International Journal of Scientific & Engineering Research, Volume 5, Issue 3, March-2014
ISSN 2229-5518

A Research on Improved Controllers to Stabilize the Frequency in Multi-Area Interconnected Power Systems

Ngoc-Khoat Nguyen*, Qi Huang, and Thi-Mai-Phuong Dao

Abstract— This work deals with a stability problem of the frequency in multi-area interconnected power systems resulting from load disturbances at generation stations by using different controllers. Traditionally, an integral controller can be used to obtain the zero-steady-state frequency deviation with the poor control performances, i.e., high overshoots and long settling times. In order to achieve the better control performances, improved control strategies must be investigated by applying advance controllers, such as PID, fuzzy logic, artificial neural network, etc. For the most practical and efficient application, fuzzy logic controllers are used to make sure that the frequency in multi-area power system tends to the nominal values as soon as possible after the appearance of load disturbances. Simulation results of this control technique are carried out for different multi-area interconnected power systems in comparison with the conventional control strategy.

Index Terms— Multi-area interconnected power system, Control, Frequency, Load disturbance, Integral, PID, FLC, and Simulation.

◆

1 INTRODUCTION

POWER systems have become more and more massive and complex today with the concepts of large-scale or multi-area power networks. In these power systems, the areas including coherent generators groups are interconnected via tie lines (Fig. 1) which are used for economy and continuity of power supply [9]. Under the normal working conditions, the frequency of a power system is kept at the nominal values, such as 50 Hz or 60 Hz, also the deviations of frequency and tie-line power flow are equal to zero. However, it is the fact that a power network often has to work under abnormal conditions, i.e. load disturbances in random areas [10], causing the non-zero biases of both the frequency and tie-line power. As a result, the change of frequency affects the power generation of the network [2], [4], [9], [10]. Hence, it is necessary to build control strategies to stabilize the frequency in multi-area interconnected power systems.

In order to solve this problem, many researches have been implemented [2], [3], [4], [5], [12]. Most of them are based on the bias control theory [9] which uses area control errors (*ACEs*) as the control inputs of the given controllers. According to this control technique, a conventional control strategy using an integral (*I*) controller is traditionally used. Although this control method can obtain the zero steady state of frequency deviation, it is the fact that newly improved control strategies have to be still built to obtain the better technical performances such as lower overshoots, shorter settling times, etc. This study carries out an investigation of these strategies focusing on proportional-integral-derivative (*PID*) controller and fuzz-logic controller (*FLC*) which have been strongly developing in practical systems. Obtained simulation results demonstrate the exceptional features of these techniques in comparison with the conventional control strategy.

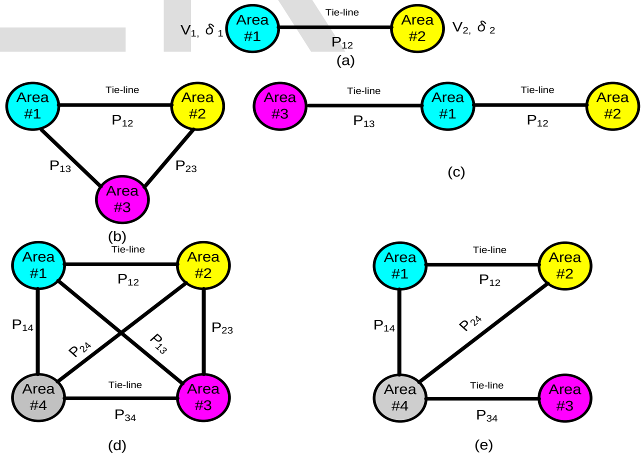


Fig. 1. Multi-interconnected power systems

(a) two-area network
(b), (c) three-area network
(d), (e) four-area network

The rest of this paper is arranged as follows: the next section is used to present the model of a two-area interconnected power system, the third one will investigate frequency control strategies, the fourth one is performed to express the application of the given control methods in multi-area power systems, and the

---

- *Prof.Dr. Qi Huang is the Deputy Dean with the School of Energy Science and Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan, China. Email: huangqi@uestc.edu.cn*
- *Ngoc-Khoat Nguyen is currently pursuing PhD degree program in the field of Electronic Engineering in University of Electronic Science and Technology of China, China. At present, he is also a lecturer in Electricity Power University, Hanoi, Vietnam. Phone:+8613088051248, E-mail: khoatnn@epu.edu.vn*
- *Thi-Mai-Phuong Dao is currently pursuing PhD degree program in the field of Automation in Hunan University, China. At present, she is also a lecturer in Hanoi University of Industry, Hanoi, Vietnam. Phone: +8615200931744, E-mail: bkblackrose@yahoo.com*

** Corresponding author*

last section contains conclusive notices and efficient discussions for the future work.

