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# A Novel Method for Designing PSS-AVR by Imperialist Competitive Algorithm (ICA) for three-area AGC System

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***Abstract** – Automatic Generation Control (AGC) is a very imperative issue in power system operation for providing electric power with high quality and reliability. In this paper, the three-area multi-units Automatic Generation Control (AGC) is studied. This paper presents the comparative performance analysis of the two specific varieties of controller devices for optimal transient performance of automatic generation control (AGC). Proportional Integral Derivative (PID) controller and Power System Stabilizer (PSS) with Automatic Voltage Regulator (AVR) have been designed for solving AGC problem. In this paper a new design method to determine optimal PID and PSS-AVR controller parameters by using imperialist competitive algorithm (ICA) has been proposed. Finally the results have been compared.*

***Keywords**: Automatic Generation Control (AGC), proportional Integral Derivative (PID), Automatic Voltage Regulator (AVR), imperialist competitive algorithm (ICA)*

ORIGINAL ARTICLE

| | |
|---|---|
| Tpi | power system time constants |
| Kpi | power system gains |
| Tws | water time constant |
| Tr | reheat time constant of thermal area |
| Tti | thermal turbine time constant |
| Tgi | governor time constant of thermal area |
| TR, Ti | time constants of the hydro governor |
| Ri | governor speed regulation of the units of two-areas (i = 1,2,3,4,5,6) |
| Pri | rated area capacities (aij = Pri/Prj) |
| Tij | frequency bias coefficients of two-areas, respectively |
| US | maximum undershoot |
| OS | maximum overshoot |
| ts | settling time |
| Kdeg, Kpeg, Kieg | electric governor derivative, proportional and integralgains, respectively |
| Kr | reheater gain |
| apfi | areai control error participation factor |
| Kdiesel | gain constant of the diesel generator |
| θ, x | random numbers with uniform distribution |
| d | distance between colony and the imperialist |
| β | a positive number less than 2 |
| $\Delta fi$ | Frequency fluctuations in the areai |
| $\Delta Pij$ | power fluctuations between areai and areaj |
| Td1, Td2, Td3, Td4 | time constants of the power system stabilizer block |
| Ks1, Ks2 | power system stabilizer gains |
| ACE | area control error |

## INTRODUCTION

In the power system, any unexpected load perturbation causes the deviation of tie-line exchanges and the frequency variations. So, AGC is very significant for supplying electric power with good quality [1]. AGC with load following is treated as an auxiliary service that is necessary for maintaining the electrical system reliability at a suitable level [2]. The main objectives of the AGC in multi-area power system are maintaining scheduled system frequency and tie line flow during normal operating condition and also during small perturbations [3].

In recent year many investigations in the area of isolated and interconnected power systems have been done. For example, Praghnesh Bhatt et al presented two specific varieties of controller Devices, thyristor-controlled phase shifter (TCPS) and capacitive energy storage (CES) for optimal transient performance of automatic generation control (AGC) [4]. An approach for the design of multiple Power System Stabilizers (PSS) for multi-area Automatic Generation Control (AGC) system has been proposed by Raseswari Pradhan and Sidhartha Panda [5]. J. Nanda presented automatic generation control (AGC) of interconnected two equal area thermal system, two equal area hydrothermal System and five unequal area thermal system [6]. Weihua Luo and Yibin Shi proposed

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Automatic Generation Control Strategies under CPS Based on Particle Swarm Optimization Algorithm [7].
This paper presents the comparative performance analysis of the two specific varieties of controller devices for optimal transient performance of automatic generation control (AGC). In this paper Proportional Integral Derivative (PID) controller, and Automatic Voltage Regulator (AVR) equipped by Power System Stabilizer (PSS) have been designed for solving AGC problem. Imperialist competitive algorithm (ICA) has been used for tuning the parameters of PID and PSS-AVR controllers. Finally the results of the two controllers are compared.

## DESCRIPTION OF THE AGC SYSTEM

The system investigated for AGC which is consisted of interconnected three-areas is shown in Fig. 1.

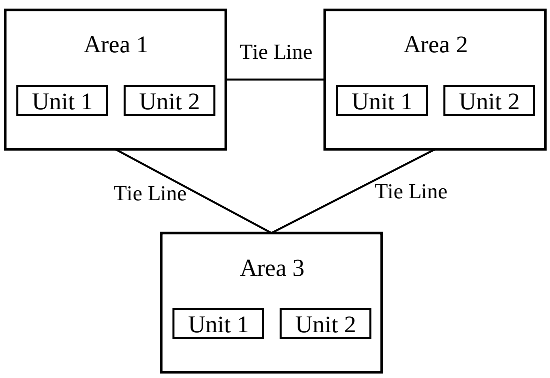


**Fig. 1** Three-area generalized AGC block diagram.

Area 1 has two thermal units. Areas 2 and 3 have two hydro and diesel units. The characteristics of hydro turbine differ from steam turbine in many ways. The typical value of permissible rate of generation for hydro plant is much higher (a typical value of generation rate constraints (GRC) being 270%/min for raising generation and 360%/min for lowering generation), as compared to that for reheat type thermal units having GRC of the order of 3%/min [8].
The detailed transfer function models of speed governors and thermal-reheat turbines are described and developed in the IEEE Committee Report on Dynamic Models for steam and hydro turbines in Power System Studies [9]. The transfer function model of diesel generator is given in [10]. Figures 2 to 5 show steam, Hydro and diesel turbines that have been used in system.

