Load Frequency Control for Non-Reheat Power Systems Tuned by Heuristic Optimization Techniques

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Abstract- *In this paper, a robust Tabu Search Proportional Integral Derivative (TSPID) controller is presented for Load Frequency Control (LFC) problem of multi area interconnected power systems. LFC is to regulate the frequency deviation of an individual and interconnected power system within the prescheduled limits. The design of objective function is done based on performance index that consider the entire closed loop response. The performance criteria considered in the control design are the Integral Time Absolute Error (ITAE). The robustness of the TS-PID controller is shown by tuning it with ITAE for various load Perturbations. The results show that the dynamic performance of TS-PID controller is better than GA-PID controller for a four area power system.*

Keywords- ITAE, Load frequency control, Multi area power system, PID controller, Tabu search

I. INTRODUCTION

Power system control is the most significant task for its secure operation because of increase in system size, complexity and dynamic nature of the loads. Load frequency controller is a major component in power system to achieve stable system operation and also to provide reliable power supply. For multi area interconnected power system, optimal controller is the only possibility instead of fixed controller for solving the LFC problem. The main aim of LFC is to keep the individual system frequency and an inter area tie line power as near to the predetermined values as recommended. A wide variety of different control techniques have been proposed in the literature for LFC. A PI controller design on a three area interconnected power plant is presented in [1], where the controller parameters are tuned using trial and error approach. LFC for a two-area interconnected system taking into account the nonlinearity and stochastic nature of the load and using an optimal linear strategy aided by stability analysis has been discussed in [2]. In [3], a method is suggested to determine the optimum gain value of PID controller for LFC in two area interconnected power system using Particle Swarm Optimization (PSO) and the same analysis is extended to multi area power system in [4]. An adaptive controller with self adjusting gain setting has been proposed for LFC in [5]. In [6, 7], a centralized method is introduced for multi area power system in order to implement optimization techniques. An adaptive decentralized control technique has been applied for solving LFC in multi area power systems [8]. In [9, 10],

the design of robust controller have been used for resolving LFC problem. A robust PID load frequency controller for multiarea power systems based on maximum peak resonance specification is presented in [11]. The Artificial Neural Network has been successfully applied to the LFC problem in [12]. Genetic Algorithms (GA) [13], Fuzzy Logic [14] and optimal control [15] to solve LFC problem have been reported.

In this paper, the design of TSPID controller for solving the LFC in multi area interconnected power system. The proposed TSPID controller provides robust and reliable performance of the system. In this work, an ITAE objective is used to tune the TSPID controller. The results reveal that ITAE of TS-PID controller has better dynamic response for various load perturbations than GA-PID.

II. MODELING OF FOUR AREA POWER SYSTEM

A. Four Area System Model

A four area power system is considered as a test model and is connected by six tie lines as illustrated in Fig. 1.

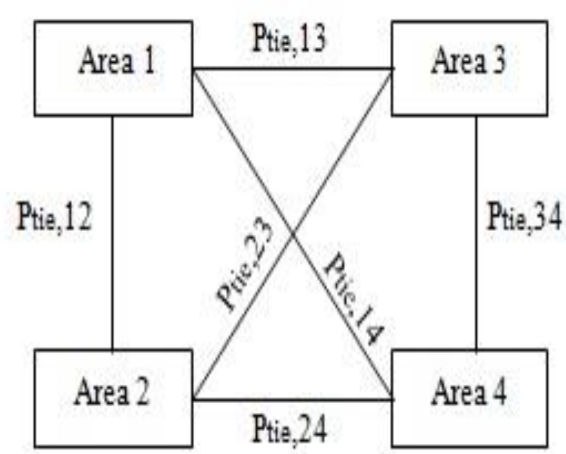

Fig. 1. Four interconnected areas with six tie-lines

Each area has a turbine, governor and generator. The block diagram of single area system with ITAE based design is shown in Fig. 2.