2 TWO AREA INTERCONNECTED POWER SYSTEM MODEL

According to [9], an interconnected power system consists of control areas, in which all generators are assumed to form a coherent group. In this network, each area is connected by tie-lines to the other areas as shown in Fig. 1. From this viewpoint, let us consider a two-area interconnected power network as presented in Fig. 1a.

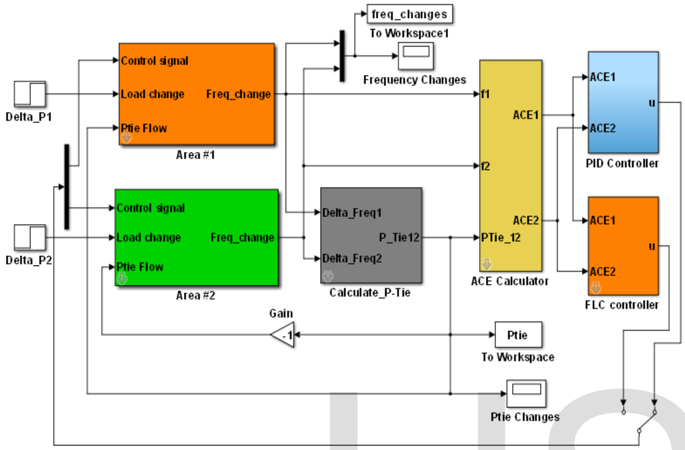
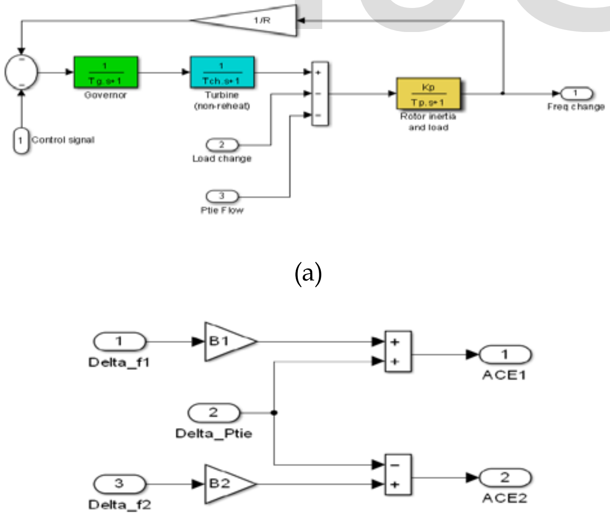


Fig. 2. Two area interconnected power system



(a)

(b)

Fig. 3. Details of two area interconnected network model

(a) Area #1 block

(b) ACE calculator block

The deviations of frequency Δf and tie-line power flow ΔP_{12} can be calculated by following equations

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}\Delta\delta \tag{1}$$

$$\Delta P_{12} = 2\pi T_{12}^{0}\left(\int \Delta f_1 dt - \int \Delta f_1 dt\right) \tag{2}$$

where, $\Delta\delta = \Delta\delta_1 - \Delta\delta_2$ is the bias of the generator rotor angle changes in 1st area and 2nd area, T^0_{12} is a synchronizing coefficient of the tie-line, Δf_1, Δf_2 are the frequency changes of areas.

By taking the Laplace transform, the block diagram for a two area interconnected power system can be yielded as depicted in Fig. 2. The details of Area #1 and *ACE* calculator blocks are presented in Fig. 3. In this paper, each area is formed by combining a governor, a non-reheat thermal turbine, and a generator which can be modeled by transfer functions as indicated in Fig. 3. For the tie-line bias control strategy, area control error (*ACE*) for the ith area is computed by (3)

$$ACE_i = \Delta P_{tie,i} + B_i.\Delta f_i \tag{3}$$

where, ACE_i, $\Delta P_{tie,i}$, B_i, and Δf_i are the area control error, tie-line power change, area frequency response characteristic, and frequency change, respectively.

