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Fuzzy logic based load frequency control of power system

Sophia Jasmine G [a,*], Magdalin Mary D [a], Thenmalar K [b]

[a] Sri Krishna College of Technology, Coimbatore, India
[b] Vivekanandha College of Engineering for Women, Tiruchengode, India

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ABSTRACT

Power system is a large interconnected and complex network with several sources and loads. The rise in population leads to changes and uncertainty in load demand. It is the accountability of the utilities to meet the load demand without violating power system operational constraints. Load frequency control is solely responsible for supplying reliable electrical power to the consumers. Its ultimate function is to regulate the output power of the utility generator with respect to load change without affecting system frequency and also to control the tie-line power such as to sustain the frequency and power flow in further areas within recommended limits. The concept proposed in the paper represents the load frequency control of two area system with conventional proportional integral controller, proportional integral derivative controller, fuzzy logic controller and fuzzy tuned proportional integral controller. Simulation studies are carried out using SIMULINK.
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1. Introduction

In modern power system, load demand and the system complexity upsurge every day. The sudden changes in the demand lead to the frequency deviation and it is essential to keep the frequency within the limit ± 0.5 Hz, which is decided by the speed of turbine. The frequency variation is called as LFC error, which plays a significant part of the Automatic Generation Control (AGC). If there are more than one area in the power system, then tie line between the areas is also maintained within the specified limits so that the reliable operation of the system can be ensured [1,4]. Among various controllers, Fuzzy logic with PI controllers [20], Fuzzy logic based PID controllers [17], Neuro-fuzzy controllers [19] are widely used in multi area system [4] especially in two area system. Fuzzy controllers aid in restoring the stability and sturdiness of the system as well [7,8,12]. Apart from conventional controllers, recent controllers based on evolutionary algorithms [6,15,21] play a major role in AGC. In the midst of ample research in AGC [13,20] the design of the controller has been analyzed which maintains the frequency deviation as zero even under varying load conditions. Here, different controllers such as PI, PID, FLC and FTPI are used for maintaining the constant frequency. PID controllers are also used in reducing the noise that arise during LFC operation [22]. While using controllers, tuning their parameters is of greater importance. Some of the tuning methods include Ziegler Nichols tuning [16], self-tuning [1,3,10], Evolutionary algorithms [9,11]. Researchers have proposed certain procedures for controller design [14]. Various intelligent controllers including Neural network [5], optimized Fuzzy PID controller [21] were used to achieve load frequency control. The model of two area system consists of governor, turbine and generator [2].

2. Load frequency control model of single area system

The physical representation of speed governing mechanism is given in Fig. 1. The speed governor is the main tool for load frequency control. By controlling the position of control valve, the flow of high pressure steam to the turbine can be controlled. If the load increases, the speed of the turbine decreases and the speed changer gives the raise command. So, the fly ball speed governor move outwards, which controls the linkage mechanism, thereby increasing the steam input to the turbine and hence the power generation. If the load decreases, the turbine speed increases and the speed changer gives the lower command, which makes the linkage mechanism to lower the generation depending

* Corresponding author at: Department of EEE, Sri Krishna College of Technology, Coimbatore-42, India.
E-mail address: gsophiaa@gmail.com (S.J. G).

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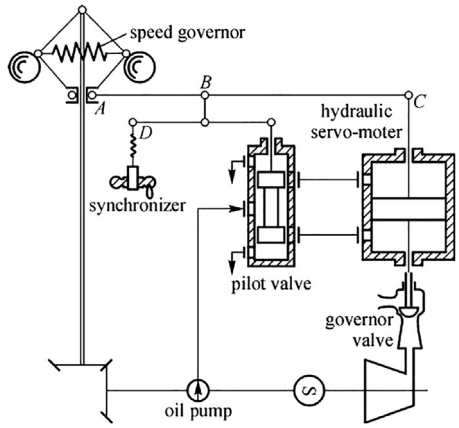


Fig. 1. Speed governing system.

on the demand [18]. Hence the speed governor is used to measure and regulate the speed of the generator coupled to turbine.

