IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 6, Issue 5, May 2018

Application of Unified Power Flow Controller and Superconducting Magnetic Energy Storage Device for AGC Problem

***G.T.Chandra Sekhar[1], S. Halini, L[2]. Narasinga Rao[3]**

Department of Electrical and Electronics Engineering, Sri Sivani College of Engineering, Chilakapalem, Srikakulam, Andhra Pradesh[1,2,3]

Abstract: The load variation in the power system is unpredictable which cause the drift in frequency, voltage to change from their nominal value resulting loss of generation and even blackout. So an approach has been undertaken for investigating the automatic generation control considering three equal area power systems at the first instant. In the present work, a proportional derivative controller with derivative filter (PIDF) is proposed and the gain values of the proposed controller are tuned using Differential Evolution (DE) algorithm. The superiority of the proposed controller is demonstrated by comparing the results with Proportional Integral Derivative (PID) controller. In the next step, proposed approach is extended to three unequal area reheat thermal power systems considering nonlinearities like Generation Rate Constraint (GRC) and Governor Dead Band (GDB). Further, Unified Power Flow Controller (UPFC) is placed in the tie-line to improve the dynamic response of the system based on integral time multiplied absolute error (ITAE), settling times and peak over shoot. Furthermore, Superconducting Magnetic Energy Storage (SMES) is incorporated in area-1 for further improvement in responses of the system. From the results, it is clear that the combination of UPFC and SMES provides better results.

Keywords: PIDF, DE, GRC, GDB, PID, UPFC, SMES, ITAE.

1. INTRODUCTION

The power systems means, it is the interconnection of more than one control areas through tie lines. The generators in a control area always vary their speed together speed up or slow down) for maintenance of frequency and the relative power angles to the predefined values in both static and dynamic conditions. If there is any sudden load change occurs in a control area of an interconnected power system then there will be frequency deviation as well as tie line power deviation [1-7].

The two main objective of Automatic Generation Control (AGC) are

- To maintain the real frequency and the desired power output (megawatt) in the interconnected power system.
- To control the change in tie line power between control areas.

If there is a small change in load power in a single area power system operating at set value of frequency then it creates mismatch in power both for generation and demand. This mismatch problem is initially solved by kinetic energy extraction from the system, as a result declining of system frequency occurs. As the frequency gradually decreases, power consumed by the old load also decreases. In case of large power systems the equilibrium can be obtained by them at a single point when the newly added load is distracted by reducing the power consumed by the old load and power related to kinetic energy removed from the system. Definitely at a cost of frequency reduction we are getting this equilibrium. The system creates some control action to maintain this equilibrium and no governor action is required for this. The reduction in frequency under such condition is very large.
However, governor is introduced into action and generator output is increased for larger mismatch. Now here the equilibrium point is obtained when the newly added load is distracted by reducing the power consumed by the old load and the increased generation by the governor action. Thus, there is a reduction in amount of kinetic energy which is extracted from the system to a large extent, but not totally. So the frequency decline still exists for this category of equilibrium. Whereas for this case it is much smaller than the previous one mentioned above. This type of equilibrium is generally obtained within 10 to 12 seconds just after the load addition. And this governor action is called primary control [9-14].
Science after the introduction of governors action the system frequency is still different its predefined value, by another different control strategies it is needed the frequency to bring back to its predefined value.

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Conventionally Integral Controllers are used for this purpose. This control is called a secondary control (which is operating after the primary control operation) which brings the system frequency to its predefined value or close to it. Whereas, integral controllers are generally slow in operation.

2. METHODOLOGY

Firstly, multi area thermal power system is considered as shown in Fig. 1 [15]. The power system considered is three unequal areas having 2000MW, 4000MW and 8000MW as ratings. Each area consists of only one thermal units. To analyse the power with more realistic in nature non linearities such as GDBs and GRCs are included. Governor dead band has a great effect on the dynamic performance of the system and it degrades the system performance. The governors may not respond instantly for a change of input signal until the input reaches to a specified value. In a power system, power generation can change only at a specified maximum rate known as Generation Rate Constraint (GRC). In the present study, governor dead band of 0.05% for the thermal generating unit and 0.02% for hydro generating unit is considered. A GRC of 3% per min is considered for thermal units. The GRC's for hydro unit are 270% per minute for raising generation and 360% per minute for lowering generation are considered [9-14]. The nominal parameters of the system under study are given in Appendix.

