LOAD FREQUENCY CONTROL OF THREE AREA THERMAL SYSTEM USING GWO ALGORITHM OPTIMIZED 2DOF-IDD CONTROLLER

Bhawana Gurjar[1]
M.tech Scholar
Electrical Engineering
SITE,Nathdwara

Kapil Parkh[2]
Assistant Professor
Electrical Engineering
SITE,Nathdwara

Raunak Jangid[3]
Assistant Professor
Electrical Engineering
SITE,Nathdwara

ABSTRACT— Now a days due to random variation in load demand it is very complicated to keep the load frequency constant for operation of power system. Many researches are going on for load frequency control which incorporates automatic generation control criterion with different optimization algorithms to optimize the controller parameters to maintain load frequency within permissible limit.

In this presented work, 2-Degree of Freedom-Integral Double Derivative (2DOF-IDD) controller is proposed for load frequency control of 3-unequal areas thermal power system. Each area consists 3%/min generation rate constraint.2DOF-IDD controller parameters are optimized using grey wolf optimizer(GWO) algorithm and obtained result are also compared with cuckoo search(CS) algorithm result for same interconnected power system. Simulation is performed for different conditions and sensitivity analysis (change in loading condition, random load pattern).Analysis is done by MATLAB/Simulink , proposed controller shows very effective result for improving stability and load frequency control.

Keywords— *Automatic Generation Control; CS Algorithm;GWO Algorithm , 2DOF-IDD Controller; Load Frequency Control;GRC*

1. INTRODUCTION

1.1Introduction

Due to increasing load demand power system becomes more complex to maintain their system parameters within permissible limits. To manage tie line power and frequency constant to its rated value is also a vital problem. AGC play major role to maintain frequency and tie line power constant. Due to sudden load changes and disturbances produced active power becomes less than power demanded which resulting into decreasing in frequency and vice versa. To keep the every unit generation at most economical level, balance is required between net generation and demanded loads with losses[1]. Many investigations and researches are done or ongoing for automatic generation control of isolated and interconnected power system.Comparative performance of various controllers like integral, proportional integral, integral derivative, proportional integral derivative and integral double derivative are also introduced for LFC purpose[2]. In this presented work 2DOF-IDD controller is used with grey wolf optimization algorithm.

Some most commonly used optimization algorithms for load frequency control are fuzzy logic[3], ANN[4], GA[5], PSO[6], DE[7], firefly algorithm[8]. To obtain better performance in AGC some authors uses supervised ANN and some author's uses fuzzy logic based controllers. Modern metaheuristic techniques are enhanced with a target to carryout inclusive search which can't be solved by classical techniques. Performance of metaheuristic algorithms are enhanced to meet the best features in nature selecting by fittest in biological systems which evolved by natural selection.GA is used for optimization of controller gains but in recent research it have some difficulties. To resolve these problems of local optimum methods, Bacteria Foraging technique[9] is used for optimization by researchers. Firefly algorithm[10] is developed and applied successfully for AGC of an isolated CCGT plant.

Recently Cuckoo search (CS) has been developed by Yang and Deb. CS algorithm is based upon the obligate brood parasitic nature of some cuckoo species in combination with flight behavior[11].

In this paper GWO algorithm for optimization of 2DOF-IDD controller gains for unequal 3-area reheat thermal system.GWO having effective features among the other population based algorithms due to the features of parameter control, automatic zooming and frequency control. For proposed work sensitivity analysis is also done and compared with results of CS algorithm. 1.2 **Objective Function**

Main purpose the paper is to achieve load frequency control and maintain stability of the system By minimizing the cost function which is given by ITAE type objectives function is used

$$J = \int_0^T \{(\Delta F_i)^2 + (\Delta P_{Tiej-k})^2\} dt \qquad (1)$$

Where,

J=area number (1, 2), k=2(for j≠k), 3.

ΔF_i= change in frequency; $\Delta P_{Tie-j-k}$=change in tie line and area j &k

2. SYSTEM MODEL

2.1 Three Unequal Multiarea Thermal System

In the presented consisting 3-unequal area thermal system of capacities- area-1,2,3 as 2000MW,6000MW & 12000MW respectively .All areas are implemented with single reheat turbine & 3%/min generation rate constriant.Fig.1 shows the proposed model of three unequal area[12].