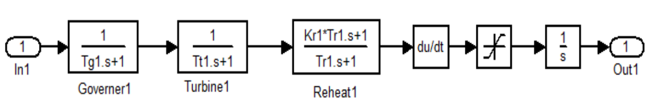


**Fig. 2** Steam generator model of area1

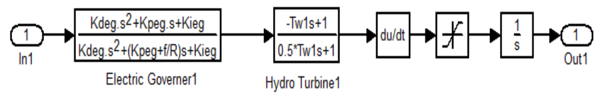


**Fig. 3** Hydro generator model of area 2

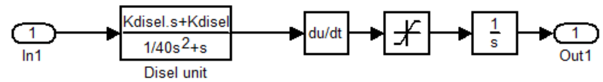


**Fig. 4** Diesel generator model of area 2and 3

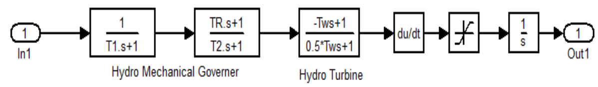


**Fig. 5** Hydro generator model of area 3

## DESIGNING AUTOMATIC VOLTAGE REGULATOR (AVR) AND POWER SYSTEM STABILIZER (PSS)

In this paper Power System Stabilizer (PSS) with Automatic Voltage Regulator (AVR) have been designed for solving AGC problem. The PSS is a supplementary control system applied in many cases as a part of excitation control system. The basic function of PSS is applying a signal to the excitation system, creating electrical torques to the rotor in phase with speed variation which damp out power oscillations. Nowadays AVR system in most units of electrical energy production is used In order to solve the power control [11]-[12].
Figure 6 shows the AVR system controlled by PSS. For optimum designing, the parameters of PSS and AVR have been calculated by the ICA algorithm.

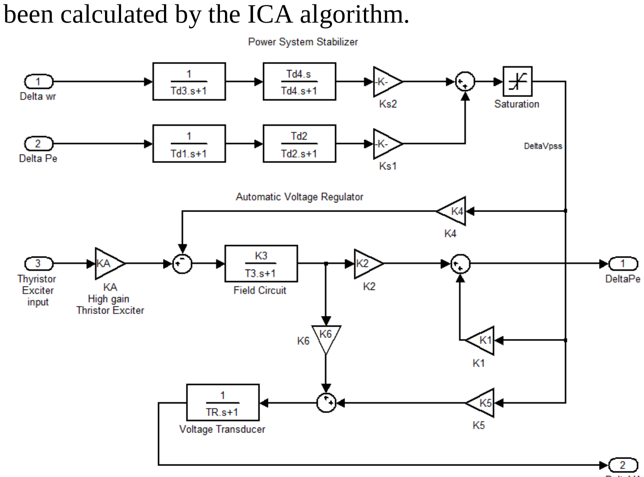


Fig. 6 AVR system controlled by PSS

The amounts of K1 - K6 obtained from equations (1) - (6).

$$K1=\frac{Xq-Xd'}{Xe+Xd'}\times iq0\times E0\times \sin\delta 0\times \frac{Eq0\times E0\times \cos\sigma 0}{Xe+Xq} \quad (1)$$

$$K2=\frac{E0\times \sin\sigma 0}{Xe+Xd'} \quad (2)$$

$$K3=\frac{Xe+Xd'}{Xe+Xd} \quad (3)$$

$$K4=\frac{Xq-Xd'}{Xe+Xd'}\times E0\times \sin\delta 0 \quad (4)$$

$$K5=\frac{Xq}{Xe+Xd'}\times\frac{Vd0}{Vt0}\times E0\times \cos\delta 0-\frac{Xd'}{Xe+Xd'}\times\frac{Vd0}{Vt0}\times E0\times \sin\delta 0 \quad (5)$$

$$K6=\frac{Xe}{Xe+Xd'}\times\frac{Vq0}{Vt0} \quad (6)$$

The other parameters obtained from equations (7) – (13)

$$Iq0=\frac{P0\times Vt0}{\sqrt{(P0\times Xq)^2+(Vt0^2+Q0\times Xq)^2}} \quad (7)$$

$$Vd0=iq0\times Xq \quad (8)$$

$$Vq0=\sqrt{Vt0^2-Vd0^2} \quad (9)$$

$$Id0=\frac{Q0+Xq\times Iq0^2}{Vq0} \quad (10)$$

$$Eq0=Vq0+id0\times Xq \quad (11)$$

$$E0=\sqrt{(Vd0+(Iq0\times Xe))^2+(Vq0-(id0\times Xe))^2} \quad (12)$$

$$\sigma=\tan-1\,\frac{Vd0+(Iq0\times Xe)}{Vq0-(Id0\times Xe)} \quad (13)$$

Where:

| | |
|---|---|
| Xd | d-axis reactance of the machine |
| Xd' | d-axis transient reactance of the machine |
| Xq | q-axis reactance of the machine |

## IMPERIALIST COMPETITIVE ALGORITHM (ICA)

Imperialist competitive algorithm (ICA) has been used for tuning the parameters of PID and PSS-AVR controllers. Figure 7 shows the flowchart of the proposed algorithm. Imperialist Competitive Algorithm (ICA) is a novel global search investigative that uses imperialism and imperialistic rivalry process as a source of inspiration like other evolutionary ones, this algorithm starts with an initial population.

