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Tuning of PID Controller for Multi Area Load Frequency Control by Using Imperialist Competitive Algorithm

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ABSTRACT

In this paper a new evolutionary computing method based on imperialist competitive algorithm (ICA) is used for tuning the parameters of a PID controller which is applied in a load frequency control system (LFC) in a multi area electric power system. If a large power imbalance is suddenly happened in a multi area power electric system, generation units and also consumer sides will be affected by the distortion in the energy balance between both two sides. This imbalance is initially handled by the kinetic energy of the system rotating components such as turbines, generators and motors, but, eventually, the frequency will change. Therefore, Load Frequency Control (LFC) is considered as one of the most challenging issues in power system control and operation. PID type controllers are conventional solutions for LFC. The parameters of the PID controllers have been tuned traditionally. In this paper, a PID controller is applied for the LFC problem and then its parameters are tuned by using Imperialist Competitive Algorithm (ICA) method. To illustrate the application of the method, a multi area network with some uncertainties is provided. Finally the results of the ICA- PID controller are compared with the ones of GA optimized controllers. The simulation results show the success and the validity of the ICA-PID controller in compare with the GA - PID controller.

KEY WORDS: Multi Area Electric Power System, Load Frequency Control, Genetic Algorithms, Imperialist Competitive Algorithm, PID Controller.

1. INTRODUCTION

In the large scale electric power systems with interconnected areas, Load Frequency Control (LFC) plays an important role. The LFC is aimed to maintain the system frequency of each area and the inter-area tie power within tolerable limits to deal with the fluctuation of load demands and system disturbances. These important functions are delegated to LFC due to the fact that a well-designed power system should keep voltage and frequency in scheduled range while providing an acceptable level of power quality. A wide variety of different advanced control methods have already been proposed in the literature for LFC. Zribi et al. [1] the adaptive decentralized control system has been applied to deal with the LFC challenge in multi-area power systems. Moreover, the capabilities of the robust control methods have been used for resolving load frequency control problems in [2, 3]. The applications of artificial intelligent (AI) such as artificial neural network, genetic algorithms, Fuzzy Logic and optimal control to LFC have been reported in [4-6]. These methods are aimed to improve the performance; however, these methods need to have information on the system states or an online identifier which works efficiently, thus they may be difficult to apply in practice [7].

Meanwhile, PID controllers for LFC were studied because of their ease of use. References [8] and [9] proposed fuzzy PI controllers for LFC of power systems; [10] suggested a method to determine the parameters of a PID controller for LFC in a single area power system by using particle swarm optimization (PSO) and the method is extended to multi area power system network case [11]. It is shown that the obtained PID parameters need to be modified to achieve optimum and desired performance [7]. However, the main reason for such a modification is not proven yet.

In this paper, ICA is used to tune the parameters of a PID controller for the LFC system in a multi area electric power system network. Integral of the Time multiplied Absolute value of the Error (ITAE) is chosen as the performance index.

The controller designed by ICA is compared with one of the GA method. The simulation results showed that the method, which has been proposed in this paper for designing a PID controller in a multi-area power system, has a better convergence rate than GA one. Furthermore, the ICA-PID controller shows robust control performance in deal with system uncertainties and also under different operating conditions.

The remainder of the paper is organized as follows. The system under study and its steady state parameters are presented in Section 2. The design methodology for solving the LFC problem is developed in

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Section 3 and in Section 4, the PID controller tuning by using ICA is presented. Finally the results and discussions are discussed in Section 5.

2. SYSTEM MODEL:

In this study, the test system is a four-area electric power system which is shown in Fig.1. Each area has its own block diagram which is depicted in Fig. 2 [12].