3 NETWORK FREQUENCY CONTROL STRATEGIES

As mentioned earlier, our control goal is to protect the interconnected power system in normal operating state which can be implemented successfully by keeping the deviations of the frequency and tie-line power flow under the enough small tolerances and meeting different control characteristics, such as the low overshoot and settling time after the occurrence of the load disturbances. In order to carry out this work, two control strategies can be applied: conventional and improved control strategies.

3.1 Conventional Control Strategy

Because machines and components of a power system are characterized by the inherent nonlinearities, integral controllers are conventionally used. According to the principle of this control method, the command signal for the ith area can be calculated by the following equation

$$u_i = -K_{Ii}\int ACE_i(t)dt = -K_{Ii}\int(\Delta P_{tie,i} + B_i\Delta f_i)dt \tag{4}$$

where, K_{Ii} is the ith integral controller gain constant. This gain constant has to be defined to satisfy both conditions of the systematically dynamic response: the fast transient restoration and the low overshoot. In fact, the implementation of this controller is too slow to stabilize multi-interconnected power networks which comprise non-linear elements. As a result, it is necessary to design improved controllers for advanced control strategies.

3.2 Improved Control Strategies

In order to achieve the better control results, improved control strategies have been developed by using advanced controllers, such as *PI*, *PD*, *PID*, fuzzy logic, and so on. For the practical and ordinary applications, *PID* and fuzzy logic controllers are investigated in this study. Principles and obtained simulation results of these controllers will be considered in comparison with the conventional controller.

3.2.1 PID Controller

PID controllers have been widely used in control systems, particularly in the frequency protection strategy of a lare-scale power network. Traditionally, the principle of a *PID* controller can be indicated as follows

$$
\begin{aligned}
u_i(t) &= K_{pi}.ACE_i(t) + K_{Ii}\int_0^t ACE_i(\tau)d\tau + K_{Di}\frac{d}{dt}ACE_i(t) \\
&= K_{pi}\left(ACE_i(t) + \frac{1}{T_{Ii}}\int_0^t ACE_i(\tau)d\tau + T_{Di}\frac{d}{dt}ACE_i(t) \right)
\end{aligned}
\tag{5}
$$

where, $u_i(t)$ is control signal, $ACE_i(t)$ is i^{th} area control error, K_{pi}, K_{Ii}, K_{di}, T_{Ii}, and T_{Di} are proportional, integral, derivative gain coefficients, integral time, and derivative time constants, respectively.

As mentioned in [7], the control properties of a system are affected strongly by the above gain coefficients. The proportional factor K_p calibrates the transient of the *ACE*, K_I corrects the accumulation of the error, and the derivative factor K_D implements the correction of the present *ACE* versus it in the previous step. The larger the proportional gain, the smaller the steady state error, however, the loop is also to become unstable. The shorter the integral time, the more impetuous the implementation of an integral is. The larger the derivative coefficient, the more changeable the error becomes.

3.2.2 Fuzzy Logic Controller

Because of the non-linear and complicated characteristics of multi-area power networks, a conventional control technique can be replaced efficiently by using an intelligent controller, namely the fuzzy logic controller. According to [3], a *FLC* cannot be affected by the parameters of a power system, and it has some advantages as indicated below:

(a) it can utilize efficiently the incomplete information to make a control decision for the system;
(b) it is very flexible to make any control decision with applying *FLC*;
(c) by using rules of a *FLC* in a control system, an effective *HMI* (Human Machine Interface) will be yielded.

The essential advantage by applying a *FLC* is that the control parameters can be changed very fast in response to variations in the system dynamics since none of parameter estimations is needed [3], [8]. As a result, this leads the efficiency of the use of *FLCs* in industrial control systems.