In this algorithm each individual of the population is called a country. Some of the best countries in the population are selected to be the imperialist states and all the other countries form the colonies of these imperialists. All the colonies of initial population are divided among the mentioned imperialists based on their power which are inversely proportional to their cost. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist country. This movement is a simple model of assimilation policy that was perused by some imperialist states [13]-[14].

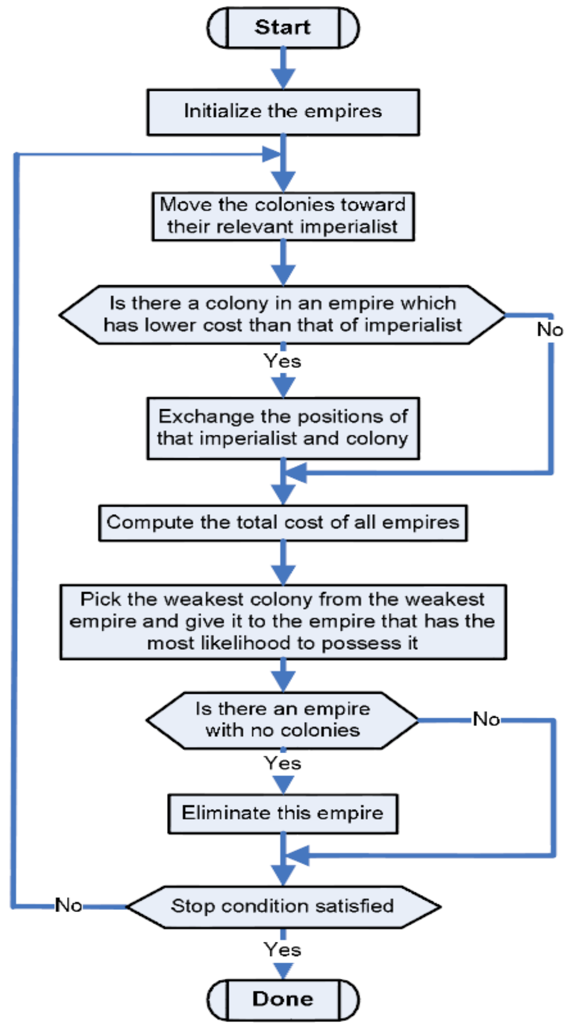


**Fig. 7** Flowchart of the ICA

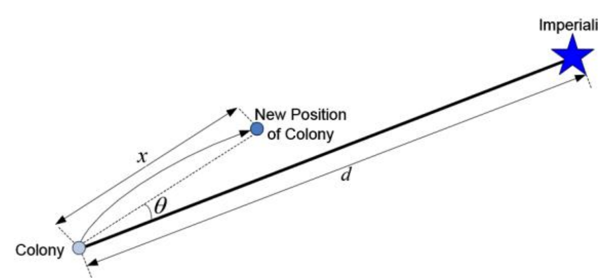


**Fig. 8** Colonies movement into their relevant imperialist.

Fig.8 shows the motion of a colony into its relevant imperialist. In this motion, θ and x are random numbers with uniform distribution as demonstrated in formula 14 and 15.

$$X \sim U(0, \beta \times d) \quad (14)$$

$$\Theta \sim U(-\gamma, \gamma) \quad (15)$$

Where β is a positive number less than 2, d is the space between the imperialist and its colony and order the derivation from original direction [14]-[15]. In this paper β and γ are considered as 1.5 and 0.3 respectively. In order to damp power and frequency fluctuations between areas, the objective function for optimization by ICA algorithm is presented as below:

$$\text{Fitness}=\int\begin{pmatrix}(\sum(\Delta f1^2+\Delta f2^2+\Delta f2^2))+\\(\sum(\Delta P12^2+\Delta P13^2+\Delta P23^2))\end{pmatrix} \quad (16)$$

Where:

$\Delta fi$ is the frequency fluctuations in the areai

$\Delta Pij$ is the power fluctuations between $area_i$ and $area_j$

## SIMULATION AND RESULTS

In this paper, the three-area multi-units Automatic Generation Control (AGC) is studied. Area 1 consists of two parallel steam generator that each one produces 50 percent of power in area1. Area 2 and 3 consist of two parallel hydro and diesel generator that hydro generator produces 70 percent and diesel generator produces 30 percent of power in area 2 and 3. Total of ACE participation factors (APF) in each area should be equal to one.

