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Design of TIDF Controller for LFC of Interconnected Power System

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Abstract
This paper presents comparative performance analysis of Differential Evolution (DE) algorithm optimized classical controllers i.e. Integral (I), Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controller with a new Tilt-Integral-Derivative with derivative filter (TIDF) controller for load frequency control. Here, a five unequal reheat thermal area with generation rate constraint (GRC) and Governor Dead Band (GDB) non-linearity is considered for study. The gains of above controllers are optimized using the Integral of Time multiplied by Absolute Error (ITAE) objective function. The simulation results show that the TIDF controller provides better dynamic performance than classical controllers.

Keywords—***Differential Evolution (DE) Algorithm, Tilt-Integral-Derivative with derivative filter (TIDF), Load Frequency control (LFC), Generation Rate constraint (GRC), Governor dead band (GDB)***

Introduction
The main objective of modern power system operation and control is to provide reliable power supply to the consumers with good quality. For reliable power supply, there should be a balance between power generated and total load demanded plus associated losses and the system frequency and tie-line power interchanges between different control areas must be maintained within tolerable limits with variation in load demands[1]. This can be achieved through load frequency control (LFC).For the past decades, so many researches were done in the field of LFC by improving the existing controllers and designing new ones. Various optimization techniques have been proposed by researchers for optimal tuning of controller parameters. In this paper, a new controller i.e. tilt- integral-derivative with derivative filter(TIDF) controller is used for LFC and its performance is compared with classical controllers. Differential Algorithm is used for optimization of above controller parameters.

Material and Method
System under Invistigation
The system considered for study consists of five unequal area thermal system of area1: 2000MW, area2: 4000MW, area3: 8000MW, area4: 10000MW and area5: 2000MW.The thermal systems are provided with single reheat turbine, Generator rate constraint (GRC) of 3%/min [2], Governor dead band (GDB) of 0.06% (0.036Hz) [3] in each area. The nominal system parameters for the system are shown in the appendix. The per unit values are considered to be same on their corresponding bases for various parameters of the unequal areas. For modeling interconnected areas of different capacities for five area system, the quantities a_{12}, a_{13}, a_{14}, a_{15}, a_{23}, a_{24}, a_{25}, a_{34}, a_{35}, a_{45} are considered as

$$a_{12}=\frac{-P_{r1}}{P_{r2}}, a_{13}=\frac{-P_{r1}}{P_{r3}}, a_{14}=\frac{-P_{r1}}{P_{r4}}, a_{15}=\frac{-P_{r1}}{P_{r5}}, a_{23}=\frac{-P_{r2}}{P_{r3}}, a_{24}=\frac{-P_{r2}}{P_{r4}}, a_{25}=\frac{-P_{r2}}{P_{r5}},$$

$$a_{34}=\frac{-P_{r3}}{P_{r4}}, a_{35}=\frac{-P_{r3}}{P_{r5}}, a_{45}=\frac{-P_{r4}}{P_{r5}}.$$ The transfer function model of five area system with TIDF controller is shown in Fig. 1. A step load disturbance of 1% in area1 is considered.

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ACE_1, ACE_2, ACE_3, ACE_4 ,ACE_5, are area control errors; B_1, B_2, B_3, B_4, B_5 are the frequency bias parameters in p.u. MW/Hz;R_1, R_2, R_3, R_4, R_5, are the governor speed regulation parameters in Hz/p.u. MW; T_{g1}, T_{g2}, T_{g3}, T_{g4}, T_{g5} are the speed governor time constants in sec; T_{r1} , T_{r2} , T_{r3} , T_{r4} , T_{r5} are the reheat turbine time constants in sec; K_{r1} ,K_{r2} K_{r3} ,K_{r4} ,K_{r5} are reheat coefficients; ΔP_{L1} is the step load disturbance in area1; ΔP_{tie} is the change in tie line power in p.u.;K_{p1} , K_{p2} ,K_{p3} ,K_{p4} ,K_{p5} are the power system gains; T_{p1} , T_{p2} ,T_{p3} ,T_{p4} ,T_{p5} are the power system time constant in sec; T_{12} , T_{13} , T_{14} , T_{15} , T_{23} , T_{24} , T_{25} , T_{34} , T_{35} , T_{45} are the synchronizing coefficients and ΔF_1, ΔF_2, ΔF_3, ΔF_4, ΔF_5 are the system frequency deviations in Hz.