The speed governor is considered as the heart of load frequency control. By controlling the position of control valve, the flow of high pressure steam to the turbine can be controlled. If the load increases, reduction in turbine speed is observed and the raise signal or command is provided by the speed changer. So, the fly ball speed governor move outwards, which controls the linkage mechanism, thereby increasing the steam input to the turbine and hence the power generation. If the load decreases, the turbine speed increases and the speed changer gives the lower command, which makes the linkage mechanism to lower the generation depending on the demand. The block diagram of LFC as given in Fig. 2 of an isolated power system is obtained by the combination of the governor model, turbine model and generator load model.

2.1. Model of load frequency control of two area system

The system in which more than one single area system are connected using tie lines are multi area system. Such system are characterized by same frequency and when a small load change occur in any area, all the turbine-generator units swing together with other groups of turbine-generator units in other area. The working of two area power system is similar to the single area power system but the tie line connects the two area. Here the command signal is generated depending on the frequency deviation and tie line power.

3. Controllers in LFC

3.1. Pi controller

The Proportional Integral controller is the most commonly used controller in industries. It is used to reduce the steady state error in the system.

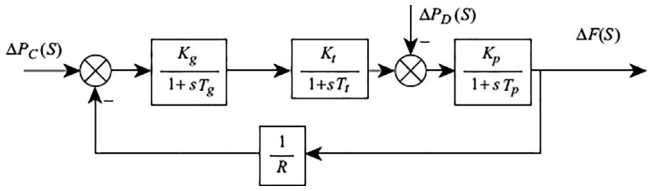


Fig. 2. Model of LFC of single area system. Where, R = Speed regulation of the governor in Hz/MW. K_G = Gain of speed governor. T_G = Time constant of speed governor, T_G < 100 ms. T_t = Time constant of turbine. K_t = Gain constant. ΔPv = change in valve position. K_p = Power system gain. T_p = Power system time constant.

3.2. Pid controller

The Proportional Integral and derivative controller is also used to control the process in the industries. It is generally used to improve the transient response.

3.3. Fuzzy controller

Fuzzy logic finds its application in wide range of machine control. Various stages involved in fuzzy system are as follows,

Fuzzification: It is the process of conversion of crisp inputs of fuzzy controller to the linguistic variable using the membership function in the fuzzy rule base.

Defuzzification: It is the process by which the linguistic variable from the fuzzy rule base are converted into the crisp output for the further process in the control of system.

3.4. Fuzzy tuned PI controller

The fuzzy controller selects the proportional gain and integral gain for the load frequency control of the system. The gain values can be calculated by trial and error method or mathematical method.

4. Simulation results

Simulation studies for designing controllers for LFC have been carried out under two cases. In former case, the gain values of Proportional Integral and derivative controllers were obtained by trial and error method. In later case Cohen coon technique is applied to obtain the gain. The two area power system have the tie line which interconnects the two areas. The parameters and its values of two areas are given in Table 1. Tie line time constant T_{12} = 0.086.

The simulation results of frequency deviation for 10% change in load demand with PID, PI and Fuzzy controller are given in Fig. 3 (a), (b) and (c) respectively.

Frequency error and change in frequency error are the input membership function and the gain values of controller are the output membership function.

Fig. 4, Fig. 5 and Fig. 6 show the respective membership functions.

For a load change of 10%, the response of various controllers are tabulated in Table 2. It shows the reduction in frequency deviation while using conventional PI controller whereas minimization of settling time is realized with fuzzy controller.

5. Cohen-coon technique of controller tuning

In this paper, the gain values of the controller are calculated by using the cohen-coon technique of controller tuning. From the open loop response of the system, the gain value (k), delay time (t_d), transient time (τ) are calculated and used for simulation.