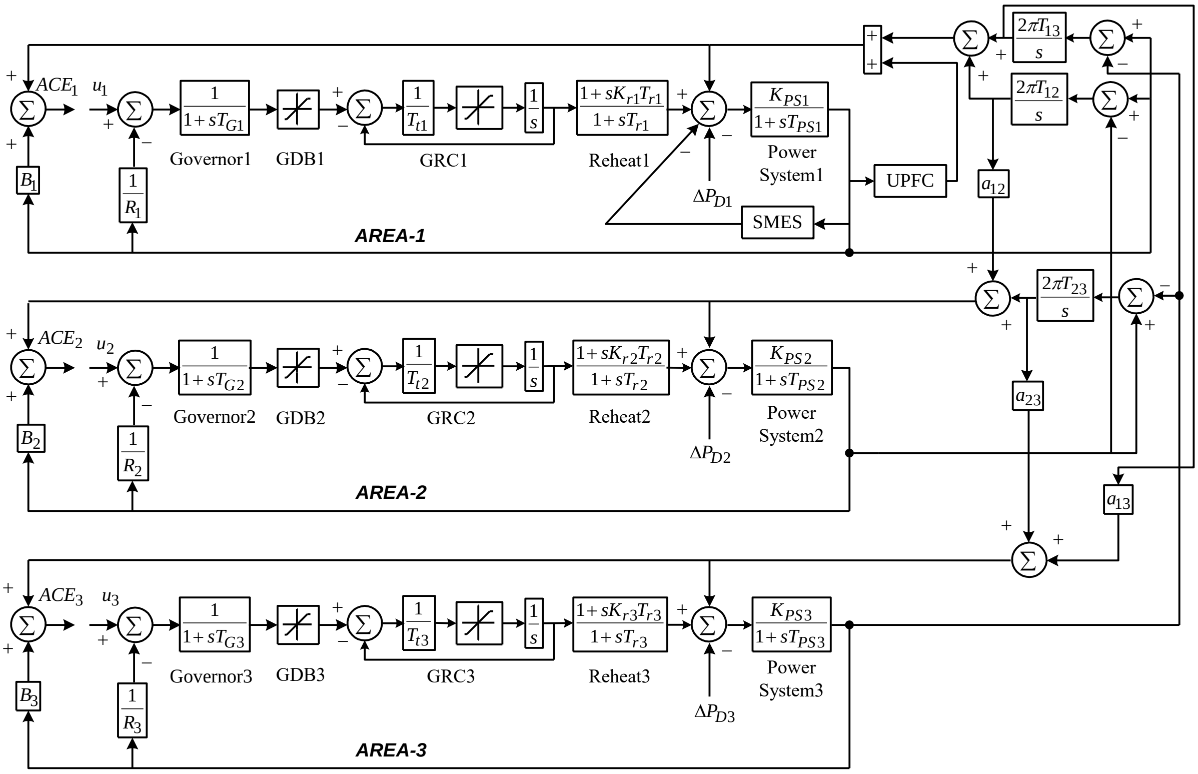

Fig. 1 Transfer function model of three-unequal-area thermal system with, UPFC and SMES

3. CONTROL STRUCTURE AND OBJECTIVE FUNCTION

A proportional controller has the effect of reducing the rise time, but never eliminates the steady-state error. An integral control has the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control has the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Proportional integral (PI) controllers are the most often type used today in industry. A control without derivative (D) mode is used when: fast response of the system is not required, large disturbances and noises are present during operation of the process and there are large transport delays in the system. PID controllers are used when stability and fast response are required. Derivative mode improves stability of the system and enables increases in proportional gain and decrease in integral gain which in turn increases speed of the controller response. However, when the input signal has sharp corners, the derivative term will produce unreasonable size control inputs to the plant. Also, any noise in the control input signal will result in large plant input signals [16-19]. These reasons often lead to complications in practical applications. The structure of PID controller with derivative filter is shown in Fig. 2 where K_P, K_I and K_D are the proportional, integral and derivative gains respectively and N is the derivative filter

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coefficient. The control inputs of PIDF controller are the respective ACEs and the output of PIDF controllers are the input of power system u_1 and u_2.

