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Jaya Algorithm Based Automatic Generation Control of Two Area Load Frequency Control with Nonlinearities

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Abstract: In a complex power system, often two or more areas are interconnected to each other for having the mutual benefits of peak load supply, reliability of supply, increase in reserve capacity and diversity factor etc. For a proper operation interconnected powers system it is of utmost importance to have constant frequency and tie line power exchange. To manage the changes and keeping record of it, in each area uses Automatic Generation control (AGC) is provided. The difference between the load side demand and the generation at the moment is Area Control Error (ACE). The AGC in each area is carried out by a controller. In the present piece of work to regulate AGC Proportional Integral Derivative (PID) controller is installed in each area. It is one of the conventional methods. For enhancing the performance of controller in the past many optimization techniques have been involved. To name some of it are, hybrid Firefly Algorithm and Pattern Search (hFA–PS) technique, Bacteria Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA) and conventional Ziegler Nichols (ZN) which are separately based on PI or PID controller.

The use of very new technique in this field has been made here which is JAYA algorithm. It is partly based on Artificial Intelligence. To optimize the PID controller Integral Time multiply Absolute Error (ITAE) as objective function is utilized. Under different loading conditions, system parameters of controller are changed to test its sensitivity. Also, it variation of time constants for speed governor, turbine and tile line power were considered here under the Generation Rate Constraint(GRC) values of ±0.05 and ±0.025. While performing all these analysis certain definite constraints are considered such as time delay, reheat turbine, and GRC. The typical GRC for a thermal power plant lies between 2% and 5% per minute. Later it was compared with the conventional and several other techniques to evaluate its performance particularly conventional ZN controllers, GA PID controller and BFOA PID controller. The proposed system model has been developed using the platform provided by the MATLAB/SIMULINK.

Keywords: Automatic Generation Control (AGC), Jaya Algorithm, Load frequency control, Sensitivity analysis, Two area system

I. INTRODUCTION

Power system is a vast network that has several ways to generate power. To have the maximum benefit of such a vast network these power generation sources are usually connected to each other. Therefore, these are commonly termed as different areas that are interconnected. To name some of the benefits from such a state of power system are reduces reserve capacity, reliability of operation, supplying peak load, operation would be much cost effective and increase in diversity. The areas are interconnected via tie line therefore, it is necessary to keep the tie line power and frequency of the interconnected areas at constant or scheduled values. This is a very complex task. It requires continuous monitoring of the system. If the values deviate from the desired one than the stable point of the operation will also deviates and it will affect the entire operation of tie line and area connected via it. Hence, a system is needed to keep the track of these parameters of interconnected areas[1]. Automatic Generation Control (AGC) is the system to satisfy the above mention needs of interconnected areas in power system. Like it was already mentioned, it will keep a track of the generated power in the system it is connected in. It will keep the system update with the most recent load demand or the demand by the any other area connected to area it is connected in. In short it observes the tie line power and frequency regularly. Its working concept is quiet simple to understand. Each time a load demand changes, it see the present stats of the generating units of the area for the amount of power generated and determines how much more power is needed to be generated. Or it could give commands to one or two generating units to slow down in case there is decrease in load demand. The difference calculated between the present generated power and the demand at the same time is known as Area Control Error (ACE). It includes the change in frequency as well as tie line power too[5]. In the present context, the AGC is provided to maintain the frequency of areas at the same level whenever there is change. This type of AGC is called as Load Frequency Control (LFC). This problem has been addressed several times in the past and still being addressed with the better solution each time. From traditional ways of controlling via only simple controllers only like Proportional (P), Proportional Integral (PI) and Proportional Integral Derivative (PID) to methods where these controllers are further modified to give better results[6]. The modification has been incorporated using many optimization techniques such as Genetic Algorithm (GA), Neural Network (NN), fuzzy logic Genetic Algorithm (GA), Particle swarm optimization (PSO) or Bacteria Foraging Optimization Algorithm (BFOA) etc. Also some recently used developed optimization techniques too like hybrid Firefly Algorithm (FA) and Pattern Search (PS) or Teaching learning Based Optimization Technique (TLBO). But the present work has taken very newly developed techniques inspired by TLBO named as JAYA Algorithm (JA)[4]. The system which has been outlined as discussed so far has been developed and realized using the platform provided by the MATLAB/SIMULINK. The two area non reheat interconnected system has been analyzed by utilizing this software tool with different load conditions under variable system parameters.

II. SYSTEM MODELING

Fig.1 shows two area non reheat thermal power systems and their rating are 2000 MW (area-1 and area-2) with a nominal load of 1000 MW. Two area non-reheat thermal system is extensively used in the literature for design and investigation of automatic load frequency control of interconnected areas [25]. Fig.1 shows different parameter classifies as B1& B2-frequency bias parameters; ACE1 & ACE2 -area control errors; u1&u2 -control outputs from controller; R1 &R2 - governor speed regulation parameters(p.u.); TG1 &TG2-speed governor time constants(seconds); ΔPV1 &ΔPV2 -change in governor valve positions (p.u.); ΔPG1& ΔPG2 - governor output command (p.u.); TT1 & TT2 - turbine time constant(seconds); ΔPT1 & ΔPT2 - change in turbine output powers; ΔPD1 & ΔPD2-load demand changes; ΔPtie -incremental change in tie line power (p.u.); KP1 &KP2 -power system gains; TP1 &TP2 - power system time constant(seconds); T12 - synchronizing coefficient and ΔF1 &ΔF2 -system frequency deviations(Hz). The generation of power by Thermal power plants can be modified or changed at a specific maximum rate (2-5% per min) and this is Generation Rate Constraint (GRC). Both areas of the power system consist of the speed governing system, turbine and generator. Both areas have three inputs and two outputs. The inputs are the controller input ΔPref (also denoted as u), load disturbance ΔPD and tie-line power error ΔPtie the outputs are the generator frequency ΔF and Area Control Error (ACE).