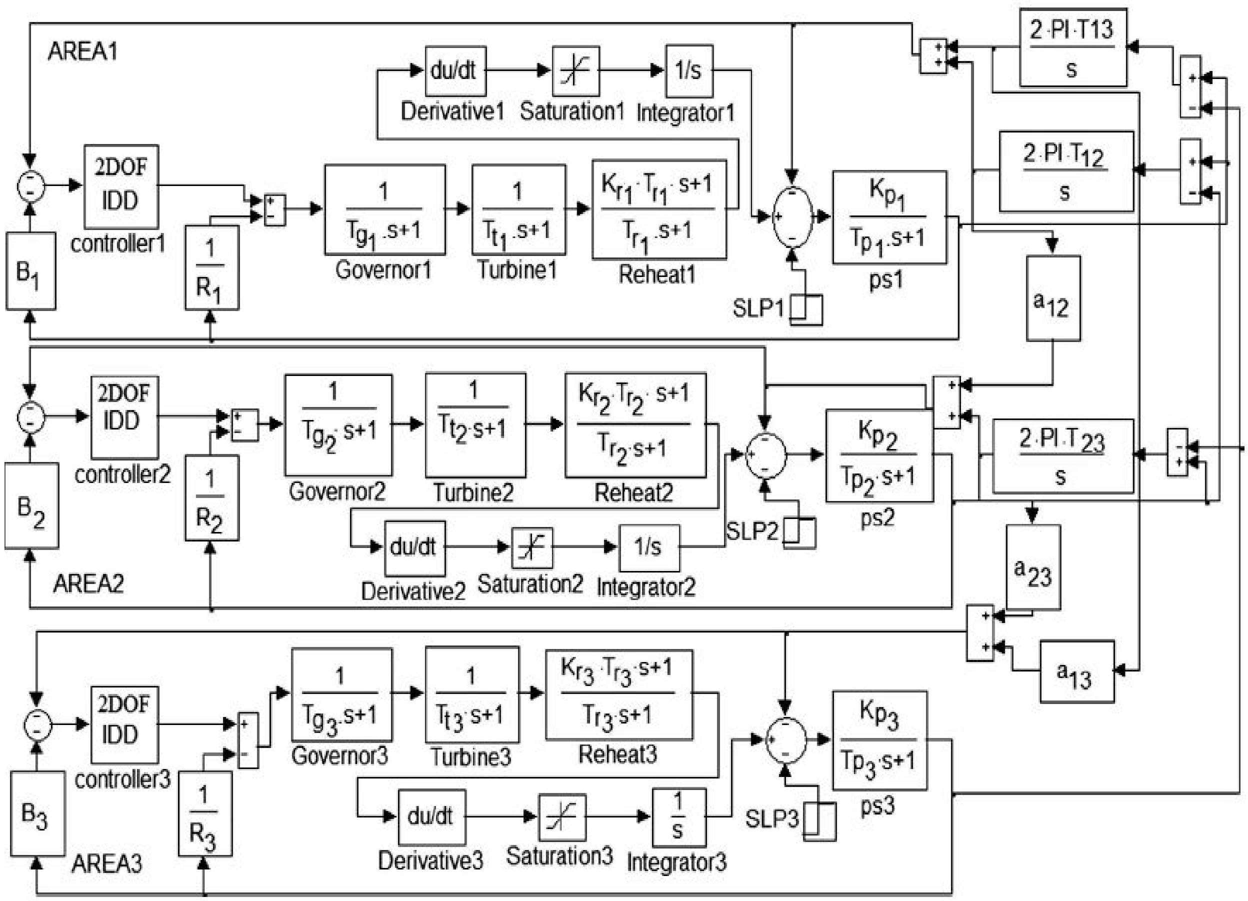

Fig.1 Two area Non Reheat Thermal System.

In this system parameter of speed regulation of governor is R_i=2.4Hz/pu MW and frequency bias B_i=$ß_i$ is considered.Different parameters of per unit values of the unequal areas are respective bases. In this system we use 2DOF-IDD controller are considered.Dynamic performance of developed system is evaluated using 1% SLP in Area-1.

3. GWO Tuned 2DOF-IDD Controller

3.1 Grey Wolf Optimizer(GWO)

A novel technique inspired by grey wolves is called GWO.This technique follows leadership and hunting mechanism. In live in pack there is a leader who in Alpha indicates their strict social dominant strategy and most of decision for group is also taken by him which decisions followed by other members of group. Common decisions include sleeping place at night, walking time, hunting etc. Alpha may not be the strongest member of group but it well manages the whole group, this implies that the discipline and organization in the pack is considered prior to the strength. Group have also subordinates members named as β (Beta) who helps alpha for decision making ,in other words we can say they are the advisor for leader to take correct decision and maintain discipline in group . β are also come next in line to become α if the present α passes away or has become old. It obeys the Alpha and gives command to other wolfs. β also provide feedback to the α [13].

The main function in hunting are,

- Followup the prey, encircling, of prey.
- Attack on prey.

3.2 Mathematical Model and Algorithm

It is a versatile algorithm. Wolfs lives in social pack and hunts too in pack. This is the very appealing behavior of algorithm. GWO mimics this. Here is the outline of the process showing how it does it [14].

3.2.1 Social Hierarchy

First best solution is α, second best solution is ß and third best solution is δ. Apart from these all the candidate solutions falls under ω.

3.2.2 Prey Encircling

Prey is encircled by Grey wolfs while hunting. To reflect it mathematically,Fig.2 shows a gray wolf social hierarchy & fig.2 shows possible of next location.