The transfer function of the controller is given by:

$$TF_{PID} = \left[K_P + K_I \left(\frac{1}{s} \right) + K_D \left(\frac{Ns}{s+N} \right) \right] \quad (1)$$

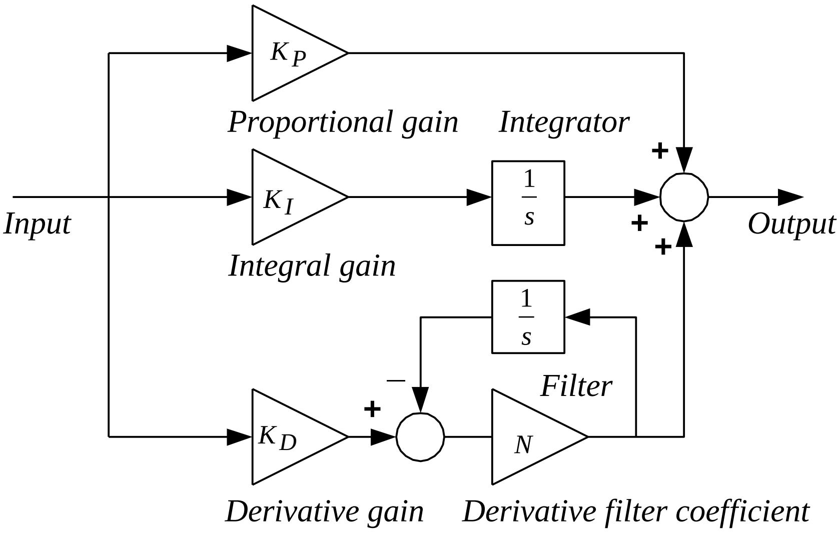

Fig. 2 Structure of PID controller with derivative filter

In the design of a modern heuristic optimization technique based controller, the objective function is first defined based on the desired specifications and constraints. Performance criteria usually considered in the control design are the Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied Squared Error (ITSE) and Integral of Absolute Error (IAE). ITAE criterion reduces the settling time which cannot be achieved with IAE or ISE based tuning. ITAE criterion also reduces the peak overshoot. ITSE based controller provides large controller output for a sudden change in set point which is not advantageous from controller design point of view. It has been reported that ITAE is a better objective function in LFC studies [20-25]. Therefore in this paper ITAE is used as objective function to optimize the scaling factors and proportional, integral and derivative gains of PIDF controller. Expression for the ITAE objective function is depicted in equation.

$$J = ITAE = \int_0^{t_{sim}} \left(|\Delta F_i| + |\Delta P_{Tie-i-k}| \right) \cdot t \cdot dt \quad (2)$$

In the above equations, ΔF_i is the incremental change in frequency of area i, $\Delta P_{Tie-i-k}$ is the incremental change in tie line power connecting between area i and area k; t_{sim} is the time range of simulation. The problem constraints are the PIDF controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem.

Minimize J

Subject to

$$K_{P\min} \le K_P \le K_{P\max},\ K_{I\min} \le K_I \le K_{I\max},\ K_{D\min} \le K_D \le K_{D\max},\ n_{\min} \le n \le n_{\max} \quad (3)$$

4. SIMULATION RESULTS

The unequal three area power system transfer function model under study shown in Fig. 1 is developed in MATLAB/SIMULINK environment. The developed model is simulated in MATLAB/SIMULINK environment by considering a 10% step load change in area 1. Initially, classical controllers such as PID and PIDF controllers are considered and these controllers are optimized by using Differential Evolution (DE) algorithm. The Differential Evolution algorithm is briefly discussed in [13, 26, 27, 28] Further, UPFC is incorporated in area 1 to improve the dynamic performance of the system and also improves the transient response of the system. The modelling of UPFC for AGC is considered in Ref. [21] Finally, SMES is installed in area-1 for further improvement in dynamic performances of the system and its modelling is considered from the Ref. [29]. In the present work, the minimum and maximum values of K_P, K_D, K_I are chosen as -2.0 and 2.0 respectively. The range for filter coefficient n_c is selected as 10 and 300.