APF1=0.5, and APF2=1-0.5=0.5.
APF3=0.7, and APF4=1-0.7=0.3.
APF5=0.7, and APF6=1-0.7=0.3.
The required values given below:

**Table1**
the parameters of AGC system

| | | | |
|---|---|---|---|
| $Tg_{1,2}$=0.08 | $Tt_{1,2}$=0.3 | $Kr_{1,2}$=0.5 | $Tr_{1,2}$=10 |
| $Kd_{eg}$=4 | $Kp_{eg}$=1 | $Ki_{eg}$=5 | $Tw_{1,2}$=1 |
| $K_{diesel1,2}$=16.5 | TR=5 | T1=48.75 | T2=0.513 |
| KA=250 | K1=0.599 | K2=0.926 | K3=0.529 |
| K4=0.4319 | K5=-0.087 | K6=0.600 | TR=0.001 |
| Td1=1.341 | Td2=0.39 | Td3=0.031 | Td4=0.063 |
| Ks1=-21.92 | Ks2=39.56 | Ri=2.4 | Tp=20 |
| Kp=120 | a12=-1.5 | a13=-1.5 | a23=-1 |
| Tij=0.0544 | Bi=0.545 | Kp1=0.592 | Ki1=0.728 |
| Kp2=0.8110 | Ki2=2.450 | Kp3=2.251 | Ki3=4.337 |
| $\Delta PL = 0.02$ | $Pr1=1800_{MW}$ | $Pr2=1200_{MW}$ | $Pr3=1200_{MW}$ |

Figures 9, 10 show the three-area multi-units AGC. In figure 9, the PID controllers in each area that optimized by GA [16], PSO [17], and ICA algorithms, for system stabilization have been used. In figure 10 this is done by using AVR that equipped by (PSS).

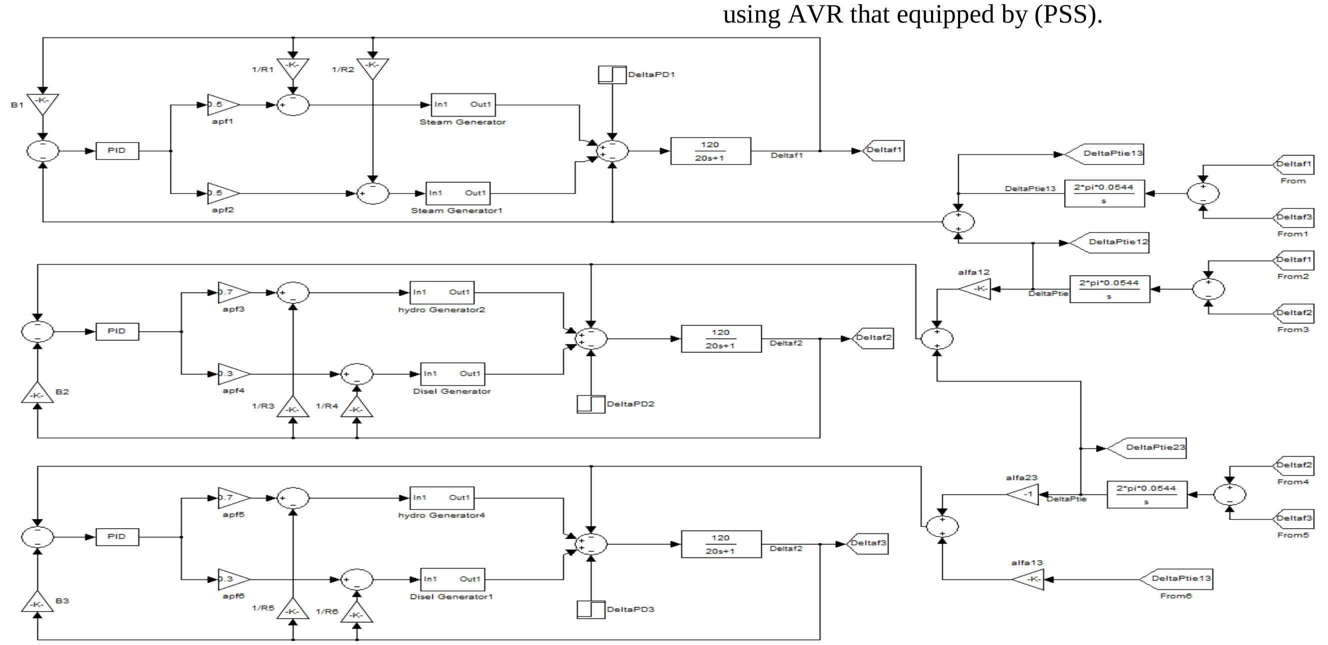

Fig. 9 MATLAB-SIMULINK based complete three-area block diagram comprise steam, hydro and diesel turbines with PID controller.