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \tag{2}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \tag{3}$$

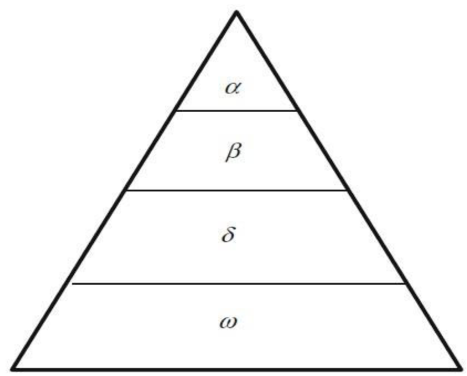

Fig. 2: Grey Wolf Social Hierarchy

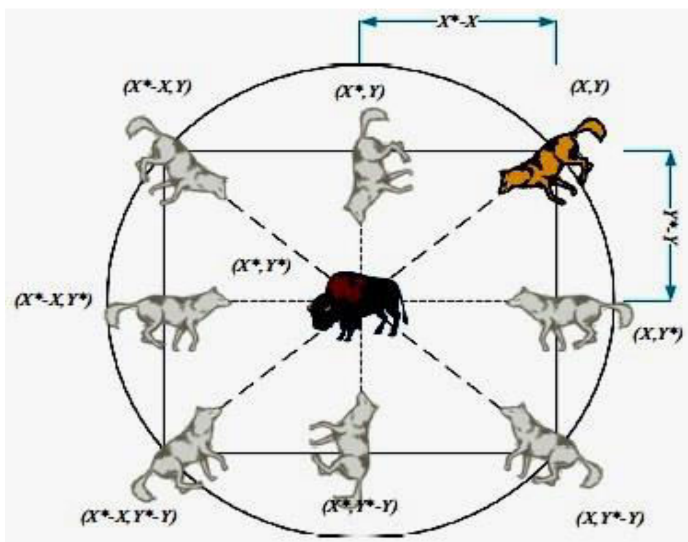

Fig.3: 2D Position Vector with Possible Next Location

In the above figure, it is clear that as the position of prey (X*, Y*) changes a grey wolf will also change its position (X, Y).

3.2.3 Hunting

α guides the hunting while ßand δ might take part in it sometimes. Grey wolfs can identify prey location and encircle them. Although, in a search space the location of prey is unknown i.e. optimum. To simulate the hunting by grey wolf mathematically, it is assumed that the Alphas i.e. best candidate solution; ß and δ have the better knowledge regarding prey possible location.

3.2.4 Attacking

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The moment prey stop moving, grey wolf initiate attacking it i.e. the step after hunting. It is the process of exploitation. The value of $\vec{a}$ is reduced so as to get mathematical realization of it. Hence, variation range for $\vec{A}$ reduces where it is a random value falls in [-2a, 2a] and during the iteration $\vec{a}$ changes from 2 to 0. If, $\vec{A}$ has the random value in[-1,1], then search agent can have its search position anywhere between its existing position and prey's position, as depicted in figure below, where, |A| <1 shows that wolves are attacking prey. [15]

3.2.5 Prey Searching

Searching depends upon the alpha, beta and delta positions. At, first they diverge and then they converge for attack. For mathematical realization of divergence, $\vec{A}$ is used having random values > 1 or <-1 to depict the action of diverge of search agent. It emphasizes on exploration allowing GWO to search globally. |A| > 1, for getting the fitter prey. Exploration favors by vector $\vec{C}$. It is clear from the eqn, it has random values in [0, 2].

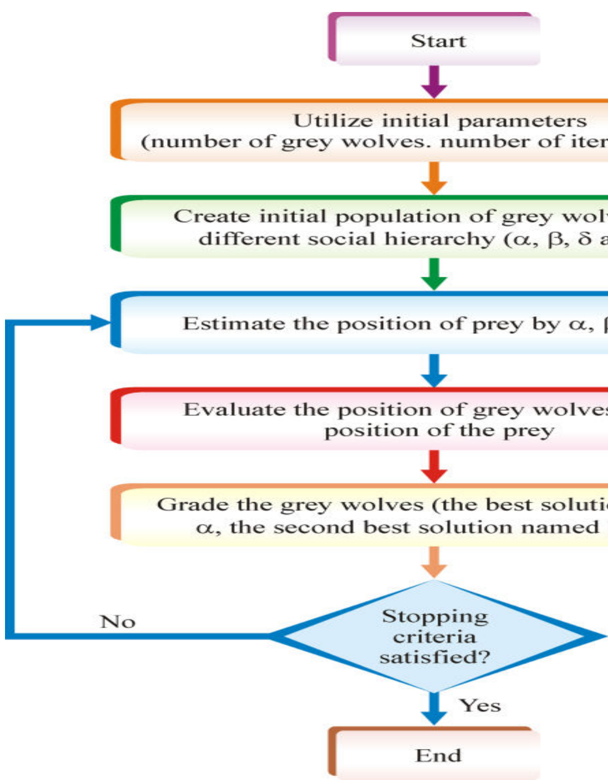

Fig.4.: Flow Chart of GWO Algorithm[15]

