Load Frequency Control of Three Area System using FOPID Controller

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Abstract: - In present scenario, the power systems are operated to its maximum load ability due to the increase in demand. This affects the power flow as well as the system frequency. This paper addresses the issue of load frequency control of a three area system. A modified Proportional Integral Derivative controller called Fractional Order PID (FOPID) controller is employed to resolve this issue. The proposed FOPID controller is effectively tuned to control the Load frequency of the system. A three area system with different generating units is considered to evaluate the performance of the proposed controller. The robust performance of the FOPID controller is assessed by injecting several disturbances on to the system. At the same time its performance is appraised by comparing it with conventional PI and PID controller. The results have proved that the FOPID controller was very efficient and robust to handle the problem of load frequency changes in the system. The system simulation is realized by using Matlab/Simulink software.

Key-Words: - Frequency regulation, FOPID, PID, PI Controller

1 Introduction

Reliable and quality power delivery is a significant issue in power system operation and control. Load frequency control is mainly responsible for the interchange of power with neighbouring control areas at scheduled values. Also it maintains a constant frequency with zero Area Control Error (ACE). To maintain constant frequency, Suryaparakash et.al [1] has proposed an AGC feedback control system. In general, ordinary LFC systems are designed with Proportional-Integral (PI) controllers [2]. In [3], the relation between active power, frequency and the significance of automatic generation control in a three area system has been discussed. With the evolution of power system control, the load frequency control of power system has been stepped in to the next level by the linear control theory concepts [4-8]. Optimal line regulatory theory based linear regulator design is proposed by Milon Calovic in [9]. In [10], the consequence of plant response time on the closed loops poles has been discussed. Moorthi VR et al. [11] have developed a LFC control system together with the voltage regulator excitation system. Kwatny et al. [12] have presented the control of an optimal linear regulator for LFC. Hsu and Chan presented an efficient approach to design an optimal variable-structure controller (VSC) for the LFC in an interconnected power system [13]. For the Automatic Gain control in LFC a State estimator with decaying error has been proposed as the local observer. This local observer is modeled using non linear transformation technique. Also non linear observers for load frequency control have also been discussed [14-16]. In [17], a new methodology called Elephant Herding Optimization is presented for the design of load frequency controller applicable to single-area non-reheat power system. This approach mitigates the frequency response oscillations in the power system. Otchere IK et al. [18] in his work have discussed a Genetic Algorithm tuned discrete wavelet transform (DWT) for automatic generation control (AGC) systems. This controller ensures a zero steady state error for frequency deviation, mitigates inter area oscillations between interconnected power system and wipes out the noise from the Area Control Error (ACE) signal. In [19], a decentralized feedback control is advised for large scale network control systems. The robustness of the decentralized feedback controller is ensured by providing acceptable time delay, interaction and disturbance between the systems. Jyothi TVD et.al [20] have proposed three different techniques known as Ziegler-Nichols, Genetic algorithm (GA), Linear Matrix Inequalities (LMI) for load frequency control in power systems.

In this paper, FOPID controller was used for load frequency control in a three area power system. The performance of the proposed FOPID controller is compared with the conventional PI and PID controllers. The overshoot, undershoot and the settling time post disturbance are the three parameters considered to assess the performance of the proposed controller. In section 2, the modeling of three area system has been discussed. Section 3 describes about the FOPID controller. Section 4 validates the performance of FOPID controller with the conventional PI and PID controllers. Section 5 concludes the research work.

2 Modeling of three area system

The three area inter connected power system is shown in Fig. 1. There are two control loops in Automatic Gain Control (AGC) namely primary and secondary control. Primary control deals with local plant control and secondary control refers to the minimization of Area Control Error (ACE).

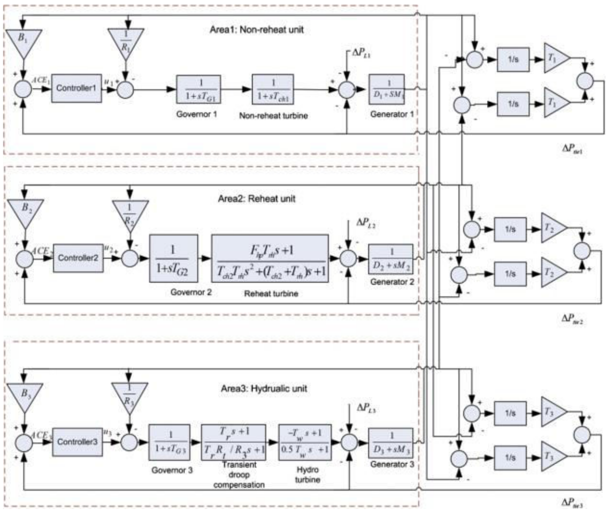

Fig. 1 Load Frequency Control of a three area system

Change in the tie line power between area 1 and 2

$$\Delta P_{tie,1-2} = \frac{2\pi}{s} T_{12} (\Delta F_1(S) - \Delta F_2(S)) \tag{1}$$