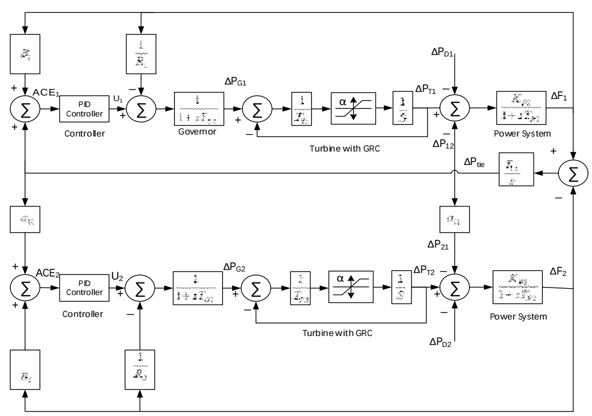

Fig.1 Two area non-reheat thermal plant consideration of with GRC [1]

$$ACE = B\Delta F + \Delta P_{tie} \quad (1)$$

where, B is the frequency bias parameters.

The turbine is represented by the transfer function

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+sT_T} \quad (2)$$

The transfer function of a governor is given in (2) as above.

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+sT_G} \quad (3)$$

The speed governing system has two inputs ΔP_{ref} and ΔF with one output $\Delta P_G(s)$ given as in (4),

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \quad (4)$$

The generator and load is represented by the transfer function

$$G_P(s) = \frac{K_P}{1+sT_P} \tag{5}$$

Where, K_P=1/D and T_P =2H/FD

The generator load system has two input ΔP_T(s) and ΔP_D(s) with one output ΔF(s) is specified by (6) and referred to [22],

$$\Delta F(s) = \Delta G_P(s)[\Delta P_T(s) - \Delta P_D(s)] \tag{6}$$

III. JAYA ALGORITHM

A. Introduction

There are several algorithms for optimizing in case of different problems. These are mostly categorized as evolutionary based and swarm intelligence based. Some of the examples are Genetic algorithm (GA), Differential Evolution (DE), Particle swarm optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Fire Fly (FF) algorithm and many more like these. The criterion for the optimization is to work with control parameters as these are probabilistic. Some algorithm like GA, DE may use parameters more specific to terms of the algorithm i.e. algorithm specific parameters. Therefore, in case of such algorithm it is important to tune the algorithm specific control parameters carefully. Any error in tuning would cause the computational work to increase and may result in the local optimal solution. Taking account of this very point an algorithm that does not uses algorithm specific parameters for control is developed for example it uses population size and generation number as the controlling parameters. This algorithm was developed in 2011 and named as teaching learning-based optimization (TLBO). Development of this algorithm has leaded the new algorithm which has only one phase of operation instead of two as in TLBO. Also, due to this it is very simple. Its working is different form TLBO and is known as Jaya Algorithm (JA)[1]. Fig.2 shows the flow chart of Jaya Algorithm.

B. Description

Let,,f(x)= objective function to be minimized
i= iteration
j= designed variables
m= number of designed variables (j=1, 2,…, m)
k= population size
n= number of candidate solution (k=1, 2…, n)