3.3 GWO Tuned 2-DOF-PID Controller

Degree of freedom(DOF) is defined as closed loop transfer function which are adjusted independently for a system.2-DOF structure is applied in the field of control engineering to enhance control quality meant for not only fine set point variable tracking but also for better disturbance rejection.2-DOF controller have two inputs named as reference signal and measured output signal.2-DOF scheme yields output signal which depends on variation of a reference signal R(s) and calculated system output Y(s).2-DOF structure having proportional set point weightings ,weighted modified signal for derivative ,integral and proportional actions is calculated. Each specified action is weighted in accordance to the selected gain limits. Figure shows the control scheme of 2-DOF controller where R(s) denotes the reference signal, Y(s) denotes feedback from measured system output, C(s) is 1-DOF controller & F(s) is pre filter on R(s) and U(s) represents output signal. For 2-DOF –PID controller F(s) and C(s) are given by[16]:

$$F(s)=\frac{(bK_{pi}+cK_{Di}N_i)s^2+(bK_{pi}N_i+K_{Ii})s+K_{Ii}N_i}{(K_{pi}+K_{Di}N_i)s^2+(K_{pi}N_i+K_{Ii})s+K_{Ii}N_i} \tag{4}$$

$$C(s)=\frac{(K_{pi}+K_{Di}N_i)s^2+(K_{pi}N_i+K_{Ii})s+K_{Ii}N_i}{(s+N_i)s} \tag{5}$$

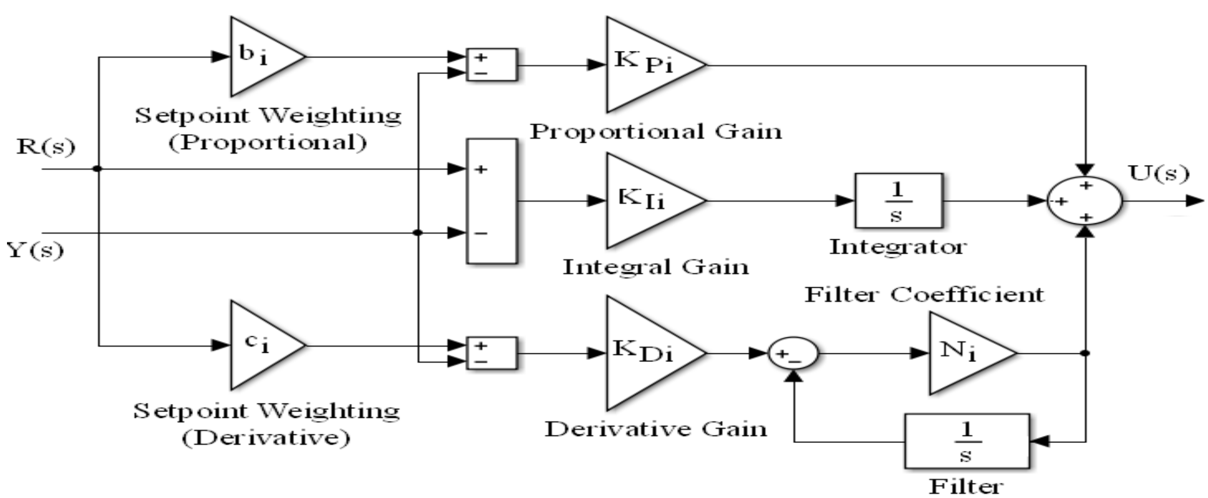

Fig.5: 2DOF-PID Controller transfer function model.

Where K_{Di}, K_{Ii} and K_{Pi} are the derivative, integral and proportional gains respectively, b_i and c_i are the set point weights of proportional and derivative actions respectively and N_i is the filter coefficient for derivative action.2DOF-PID controller transfer function model is shown in fig. 5.

4. RESULT AND DISCUSSIONS

In this paper a novel Gray Wolf Optimization(GWO) is apply for 3-unequal areas non-reheat thermal power system with consideration of GRC of 3%/min. AGC in 3- areas thermal power system to be design with integral plus double derivative (2DOF-IDD) controller and optimal parameters of system are get by Gray Wolf Optimization (GWO) technique and objective function is Integral Time multiplied Absolute Error. The result of this technique has been compared and analysis with the recent heuristic optimization techniques as cuckoo search (CS) algorithm based 2DOF-IDD controller for same interconnected power system. The simulation result is analyzed with various condition and sensitivity analysis.The various graph plotted with respect to time as change in deviation in area1 and tie line power. The system performance is evaluated by MATLAB/Simulink environment. GWO optimized based 2DOF-IDD controller shows superior response than other recently publish algorithm and finally proposed system shows robust and satisfactory result at all disturbance conditions.

4.1 MATLAB Model of Three –unequl Areas of Thermal System

Fig.6 shows a MATLAB/Simulink model of 3-unequal areas thermal system with no reheat turbine. The system is divided in 3- areas and each area equipped with controller.