Cohen coon formula for PI controller:

Table 1
Two area system-parameters.

Parameters	area 1	area 2
K_p	120	120
T_p	20	20
T_g	0.08	0.5
Tt	0.3	0.2
R	2.4	2.4
B	0.425	0.8

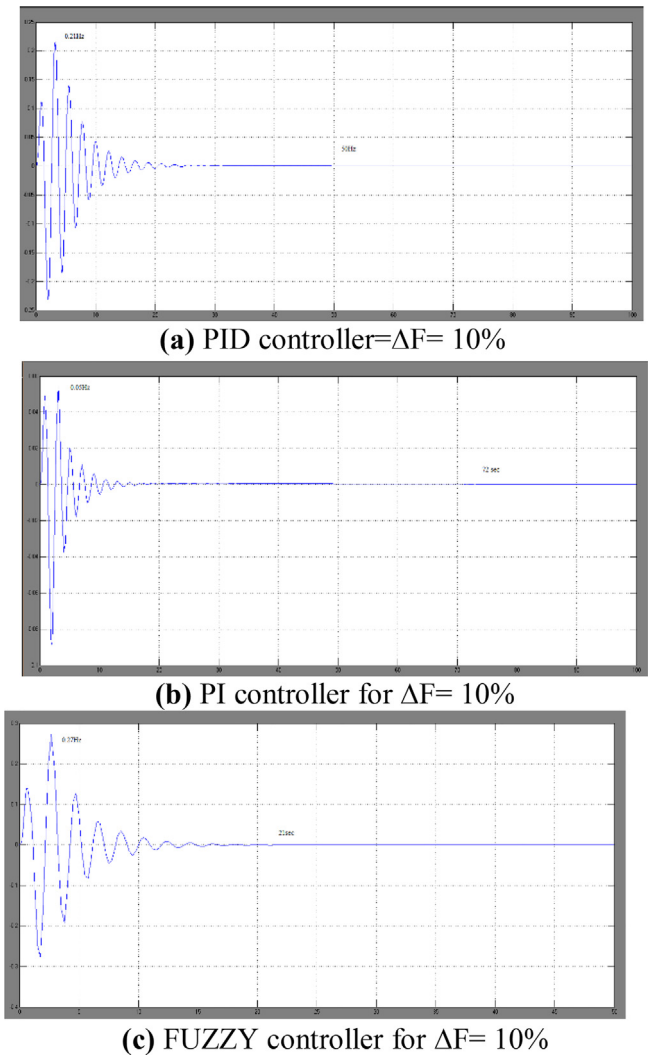


Fig. 3. Frequency deviation (ΔF) with change in load demand using various controller.

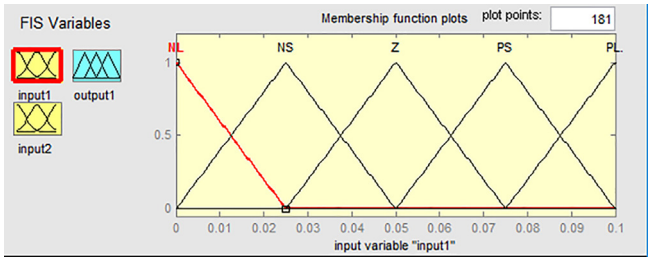


Fig. 4. Input 1 membership function.

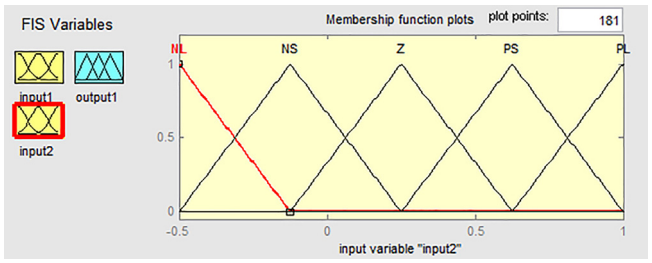


Fig. 5. Input 2 membership function.