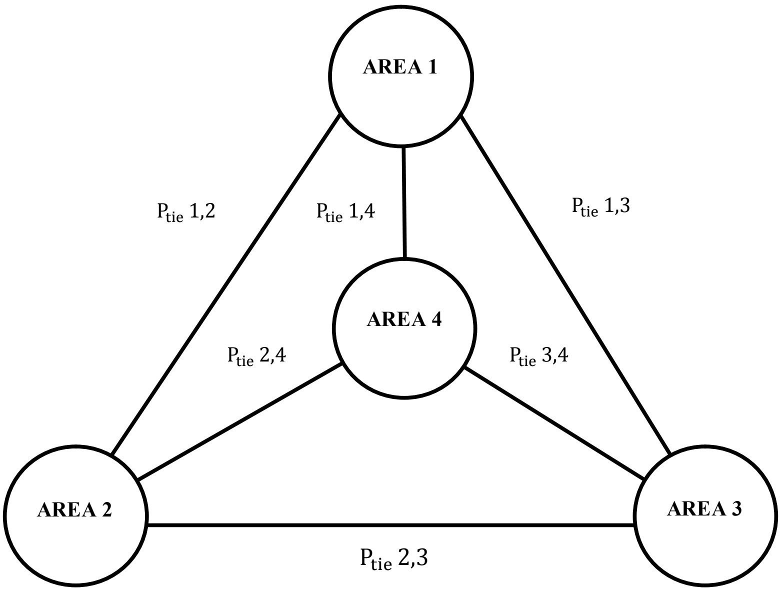


Fig. 1. Four-area electric power system with its interconnected [12].

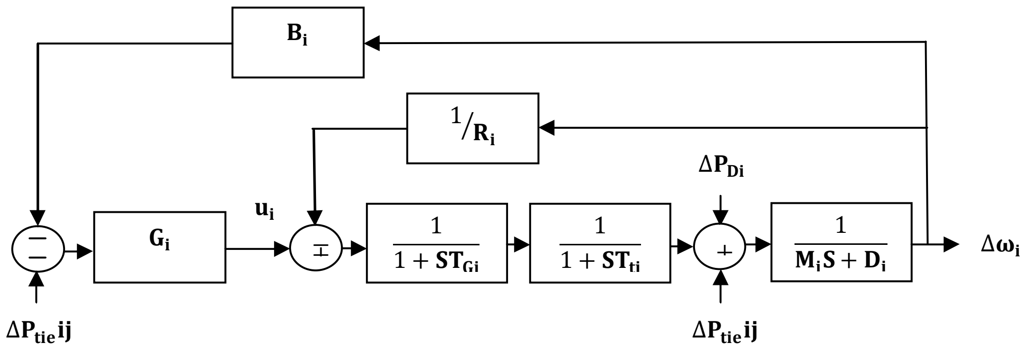


Fig. 2. Block Diagram for one area of system (i^{th} area) [12].

The parameters for the model which is shown in Fig. 2 are defined as follow:

Δ: Deviation from nominal value
$M_i = 2H$: Constant of inertia of i^{th} area
D_i : Damping constant of i^{th} area
R_i : Gain of speed drop feedback loop of i^{th} area
T_{ti}: Turbine Time Constant of i^{th} area
T_{Gi}: Governor Time constant of i^{th} area
G_i: Controller of i^{th} area
P_{Di} : Load change of i^{th} area
u_i: Reference Load of i^{th} area
$B_i = (1/R_i) + D_i$: Frequency bias factor of i^{th} area
$P_{tie}ij$: Inter area tie power interchange from i^{th} area to j^{th} area
where: $i = 1,2,3,4$ $j = 1, 2, 3, 4$ and $i \neq j$

The inter- area tie power interchange is given by [12]:

$$\Delta P_{tie} ij = (\Delta\omega_i - \Delta\omega_j) \times \left({T_{ij}}/{S}\right) \quad (1)$$

where:
$T_{ij} = 377 \times (1 \times X_{tie} ij)$ (for a 60HZ system)
$X_{tie} ij$: Impedance of the transmission line between i and j areas.
The $\Delta P_{tie} ij$ and its parts is illustrated in Fig. 3 [12].

