right]^2 \qquad \text{... (11)}$$

σ^2 in the above equation (13) is group fitness variance which reflect 'convergence' level of all particles. Where f_i is the ith particle's fitness, f_{avg} is the current average fitness of the population and

$$f = f_{\max i}\{i \mid f_i - f_{avg}|\} \qquad i = 1,2,..... \qquad \text{... (12)}$$

When σ^2 is small and the deviation between the global optimum of PSO algorithm and the theoretical optimal value is huge, disturbance factor is cited. The formula of mutation rate and new pbest is:

$$p_m = \begin{cases} \gamma & \sigma^2 \langle \mu \quad and \quad | f_{(gb)} - f_m |\rangle \delta \\ 0 & other \end{cases} \qquad \text{... (13)}$$

$$Npbest(i) = pbest(i) * (1 + rand) \qquad \text{... (14)}$$

Main objective of this paper is to minimize the settling time of tie line power and frequency error.

6. ANALYSIS

Here the performance of PSO based fuzzy logic controllers has been tested in two area thermal-thermal system and optimized values of scaling factor found as Ta(1)=4.4768 Ta(2)= -21.2585 and Ta(3)= -0.0229 compared with PI and convention FLC for 1% disturbance in first area.

Firstly deviation in frequency in area-1 of a two area Thermal System is tested when 1% disturbance in area-1 and response is compared as shown in Figure 8. The performance of PSO based FLC gave fast steady state response and same is given in table 2.

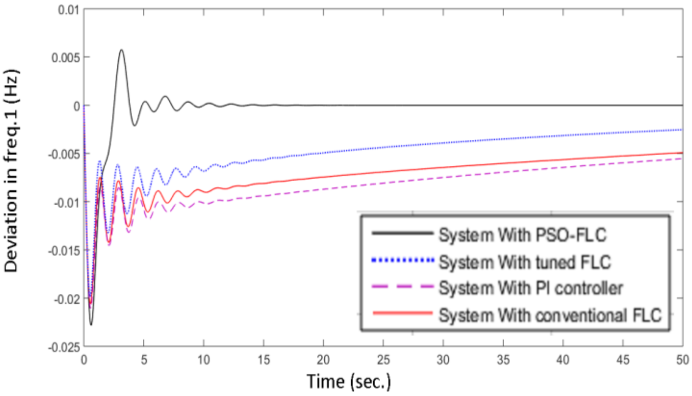

Figure 8: Comparison the deviation in frequency of area-1 of a two area Thermal System when 1% disturbance in area-1

Table 2: Time analysis parameters of simulations of area-1 for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With conventional FLC Controller	System With tuned FLC Controller	System With PSO-FLC
Undershoot(Hz)	0.021	0.021	0.020	0.023
Settling time (sec.)	Above 150	Above 100	Above 100	10

Deviation in frequency in area-2 when 1% disturbance in area-1 is recorded and response are shown in Figure 9. The performance of controllers is given in table 3.

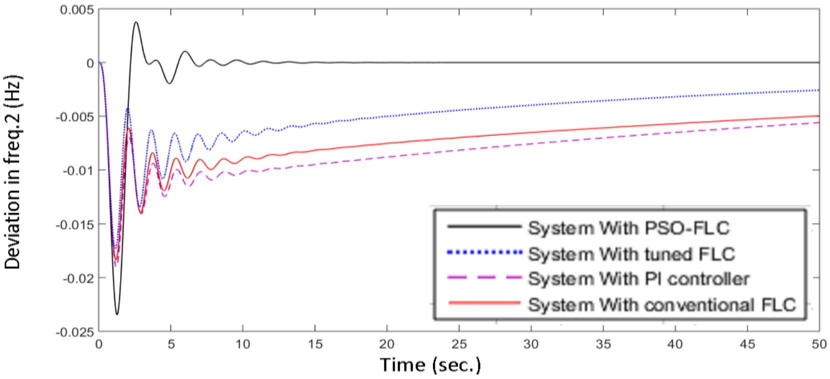

Figure 9: Comparison the deviation in frequency of area-2 of a two area Thermal System when 1% disturbance in area-1

Table 3: Time analysis parameters of simulations of area 2 for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With conventional FLC Controller	System With tuned FLC Controller	System With PSO-FLC
Undershoot(Hz)	0.019	0.019	0.018	0.023
Settling time (sec.)	Above 150	Above 100	Above 100	15

Performance of PSO based FLC is better as compared to the conventional FLC and PI controller as given in table 2 and 3. Frequency settled in 15 seconds and change in undershoot is insignificantly.