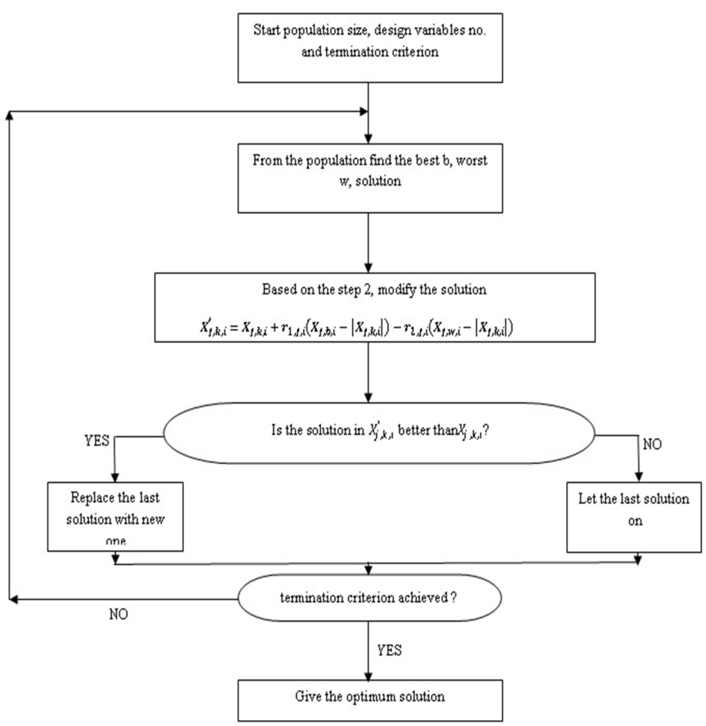

Fig.2: Flow chart of Jaya algorithm

It assumed that there are two types of candidates exist i.e. best and worst where best candidates acquires the best value of f(x) ($f(x)_b$). On the other hand worst candidate acquire the worst value for f(x) ($f(x)_w$) in the pool of whole solution of candidates.
Above is the flow chart description Jaya Algorithm. Where it has each and every step involved in the process of deciding optimal solution from the given set of population.
Let it be i^{th} iteration. Here, k^{th} candidate
j^{th} variable= $X_{j,k,i}$ (value)
The above value of variable is modified as for i^{th} iteration within [0,1],

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\left(X_{j,b,i} - |X_{j,k,i}|\right) - r_{2,j,i}\left(X_{j,w,i} - |X_{j,k,i}|\right) \quad (7)$$

where,
$X_{j,b,i}$=Best candidate value of j^{th} variable
$X_{j,w,i}$= Worst candidate value of j^{th} variable
$X'_{j,k,i}$=$X_{j,k,i}$'s modified value
$r_{1,j,i}, r_{2,j,i}$= nay tow arbitrary number for j^{th} variables
$r_{1,j,i}\left(X_{j,b,i} - |X_{j,k,i}|\right)$=represents inclination of solution towards best solution
$-r_{2,j,i}\left(X_{j,w,i} - |X_{j,k,i}|\right)$= represents affinity of solution to evade worst solution
If the $X'_{j,k,i}$ has the better value than the$X_{j,k,i}$, then it will be maintained and treated as the input to the next iteration.
The concept of above algorithm is very simple. As, in every iteration it will always tend to put effort to acquire the best solution while getting away from the worst solution. Hence, it can be said that the algorithm will achieve victory on getting the best solution which its name Jaya, Sanskrit word synonymous to victory[4].

C. *Objective Function*

The objective function, here for the designing of controller, there are certain criterions to follow. The criterion used here is the Integral of Time multiplied Absolute Error (ITAE). It was observed that ITAE use in AGC is better option as an objective function.

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}|).t.dt \quad (8)$$

Where,
ΔF_1 & ΔF_2 = change in system frequency
ΔP_{Tie}= Change in the power of tie line (increasing change), t_{sim}= simulation time
While designing PID controllers it is restricted by certain constraints too. Hence, the given problem is expressed as,
For minimizing the function J, the following constraints bound it,

$$K_{Pmin} \le K_P \le K_{Pmax}, K_{Imin} \le K_I \le K_{Imax}, K_{Dmin} \le K_D \le K_{Dmax} \quad (9)$$

IV. RESULT AND DISCUSSION

The systematic study with different cases as dynamic response analysis with SLP in area-1,area-2, area-1 and area-2 simultaneously & sensitivity analysis with parameter variations for TG, TT, T12. The influence of the proposed JA based PID controller has been verified by comparing the results with some newly published heuristic optimization techniques such as the BFOA, GA and conventional ZN based PID controllers same kind of system. Table 1 shows value of different parameters of KP, Ki, Kd at different algorithm as BFOA, GA, conventional ZN and JA at Generation rate constraint ± 0.05 & ± 0.025[26]

TABLE: 1

Controller parameters for different cases

		Conventional Controller (ZN)	GA PID Controller	BFOA PID Controller	JAYA PID Controller	
					GRC = ± 0.05	GRC = ± 0.025
Controller parameters	Kp	0.5865	0.0955	0.1317	2.5279	0.001
	Ki	0.51	0.4712	0.4873	0.8106	0.3381
	K_d	0.1686	0.0679	0.2506	0.8741	0.2705

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A. Analysis of Results And Discussion

The proposed JA is compared with other conventional approaches suggested in and heuristic techniques such as ZN, GA and BFOA as shown in table 2 from which it is clear that with same PID controller structure, the saturation limit (GRC = ±0.05), objective function, least ITAE values is obtained with proposed JA (ITAE = 00.10617) compared to BFOA (ITAE = 0.4788), GA (ITAE = 0.5513) and ZN (ITAE = 0.6040) techniques. Hence, it can be concluded that the proposed Jaya algorithm better the conventional ZN technique and heuristic techniques GA, BFOA as least objective function cost is obtained with the proposed Jaya algorithm. Therefore, superior system performance in term of min^m conditions least settling times in frequency and tie-line power deviations is achieved with proposed Jaya optimized PID controller compared to others.

TABLE: 2
Settling time and error

Techniques	GRC = ± 0.05				GRC = ± 0.025			
	Settling time Ts (Sec.)			Performance indices	Settling time Ts (Sec.)			Performance indices
	ΔF_1	ΔF_2	ΔP_{tie}	ITAE	ΔF_1	ΔF_2	ΔP_{tie}	ITAE
Proposed JAYA	2.7	2.8	3.2	0.10617	5.3	3.7	7.1	0.462
BFOA	4.7	6.4	5.1	0.4788	9	7.9	8.3	1.5078
GA	6.9	8	5.7	0.5513	11.1	11.2	11	2.4668
ZN	8.1	9.2	6.7	0.604	15.3	14.1	15.3	3.4972

B. Dynamic Response Analysis

To understand the dynamic response of the system given below different Step Load Perturbation (SLP) and GRC values, the subsequent cases are considered. Table-3 shows the controller parameters for different cases.