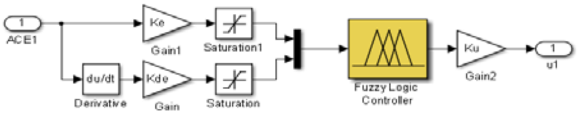


Fig. 4. Proposed fuzzy logic controller

TABLE 1
A 7-LEVEL RULE BASE

ACE	*dACE*						
	BN	**MN**	**SN**	**Z**	**SP**	**MP**	**BP**
BN	BP	BP	BP	MP	MP	SP	Z
MN	BP	MP	MP	MP	SP	Z	SN
SN	BP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	NM	MN
SP	MP	SP	Z	SN	SN	MN	BN
MP	SP	Z	SN	MN	MN	MN	BN
BP	Z	SN	MN	MN	BN	BN	BN

***N**-Negative, **P**-Positive, **B**-Big, **M**-Medium, **S**-Small, **Z**-Zezo*

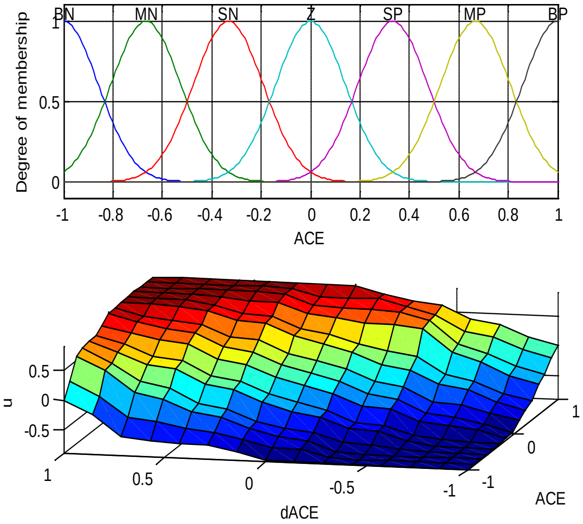


Fig. 5. Membership function of *ACE* and 3D-surface graph of the given FLC

In general, a *FLC* is structuralized by three components: fuzzification unit, rule base unit, and defuzification unit. Details of these components can be found in [1], [3], [8]. In this paper, the *FLC* which is used as a controller for each area can be indicated in Fig. 4. Here, the *ACE* and the derivative of *ACE*, *dACE*, are used as inputs of the *FLC*. The output of this controller is the control signal, *u*, which will be taken directly to the corresponding area of the interconnected power system. In this controller, the embedded factors of *ke*, *kde*, and *ku* are correct coefficients of *ACE*, *dACE*, and *u*, respectively. In order to make the better control result, the multi-level rules can be applied. Table 1 indicates conventionally a 7-level rule base which is used for our *FLC*. The fuzzy logic membership functions of *FLC*'s inputs and output are illustrated in Fig. 5.

4 DIFFERENT CONTROL STRATEGIES FOR MULTI-AREA INTERCONNECED POWER SYSTEMS

In this section, different control strategies mentioned above will be applied in multi-area interconnected power systems: two-area, three-area, and four-area networks. Simulation results will be also implemented in the Matlab/Simulink environment to validate the proposed investigation earlier.

4.1 Multi-area Interconnected Power Network Models

Based on the principle of two area power network model, a three-area and a four-area model are built in Fig. 6 and Fig. 7. These models are well matched with the block models Fig. 1(b) and Fig. 1(d). These control models are also based on the tie-line bias control method using *ACE*s as the control signals of the different controllers: *I* (integral), *PID*, and FLC.

4.2 Simulation results

A three-case simulation process that is implemented in this work for the given models is presented as follows

(1) simulation by using *I* controller;
(2) simulation by using *PID* controller;
(3) simulation by using *FLC* controller.