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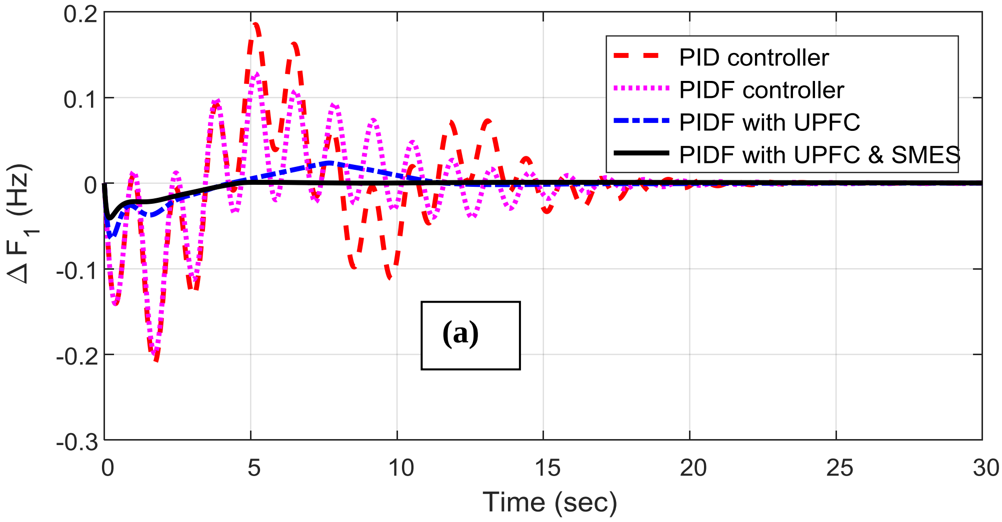
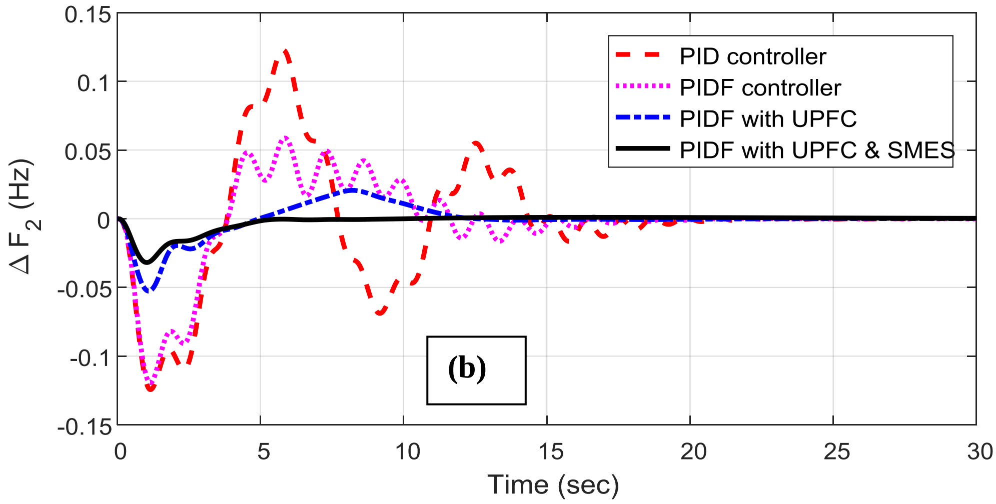
The proposed controllers are optimized by using DE algorithm. The optimal controller parameters of different cases such as only PID controller, only PIDF controller, PIDF controller with UPFC and PIDF controller with UPFC and SMES are shown in Table 1. The corresponding responses of the system are shown in Figs. 3 (a-f). Form these Figs. 3 (a-f) it is evident that UPFC & SMES incorporated PIDF controlled power system performs better than others. The related performance index values are provided in Table 2.