1) Case (i): Step load perturbation in area-1 with saturation limit (GRC = ±0.05)

Fig.3-5 show Frequency deviation of area-1, area-2, & tie line power deviation of 5% SLP applied in areas-1 at t=0 with GRC=±0.05. It is clear from Fig. 3–5, the proposed Jaya algorithm optimized PID controller shows best dynamic performance compared to ZN, GA, BFOA optimized PID controllers.

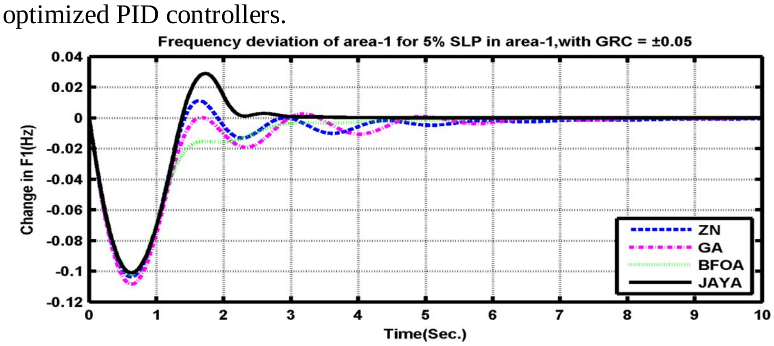

Fig.3 Frequency deviation of area-1for 5% SLP in area-1 with GRC=±0.05

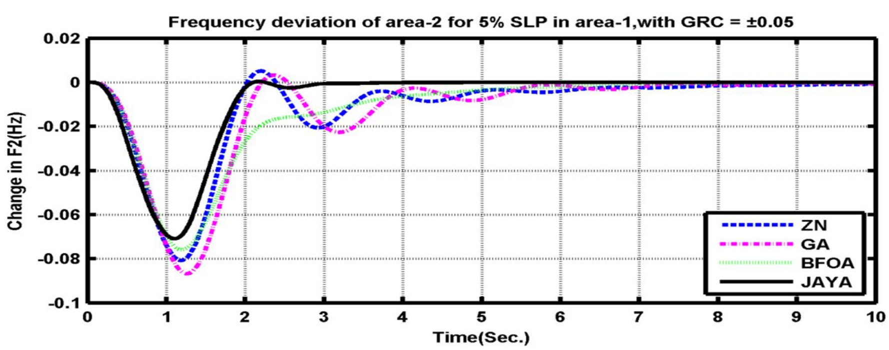

Fig.4 Frequency deviation of area-2 for 5% SLP in area-1 with GRC=±0.05

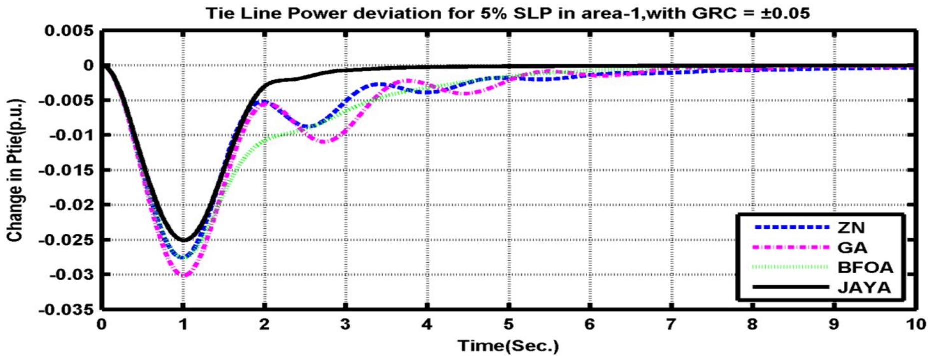

Fig.5 Tie line power deviation for 5% SLP in the area-1, with GRC=±0.05

2) Case (ii): Step load perturbation in area-1 and area-2 simultaneously with saturation limit (GRC = ±0.05)

Fig.6-8 show frequency deviation of area-1for 5% SLP in area-1 and 2% SLP in the area-2, at t=0 with GRC=±0.05. It is clear from Fig. 6–8 that the designed controllers are emphatic and carry out satisfactory operation when we employ Jaya Algorithm and system show less settling times compared to newly published ZN, GA and BFOA optimized PID controllers.