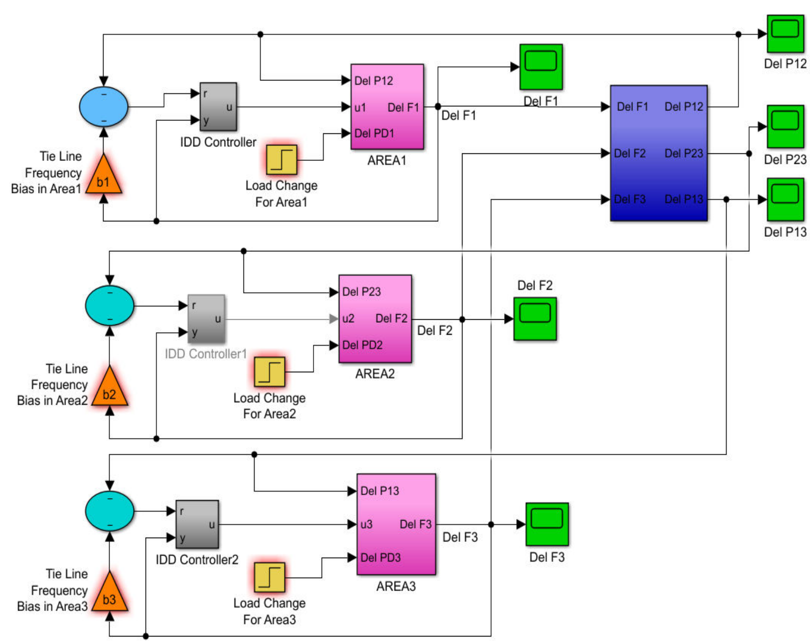

Fig. 6. MATLAB/simulink Model of 3- Area Thermal System

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Each area equipped with single reheat turbine and has a GRC of 3% per minute. Different parameters of system are shows in appendix. System performance has been checked by 1% SLP in Area-1. The system evaluated with various deviation and parameters variation.

4.2 GWO Optimized 2-DOF-PID Controller Parameters

Table-1 shows various parameters of 2DOF-PID controller tuned by GWO technique and fig.7 show the graph of best cost v/s iteration graph of GWO technique.This graph shows performance of GWO technique.

Table 1 Parameters of 2DOF-PID Controller

Controller Gain	Parameters Based on CS(Cuckoo Search)	Parameters Based on GWO(Gray Wolf Optimization)
K_{I1}	0.10710	0.9217733
K_{I2}	0.05500	0.2545
K_{I3}	0.12420	0.1486
K_{DD1}	0.01110	0.2728
K_{DD2}	0.00720	0.130508
K_{DD3}	0.0561	0.153211
N_1	83.6801	285.8158
N_2	54.8838	398.45
N_3	49.6356	351.33
C_1	0.0927	0.02247
C_2	0.0303	1.0
C_3	0.13507	0.039039

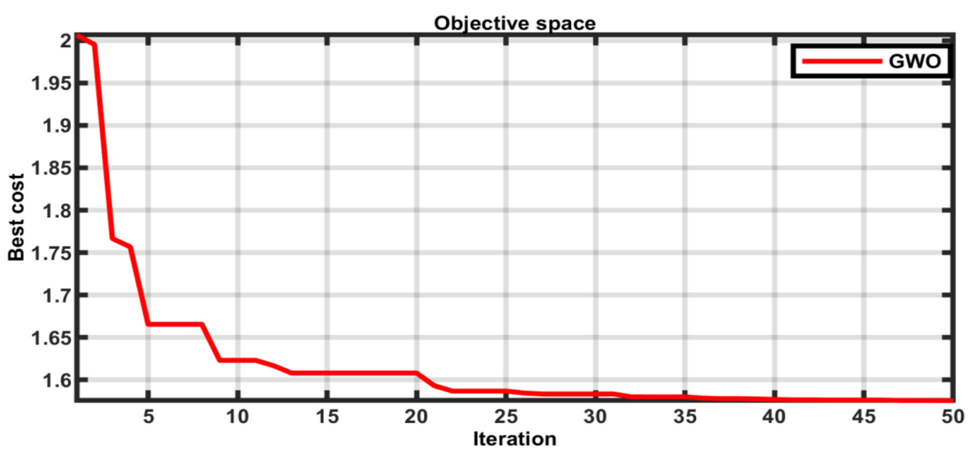

Fig.7: Best Cost v/s Iteration Graph of GWO Algorithm

4.3 Time Domain Simulation

In this paper we have consider 3-unequal area thermal systems and GRC is included in the system. The performance analysis of system is done by change in area-1 and sensitivity analysis. The first the system is apply in change in area-1 by two algorithms CS and GWO and then apply sensitivity analysis by GWO algorithm at various cases. The various parameters of this controller and controller parameters are optimized by GWO algorithm is present in tabular form.

4.3.1 Case-1:1% Change at Area-1

Fig.8 to 11 is shows that proposed 2DOF-PID controller tuned with GWO algorithm and their performance compare with CS algorithm as same controller and same system. The system shows better response in term of settling times in frequency, tie line power deviation when system is applied with GWO tuned 2DOF-PID controller. The various deviations are presented in graphical form as frequency deviation of area-1to 3 and tie line power deviation of area 1 & 2. The comparison of different settling time with two techniques is shown in table 2.