Now deviation in tie line power of a two area Thermal System when 1% step load change in area-1 is compared and response are shown in Figure 10. The performance of controllers is given in table 4.

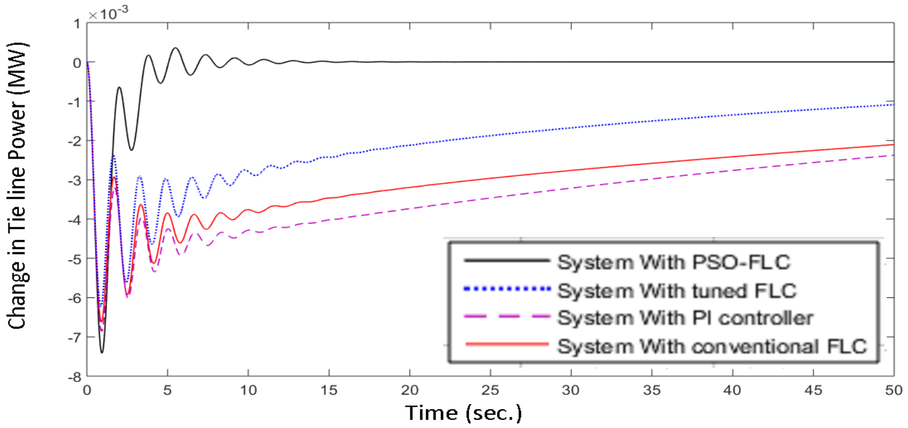

Figure 10: Comparison the deviation in tie line power of a two area Thermal System when 1% disturbance in area-1

Table 4: Time analysis parameters of simulations of tie line for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With conventional FLC Controller	System With tuned FLC Controller	System With PSO-FLC
Undershoot(Hz)	0.0066	0.0068	0.0064	0.0074
Settling time (sec.)	Above 150	Above 100	Above 100	10

Hence, the change in tie line power is compared for two area thermal system with PI, conventional FLC and PSO based FLC. The settling time with PSO based FLC is only 10 seconds where it is above 100 seconds with PI and conventional FLC. The change in undershoot value is insignificantly.

In order to examine the performance of the two area control system using the designed PSO based fuzzy logic controller at diferenct loading conditions, now deviation in frequency in area 1 is recorded for 1%, 2% change load change in area 1 and 1%, 2% load change in area 2 and it is shown in Figure 11. By observing the responces in figure 11, it is concluded that proposed PSO based fuzzy logic controller works well on other different loading conditions also.

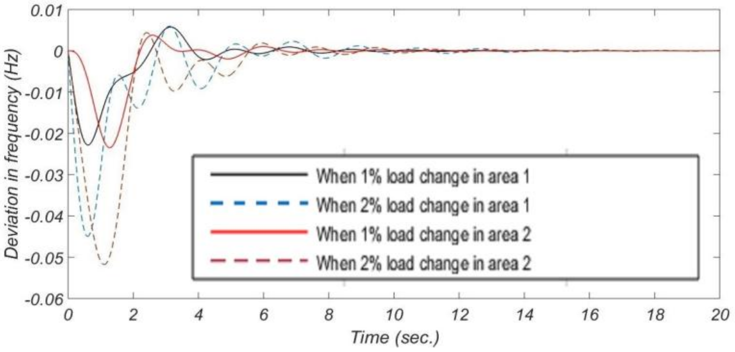

Figure 11: Deviation in frequency in area 1 for different load change in area 1 and area 2 with PSO based fuzzy logic controller

7. CONCLUSION

The fuzzy logic controller is primarily proposed to solve the load frequency control problem of two area system which gives better result as compared to PI controller but its tuning is also a complicated task. Therefore PSO based scaling factor tuning for fuzzy logic cotroller is proposed in this paper.

A simulation study of two area thermal system with automatic generation control is carried out using MATLAB and results are analyzed for PI, conventional FLC and PSO based FLC. It is found that PSO based fuzzy logic controller can restore the frequency and tie line power to its steady state values in the shortest possible time.

The PSO based fuzzy logic controller approach is easy to use for adjusting the frequency and tie line power as well as it gives good performance on other loading conditions also.