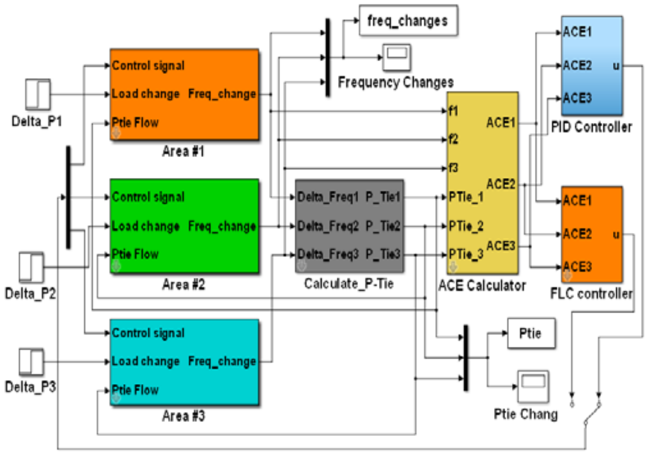


Fig. 6. A three-area interconnected power system model

The optimal parameters which are used to simulate above models can be found in the Appendix of this paper. Two objective parameters in this study, frequency changes Δf_i, tie-line power flow changes $\Delta P_{tie,i}$, will be simulated in the time domain by using the Matlab/Simulink environment. Fig. 8 and Fig. 9 show the frequency and tie-line power flow changes for the two-area power network. Fig. 10 depicts frequency changes in a three-area interconnected power system for two cases: using *I* controller and *FLC* controller. Fig. 11 and Fig. 12 present the comparisons of the frequency change and tie-line power flow, respectively, in a four-area interconnected power network for two cases: using *I* controller and *PID* controller. Fig. 13 is the other case simulation for this model using *FLC*. In addition, the comparison of obtained simulation results is represented in Table 2. According to this Table, it is well known to decide that the *FLC* is the best controller which may be used to obtain our control goals.

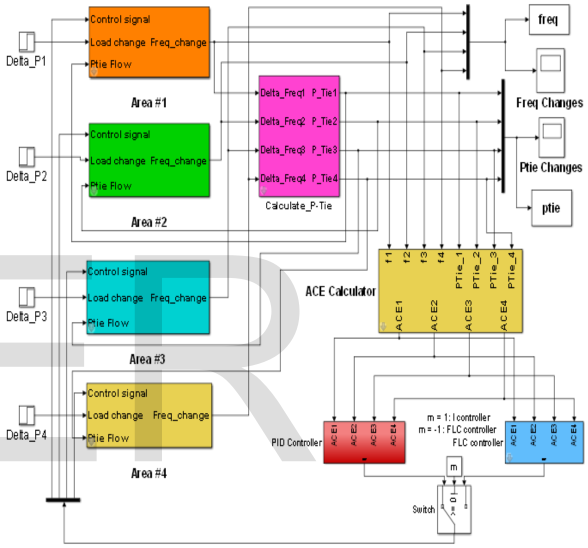


Fig. 7. A four-area interconnected power system model

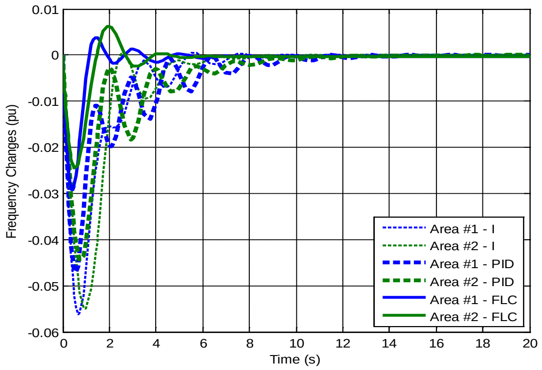


Fig. 8. Frequency deviations in a two-area interconnected power system

TABLE 2
A COMPARISON OF SIMULATION RESULTS FOR AREA #1

Model	Characteristics	I	PID	FLC
Two-area	Overshoot (pu)	-0.057	-0.048	-0.028
	Settling time (s)	16.5	15.2	8.1
Three-area	Overshoot (pu)	-0.043	-0.035	-0.025
	Settling time (s)	12.3	10.4	8.9
Four-area	Overshoot (pu)	-0.045	-0.042	-0.028
	Settling time (s)	14.9	13.5	11.3

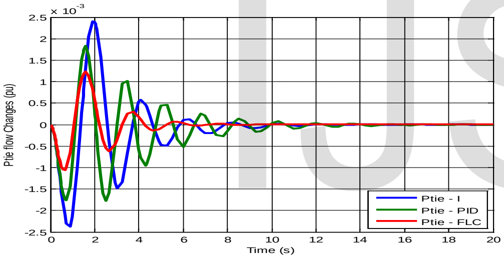


Fig. 9. Ptie flow changes in a two-area interconnected power system using different controllers