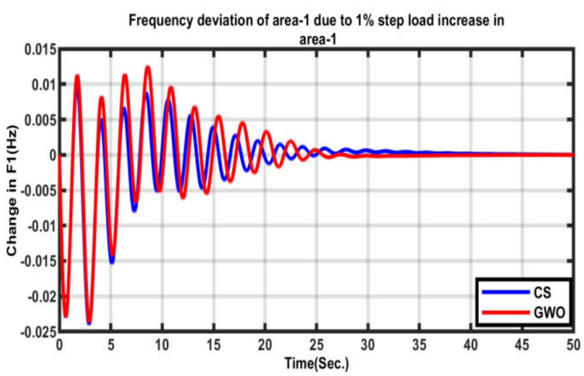

Fig.8Frequency Deviation of Area-1 for 1% SLI in Area-1

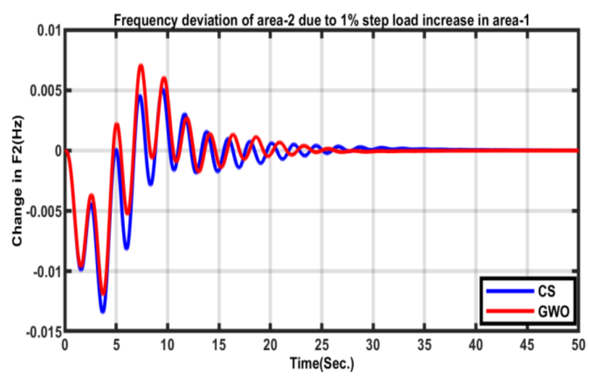

Fig.9 Frequency Deviation of Area-2 for 1% SLI in Area-1

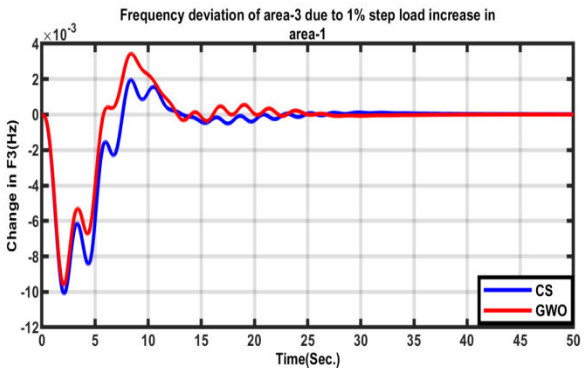

Fig.10 Frequency Deviation of Area-3 for 1% SLI in Area-1

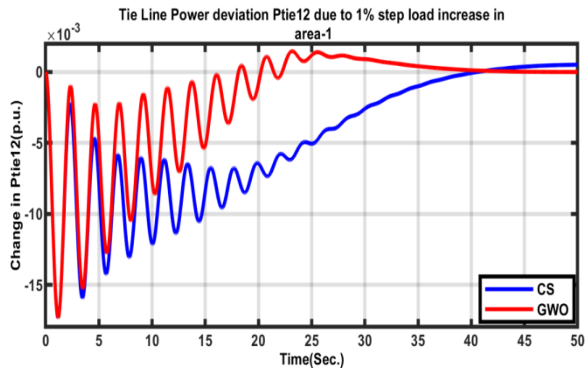

Fig.11 Tie Line Power Deviation of Area-1& 2 for 1% SLI in Area-1

Table -2 Settling Time at 1% Change in Area-1

Deviation	CS(Cuckoo Search) Settling Time (Second)	GWO(Gray Wolf Optimization) Settling Time (Second)
ΔF_1	31.9963	25.2047
ΔF_2	28.8593	23.6578
ΔF_3	28.8593	23.6578
ΔP_{tie12}	41.9817	35.7228

4.3.2 Sensitivity Analysis

In this condition we have consider various types of cases consider and system performance check with various loading and operating condition as change in loading condition, size of SLP, random load pattern, All sensitivity analysis is done by GWO algorithm. It can be concluded that performance values vary within satisfactory ranges and close equal to the respective values obtained with nominal system parameter. It can be observed that the proposed controller gives better dynamic performance than optimized by GWO algorithm.

4.3.2.1 Change in Loading Conditions

Fig.12 to 15 shows various response of $\pm 25\%$ increase/decrease in nominal loading condition. We have obtain frequency deviation in each area and tie line power deviation of different area .The controller parameters as nominal condition and parameters variation are define by table 3.The parameter variation does not affect the system performance and finally concluded that the proposed GWO tuned 2DOF-PID controller provides robust control under large changes of system loading.