Change in the tie line power between area 1 and 3

$$\Delta P_{tie,1-3} = \frac{2\pi}{s} T_{13} (\Delta F_1(S) - \Delta F_3(S)) \tag{2}$$

Change in the tie line power between area 2 and 3

$$\Delta P_{tie,2-3} = \frac{2\pi}{s} T_{23} (\Delta F_2(S) - \Delta F_3(S)) \tag{3}$$

where

T_{ij} -Tie line power between i^{th} and j^{th} areas

F_i - Frequency of i^{th} area

So the total tie line power change between area 1 and the other two areas is calculated as

$$\Delta P_{tie,1} = \Delta P_{tie,1-2} + \Delta P_{tie,1-3} \tag{4}$$

When the load on the system decreases, the system frequency rises. Similarly the system frequency drops when the load on the system increases. However the frequency deviation has to be maintained as zero. To keep the load frequency constant, tie line power flow is to be controlled. It allows bi directional flow of power by maintaining a constant frequency. Tie line power flow is helpful in load frequency control by keeping Area Control Error as zero. Let the parameters of the three area system are as given below:

Non Reheat (Area 1)	
M_1 (p.u.s)	10
D_1 (p.u./Hz)	1
T_{ch1}(s)	0.3
T_{G1}(s)	0.1
R_1(Hz/p.u.)	0.05
B_1 (p.u./Hz)	21
T_1 (p.u./rad)	22.6

Reheat (Area 2)	
M_2 (p.u.s)	10
D_2 (p.u./Hz)	1
T_{ch2}(s)	0.3
F_{hp}	0.3
T_{rh} (s)	7
T_{G2}(s)	0.2
R_2 (Hz/p.u.)	0.05
B_2 (p.u./Hz)	21
T_2 (p.u./rad)	22.6

Hydraulic (Area 3)	
M_3 (p.u.s)	6
D_3 (p.u./Hz)	1
T_{G3}(s)	0.2
T_r (s)	5
R_t (Hz/p.u.)	0.38
R_3 (Hz/p.u.)	0.05
B_3 (p.u./Hz)	21
T_w (s)	1
T_3 (p.u./rad)	22.6

3 FOPID Controller

Podlubny proposed the concept of FOPID controller. In FOPID the order of derivative and integral is not integer. This characteristic provides extra degrees of freedom. This improves the dynamic response of the system. The formulation of FOPID controller is given in equation 5.

$$K(S) = K_p + \frac{K_i}{S^{\lambda}} + K_d S^{\mu} \tag{5}$$

where K_p, K_I, and K_d are proportional, integral, and derivative gain, respectively. Also, k and l are orders of integral and derivative, respectively. It is shown that implementing FOPID controller for LFC improves the power system response in terms of settling time, overshoot, and undershoot. Moreover, this controller is robust to changes in power system parameters.

4 Results and Discussion

Load Frequency Control behaviour of a three area power system is studied using MATLAB simulation. LFC of a three area system with three different controllers and their response for an input disturbance are studied. If the disturbance is given to any one of the three areas, the power to compensate the tie-line power change initially comes from all the three areas and frequency drops in all the areas and this drop of frequency is sensed by the speed governors of the three areas. However, after a few seconds steady state is achieved by nullifying the frequency deviation using the control action of the controllers. The frequency deviation and the settling time post disturbance in area 1 for PI controller are tabulated in Table 1. The frequency deviation response of three areas using PI controller due to disturbance in Area 1 is shown in Fig. 2, Fig. 3 and Fig. 4 respectively.