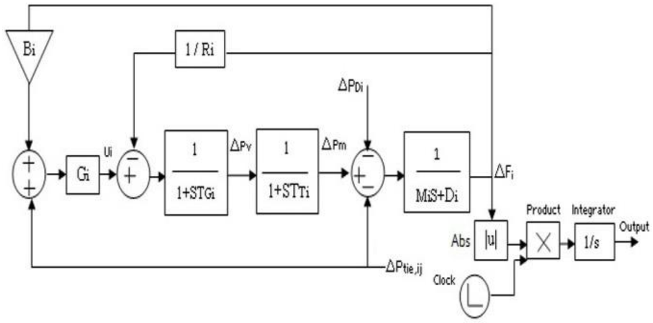

Fig. 2. Block diagram of single area power system using ITAE design

The parameters for the model in Fig. 2 are defined as follow,

ΔP_V : Change in steam valve position

ΔP_m : Change in mechanical power

ΔP_{Di} : Change in load of ith area

ΔF_i : Frequency deviation of ith area

R_i : Regulation of governor of ith area

u_i : Control input of ith area

G_i : Controller of ith area

T_{Ti} : Turbine time constant of ith area

T_{Gi} : Governor time constant of ith area

B_i : Tie line frequency bias factor of ith area

$M_i = 2H$: Inertia constant of ith area

D_i : Damping constant of ith area

Abs: Absolute value of the input

ACE: Area Control Error

$\Delta P_{tie,ij}$: Inter area tie line power from ith area to jth area

where, i=1,2,3,4 and j=1,2,3,4 $i \neq j$

The typical values of the four area power system parameters and tie-line parameters are shown in Appendix A. The four area power system interconnected with tie line. Therefore, the basic tie line model is shown in Fig. 4.

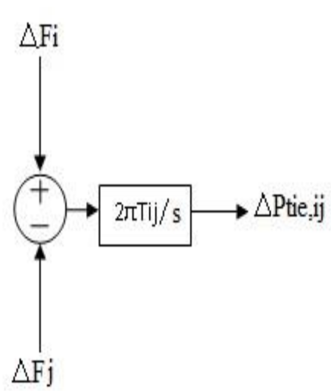

Fig. 4. Block diagram of tie line model

The inter area tie line power ($\Delta P_{tie,ij}$) interchange is given by

$$\Delta P_{tie,ij} = \frac{2\pi T_{ij}}{S}(\Delta F_i - \Delta F_j) \quad (1)$$

where, Tie line of i to j, $T_{ij} = 377 \times \frac{1}{X_{tie,ij}}$

In the four area power system, each block is represented interms of state variables. The state space representation of a four area inter-connected power system in equation (2),

$$\begin{aligned} \dot{X} &= Ax + Bu + \Gamma d \\ Y &= Cx + Du \end{aligned} \quad (2)$$

A constant magnitude 'Γd'=0 for a step load change. However, in the feedback control system, the matrix D is assumed to be zero. Hence the system state space representation is rewritten as

$$\begin{aligned} \dot{X} &= Ax + Bu \\ Y &= Cx \end{aligned} \quad (3)$$

where,

$u = [u_1 \; u_2 \; u_3 \; u_4 \; \Delta P_{D1} \; \Delta P_{D2} \; \Delta P_{D3} \; \Delta P_{D4}]$

$Y = [\Delta F_1 \; \Delta F_2 \; \Delta F_3 \; \Delta F_4 \; \Delta P_{tie,12} \; \Delta P_{tie,13} \; \Delta P_{tie,14} \; \Delta P_{tie,23} \; \Delta P_{tie,24} \; \Delta P_{tie,34}]$

$x = [\Delta F_1 \; \Delta P_{m1} \; \Delta P_{v1} \; \Delta F_2 \; \Delta P_{m2} \; \Delta P_{v2} \; \Delta F_3 \; \Delta P_{m3} \; \Delta P_{v4} \; \Delta F_4 \; \Delta P_{m4} \; \Delta P_{v4} \; \Delta P_{tie,12} \; \Delta P_{tie,13} \; \Delta P_{tie,14} \; \Delta P_{tie,23} \; \Delta P_{tie,24} \; \Delta P_{tie,34}]$ The

values of 18x4 control matrix (B) ,18x18 system matrix (A), and 4x18 output matrix (C) are given in the equations (4), (5) and (6),