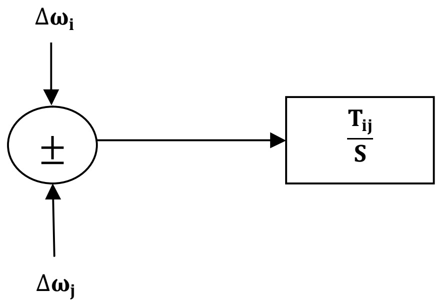


Fig. 3. Block diagram of tie power ($P_{tie} ij$) [12].

Figure 2 illustrates the block diagram of each area (i^{th} area) and Figure 3 shows how two areas are connected to each other.
The state space representation of a four-area interconnected power system is [12]:

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX \end{cases} \quad (2)$$

where:

$U = [\ \Delta P_{D1} \quad \Delta P_{D2} \quad \Delta P_{D3} \quad \Delta P_{D4} \quad u_1 \quad u_2 \quad u_3 \quad u_4\ ]$
$Y = [\ \Delta\omega_1 \quad \Delta\omega_2 \quad \Delta\omega_3 \quad \Delta\omega_4 \quad \Delta P_{ti} 1,2 \quad \Delta P_{ti} 1,3 \quad \Delta P_{ti} 1,4 \quad \Delta P_{ti} 2,3 \quad \Delta P_{ti} 2,4 \quad \Delta P_{ti}\ 3,4\ ]$
$X = [\ \Delta P_{G1} \quad \Delta P_{T1} \quad \Delta\omega_1 \quad \Delta P_{G2} \quad \Delta P_{T2} \quad \Delta\omega_2 \quad \Delta P_{G3} \quad \Delta P_{T3} \quad \Delta\omega_3 \quad \Delta P_{G4} \quad \Delta P_{T4} \quad \Delta\omega_4$
$\Delta P_{ti} 1,2 \quad \Delta P_{ti} 1,3 \quad \Delta P_{ti} 1,4 \quad \Delta P_{ti} 2,3 \quad \Delta P_{ti} 2,4 \quad \Delta P_{ti} 3,4\ ]$

The matrices A and B which are used in (2) and also the typical values of the system parameters for the nominal operating condition are given in the appendix.

3. DESIGN METHODOLOGY

As mentioned in the first section of this paper, a PID controller is considered for solving the LFC problem. ICA is used to obtain the Parameters of this PID controller. The structure of the PID controllers which is defined in (3) is formed by three parameters.

$$\text{PID Controller} = K_p + \frac{K_I}{S} + K_D S \quad (3)$$

K_p, K_I and K_D which are the PID controller parameters are obtained by using the ICA. In the next section a brief discussion about the Imperialist Competitive Algorithm (ICA) is presented.

3.1 Imperialist Competitive Algorithm (ICA)

Imperialist competitive algorithm (ICA) is one of the newest optimization algorithms which are formulated [13]. ICA, like the other evolutionary algorithms, starts with an initial population over the search space. The population consists of parts which are called "countries". This part is defined as an array. If the dimension of the optimisation problem is defined as N_{var}, a country is a $1\times N_{var}$ array. This array is given by [13]:

$$country = \left\lfloor y_1, y_2, y_3, y_4, \dots, y_{N\,\text{var}} \right\rfloor \quad (0)$$

where Y_i's are the variables which need to be optimized.

The cost of each country is computed and found by evaluation of the cost of function f which is unique for any problem. The cost of this function should be found at variables Y_i's, therefore the cost is defined by [13]:

$$Cost = f(country) = f(y_1, y_2, y_3, y_4, ..., y_{N\,\mathrm{var}}) \tag{5}$$

Power of each country originates from the cost of that country so that the least cost is equal to most power. The countries based on their costs are characterized as two main groups: imperialists and colonies. The imperialists are different from colonies and each other based on their own power and the number of their colonies. If they have more colonies it means that they are more powerful. The more power full imperialists are the solution of the optimization problem with the lowest cost. This concept is shown in Fig. 4.