Control strucutre and objective function

Tilt-Integral-Derivative with derivative filter (TIDF) controller is used in each area as it is robust and provides ease in tuning. The disturbance rejection ratio is better and its transient response to command input ratio remains good over a wider range of plant parameter variations as compared to classical controllers [4]. The structure of TIDF controller is shown in Fig. 2. A tilted component having the transfer function $s^{-\frac{1}{n}}$ replaces the proportional component of the controller. In Fig. 2, K_P, K_I, K_D are proportional, integral, derivative gains and n is a nonzero real number respectively. N_C is the derivative filter coefficient. The mathematical model of TIDF controller is given by:

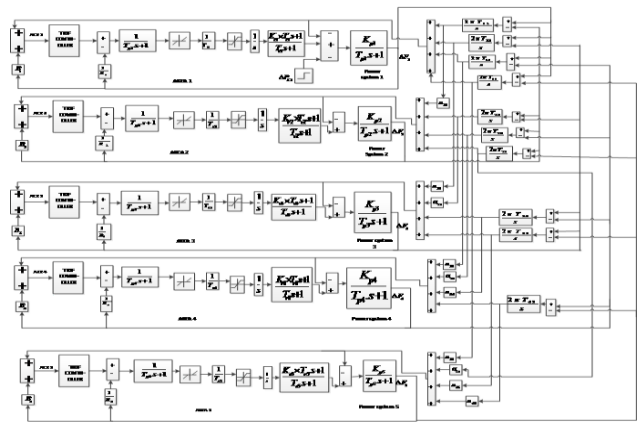

Fig.1 MATLAB/SIMULINK model of five-area reheat thermal interconnected power system

$$TF_{TIDF} = \frac{K_P}{s^{\frac{1}{n}}} + \frac{K_I}{s} + K_D\left(\frac{N_C s}{s + N_C}\right) \qquad (1)$$

The objective function is first defined based on the desired specifications and constraints for the designing of a heuristic optimization technique based controller. Performance criteria generally considered in the control design are the Integral of Time multiplied Absolute Error (ITAE), Integral of Absolute Error (IAE), Integral of Time multiplied Squared Error (ITSE) and Integral of Squared Error (ISE). It has been shown that ITAE is a better objective function as compared to IAE, ITSE and ISE in LFC studies [3]. Thus, in the present study, ITAE is employed as objective function to optimize the gain of classical controllers and the proposed new controller.

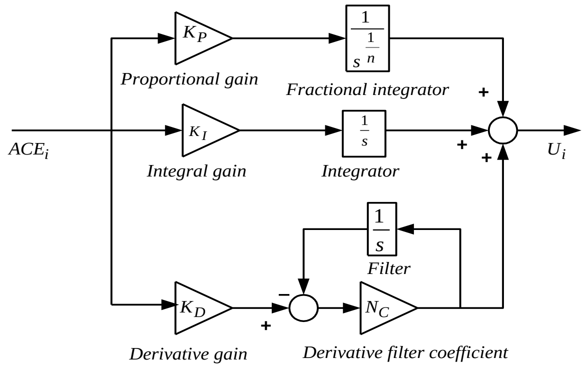

Fig. 2 Structure of TIDF controller

Optimal Gain Values of controllers

Controller Parameter	I	PI	PID	TIDF
K_{P1}	-	0.5769	-0.3066	-1.1854
K_{P2}	-	0.4926	0.1041	-0.0481
K_{P3}	-	0.2337	0.1169	-1.9420
K_{P4}	-	0.1537	-0.8664	-1.7440
K_{P5}	-	0.7182	0.1639	-1.9366
K_{I1}	-0.2373	-0.5306	-0.8499	-1.8982
K_{I2}	-0.1930	-1.1146	-0.3534	-1.4160
K_{I3}	-0.3670	-0.5169	-0.4162	-1.8751
K_{I4}	-0.2896	-0.0017	-0.6877	-1.8108
K_{I5}	-0.3113	-0.3506	-0.3279	-0.0834
K_{D1}	-	-	-0.2059	-0.9398
K_{D2}	-	-	-0.5610	-0.2893
K_{D3}	-	-	-0.5184	-0.7654
K_{D4}	-	-	-0.2272	-0.4688
K_{D5}	-	-	-0.9330	-1.8173
n_1	-	-	-	3.7984
n_2	-	-	-	3.0920
n_3	-	-	-	8.0866
n_4	-	-	-	2.3770
n_5	-	-	-	3.6819
N_{C1}	-	-	-	487.7052
N_{C2}	-	-	-	141.738
N_{C3}	-	-	-	199.1410
N_{C4}	-	-	-	39.6777
N_{C5}	-	-	-	110.8881

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The ITAE objective function is expressed in equation (2).

$$J = ITAE = \int_{0}^{t_{sim}} \left(|\Delta F_i| + |\Delta P_{Tie-i-k}|\right) \cdot t \cdot dt \qquad (2)$$

In the equation given above, ΔF_i is the change in frequency of area i, $\Delta P_{Tie-i-k}$ is the change in tie line power between area i and area k; t_{sim} is the range of time for simulation.