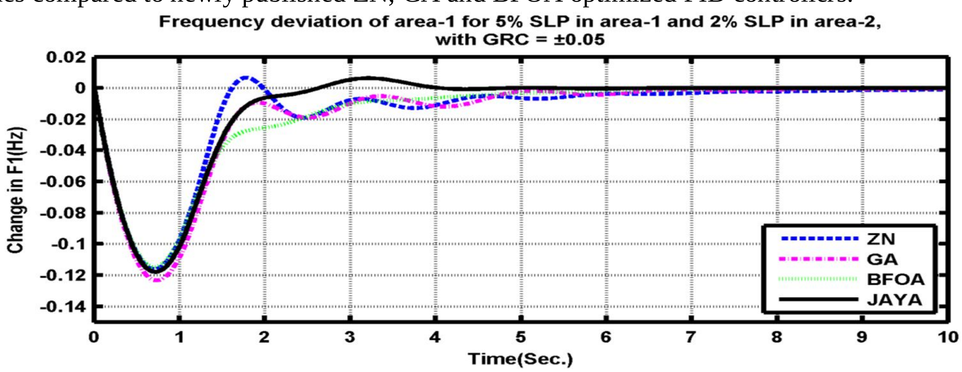

Fig.6 Frequency deviation of area-1for 5% SLP in area-1 and 2% SLP in area-2, with GRC=±0.05

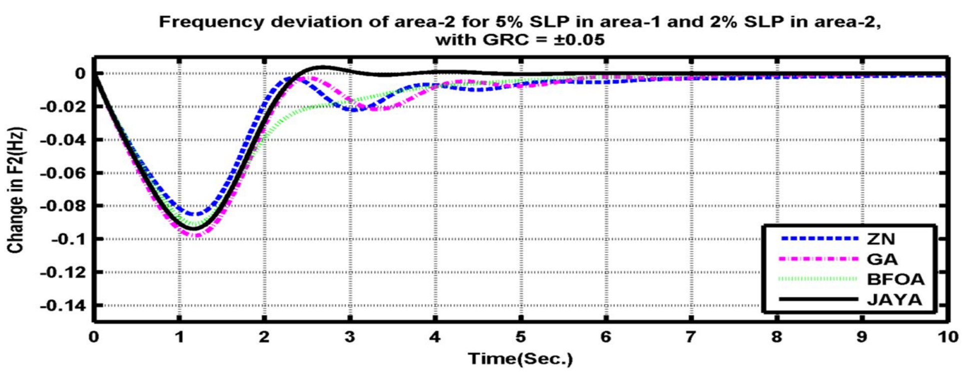

Fig.7 Frequency deviation of area-2 for 5% SLP in area-1 and 2% SLP in area-2, with GRC=±0.05

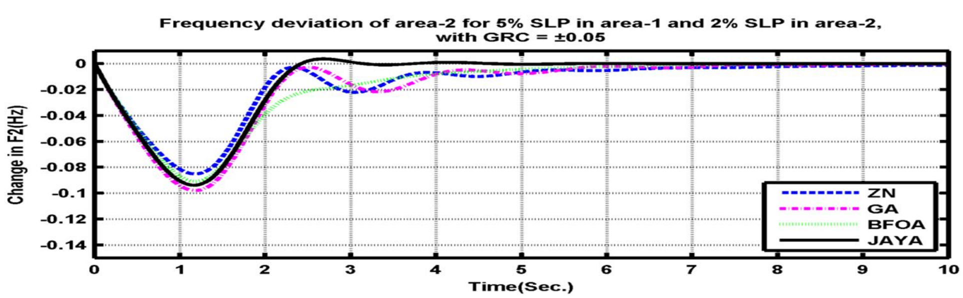

Fig.8 Tie line power deviation of 5% SLP in area-1 and 2% SLP in area-2, with GRC=±0.05

3) *Case (iii):* Step load perturbation in area-1 with saturation limit (GRC = ±0.025)

Fig.9 to11 show frequency deviation of area-1, area-2, tie line power deviation of 5% SLP applied in area-1 at t=0 with GRC=±0.25. It can be seen from Fig. 9–11 that the proposed Jaya algorithm optimized PID controller gives superior dynamic response having comparatively lesser peak overshoot and lesser settling times compared to newly published ZN, GA and BFOA optimized PID controllers.