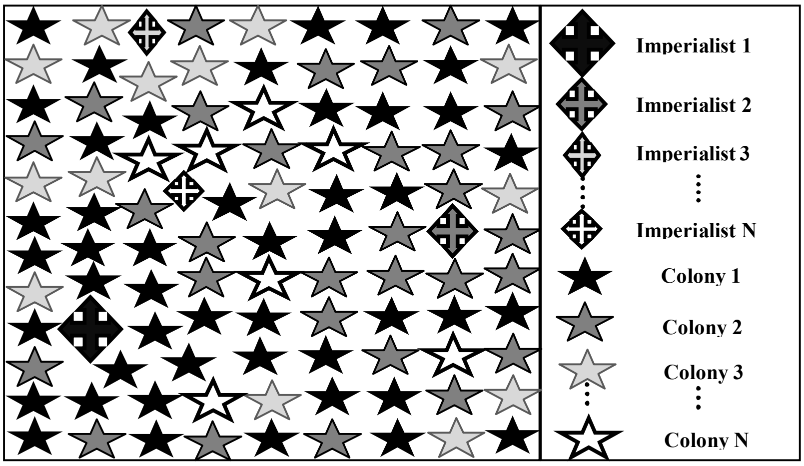


Fig.4. The Imperialists and Their colonies [13].

Competition among the Imperialists is the heart of this algorithm. During the competition, two main operations should be done. The first one which is an inherent function for all imperialists is that they try to seize more colonies to increase their power. In fact, during the competition process the weakest imperialists will be disintegrated and their colonies will be captivated by the more powerful imperialists. The second operation is called “Assimilation” which means that the colonies head toward their related imperialists. Sometimes assimilation causes an exchanging between a colony and its imperialist. It means that the colony has more power in compare to its imperialist and the colony is eligible to be promoted to the position of the imperialist. This function is illustrated in Fig. 5 [14].

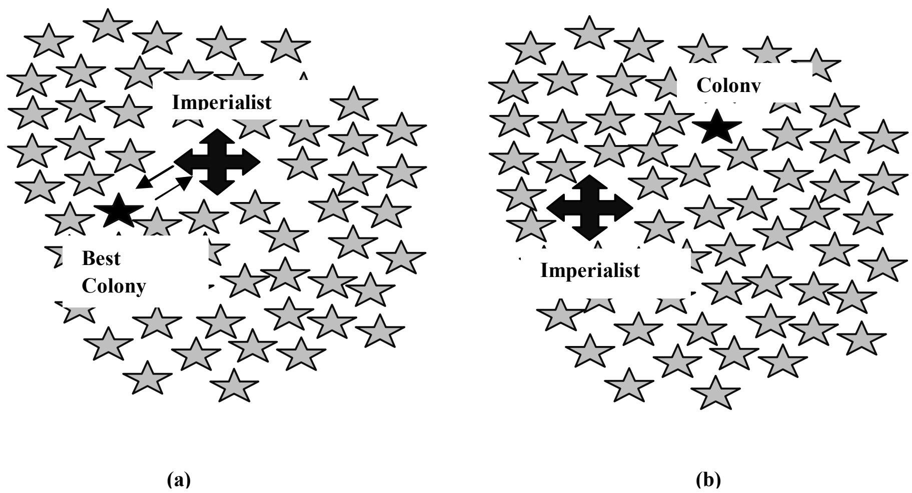


Fig.5. (a): Exchanging the positions of a colony and the imperialist

(b): The entire empire after position exchange [14].

The assimilating operation along with the imperialistic competition process and also disintegrating system will cause all the countries to converge to a position in which just one imperialist will stay on the scene. In this phase the imperialist and its colonies will have the same position. The pseudo code for this algorithm is shown in Fig.6 [13].

1) Initialize the empires by selecting some points on the function randomly.

2) Assimilating by heading the colonies toward their related imperialist.

3) Exchanging the position of the colony which has the lower cost in compare to its related imperialist.

4) Computing of the total cost of all empires which includes the power of both imperialist and its colonies

5) Do the Imperialist Competition by selecting the weakest colonies from the weakest empire and assign them to the empire which has the most chances to seize it.