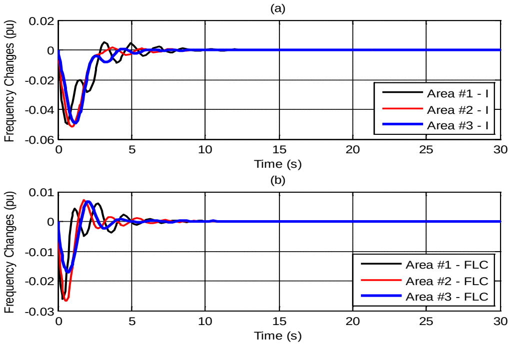


Fig. 10. Frequency changes in a three-area interconnected power system
(a) Using I controller
(b) Using FLC controller

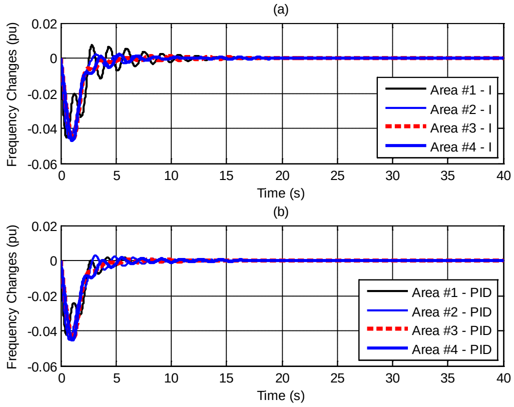


Fig. 11. Frequency changes in a four-area interconnected power system
(a) Using I controller
(b) Using PID controller

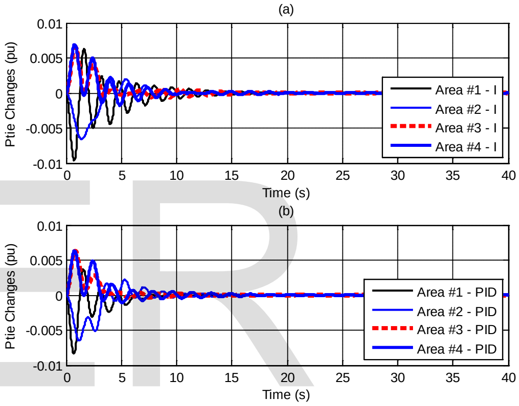


Fig. 12. Ptie flow changes in a four-area interconnected power system
(a) Using I controller
(b) Using PID controller

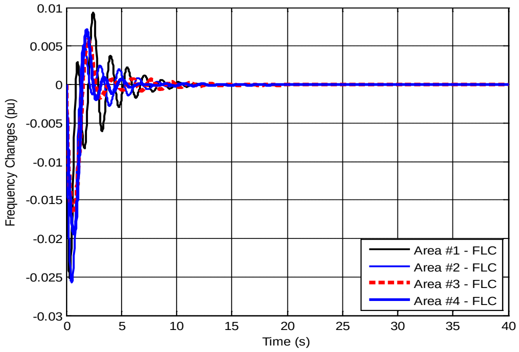


Fig. 13. Frequency changes in a four-area interconnected power system using FLC

5 CONCLUSION

Via this study, the stability problem of multi-area interconnected power systems against the appearance of the load frequency disturbance is investigated by using different control strategies. According to the conventional control strategy, integral controllers are used to reduce the changes of frequencies and tie-line power flows to be under the acceptable tolerances. By applying the improved control strategies, *PID* controller and *FLC* have been used. The obtained simulation results have shown that the conventional control strategy yields the most inefficient quality while the improved ones give the better outcomes. In the improved control strategies which have been considered in this work, a *FLC* is the best choice for the frequency control problem in a multi-area large power network. The correspondingly obtained control characteristics including the overshoot and settling time of the frequency and tie-line power deviations, however, are still needed to reduce to get the better results. Because of the complexity of the large-scale power systems, the new and mixed controllers such as *PID-FLC* and *PID-ANN* (Artificial Neural Network) should be considered as urgent problems. In the near future, we will continue these approaches for more complex interconnected power systems to make sure the stability of frequency in practical networks.