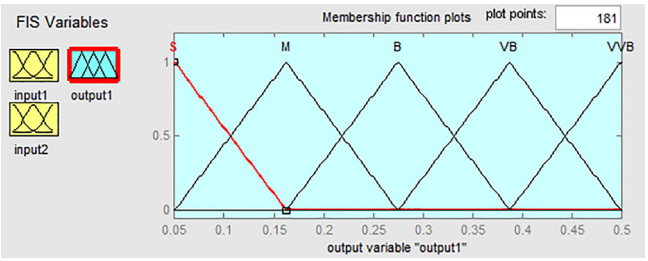


Fig. 6. Output member ship function.

Table 2
Comparison of PI, PID and Fuzzy Controllers.

Controllers Parameters	PI	PID	Fuzzy
Settling time	72 sec	50 sec	21 sec
Frequency deviation	0.05 Hz	0.21 Hz	0.27 Hz

$$k_p = \frac{1}{k}\frac{\tau}{t_d}\left(0.9 + \frac{t_d}{12\tau}\right) \quad (1)$$

$$t_i = t_d\left(\frac{30 + \frac{3t_d}{\tau}}{9 + \frac{20t_d}{\tau}}\right) \quad (2)$$

$$k_i = \frac{1}{t_i} \quad (3)$$

Where,k_p is the proportional gain and $k_i$is the integral gain.

The open loop simulation model of area-1 of single area system is shown in Fig. 7.

Fig. 8 show the output response of area 1 where, time in sec is taken across X axis and K is taken across Y axis, from which the proportional gain and integral gain are calculated. Fig. 9 show the output response of area 2 for demand variation of 2%, 4% and 6%. Table 3 shows the range of proportional gain and integral gain values for PI controller of area 1 and 2 for demand variation between 2% and 10%. Figs. 10 to 15 show the membership functions of FTPI controller.

From Table 3, the range of proportional gain and integral gain values for PI controller of area 1 for demand variation between 2% and 10%. Fuzzy rules has been depicted in Table 4.

6. Simulation results with fuzzy tuned pi controller

The dynamic response of the two area system using FTPI is given in Fig. 16 that shows the frequency deviation with respect to changes in load demand in both the areas.

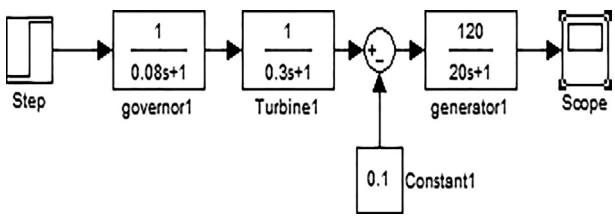


Fig. 7. Open loop simulation of area 1.

Table 3
Gain vales of area 1 and 2.

Δpd %	Open loop gain K		t_d (sec)		τ (sec)		Kp		Ki	
	Area1	Area2	Area1	Area2	Area1	Area2	Area1	Area2	Area1	Area2
2	117.5	117.6	1.195	1.29	21.5	21.73	0.138	0.129	0.28	0.26
4	115	115.2	1.125	1.5	21.4	21.75	0.149	0.114	0.29	0.22
6	112.79	112.8	1.32	1.7	21.5	21.83	0.130	0.103	0.25	0.20
8	110.4	110.5	1.29	1.55	21.6	21.9	0.137	0.115	0.26	0.22
10	108	108	1.40	1.6	21.5	21.91	0.129	0.114	0.24	0.21