6) Eliminating the weakest empires.

7) Checking the Number of the empires. If there is just one empire, discontinue, if not go to 2.

Fig.6. Pseudo code for the proposed algorithm [13].

4. PID CONTROLLER USING THE ICA:

In this section the PID controllers which have been proposed are tuned by using ICA. The PID controllers have three parameters which are symbolized by KP, KI and KD .There is one PID controller for each area hence there are four PID controllers in four areas electric power system and 12 parameters which are tuned. These parameters are obtained by using ICA. The system controllers which showed as Gi in Fig. 2 are replaced by PID controllers given in (3) and the optimal values of KP, KI and KD are obtained by using ICA. The first step in optimization methods is to determine a well-defined performance index for optimal search. In this study, the Integral of the Time multiplied Absolute value of the Error (ITAE) is considered as the performance index because of the fact that systems which have been designed using this criterion have small overshoots along with well-damped oscillations. ITAE is defined as (6) for this study:

$$\mathrm{ITAE} = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt \qquad (6)$$

where the “t” is the simulation time.

It is obvious that the PID controller with the lowest ITAE is better than the other PID controllers.
To obtain the optimal values for the parameters of the PID controllers, 10 % step change in ΔP_{D1} is assumed and then ITAE which is the performance index is minimized by using ICA. In order to obtain a better performance, the number of countries and also the number of iterations are chosen as 90, 100. It should be noted that the ICA is run several times and then optimal set of the parameters is selected. The optimal values of the PID controller parameters which are KP, KI and KD are acquired by using ICA and shown in the Table 1.

Table 1: Optimum values of KP, KI and KD for ICA-PID controllers

	K_P	K_I	K_D
First area PID parameters	13.7214	38.6817	1.0142
Second area PID parameters	3.1785	54.3672	2.8417
Third area PID parameters	1.7841	28.5471	1.0245
Fourth area PID parameters	12.5478	87.2354	1.2478

5. RESULTS AND DISCUSSION

In this section the proposed ICA-PID controller is applied to the system for LFC. In order to comparison of the proposed method and illustrate the effectiveness of the ICA-PID controller, another PID type controller which is tuned by the genetic algorithm is designed and applied to the system. The optimal value of the GA-PID controller parameters are obtained by using GA and shown in the Table 2.

Table 2: Optimum values of KP, KI and KD for GA-PID controllers

	K_P	K_I	K_D
First area PID parameters	3.7452	9.8721	0.3054
Second area PID parameters	5.8745	7.7521	1.4132
Third area PID parameters	5.3125	6.1448	1.3142
Fourth area PID parameters	5.6598	7.2457	2.3425

To study and analysis of the controller robustness and the system response to the uncertainties, three different operating conditions are assumed as follow:
i. Nominal or Normal operating condition
ii. Heavy or Serious operating condition (parameters are changing 20% from their normal values)
iii. Very heavy or hazardous operating condition (parameters are changing 40% from their normal values)

To highlight the robustness of the proposed method, ITAE is computed by following the step change in ΔP_D at all operating conditions (N, H and VH) and then the results are shown in Tables 3-4. It is clear from Table 3 that the performance index for the ICA-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 ICA-PID controller shows better performance index. In Table 4, it is mentioned that the ICA-PID controller, in the nominal operating condition, shows the minimum of the ITAE which is 0.0156; this value is 14.7 % less than the ITAE for the GA- PID controller in the same condition. Also, the ICA-PID controller has the better performance index in compare with the GA-PID controller in the heavy and very heavy operating conditions for 5% Step increase in demand of the1st area (ΔPD1) and 10% step increase in demand. In Table 3-4, it is obvious that the ICA-PID controller shows better performance in compare with GA-PID controller under all operating conditions.