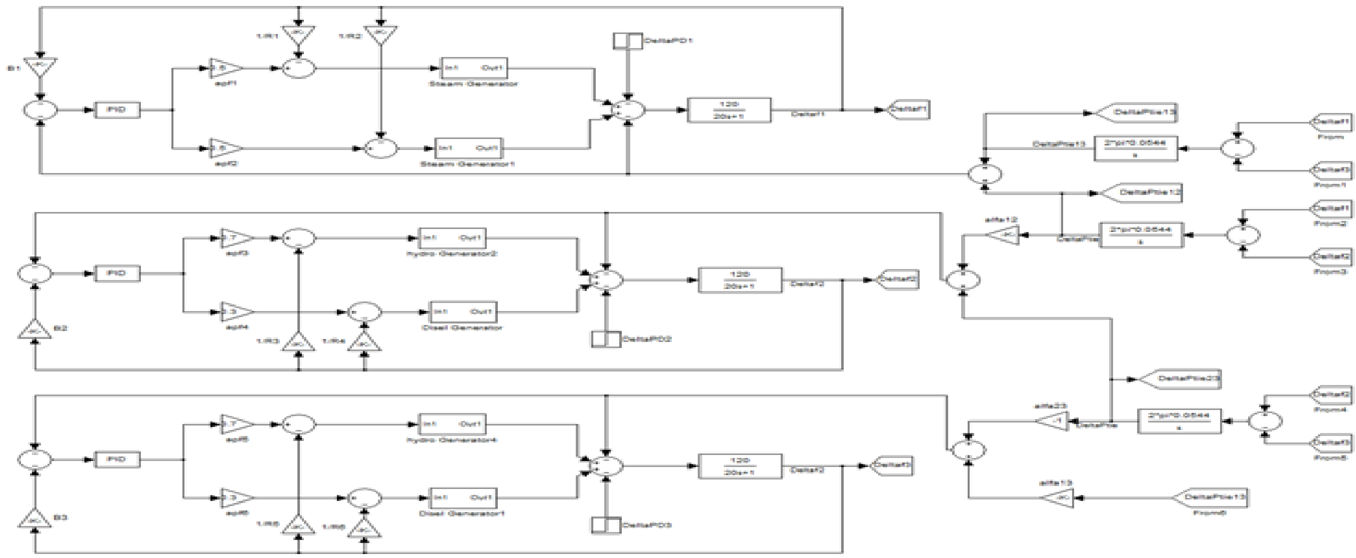

Fig. 10 MATLAB-SIMULINK based complete three-area block diagram comprise steam, hydro and diesel turbines with PSS-AVR controllers.