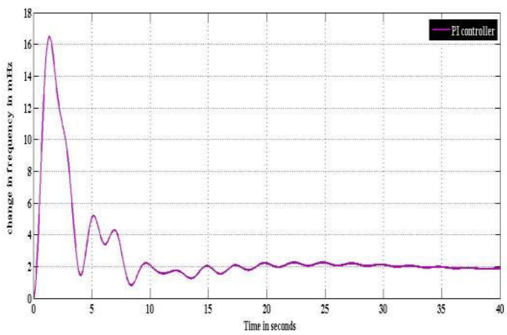

Fig. 2 Frequency deviation of Area 1 due to step input disturbance in Area 1

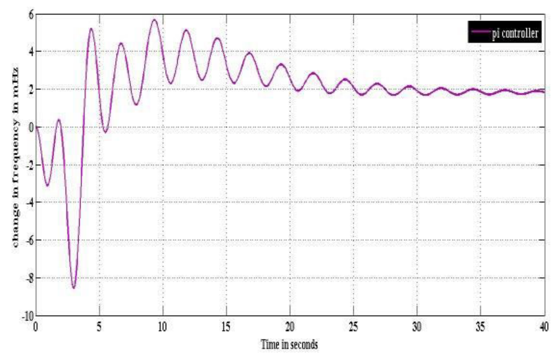

Fig. 3 Frequency deviation of Area 2 due to step input disturbance in Area 1

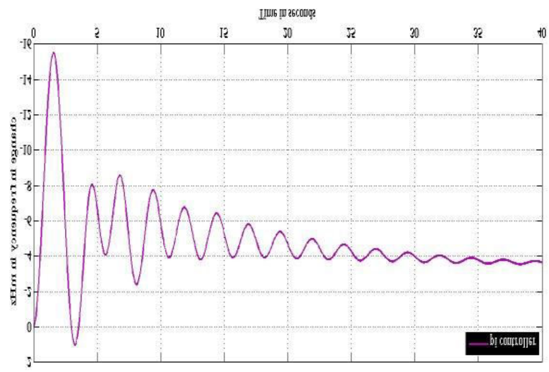

Fig. 4 Frequency deviation of Area 3 due to step input disturbance in Area 1

Table 1
Parameter variation of three area system using PI controller post disturbance in Area 1

Parameters	Area 1	Area 2	Area 3
Overshoot (mHz)	16.5	5.8	1
Undershoot (mHz)	-	-8.4	-15.8
Settling Time (Sec)	38	>40	>40

The step disturbance is applied to area1 and the frequency deviation due to the step disturbance using PI controller and its effects on the area 2 and area 3 are observed. The overshoot, undershoot and the settling time are observed for areas 1, 2 and 3. It takes 38 seconds for the oscillations to settle down in area 1 and in areas 2 and 3 the oscillations takes more than 40 seconds to settle down. The frequency deviation and the settling time post disturbance in area 1 for PID controller are tabulated in Table 2. The frequency deviation response of three areas using PID controller due to disturbance in Area 1 is shown in Fig. 5, Fig. 6 and Fig. 7 respectively.

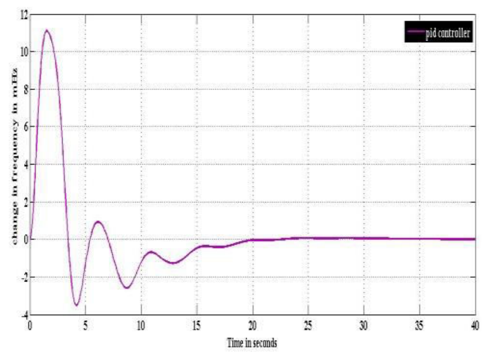

Fig. 5 Frequency deviation of Area 1 due to step input disturbance in Area 1

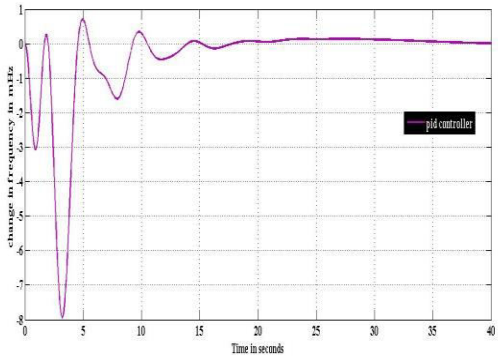

Fig. 6 Frequency deviation of Area 2 due to step input disturbance in Area 1

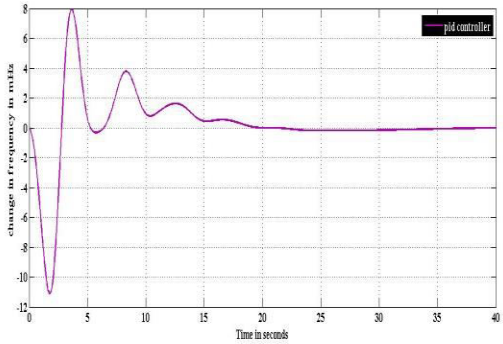

Fig. 7 Frequency deviation of Area 3 due to step input disturbance in Area 1

Table 2

Parameter variation of three area system using PID controller post disturbance in Area 1