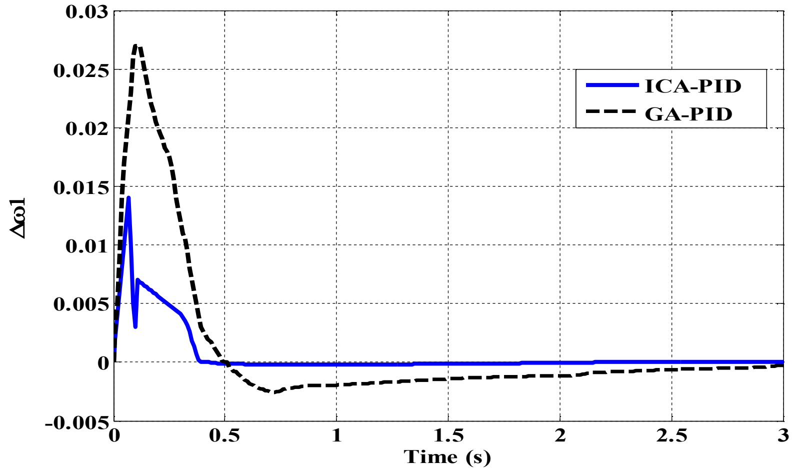
Table 3: 5% Step increase in demand of the 1st area (ΔPD1)

	$ITAE_{(GA-PID)}$	$ITAE_{(ICA-PID)}$
Nominal operating condition	0.011	0.0019
Heavy operating condition	0.0135	0.0038
Very heavy operating condition	0.0192	0.0057

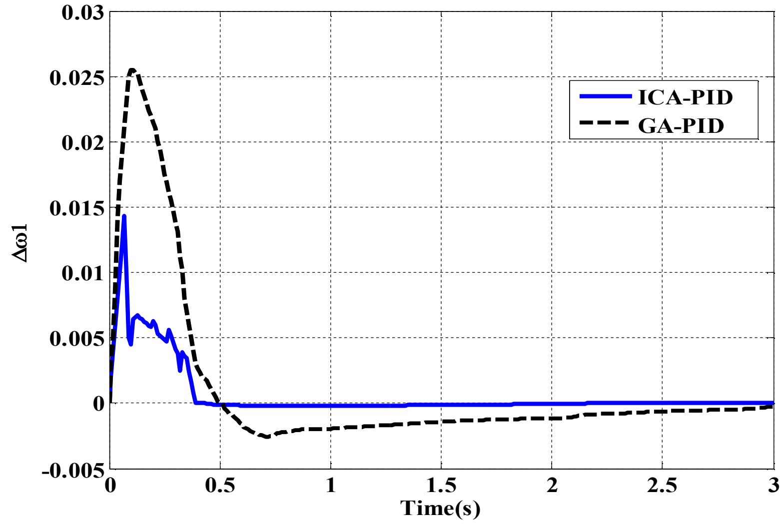
Table 4: 5% Step increase in demand of the1st area (ΔPD1) and 10% step increase in demand of 3rd area (ΔPD3)

	$ITAE_{(GA-PID)}$	$ITAE_{(ICA-PID)}$
Nominal operating condition	0.0183	0.0156
Heavy operating condition	0.0284	0.0193
Very heavy operating condition	0.0371	0.0236

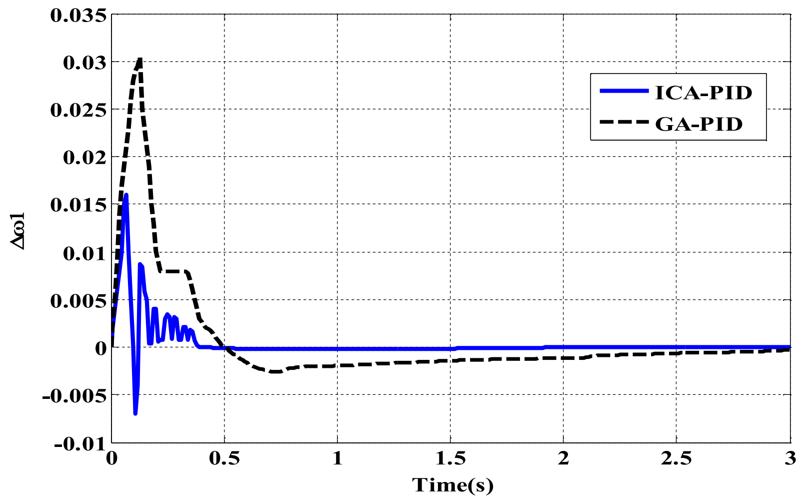
The $\Delta\omega_1$ is shown in “pu” in Fig.7 at normal, serious and hazardous operating conditions for 10 % step change in ΔP_{D1} which is the demand of first area. It is obvious that the ICA-PID controller has better performance in compare to the GA-PID controller under all operating conditions.