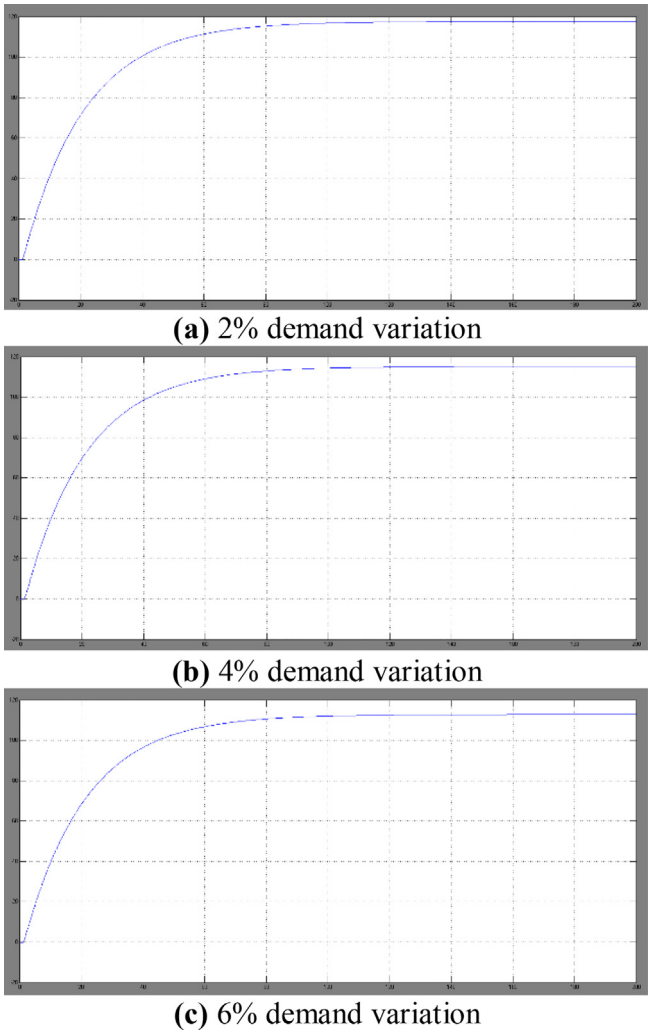


Fig. 8. Open loop response of area 1 for different load variation.