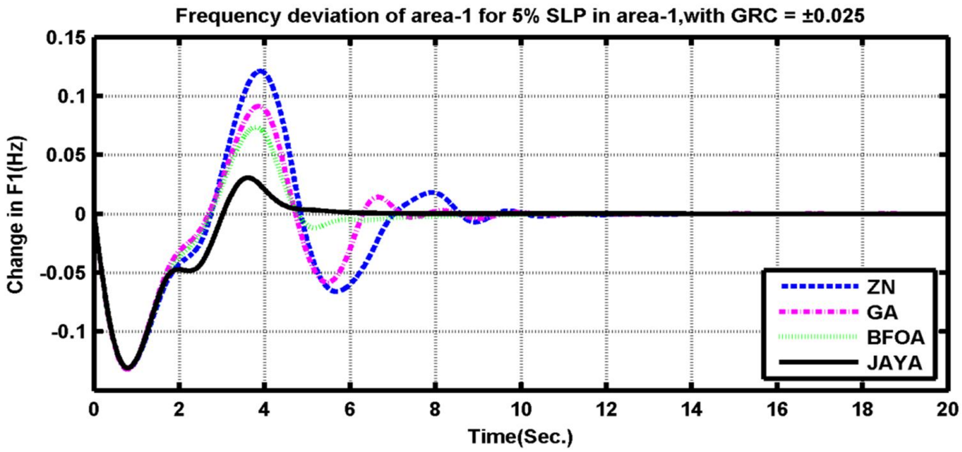

Fig.9 Frequency deviation of area-1 for 5% SLP in area-1, with GRC=±0.025

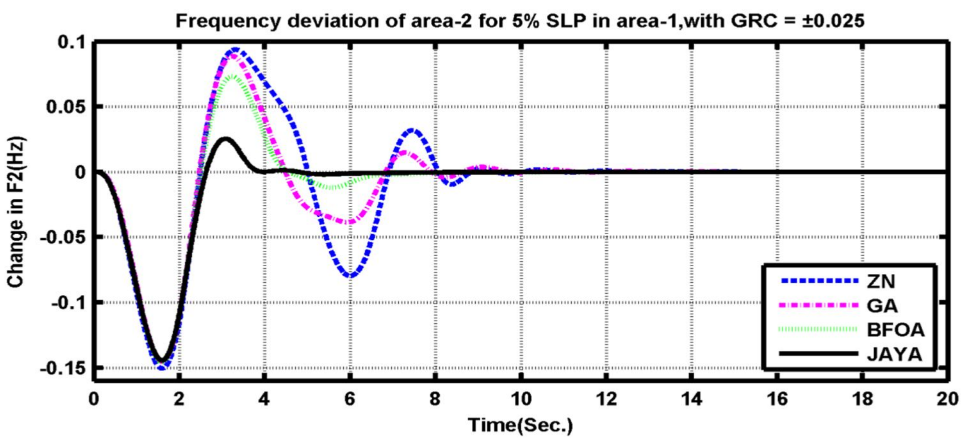

Fig.10 Frequency deviation of area-2 for 5% SLP in area-1, with GRC=±0.025

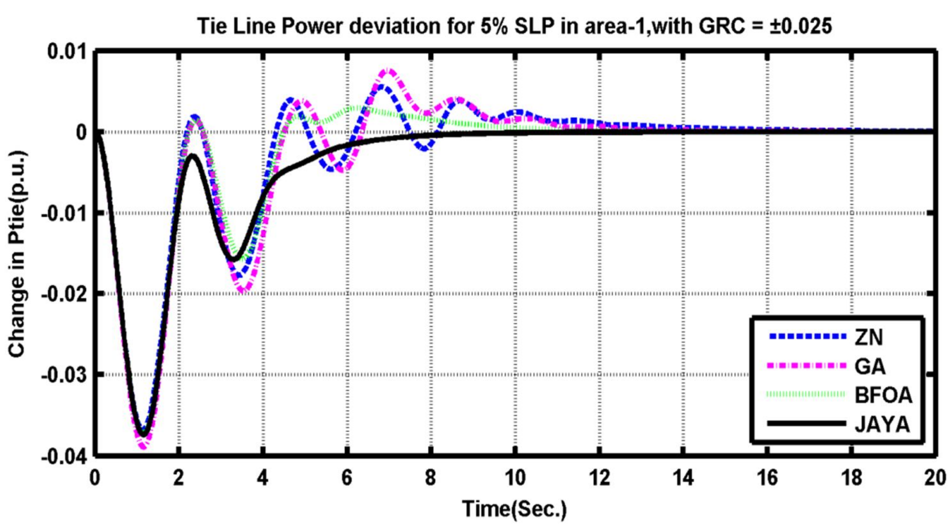

Fig.11 Tie line power deviation for 5% SLP in area-1, with GRC=±0.025

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4) *Case (iv):* Sensitivity analysis

Sensitivity analysis is carried out to study the power system due to large changes in the system parameters. Taking one at a time, the parameter variation and time constants of speed governor, turbine, tie-line power is altered from their nominal values in the value of +50% to -50% . Table 3 gives the tuned PID controller parameters under parameter variations of GRC is ± 0.05 and ±0.025. The Sensitivity analysis of parameter variations for T_g, T_t, T_{12} at different GRC of ± 0.05 and ±0.025 shows in table 4 and 5 respectively. It is obvious from Tables 4 and 5 that the dynamic performance with proposed Jaya algorithm tuned PID controller is superior to BFOA optimized PID controller for every cases. Fig. 12 to 17 show various responses at parameter variations of T_g, T_t, T_{12} increase 50%, with GRC=±0.05 and ±0.025. Hence, it can be concluded that the proposed control approach provides a strong control under large changes in the system parameter variations.

TABLE : 3
Tuned PID controller parameters under parameter variation.

Parameter Variation	% Change	GRC = ± 0.05			GRC = ± 0.025		
		K_P	K_I	K_D	K_P	K_I	K_D
Nominal Loading Condition	0	2.5279	0.8106	0.8741	0.001	0.3381	0.2705
T_g	50	10	0.7493	5.0889	1.00E-03	0.3183	0.2805
	-50	4.739	0.8519	1.3795	1.00E-03	0.361	0.2491
T_t	50	9.7975	0.793	3.9953	1.00E-03	0.322	0.3182
	-50	7.0147	0.7864	3.0209	0.001	0.3514	0.3007
T_{12}	50	4.7895	0.7317	2.6299	1.00E-03	0.3676	0.214
	-50	2.4739	0.8413	0.8631	0.0884	0.2993	0.3425