Table 1: Optimal tuned controller values

Controller Parameter	PID	PIDF	PIDF with UPFC	PIDF with UPFC & SMES
K_{P1}	-0.4332	-0.0295	-1.1509	-1.9167
K_{P2}	-1.1891	-1.0319	-0.8996	-0.7697
K_{P3}	-1.4386	-1.2093	-0.4780	-0.3235
K_{I1}	-0.7522	-0.8810	-1.2106	-0.5131
K_{I2}	-1.5007	-0.7219	-1.4795	-1.7815
K_{I3}	-0.8017	-0.0156	-0.6382	-1.5961
K_{D1}	-0.3492	-0.1328	-0.8130	-0.3533
K_{D2}	-1.0382	-0.2247	-0.6923	-0.6578
K_{D3}	-1.9475	-1.1953	-0.9721	-1.2137
N_{C1}	---	271.3910	255.0179	278.7730
N_{C2}	---	298.6607	225.1502	118.0130
N_{C3}	---	199.4174	162.3253	265.6053





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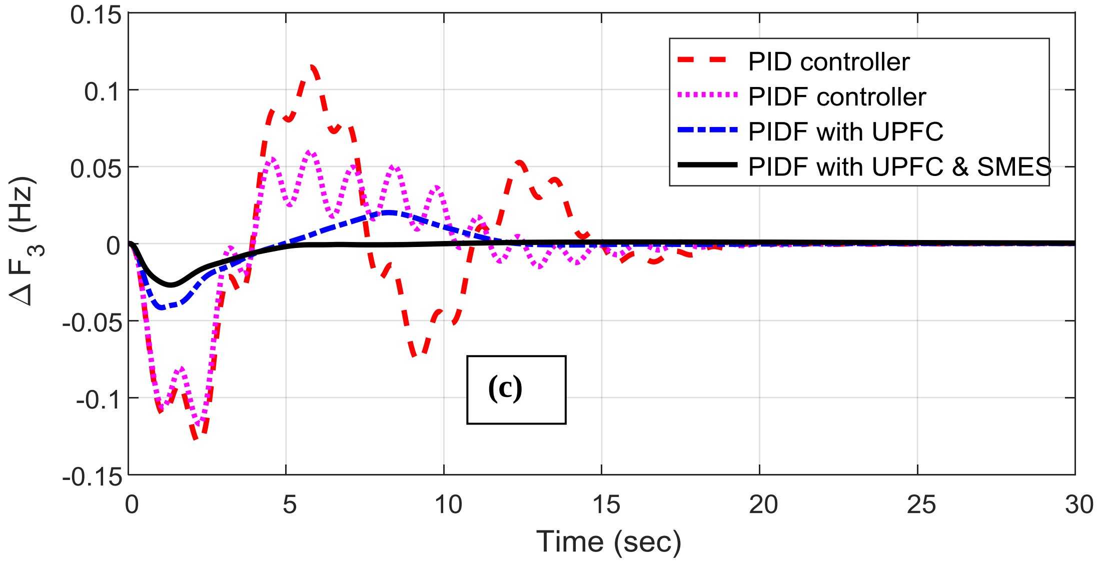