(a)



(b)



(c)

Fig. 7. Dynamic response Δω1 (pu) following step change in demand of first area (ΔPD1)
(a): Nominal (b): Heavy (c): Very heavy

6. CONCLUSION

In this paper a PID controller which is tuned by the ICA has been successfully suggested for the Load Frequency Control problem. The proposed algorithm was applied to a classic four-area electric power system including system parametric uncertainties as well as various loads condition. Simulation results verified that the PID controllers which are tuned using ICA capable to guarantee the robust stability and the robust performance under a wide range of uncertainties and various load conditions. Moreover, the simulation results confirmed that the ICA-PID controller is robust to changes in the system parameters and it has better performance in compare with the GA-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 LFC systems.

APPENDIX:

1st area parameters

TT1=0.035	TG1=0.08	M1=0.1667	R1=2.4
D1=0.0083	B1=0.401	T12=0.425	T13=0.500
T14= 0.400	T23= 0.455	T24= 0.523	T34=0.600
2nd area parameters			
TT2=0.025	TG2=0.091	M2=0.1552	R2=2.1
D2=0.009	B2=0.300	T12=0.425	T13=0.500
T14= 0.400	T23= 0.455	T24= 0.523	T34=0.600
3rd area parameters			
TT3=0.044	TG3=0.072	M3=0.178	R3=2.9
D3=0.0074	B3=0.480	T12=0.425	T13=0.500
T14= 0.400	T23= 0.455	T24= 0.523	T34=0.600
4th area parameters			
TT4=0.033	TG4=0.085	M4=0.1500	R4=1.995
D4=0.0094	B4=0.3908	T12=0.425	T13=0.500
T14= 0.400	T23= 0.455	T24= 0.523	T34=0.600

The matrices, A and B in (2), are written as follow:

B=

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

A=

$$\begin{vmatrix}
\frac{-1}{T_{G1}} & 0 & \frac{-1}{R_1 T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{1}{T_{T1}} & \frac{-1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{M_1} & \frac{-1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & \frac{-1}{R_2 T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{T_{T2}} & \frac{-1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{M_2} & \frac{-D_2}{M_2} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} & 0 & 0 & \frac{-1}{M_2} & \frac{-1}{M_2} & 0
\end{vmatrix}$$

$$\left|\begin{matrix}
0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G3}} & 0 & \frac{-1}{R_3T_{G3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T3}} & \frac{-1}{T_{T3}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_3} & \frac{-D_3}{M_3} & 0 & 0 & 0 & 0 & \frac{1}{M_3} & 0 & \frac{1}{M_3} & 0 & \frac{-1}{M_3} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G4}} & 0 & \frac{-1}{R_4T_{G4}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{T4}} & \frac{-1}{T_{T4}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_4} & \frac{-D_4}{M_4} & 0 & 0 & \frac{1}{M_4} & 0 & \frac{1}{M_4} & \frac{1}{M_4} \\
0 & 0 & T_{12} & 0 & 0 & -T_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{13} & 0 & 0 & 0 & 0 & 0 & -T_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & T_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{14} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{23} & 0 & 0 & -T_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{24} & 0 & 0 & 0 & 0 & 0 & -T_{24} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{34} & 0 & 0 & -T_{34} & 0 & 0 & 0 & 0 & 0 & 0
\end{matrix}\right|$$

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