TABLE : 4
Sensitivity analysis with GRC = ± 0.05

Parameter Variation	% Change	Proposed JAYA Technique				BFOA Technique			
		Settling Time (Sec.)			ITAE	Settling Time (Sec.)			ITAE
		ΔF_1	ΔF_2	ΔP_{tie}		ΔF_1	ΔF_2	ΔP_{tie}	
Nominal Loading Condition	0	2.7	2.8	3.2984	0.10617	4.7	6.4	5.1	0.4788
T_g	50	2.7	3.5	3.703	0.1155	4.8	6.8	5.5	0.476
	-50	2.2	2.0	2.7605	0.1021	5.2	6.5	5.4	0.4843
T_t	50	2.6	3.1	3.3579	0.1079	5	7	5.6	0.4634
	-50	2.1	3.2	3.2397	0.1073	5.2	6.2	5.1	0.4911
T_{12}	50	3.3	2.9	3.9567	0.1119	5.4	6.3	5.4	0.4771
	-50	3.3	3.7	3.9432	0.1632	**2.2**	6.9	5.6	0.5048

TABLE : 5
Sensitivity analysis with GRC = ± 0.025

Parameter Variation	% Change	Proposed JAYA Technique				BFOA Technique			
		Settling Time (Sec.)			ITAE	Settling Time (Sec.)			ITAE
		ΔF1	ΔF2	ΔPtie		ΔF1	ΔF2	ΔPtie	
Nominal Loading Condition	0	5.3	3.7	7.1582	0.462	9	7.9	8.3	1.5078
T_g	50	5.5	4.6	8.1855	0.5002	7.9	7.4	9.2	1.7988
	-50	5.2	3.7	6.1648	0.4319	9.4	8.1	8.7	1.3011
T_t	50	5.6	5.6	8.4516	0.5046	9.2	8.4	**7.5**	1.3957
	-50	5.4	3.6	5.7189	0.4272	9.6	8.6	8.3	1.1458
T_{12}	50	4.9	4.7	8.5674	0.456	8	7.6	**5.6**	1.2758
	-50	5.9	5.8	6.9284	0.5074	11.1	8.2	10.2	2.1568

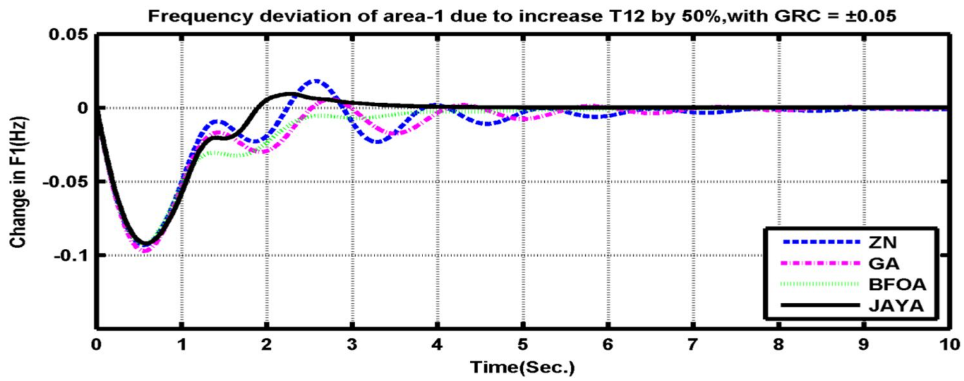

Fig.12 Frequency deviation of area-1 due to increase for T_{12} by 50%, with GRC=±0.05

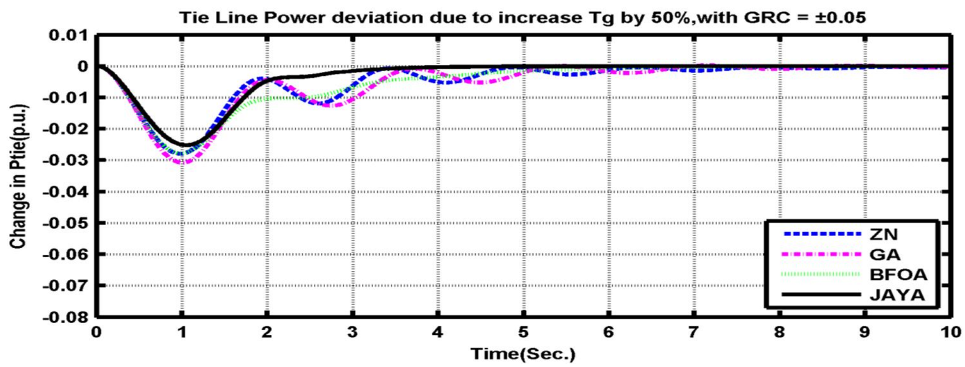

Fig.13 Frequency deviation of area-2 due to increase for Tg by 50%, with GRC=±0.05