Appendix - A

The nominal parameters for a two equal area thermal system:

$P_{r1}=P_{r2}=Pr=2000$ MW

$a_{12}=-1.0$

$T_{g1}=T_{g2}=T_g=0.08$ sec

$T_{c1}=T_{c2}=T_c=0.3$ sec

$T_{p1}=T_{p2}=T_p=20.0$ sec

$K_{p1}=K_{p2}=K_p=120$ Hz/pu MW

$H_1=H_2=H=5$ sec

$R_1=R_2=R=2.4$ Hz/pu MW

$D=0.00833$ pu MW/Hz

$B_1=B_2=D+1/R=0.425$ pu MW/Hz

$P_{D1}=0.01$ pu MW

$P_{D2}=0$

$\delta_1(0)=0^0$

$\delta_2(0)=30^0$

REFERENCES:

[1]. C. C. Lee, “Fuzzy logic in control systems: Fuzzy logic control, part I”, IEEE Transactions on Systems, Man and Cybernetics, SMC 20, 1990, pp. 404-418.

[2]. D. M. Vinod Kumar, “Intelligent controllers for Automatic Generation Control”, IEEE Transation on power systems, pp 557-574, 1998.

[3]. Bjorn H. Bakken and Ove S. Grande, “Automatic Generation Control in a Deregulated Power System” IEEE Transactions on Power Systems, Vol. 13, No. 4, pp 1401-1406, November 1998.

[4]. Alfred L. Guiffrida and Rakesh Nagi, “Fuzzy set theory applications in production management research”, a literature survey, Journal of Intelligent Manufacturing, Volume 9, Issue 1, pp 39-56, 1998.

[5]. George Gross and Jeong Woo Lee, “Analysis of Load Frequency Control Performance Assessment Criteria”, IEEE transactions on power systems, vol. 16, no. 3, pp 520-525, August 2001.

[6]. Ignacio Egido, Fidel Fernandez-Bernal, Luis Rouco, Eloisa Porras and Angel Saiz-Chicharro, “Modeling of Thermal Generating Units for Automatic Generation Control Purposes”, IEEE transactions on

control systems technology, vol. 12, no. 1, pp205-210 January 2004

[7]. J. Nanda and M. Parida, “Automatic Generation Control of a Hydro-Thermal System in Deregulated Environment’’, Proceedings of the Eighth International Conference on Electrical Machines and Systems (ICEMS 2005), vol.2, pp 942– 947, Sept. 2005.

[8]. Janardan Nanda, Ashish Mangla and Sanjay Suri, “Some New Findings on Automatic Generation Control of an Interconnected Hydrothermal System With Conventional Controllers”, IEEE Transactions on energy conversion, vol. 21, no. 1, pp 187-194, March 2006.

[9]. H. D. Mathur and H.V. Manjunath, “Frequency stabilization using fuzzy logic based controller for multi-area power system”, The South Pacific Journal of Natural Science, pp 22-30, April 2007.

[10]. Xinyi Ren, Fengshan Du, Huagui Huang and Hongyan Yan, “Application of Fuzzy Immune PID Control Based on PSO in Hydraulic AGC Press System”, International Conference on Intelligent Human-Machine Systems and Cybernetics, Hangzhou (Zhejiang), pp 427 - 430, 2009.

[11]. Byungwoon lang, “Optimal Tuning of PI-like Fuzzy Controller using Variable Membership Function' s slope”, IEEE International Symposium on Assembly and Manufacturing Suwon, Korea, November 17-20, 2009.

[12]. Guolian Hou, Lina Qin, Xinyan Zheng and Jianhua Zhang, “Design of PSO-Based Fuzzy Gain Scheduling PI Controller for Four-Area Interconnected AGC System after Deregulation”, Proceedings of the 2011 International Conference on Advanced Mechatronic Systems, Zhengzhou, China, August 11-13, 2011.

[13]. Anju G Pillai, Meera Rose Cherian, Sarin Baby and Anish Benny, “Performance Analysis of Conventional and Intelligent Controllers in Power Systems with AGC”, International Journal of Scientific & Engineering Research (IJSER), Volume 4, Issue 8, August 2013.

[14]. Roohi Kansal and Balwinder Singh Surjan, “Study of Load Frequency Control in an Interconnected System Using Conventional and Fuzzy Logic Controller”, International Journal of Science and Research (IJSR), Volume 3, Issue 5, May 2014.

[15]. Animesh Kumar Paul and Pintu Chandra Shill, “Optimizing Fuzzy Membership Function using Dynamic Multi Swarm – PSO”, 5th International Conference on Informatics, Electronics and Vision (ICIEV), Department of Computer Science and Engineering, Khulna University of Engineering and Technology Khulna, Bangladesh, 2016.

[16]. Avdhesh Sharma, Pawan Kumar and Honey Singh, “Effect of tie line bias control in two area load frequency control system using polar fuzzy controller”, International Journal of Scientific & Engineering Research (IJSER), Volume 8, Issue 4, April-2017.