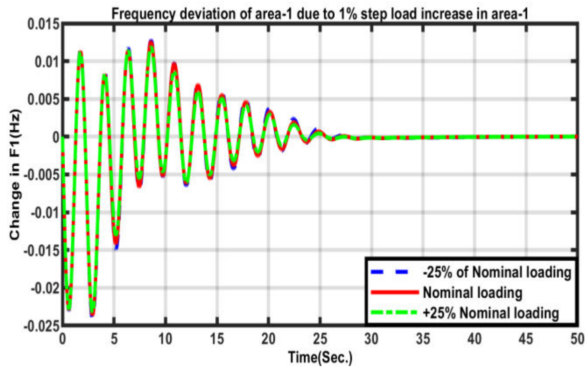

Fig.12Frequency Deviation in Area-1 for Change in Loading Condition

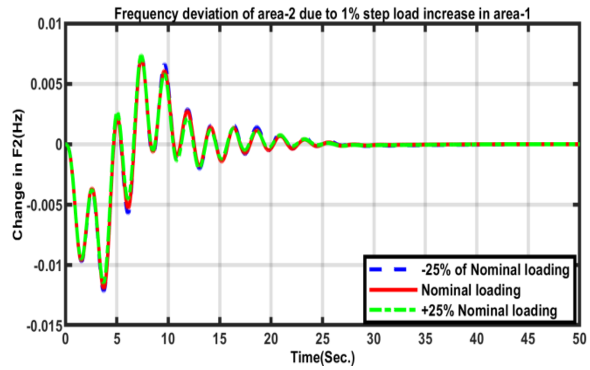

Fig.13 Frequency Deviation in Area-2 for Change in Loading Condition

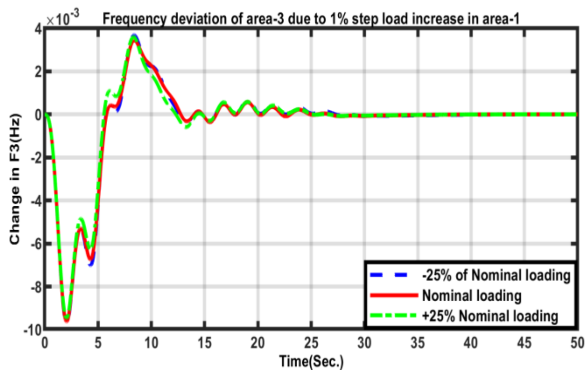

Fig.14 Frequency Deviation in Area-3 for Change in Loading Condition

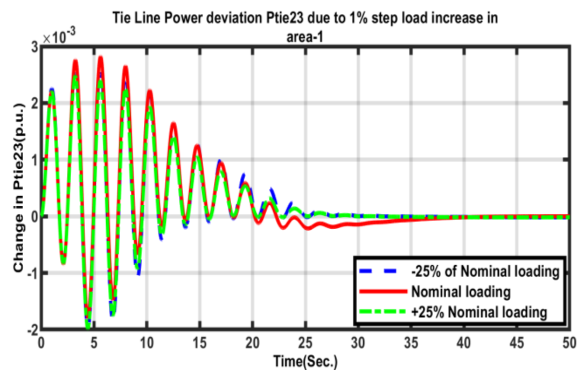

Fig.15 Tie Line Power Deviation in Area 2 & 3 for Change in Loading Condition

Table 3: Optimal Value of Controller of Parameter Variation of Change in Loading Conditions

Gains	Loading Conditions		
	Nominal	**+25%**	**-25%**
K_{I1}	0.9217733	0.9893	0.9999531
K_{I2}	0.2545	0.1108	0.1060191
K_{I3}	0.1486	0.1885	0.1578
K_{DD1}	0.2728	0.2751	0.2902
K_{DD2}	0.130508	0.1035	0.118888
K_{DD3}	0.153211	0.1532	0.1328
N_1	285.8158	74.2216	118.2415
N_2	398.45	491.1606	72.55044
N_3	351.33	240.6536	100.4081

C_1	0.02247	0.0574	0.1553
C_2	1.0	0.8162	0.047475
C_3	0.039039	0.0015	0.051507

4.3.2.2 Parameter Variation of Random Load Pattern

Fig.16 shows graph a random variable load apply in area-1.So fig.17 to 22 shows various response of random load pattern in area-1. We have obtain frequency deviation in each area and tie line power deviation of different area .The controller parameters variation are define by table 4.The parameter variation does not affect the system performance and finally concluded that the proposed GWO tuned 2DOF-PID controller provides robust control under large changes of random load varation.