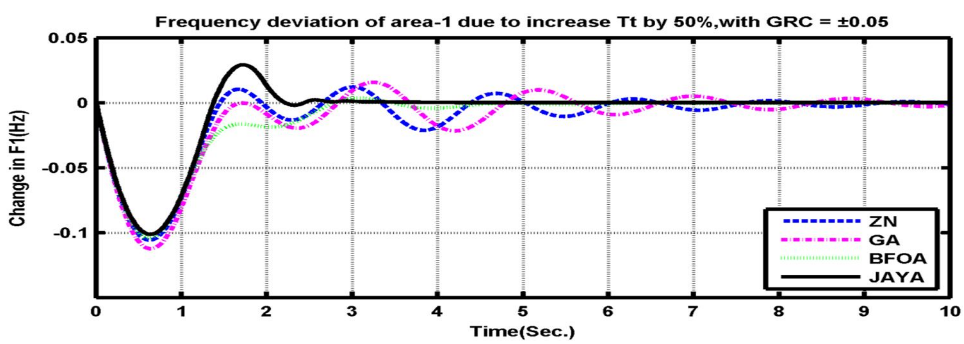

Fig.14 Tie line power deviation due to increase for Tt by 50% ,with GRC=±0.05

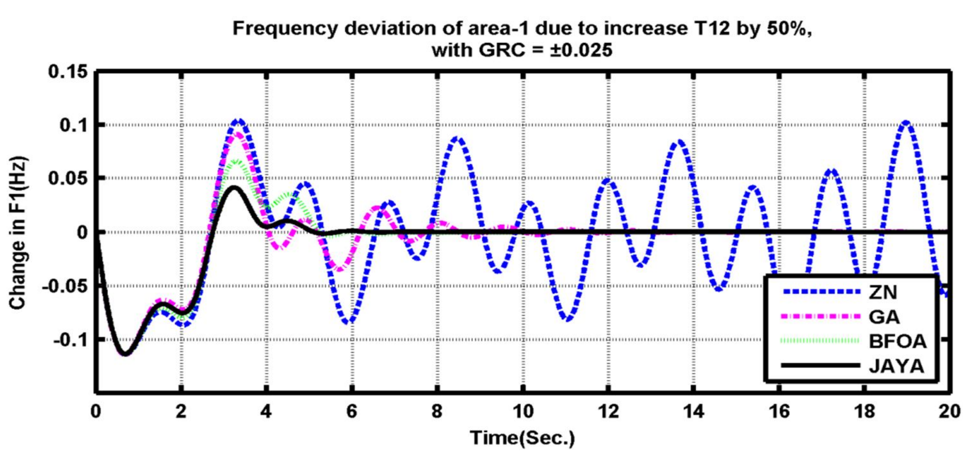

Fig.15 Frequency deviation of area-1 due to increase for $T_{12}$by 50% ,with GRC=±0.025

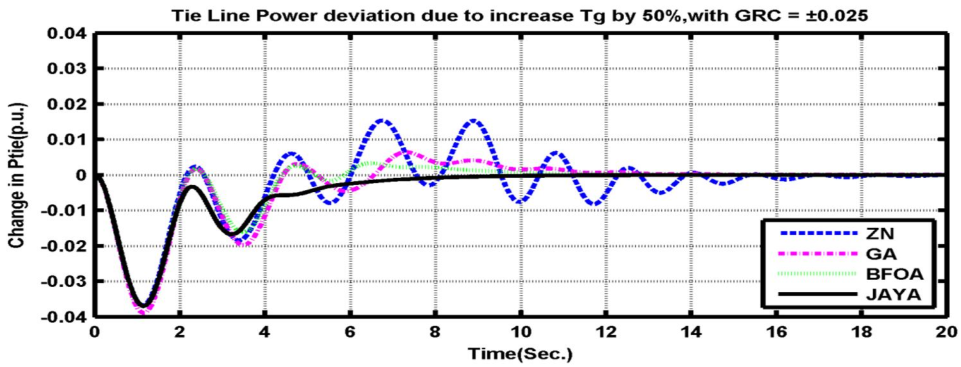

Fig.16 Frequency deviation of area-2 due to increase for T_g by 50% ,with GRC=±0.025

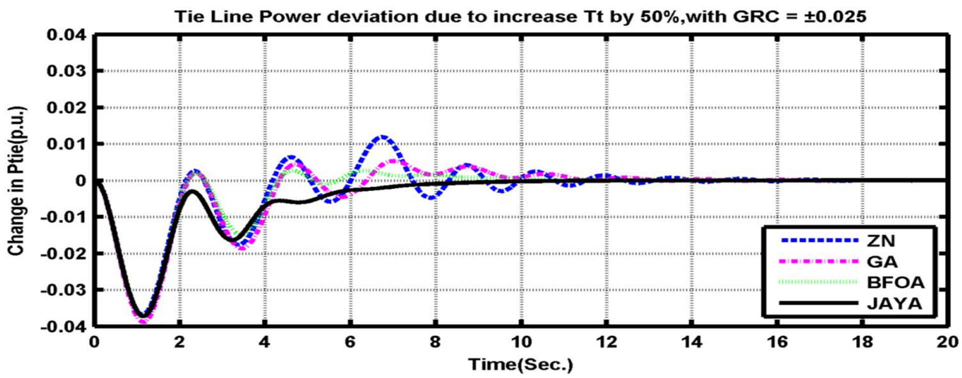

Fig.17 Tie line power deviation due to increase for T_t by 50%, with GRC=±0.02

V. CONCLUSIONS

In this paper, Jaya Algorithm (JA) is applied to optimize PID controller parameters for two area non-reheat thermal power systems with non linearity. It optimized the parameters of PID controller employing an ITAE objective function. The proposed JA based PID controllers provided better performance compared to some already applied techniques such as Ziegler Nichols, Genetic Algorithm and Bacterial Foraging Optimization Algorithms for the equal interconnected power system. Furthermore, the sensitivity analysis is performed by varying the system parameters from their nominal values. It is observed that the proposed controller is robust for wide range of system parameters variations from their nominal values.

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