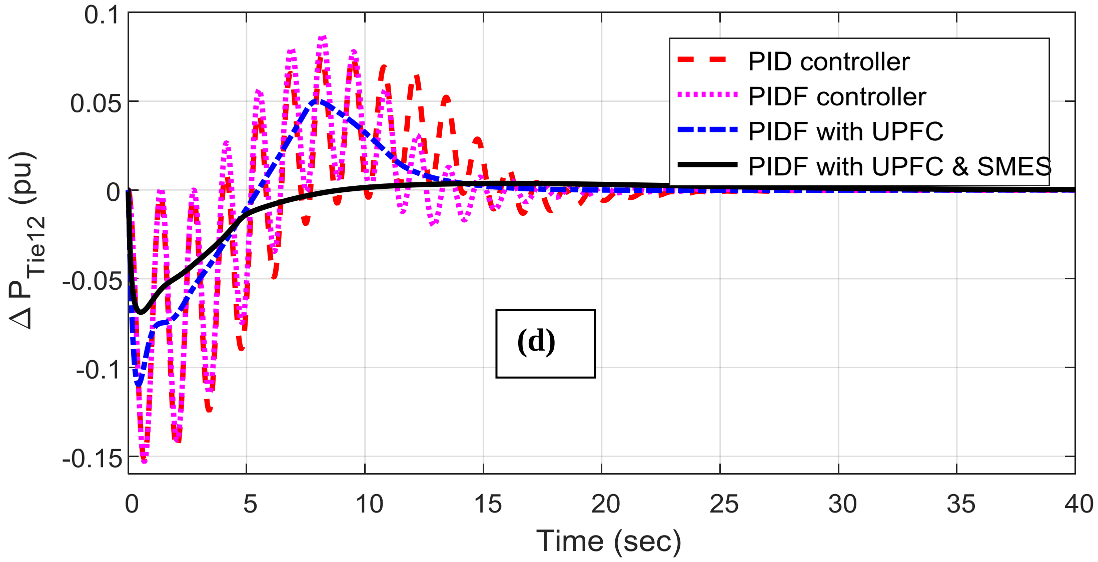

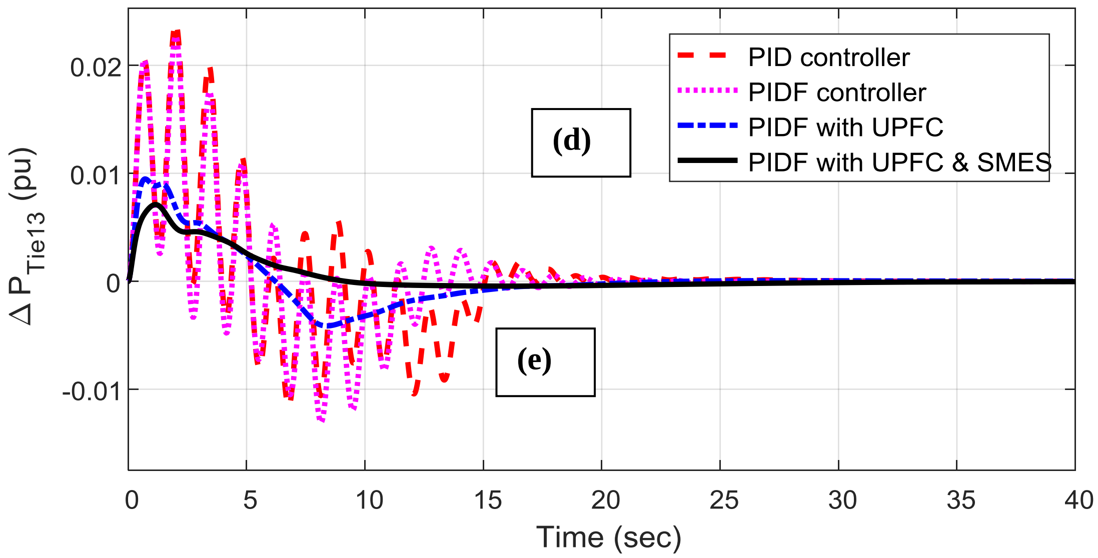

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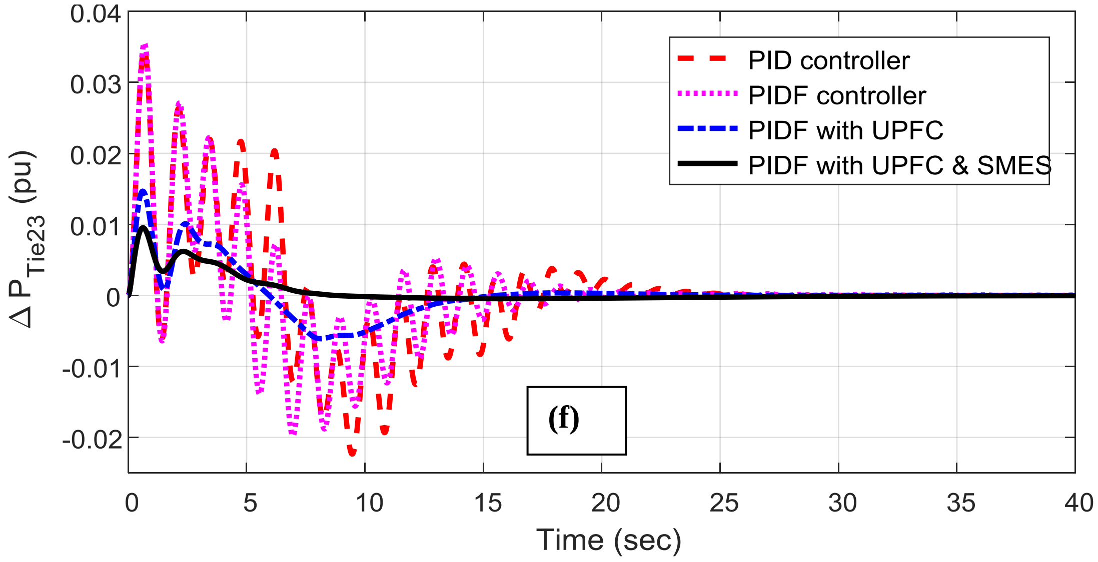

Fig. 5.4: Dynamic responses of the system for 10 % change in area 1 (a) change in frequency in area 1 (b) change in frequency in area 2 (c) change in frequency in area 3 (d) tie-line power deviation between area 1 and area 2 (e) tie-line power deviation between area 1 and area 3
(f) tie-line power deviation between area 2 and area 3.

Table 2: Performance index values

Controller/ Performance index		PID	PIDF	PIDF with UPFC	PIDF with UPFC & SMES
ITAE		23.2651	14.3538	6.0853	3.7261
Settling Time (Ts)	ΔF_1	21.62	20.52	11.13	4.23
	ΔF_2	19.50	17.51	11.67	4.88
	ΔF_3	19.24	18.26	11.62	4.98
	ΔP_{tie1}	19.73	19.54	15.25	8.03
	ΔP_{tie2}	14.89	14.26	11.60	5.55
	ΔP_{tie3}	20.27	15.79	12.16	5.19
Peak overshoot	ΔF_1	0.1853	0.1279	0.0236	0.0010
	ΔF_2	0.1228	0.0587	0.0206	0.0010
	ΔF_3	0.1146	0.0597	0.0201	0.0010
	ΔP_{tie1}	0.0756	0.0875	0.0500	0.0037
	ΔP_{tie2}	0.0239	0.0227	0.0095	0.0071
	ΔP_{tie3}	0.0347	0.0356	0.0147	0.0095

5. CONCLUSION