$$B = \begin{bmatrix} 0 & 0 & \frac{1}{M_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_4} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A = \begin{bmatrix}
\frac{-1}{T_{G1}} & 0 & \frac{-1}{R_1 T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{T_{T1}} & \frac{-1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{M_1} & \frac{-1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & \frac{-1}{R_2 T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{T_{T2}} & \frac{-1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{M_2} & \frac{-D_2}{M_2} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} & 0 & 0 & \frac{-1}{M_2} & \frac{-1}{M_2} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G3}} & 0 & \frac{-1}{R_3 T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T3}} & \frac{-1}{T_{T3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_3} & \frac{-D_3}{M_3} & 0 & 0 & 0 & 0 & \frac{1}{M_3} & 0 & \frac{1}{M_3} & 0 & \frac{-1}{M_3} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G4}} & 0 & \frac{-1}{R_4 T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T4}} & \frac{-1}{T_{T4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_4} & \frac{-D_4}{M_4} & 0 & 0 & \frac{1}{M_4} & 0 & \frac{1}{M_4} & \frac{1}{M_4} \\
0 & 0 & T_{12} & 0 & 0 & -T_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{13} & 0 & 0 & 0 & 0 & 0 & -T_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{14} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{23} & 0 & 0 & -T_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{24} & 0 & 0 & 0 & 0 & 0 & -T_{24} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{34} & 0 & 0 & -T_{34} & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$C = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

III. DESIGN METHODOLOGY

The parameters of the TSPID controller are tuned by metaheuristic Tabu Search (TS) algorithm. In this section, a brief description about the TS algorithm and design of TS-PID controller are given.

A. Tabu Search (TS)

Tabu search (TS) is a metaheuristic strategy for solving combinatorial optimization problems. Tabu search was introduced by Glover in 1986, as a technique to overcome local optimality. The underlying idea is to forbid some search directions in the present iteration in order to avoid cycling and to be able to escape from a local optimal point. This strategy can make use of any local improvement technique [16, 17]. Furthermore, TS has an Adaptive Memory Programming (AMP) and a Tabu List (TL) that can be superimposed on many other methods. The major theme behind TS is to incorporate flexible memory (short-term and/or long-term) functions into the search procedure. Hence, the search process can avoid a move that reinstate past solutions and prevents being trapped at locally optimized solutions. This method is distinct from the Simulated Annealing (SA) and GA methods. SA and GA have low memory capability and are probabilistic random search methods, while TS takes advantage of the history of the search process and embeds it into the search process.

B. Algorithm for optimizing the TSPID controller

Step 1: Initialize the TS parameters.
Step 2: Randomly generate the Kp, Ki, Kd values.
Step 3: Evaluate the fitness function.
Step 4: Update the local and global solutions.
Step 5: Choose the best solution based on TL and AMP.
Step 6: If maximum iteration is reached go to step 7, else go to step 3.
Step 7: Save the Kp, Ki, Kd values.

C. Design of proposed TSPID controller with multi objectives

In this analysis, the TSPID controller is used to solve LFC problem in multi area power system. The structure of the PID controllers is defined in equation (7),

$$G_i(s) = K_p + \frac{K_i}{s} + K_d s \tag{7}$$

The main objective of the controller design is to minimize the performance index. For this reason, the ITAE is chosen as objective functions (J), which are defined in equations (8),

$$J = ITAE = \int t\,|e(t)|\,dt \tag{8}$$

where, J is the objective function.

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

Subject to

$$\begin{aligned} K_p^{\min} &\le K_p \le K_p^{\max} \\ K_i^{\min} &\le K_i \le K_i^{\max} \\ K_d^{\min} &\le K_d \le K_d^{\max} \end{aligned} \tag{9}$$

The J for four area power system is defined as

$$J = ITAE = \int_0^t t\left|\Delta f_1\right| dt + \int_0^t t\left|\Delta f_2\right| dt + \int_0^t t\left|\Delta f_3\right| dt + \int_0^t t\left|\Delta f_4\right| dt \qquad (10)$$

The control signal for the TSPID controller has been designed by using the following equations,

$$u_i(s) = -G_i(s) * \frac{1}{ITAE} \qquad (11)$$

The control inputs are described in equation (12). They are chosen as a linear combination of feedback from all the eighteen system states that are shows in equation (2).