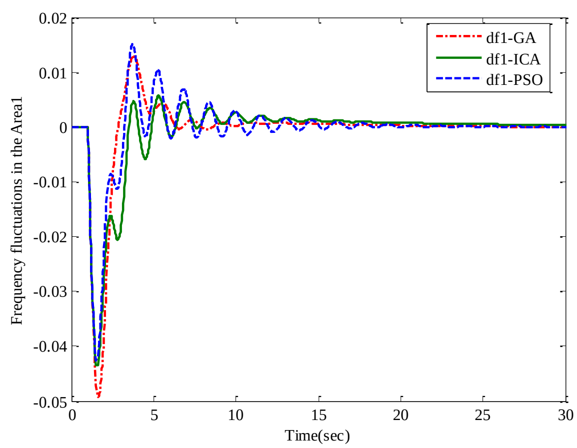


Fig. 11 Frequency fluctuations in the area1 by using PID controller

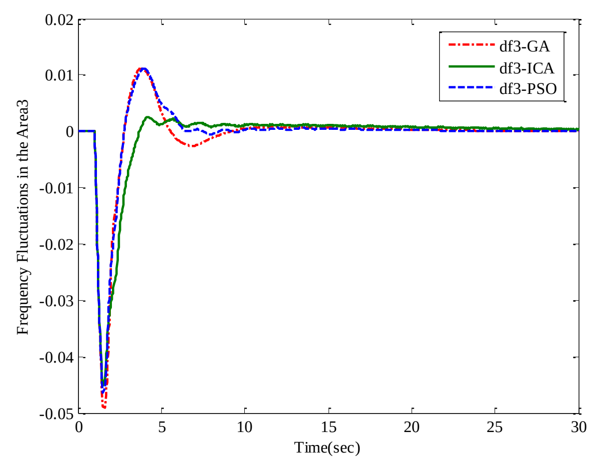


Fig. 13 Frequency fluctuations in the area1 by using PID controller

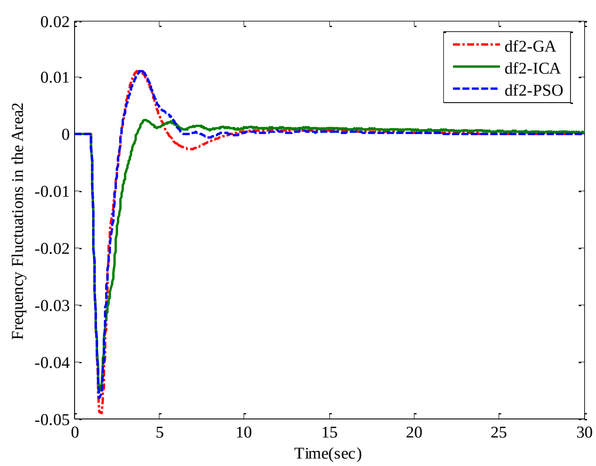


Fig. 12 Frequency fluctuations in the area1 by using PID controller

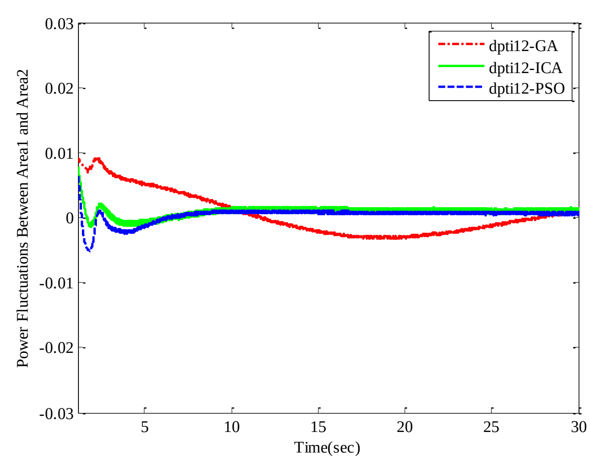


Fig. 14 Power fluctuations between area1 and area2 by using PID controller

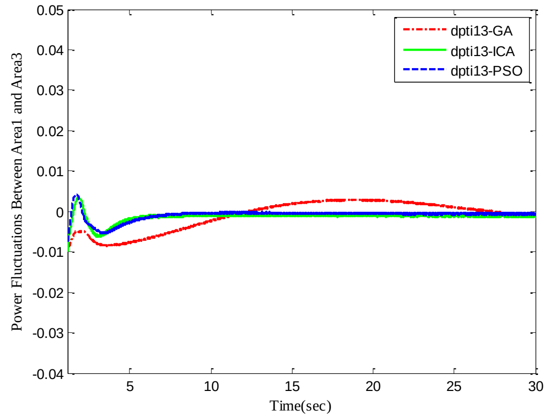


Fig. 15 Power fluctuations between area1 and area3 by using PID controller

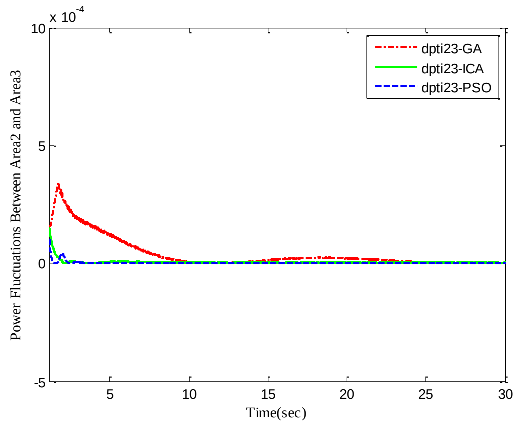


Fig. 16 Power fluctuations between area2 and area3 by using PID controller

From figure 11-16, it is clear that the performance of ICA for tuning the parameters of PID controller in order to damp power fluctuations and frequency fluctuations toward the other Algorithms is much better. Maximum overshoot (OS), maximum undershoot (US) in ICA is less than other Algorithms.

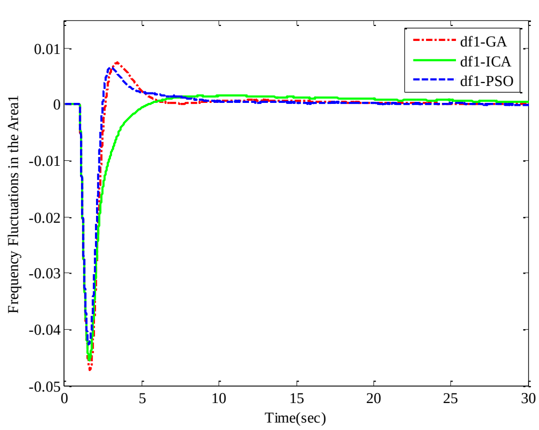


Fig. 17 Frequency fluctuations in the area1 by using PSS-AVR

**Table2**.
Performance of ICA, PSO and GA algorithms by using PID controller

| $\Delta fi_{pu}$ | OS | | | Us | | |
|---|---|---|---|---|---|---|
| | ICA | PSO | GA | ICA | PSO | GA |
| Area1 | 0.005 | 0.015 | 0.012 | -0.043 | -0.042 | -0.049 |
| Area2 | 0.002 | 0.011 | 0.011 | -0.045 | -0.046 | -0.049 |
| Area3 | 0.002 | 0.011 | 0.011 | -0.045 | -0.046 | -0.049 |

| $\Delta Pij_{pu}$ | OS | | | Us | | |
|---|---|---|---|---|---|---|
| | ICA | PSO | GA | ICA | PSO | GA |
| Area12 | 0.008 | 0.008 | 0.01 | -0.001 | -0.005 | -0.003 |
| Area13 | 0.003 | 0.004 | 0.003 | -0.006 | -0.005 | -0.009 |
| Area23 | 15e-5 | 10e-5 | 35e-5 | 0 | 0 | 0 |