Parameters	Area 1	Area 2	Area 3
Overshoot (mHz)	11	0.8	8
Undershoot (mHz)	-3.8	-8	-11
Settling Time (Sec)	25	22	21

The step disturbance is applied to area1 and the frequency deviation due to the step disturbance using PID controller and its effects on the area 2 and area 3 are observed. The overshoot, undershoot and the settling time are observed for areas 1, 2 and 3. It takes 25 seconds for the oscillations to settle down in area 1 and in areas 2 and 3 the oscillations takes 22 and 21 seconds to settle down. The frequency deviation and the settling time post disturbance in area 1 for FOPID controller are tabulated in Table 3. The frequency deviation response of three areas using FOPID controller due to disturbance in Area 1 is shown in Fig. 8, Fig. 9 and Fig. 10 respectively.

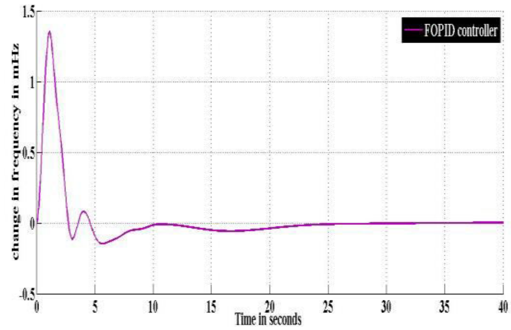

Fig. 8 Frequency deviation of Area 1 due to step input disturbance in Area 1

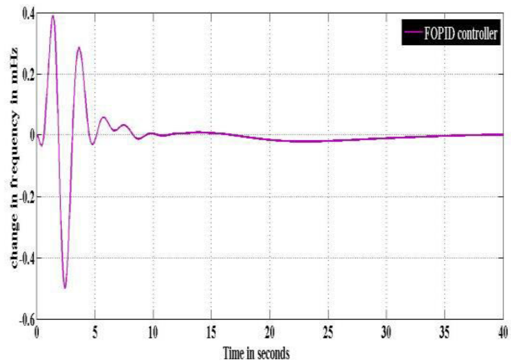

Fig. 9 Frequency deviation of Area 2 due to step input disturbance in Area 1

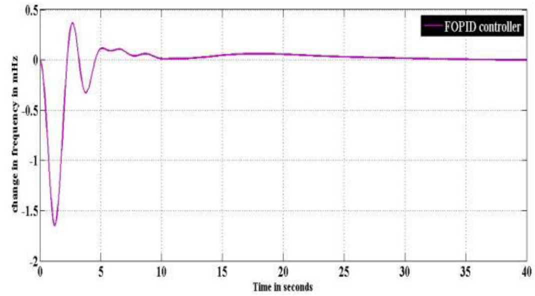

Fig. 10 Frequency deviation of Area 1 due to step input disturbance in Area 1

Table 3

Parameter variation of three area system using FOPID controller post disturbance in Area 1

Parameters	Area 1	Area 2	Area 3
Overshoot (mHz)	1.4	0.4	0.4
Undershoot (mHz)	-0.1	-0.5	-1.6
Settling Time (Sec)	25	20	20

The step disturbance is applied to area1 and the frequency deviation due to the step disturbance using FOPID controller and its effects on the area 2 and area 3 are observed. The overshoot, undershoot and the settling time are observed for areas 1, 2 and 3. It takes 25 seconds for the oscillations to settle down in area 1 and in areas 2 and 3 the oscillations takes 20 seconds to settle down. The performance comparison between PI, PID and FOPID controllers is tabulated in Table 4.

Table 4
Parameter variation of three area system using PI, PID and FOPID controller due to post disturbance in Area 1

Parameters	Area 1		
	PI	PID	FOPID
Overshoot (mHz)	16.5	11	1.4
Undershoot (mHz)	-	-3.8	-0.1
Settling Time (Seconds)	38	25	25
Parameters	**Area 2**		
	PI	PI	PI
Overshoot (mHz)	5.8	5.8	5.8
Undershoot (mHz)	-8.4	-8.4	-8.4
Settling Time (Seconds)	>40	>40	>40
Parameters	**Area 3**		
	PI	PI	PI
Overshoot (mHz)	1	1	1
Undershoot (mHz)	-15.8	-15.8	-15.8
Settling Time (Seconds)	>40	>40	>40

From Table 4 it is observed that the FOPID controller outperforms the PI and PID controllers. The magnitude of overshoot is less when FOPID controller is used for Load Frequency Control in a three area system. Similarly the settling time post disturbance is less with FOPID controllers. The change in area 1, area 2 and area 3 frequencies with PI, PID and FOPID controllers due to a step increase in demand of area 1 is shown in Fig. 11, Fig. 12 and Fig. 13 respectively.