$$\begin{aligned} u_1 &= -G_1 \int ACE_1 dt \\ u_2 &= -G_2 \int ACE_2 dt \\ u_3 &= -G_3 \int ACE_3 dt \\ u_4 &= -G_4 \int ACE_4 dt \end{aligned} \qquad (12)$$

for area 1, $ACE_1 = \Delta P_{tie,12} + \Delta P_{tie,13} + \Delta P_{tie,14} + b_1 \Delta f_1$

for area 2, $ACE_2 = \Delta P_{tie,21} + \Delta P_{tie,23} + \Delta P_{tie,24} + b_2 \Delta f_2$

for area 3, $ACE_3 = \Delta P_{tie,31} + \Delta P_{tie,32} + \Delta P_{tie,34} + b_3 \Delta f_3$

for area 4, $ACE_4 = \Delta P_{tie,41} + \Delta P_{tie,42} + \Delta P_{tie,43} + b_4 \Delta f_4$

IV. RESULT AND DISCUSSION

The proposed TSPID controller is applied to the dynamic model of four area interconnected power systems. In order to analyze the robustness of proposed controller, three operating cases are considered as follow

a) Normal load perturbation (power system parameters are having nominal value)

b) Heavy load perturbation (power system parameters are having 15% deviation from their nominal value)

c) Very heavy load perturbation (30% deviation from their nominal value)

To highlight the robustness of the proposed controller, ITAE is computed by the step change in ΔPL at three operating cases. The optimization is repeated 100 times for normal, heavy and very heavy operating cases using TS algorithm. The best final solution of Kp, Ki, and Kd are chosen after 100th iteration. The optimum gain values for TS-PID and GA-PID are tabulated in Table I and II.

TABLE I
Optimum gain value for TS-PID controller

Area	**K_p**	**K_i**	**K_d**
1	4.8379	8.0575	0.4568
2	4.4807	0.9821	7.0159
3	1.1243	1.3472	1.5192
4	1.4830	0.3231	1.0806

TABLE II
Optimum gain value for GA-PID controller

Area	**K_p**	**K_i**	**K_d**
1	9.4463	7.3394	4.5192
2	3.8649	0.7838	5.3169
3	1.1755	0.3192	3.5054
4	0.1643	0.4157	0.4483

The overshoot and settling time for TS-PID controller and GA-PID controller for four area power systems are computed in Table III.

TABLE III
Comparison of settling tine and overshoot for four area power system

Area	**Settling time in sec**		**Overshoot in p.u**	
	TS-PID	***GA-PID***	***TS-PID***	***GA-PID***
1	2.5	4.1	0.00461	0.02115
2	1.95	2.25	0.00187	0.00419
3	2	4	0.00189	0.00390
4	2.8	4.5	0.00178	0.00473

As a comparative analysis explained the Proposed TS-PID controller gives faster settling time and less overshoot compared to the GA-PID controller. For example the area 1 settling time of TS-PID (2.5) has 39.05% lesser than GA-PID (4.1) controller and also the overshoot for TS-PID (0.00461) in area1 has 78.20% lesser than GA-PID (0.02115) controller. To highlight the robustness of the proposed method, ITAE is computed by following the step change in ΔPL at all operating conditions (N, H and VH) and then the results are shown in Tables IV, which is clear from that the performance index for the TS-PID controller in the nominal operating condition is 82 % less than the performance index for the GA-PID controller. In addition, for the heavy and very heavy operating conditions the TS-PID controller shows better performance index.

TABLE IV
5% Step increase in demand of the 1st area (ΔP_{D1})

Disturbances/ controller	Normal 0% disturbance	Heavy 15% disturbance	Very heavy 30% disturbance
TS-PID	0.00170	0.00312	0.00492
GA-PID	0.01210	0.01410	0.01876

Simulation result for area 1 with normal, heavy and very heavy operating conditions are shown in figure 4, 5 and 6.