In the present work, PIDF controller is proposed for Automatic Generation Control (AGC) of multi area power system. The three unequal reheat thermal power systems considering different non linearity like GRC and GDB. Initially, PID/PIDF controllers are used to evaluate the performance of the power system. Further, the results are improved by employing UPFC device and finally SMES is incorporated in area-1 for further improvement of dynamic responses. From the simulation result, it is revels that significant improvements in the dynamic response are obtained with coordination of UPFC and SMES device.

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APPENDIX

f=60 Hz, B_1=0.3483, B_2=0.3827, B_3=0.3692 p.u. Hz; $D_1 = D_3 = 0.015$, D_2=0.016 p.u. Hz; $2H_1$=0.1667, $2H_2$ =0.2017, $2H_3$=0.1247 p.u. sec; R_1=3.0, R_2=2.73, R_3=2.82 Hz/p.u.; T_{G1}=0.08, T_{G2}=0.06, T_{G3}=0.07 sec; T_{t1}=0.4, T_{t2}=0.44, T_{t3}=0.3 sec; $K_{r1} = K_{r2} = K_{r3}$=0.5, $T_{r1} = T_{r2} = T_{r3}$=10 sec; $T_{12} = 0.2$, $T_{23} = 0.12$, $T_{31} = 0.25$ p.u./Hz; $P_{R1} = 2000$, $P_{R2} = 4000$, $P_{R3} = 8000$ MW.

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