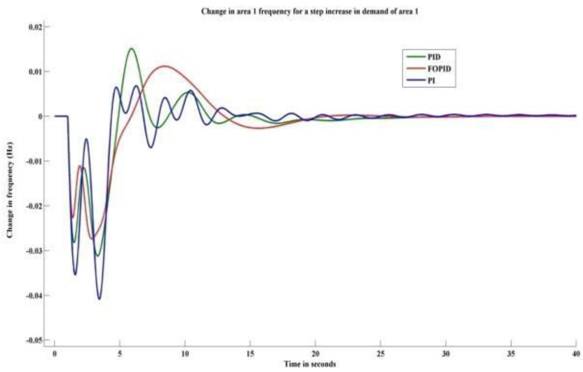

Fig. 11 Change in area 1 frequency for a step increase in demand of area 1 using PI, PID and FOPID controllers

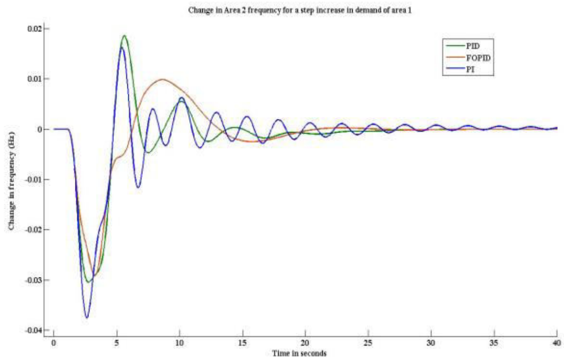

Fig. 12 Change in area 2 frequency for a step increase in demand of area 1 using PI, PID and FOPID controllers

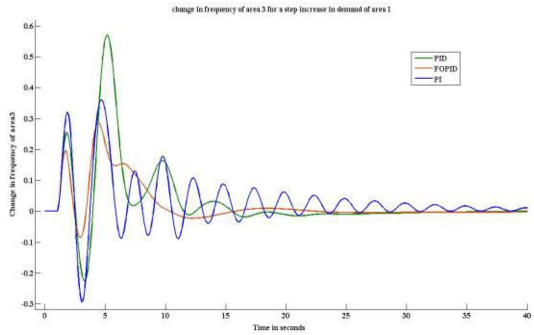

Fig. 13 Change in area 3 frequency for a step increase in demand of area 1 using PI, PID and FOPID controllers

The change in Tie line power of area 1 and Area control error due to a step increase in demand of area 1 using PI, PID and FOPID is shown in Fig. 14 and Fig. 15 respectively. From Fig. 14 it is observed that the tie line power deviation is very less with FOPID controller.

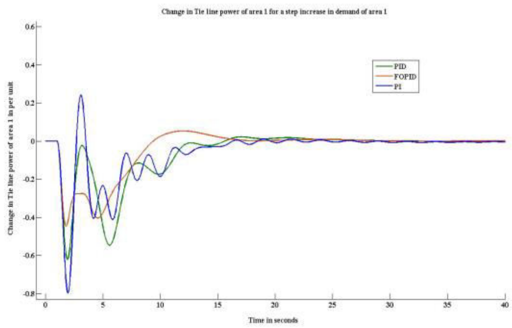

Fig. 14 Change in area 1 tie line power for a step increase in demand of area 1 using PI, PID and FOPID controllers

From Fig. 15 it is observed that the change in Area control error is relatively small and the oscillations post disturbance are settled down quickly with FOPID controller.

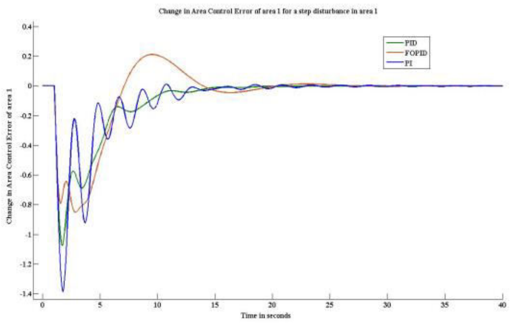

Fig. 15 Change in area 1 Area Control Error for a step increase in demand of area 1 using PI, PID and FOPID controllers

4 Conclusion

In this work three area power system network which include thermal, hydro and Non-reheat systems have been modeled and are simulated in Simulink environment. This three area power system network LFC is controlled with conventional PI controller, PID controller and FOPID controller. The performance of all these controllers has been compared. It is found that FOPID controller shows the best performance among all in terms of settling time, less frequency dip and minimum oscillations.

5 Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of the paper.

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