APPENDIX

APPENDIX – A

Nomenclature

i	index of area #i
Delta_Pi	load increment, pu
Delta_fi	change of frequency, pu
T_{gi}	time constant of governor, s
T_{chi}	time constant of non-reheat turbine, s
K_{pi}	gain of generator, Hz/pu.MW
T_{pi}	time constant of generator, s
T_{ij}	tie-line time constant, s
$P_{tie,i}$	tie line power flow, pu
B_i	bias factor, MW/pu.Hz
R_i	speed regulation
K_{Pi}, K_{Ii}, K_{Di}	proportional, integral, derivative constant
Kei, Kdei, Kui	error, error derivative, output factors of FLC

APPENDIX-B

Simulated parameters

$T_{g1} = 0.08$, $T_{g2} = 0.1$, $T_{g3} = 0.12$, $T_{g4} = 0.12$

$T_{ch1} = 0.3$, $T_{ch2} = 0.3$, $T_{ch3} = 0.32$, $T_{ch4} = 0.35$

$K_{p1} = 120$, $K_{p2} = 100$, $K_{p3} = 105$, $K_{p4} = 130$

$T_{p1} = 18$, $T_{p2} = 20$, $T_{p3} = 22$, $T_{p4} = 25$

$T_{ij} = 0.0707$

$K_{Pi} = 0.7$, $K_{Ii} = 0.05$, $K_{Di} = 0.03$

ACKNOWLEDGMENT

This work is supported by the Natural Science Foundation of China (NFSC, Grant No. 51277022).

REFERENCES

[1] M.A.M. Hassan and O.P. Malik, "Implementation and Laboratory Test Results for a Fuzzy Logic Self-tuned Power System Stabilizer", *IEEE Trans. on Energy Conversion*, vol. 8, no. 2, pp. 221-228, Jan 1993.

[2] Panna Ram and A.N. Jha, "Automatic Generation Control of Interconnected Hydro-thermal System in Deregulated Environment Considering Generation Rate Constraints," *2010 International Conference on Industrial Electronics, Control and Robotics*, pp. 148-159, 2010.

[3] Ali M. Yousef and Ayman A. Aly, "Non-linearities in Fuzzy Approach for Control A Two-Area Interconnected Power System," *Proc. IEEE International Conference on Mechatronics and Automation*, pp. 706-711, Aug. 2010.

[4] P. Subbaraj and K. Manickavasagam, "Generation Control of Interconnected Power Systems Using Computational Intelligence Techniques ", *IET Gener. Trans. Distrib*, vol. 1, no. 4, pp. 557-563, 2007.

[5] Ateeth Kumar Thirukkovulur, Harikrishna Nandagopal, and Vigneesh Parivallal, "Decentralized Control of Multi-Area Power System Restructuring for LFC Optimization," 2012 *IEEE International Conference on Power Electronics, Drives and Energy Systems*, pp. 106-112, Dec. 2012.

[6] Sujit Bhat, Jishan Khatib, Sudheer Chincholi and Ramkrishma Pai, "Design and Analysis of Fuzzy Logic Controller for Load Frequency Control of Power System," 2012 *IEEE International Conference on Computing and Control Engineering (ICCCE 2012)*, pp. 50-56, Apr. 2012.

[7] A. Sharifi, K. Sabahi, M. Aliyari Shoorehdeli, M.A. Nekoui, and M. Teshnehlab, "Load Frequency Control in Interconnected Power System using Multi-Objective PID Controller," 2008 *IEEE International Conference on Soft Computing in Indutrial Applications (SMCia/08)*, pp. 217-221, Jun. 2008.

[8] Mohammad Amin Hedari, Abbas Kamali, and Mohammad Jaafari, "Fuzzy Based Load Frequency Controller for Multi Area Power System", *Tech J Engin & App Sci*, vol. 3, no. 23, pp. 3433-3450, 2013.

[9] P. S. R. Murty, *Operation and Control in Power Systems.* BS Publications, pp. 242-280, 2008.

[10] Guorui Zhang, *EPRI Power Systems Dynamics Tutorial.* Electric Power Research Institute, pp. 252-290, 2009.

[11] Dos Santos, M.J., Pereira, J.L.R, Filho, J.A.P., De Olivera, E.J., and Da Silva, C., "A New Approach for Area Interchange Control Modeling", *IEEE Trans. on Power Syst.*, vol. 19, no. 3, pp. 1217-1276, 2004.

[12] Chown, G.A., and Hartman, R.C. "Design and Experiences with a Fuzzy Logic Controller for Automatic Generation Control (ACC)", *IEEE Trans. on Power Syst.*, vol. 13, no. 3, pp. 965-970, 1998.