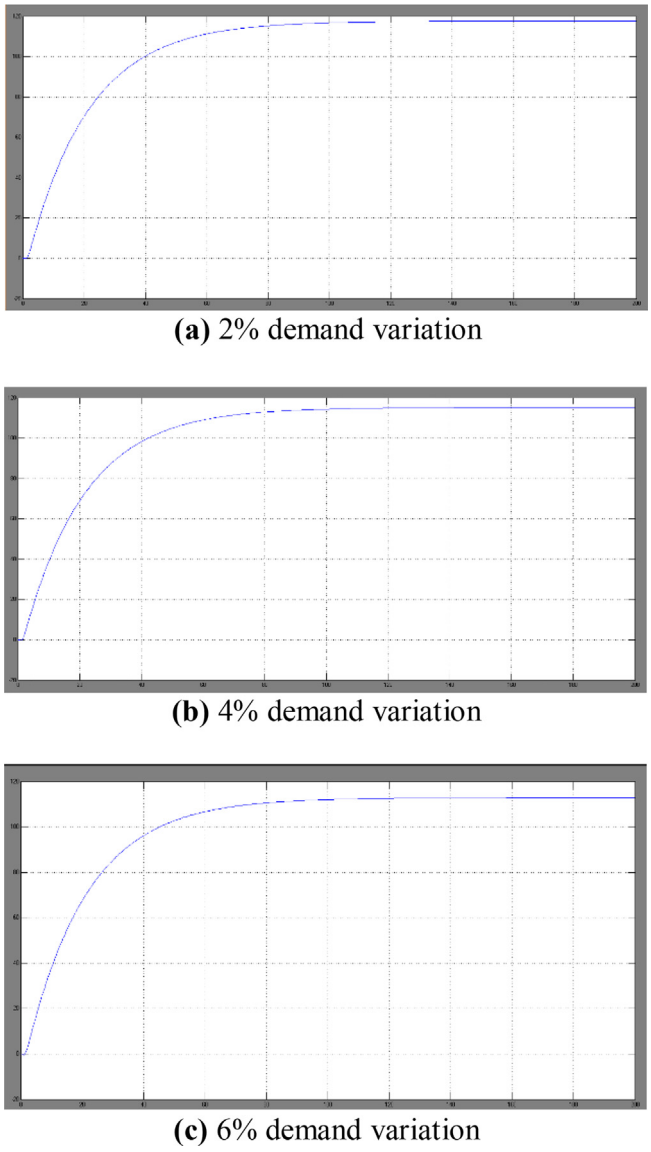


Fig. 9. Open loop response of area 2 for different load variation.

7. Conclusion

The load frequency control of single area and two area system are performed with different controllers such as PI, PID, FLC and FTPI. A comparative study has been performed to estimate the execution of the controllers. It has been reported in the results that the performance of conventional PI controller is superior for minimizing frequency deviation and the performance of FTPI is better for minimizing settling time. So, by varying the gain of PI controller and Fuzzy controller, depending on the error signal, the response is good with minimum frequency deviation and minimum settling time.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

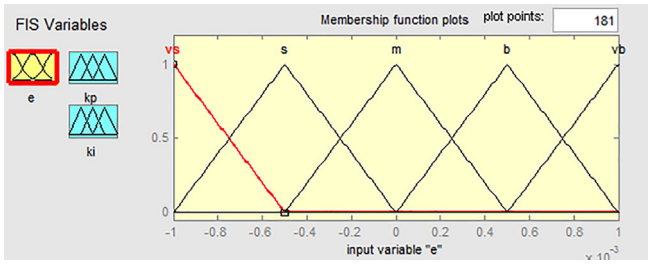


Fig. 10. Input membership function-Area 1.

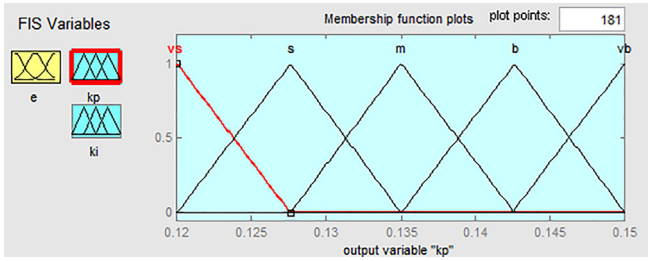


Fig. 11. Output 1 membership function-Area 1.

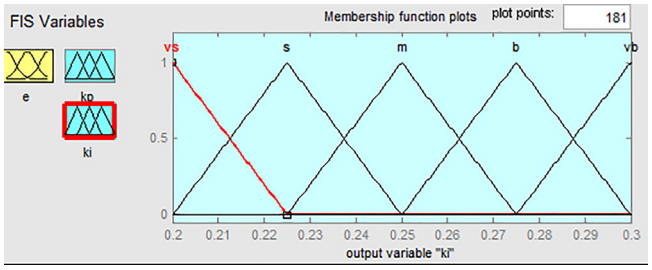


Fig. 12. Output 2 membership function- Area 1.

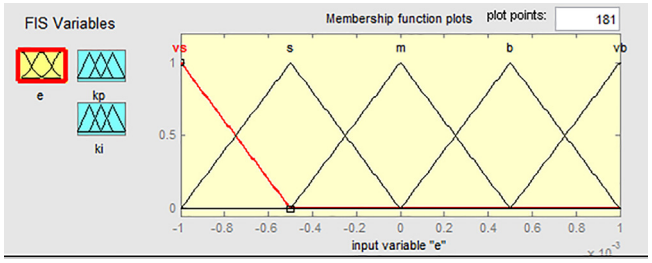


Fig. 13. Input membership function-Area 2.