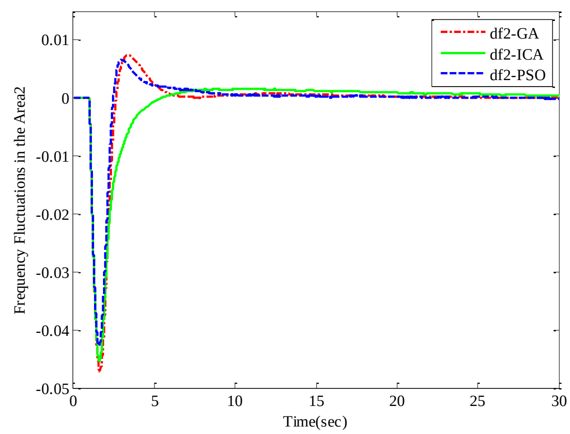


Fig. 18 Frequency fluctuations in the area2 by using PSS-AVR

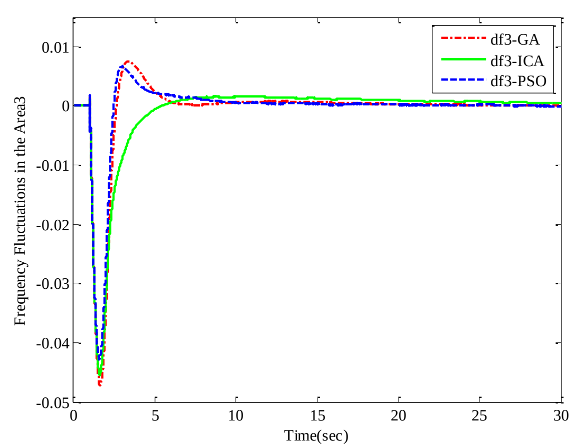


Fig. 19 Frequency fluctuations in the area3 by using PSS-AVR

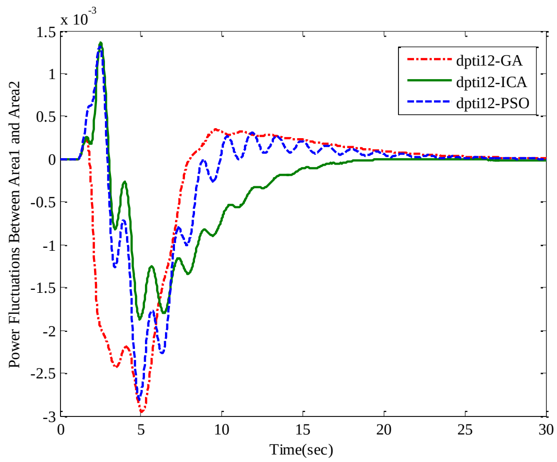


Fig. 20 Power fluctuations between area1 and area2 by using PSS-AVR

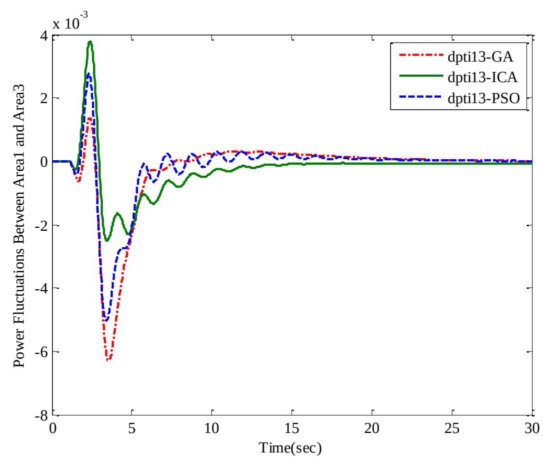


Fig. 21 Power fluctuations between area1 and area3 by using PSS-AVR

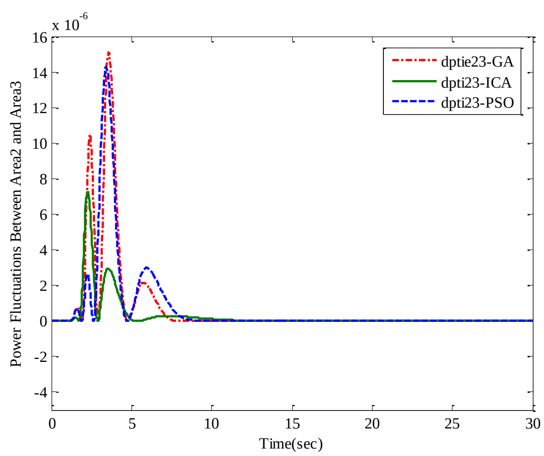


Fig. 22 Power fluctuations between area2 and area3 by using PSS-AVR

From figure 17-22, it is clear that the performance of ICA for tuning the parameters of PSS-AVR in order to damp power fluctuations and frequency fluctuations compared with other Algorithms is much better. Maximum overshoot (OS), maximum undershoot (US) in ICA is less than other Algorithms.