Performance Index Values

Controller/ Performance Index		I	PI	PID	TIDF
ITAE		3.3770	1.2892	0.7297	0.1858
Settling Time	ΔF_1	41.70	15.42	13.63	5.81
	ΔF_2	55.89	17.39	13.52	6.65
	ΔF_3	31.08	22.98	13.40	5.94
	ΔF_4	21.84	17.55	13.46	5.94
	ΔF_5	23.09	14.24	13.53	6.11
	ΔP_{tie1}	35.26	19.83	15.42	8.85
	ΔP_{tie2}	25.36	15.34	7.13	5.40
	ΔP_{tie3}	27.07	12.47	2.39	1.05
	ΔP_{tie4}	15.42	10.55	11.23	2.37
	ΔP_{tie5}	14.42	9.76	1.67	1.59
Peak Overshoot	ΔF_1	0.0101	0.0089	0.0085	0.0076
	ΔF_2	0.0035	0.0038	0.0014	0.0011
	ΔF_3	0.0022	0.0034	0.0012	0.0008
	ΔF_4	0.0019	0.0033	0.0013	0.0008
	ΔF_5	0.0016	0.0034	0.0012	0.0007
	ΔP_{tie1}	0.0014	0.0013	0.0007	0.0004
	ΔP_{tie2}	0.0027	0.0025	0.0011	0.0010
	ΔP_{tie3}	0.0010	0.0011	0.0008	0.0006
	ΔP_{tie4}	0.0010	0.0011	0.0007	0.0006
	ΔP_{tie5}	0.0009	0.0011	0.0007	0.0005
Peak Undershoot	ΔF_1	-0.0156	-0.0165	-0.0131	-0.0114
	ΔF_2	-0.0063	-0.0060	-0.0028	-0.0025
	ΔF_3	-0.0039	-0.0047	-0.0024	-0.0019
	ΔF_4	-0.0040	-0.0049	-0.0025	-0.0020
	ΔF_5	-0.0042	-0.0055	-0.0022	-0.0015
	ΔP_{tie1}	-0.0164	-0.0187	-0.0124	-0.0101
	ΔP_{tie2}	-0.0021	-0.0014	-0.0004	-0.0007
	ΔP_{tie3}	-0.0006	-0.0004	-0.0001	-0.0001
	ΔP_{tie4}	-0.0003	-0.0005	-0.0002	-0.0002
	ΔP_{tie5}	-0.0002	-0.0004	-0.0001	-0.0001

The problem constraints are the parameter bounds of TIDF controller. Therefore, the design problem can be formulated as the following optimization problem.

Minimize J Subjected to

$$K_{P\min} \le K_P \le K_{P\max}\,,\ K_{I\min} \le K_I \le K_{I\max}\,,$$
$$K_{D\min} \le K_D \le K_{D\max}\,,\ n_{\min} \le n \le n_{\max}\,,$$
$$Nc_{\min} \le Nc \le Nc_{\max}$$

where J is the objective function. In the present study, the minimum and maximum values of K_P, K_I and K_D are chosen as -2.0 and 1.0 respectively. The range for tilt component n is selected as 2 and 10.The range for filter coefficient N_C is selected as 10 and 500 [5].

Results and Discussion

The system model is simulated by considering 1% step load disturbance in area-1.The detailed description of DE algorithm is given in [7].In the study presented above, a population size of N_p =50, generation number G=100, scaling factor FC=0.8, crossover constant CR=0.8 have been used [7].The optimization is run for 30 times and the best final solution among 30 runs is chosen for controlled parameters, which are shown in Table I. The performance indices in terms of ITAE value, peak overshoot, peak undershoot and settling times (2%) in frequency and tie-line power deviations are presented in Table II. From Table II, it is observed that the ITAE value of I, PI, PID controllers are greater than proposed TIDF controller. From the Figs. 3-6 it can be observed that the dynamic performance of TIDF controller is better than classical controllers.

Conclusion

In this paper, a five-area reheat thermal system model with Generation Rate constraint (GRC) and Governor Dead Band (GDB) non-linearity is considered and differential evolution Algorithm (DE) is used to optimize the gains of classical controllers i.e. Integral(I), Proportional-Integral(PI), Proportional-Integral-Derivative (PID) and the proposed Tilt –Integral–Derivative controller with derivative Filter(TIDF) for Load Frequency Control (LFC) problem.From the

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simulation results, it is observed that the dynamic performance of proposed controller is better than classical controllers.