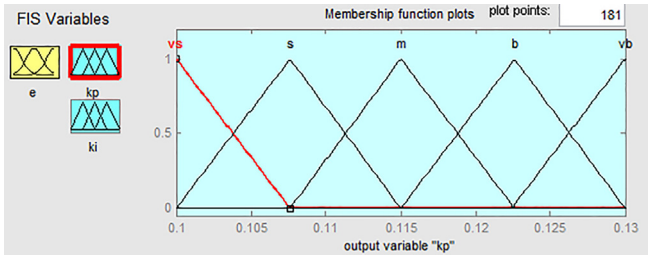


Fig. 14. Output1 membership function-Area 2.

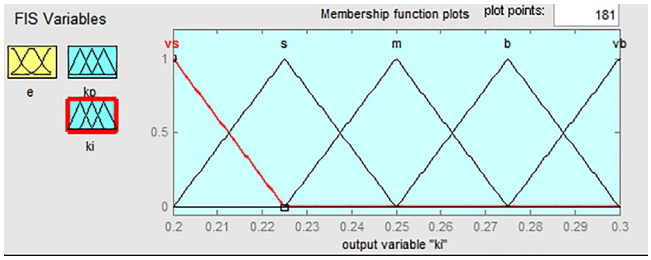
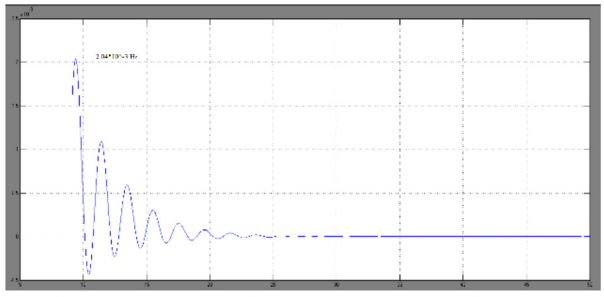


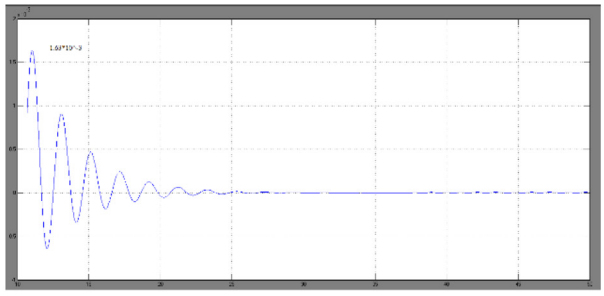
Fig. 15. Output 2 membership function-Area 2.

Table 4
Rules for FUZZY tuned PI controller.

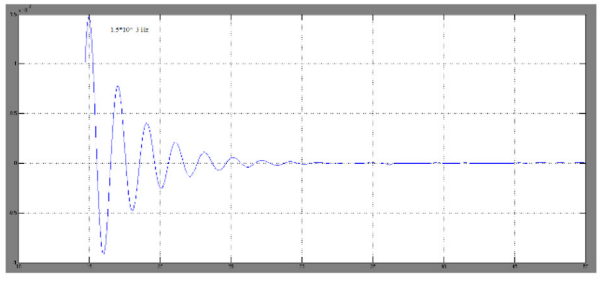
Error	Kp	Ki
VSL	BG	VBG
SL	BG	VBG
MM	SL	MM
BG	MM	SL
VBG	MM	VSL
VSL-very small	SL-Small	MM-Medium
VBG-very big	BG-Big	



(a) ΔF =2% , A1:ΔP_D =0.02 A2: ΔP_D =0.02



(b) ΔF = 2%, A1: ΔP_D =0.02 A2: ΔP_D =0.04



(c) ΔF=2% , A1: ΔP_D =0.02 ,A2: ΔP_D= 0.1

Fig. 16. Frequency deviation (ΔF)with respect to changes in load demand.

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