**Table3.**

Performance of ICA, PSO and GA algorithms by using PSS-AVR

| $\Delta fi$ pu | OS | | | Us | | |
|---|---|---|---|---|---|---|
| | ICA | PSO | GA | ICA | PSO | GA |
| Area1 | 0.0015 | 0.0066 | 0.0074 | -0.045 | -0.042 | -0.047 |
| Area2 | 0.0016 | 0.0065 | 0.0075 | -0.045 | -0.042 | -0.047 |
| Area3 | 0.0016 | 0.0066 | 0.0076 | -0.045 | -0.042 | -0.047 |

| $\Delta Pij$ pu | OS | | | Us | | |
|---|---|---|---|---|---|---|
| | ICA | PSO | GA | ICA | PSO | GA |
| Area1 2 | 0.001 | 0.001 | 0.0002 | -0.001 | -0.003 | -0.003 |
| Area1 3 | 0.003 | 0.002 | 0.001 | -0.002 | -0.005 | -0.006 |
| Area2 3 | 73e-6 | 14e-6 | 17e-6 | 0 | 0 | 0 |

## CONCLUSION

In this paper a new design method to determine optimal PID and PSS-AVR controllers' parameters by using the imperialist competitive algorithm (ICA) was proposed. These controllers were designed to improve the transient performance of the interconnected system following a disturbance in either area. The comparative performance analysis of the two specific varieties of controller devices for optimal transient performance of automatic generation control (AGC) was presented.

The main idea was to reduce the maximum overshoot (OS) and maximum undershoot (US) of power and frequency fluctuations. Results show the superiority of ICA toward the ordinary population based algorithm like GA and PSO for damping power and frequency fluctuations between areas and decreasing OS and US. It was also observed that the designed AVR equipped by PSS compared with PID has less OS and US in power and frequency fluctuations.

## REFERENCES

[1] Tripathy SC, Hope GS and Malik OP. Optimization of load–frequency control parameters for power systems with reheat steam

turbines and governor deadband non-linearity. Proc IEE; Part C 1982;129:10–6.

[2] Vaibhav Donde, M.A.Pai, and Iran. A Hiskens, “Simulation and optimization in an AGC system after deregulation,” IEEE TRANSACTIONS. ON POWER SYSTEMS, vol. 16, no.3, pp. 481-488, August 2001.

[3] Janardan Nanda, S. Mishra, and Lalit Chandra Saikia, “Maiden Application of Bacterial Foraging-Based Optimization Technique in Multiarea Automatic Generation Control”, IEEE TRANSACTIONS ON POWER SYSTEMS, vol. 24, no. 2, pp. 602-609, MAY 2009.

[4] Praghnesh Bhatt, Ranjit Roy, and S.P. Ghoshal, “GA/particle swarm intelligence based optimization of two specific varieties of controller devices applied to two-area multi-units automatic generation control”, Elsevier Ltd, 2009.

[5] Raseswari Pradhan, and Sidhartha Panda, “Application of Genetic Algorithm based PSS for Two - Area AGC System in Deregulated Scenario”, IEEE, 2009.

[6] J. Nanda, S. Mishra, P. G. Mishra, and K.V. Sajith, “A Novel Classical Controller for Automatic Generation Control in Thermal and Hydrothermal Systems”, IEEE.

[7] Weihua Luo, and Yibin Shi, “Automatic Generation Control Strategies under CPS Based on Particle Swarm Optimization Algorithm”, IEEE, 2010.

[8] Swasti R. Khuntia, and Sidhartha Panda, “Comparative Study of Different Controllers for Automatic Generation Control of an Interconnected Hydro-Thermal System with Generation Rate Constraints”, International Conference on Industrial Electronics, Control and Robotics, IEEE, 2010.

[9] IEEE Committee Report. Dynamic models for steam and hydro turbines in power system studies. IEEE Trans Power Appl Syst 1973;PAS-92(6):1904–15.

[10]Tripathy SC, Kalantar M, Balasubramanian R. Dynamics and stability of wind and diesel turbine generators with superconducting magnetic energy storage unit on an isolated power system. IEEE Trans Energy Convers 1991;6(4).

[11]O.I. Elgard, “Electric Energy Systems Theory”, McGraw-Hill, New York, pp. 299-362, 1982.

[12]V. Mukherjee, S.P. Ghoshal, “Comparison of intelligent fuzzy based AGC coordinated PID controlled and PSS controlled AVR system”, Elsevier Ltd, 2007.

[13]Esmaeil Atashpaz-Gargari, Caro Lucas, “Designing an optimal PID controller using Imperialist Competitive Algorithm”, First Joint Congress on Fuzzy and Intelligent Systems Ferdowsi University of Mashhad, Iran, 29-31 Aug, 2007.

[14]E. Atashpaz-Gargari, C. Lucas, "Imperialist Competitive Algorithm: An Algorithm for Optimization Inspires by Imperialistic Competition", IEEE Congress on Evolutionary Computation, Sigapore, 2007.

[15]N. Razmjooy, B. Somayeh Mousavi, P. Sargolzaei, and F. Soleymani, “Image thresholding based on evolutionary algorithms”, International Journal of the Physical Sciences Vol. 6(31), pp. 7203 - 7211, 30 November, 2011.

[16]A. Hasanovi c, and A. Feliachi, “Genetic algorithm based inter-area oscillation damping controller design using MATLAB”, PES, Power Engineering Society Summer Meeting 3, pp. 1136–1141. 2002.

[17]J. Kennedy, and R. Eberhart, “Particle swarm optimization,” in Proc.IEEE Int. Conf. Neural Networks, vol. IV, Perth, ustralia, pp. 1942–1948, 1995.