Appendix

Nominal Parameters of the Power System [2]

F=60 Hz;B_1= B_2 = B_3= B_4 B_5= 0.425 p.u. MW/Hz; R_1 = R_2 = R_3 = R_4 = R_5 =2.4 Hz/p.u MW.; T_{g1} = T_{g2} = T_{g3} = T_{g4} = T_{g5} = 0.08 s, T_{t1} = T_{t2} = T_{t3} = T_{t4} = T_{t5}=0.3 s ;T_{r1} = T_{r2} = T_{r3} = T_{r4} = T_{r5} =10 s;K_{r1} = K_{r2} = K_{r3} = K_{r4} = K_{r5} = 0.5; K_{P1} = K_{P2}= K_{P3} = K_{P4} = K_{P5} = 120 Hz/p.u. MW; T_{P1}= T_{P2} = T_{P3}= T_{P4} = T_{P5} =20 s; T_{12} = T_{13} = T_{14} = T_{15} = T_{23} = T_{24} = T_{25} = T_{34} = T_{35} = T_{45} =0.5438

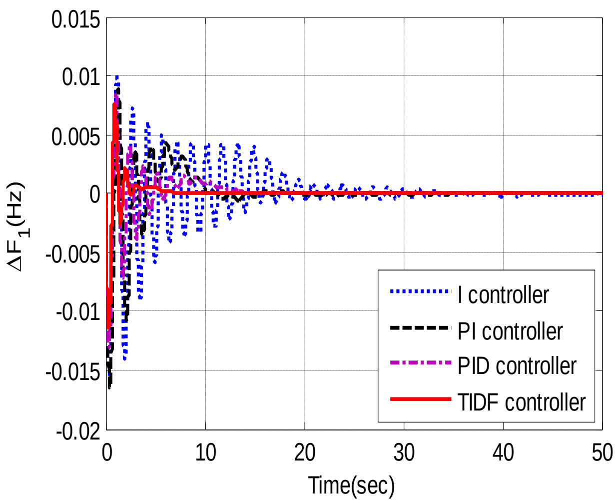

Fig.3 Change in frequency in area-1 for 1% step load disturbance

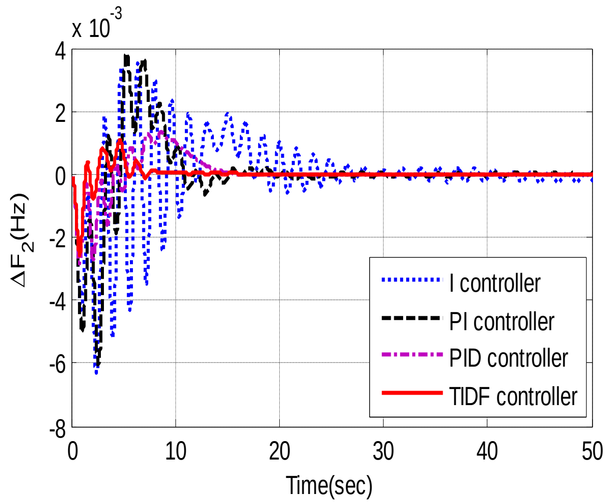

Fig.4 Change in frequency in area-2 for 1% step load disturbance

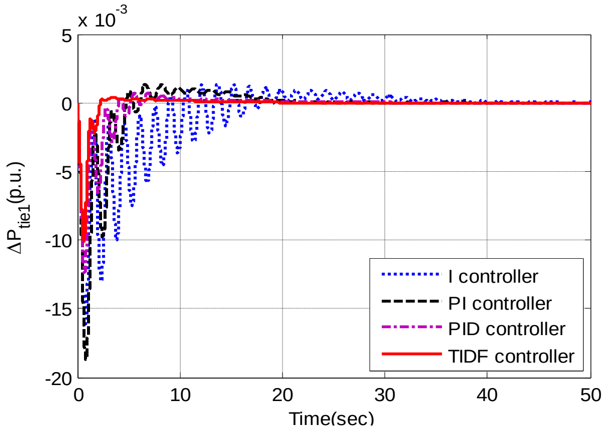

Fig.5 Change in tie-line power of area-1 for 1% step load disturbance

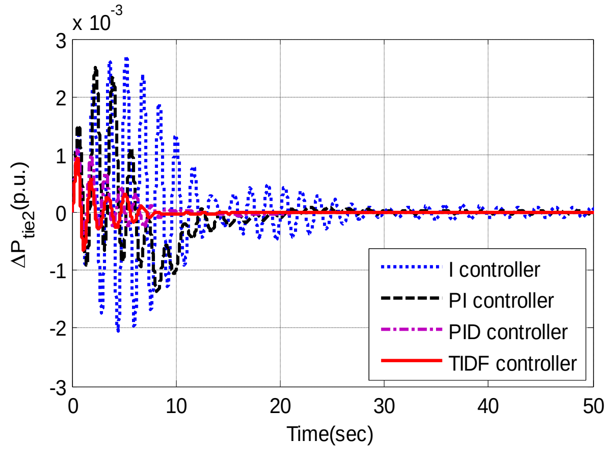

Fig.6 Change in tie-line power of area-2 for 1% step load disturbance

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