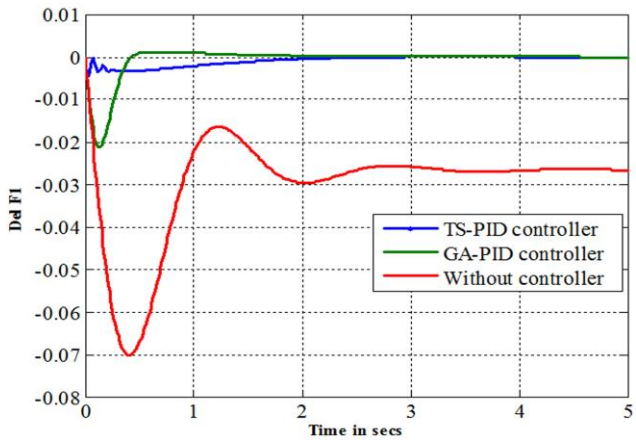

Fig. 4. Frequency deviation in area 1 at normal perturbation

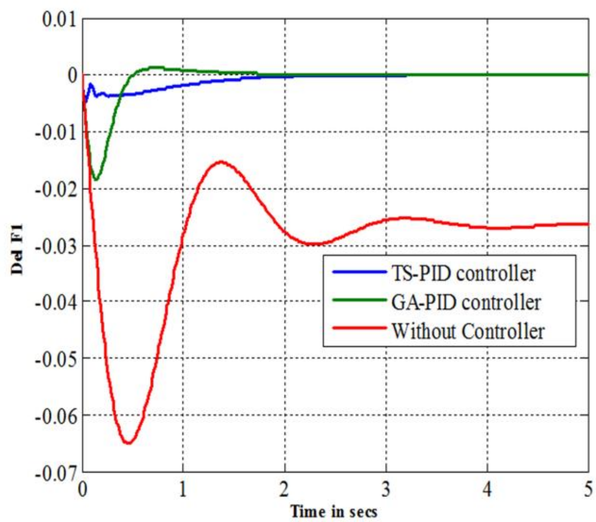

Fig. 5. Frequency deviation in area 1 at heavy perturbation

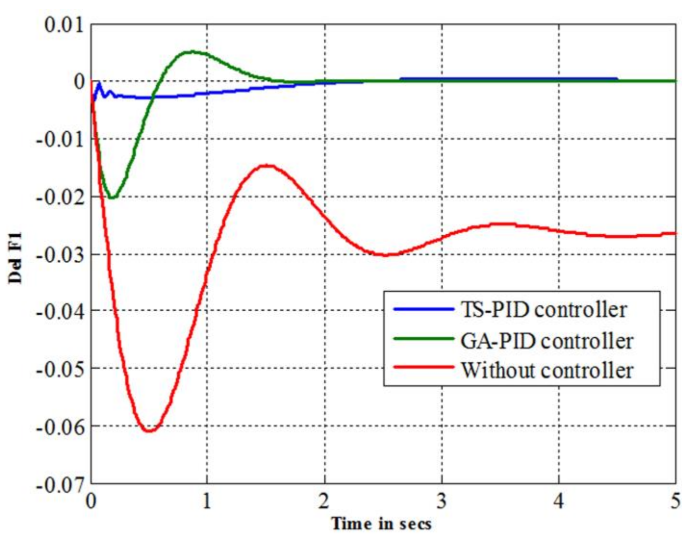

Fig. 6. Frequency deviation in area 1 at very heavy perturbation conclusion

V. CONCLUSION

In this paper a PID controller which is tuned by the TS has been successfully suggested for the MA- LFC problem. The recommended algorithm was applied to a classic four-area electric power system including system parametric uncertainties as well as different loads condition. Simulation results verified that the PID controllers which are tuned using TS capable to warranty the robustness of stability and operation under a wide range of uncertainties and various states of system and load. Moreover, the simulation results confirmed that the TS-PID controller is fairly robust to changes in the parameters of the systems and it shows much better operation in compare with the TS-PID type controller under three main operating conditions. The PID controller is widely used in practical systems; therefore the paper’s results can be applied for the practical MA- LFC systems.

APPENDIX A

TABLE V
System parameters for four area power system

System parameters	**Area 1**	**Area 2**	**Area 3**	**Area 4**
T_T	0.035	0.025	0.044	0.033
T_G	0.08	0.091	0.072	0.085
M	0.1667	0.1552	0.178	0.1500
D	0.0083	0.009	0.0074	0.0094
R	2.4	2.1	2.9	1.995
B	0.401	0.300	0.480	0.3908

TABLE VI
Tie-Line parameters for four area power system

Four area tie-line parameters	$P_{tie.12}$	$P_{tie.13}$	$P_{tie.14}$	$P_{tie.23}$	$P_{tie.24}$	$P_{tie.34}$
	0.425	0.500	0.400	0.455	0.523	0.600

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