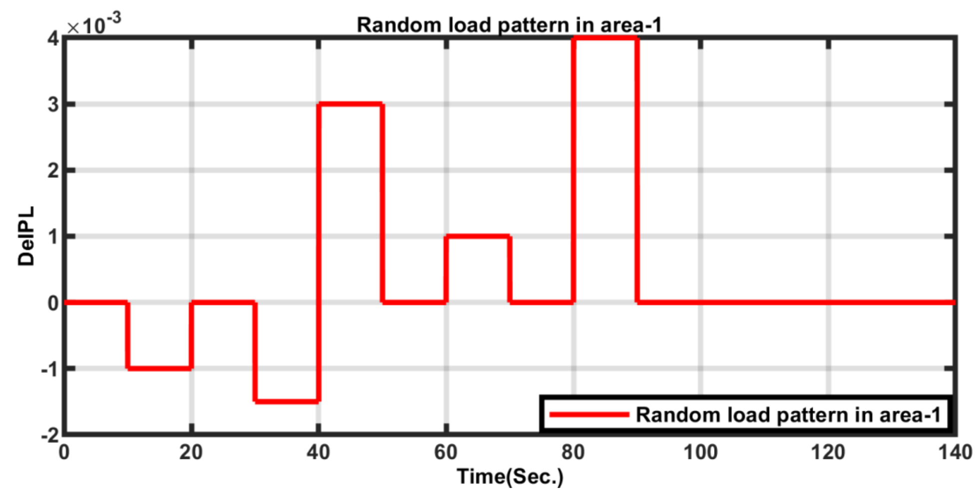

Fig.16 Random Load Variation in Area-1

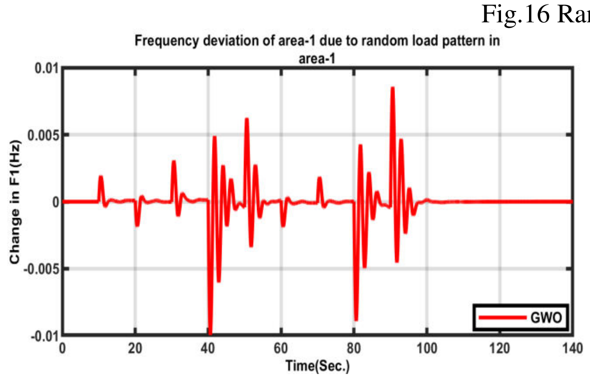

Fig.17 Frequency Deviation in Area-1 due to Random Load Pattern

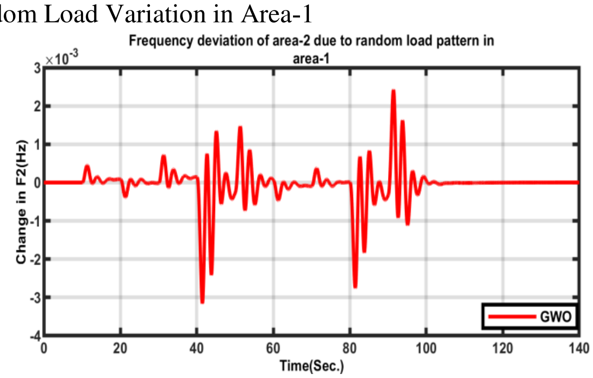

Fig.18 Frequency Deviation in Area-2 due to Random Load Pattern

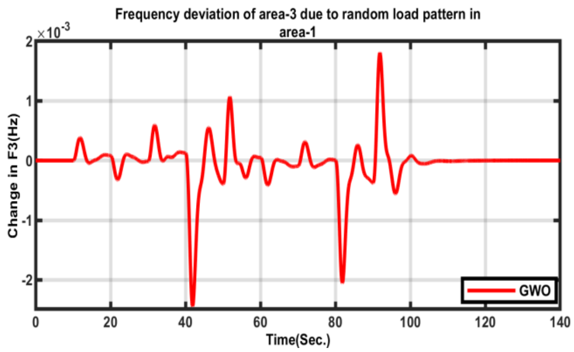

Fig.19 Frequency Deviation in Area-3 due to Random Load Pattern

Fig.20 Tie Line Power Deviation in Area 1& 2 due to Random Load Pattern

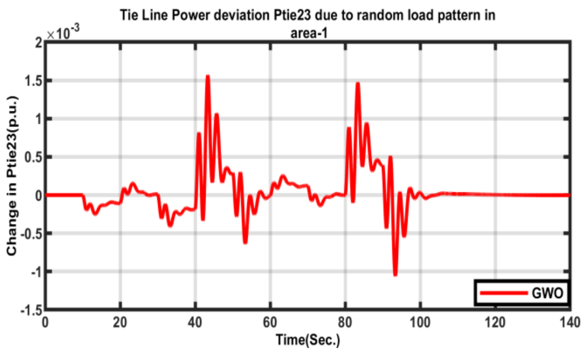

Fig.21 Tie Line Power Deviation in Area 2 & 3 due to Random Load Pattern

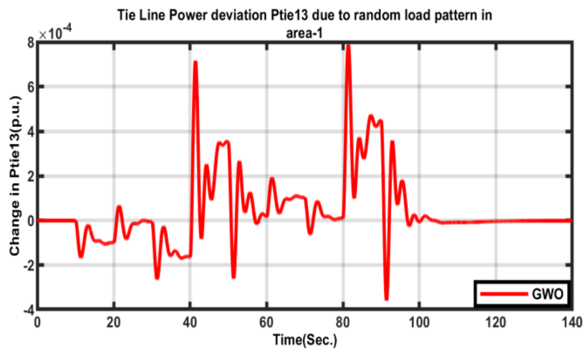

Fig.22 Tie Line Power Deviation in Area 1 & 3 due to Random Load Pattern

Table 4 Optimal Value of Controller of Parameter Variation of Random Load Pattern

Gains	Parameters of Random Load Pattern for 2DOF-PID Controller
K_{I1}	0.001
K_{I2}	0.9037147
K_{I3}	0.1965927
K_{DD1}	0.2975798
K_{DD2}	0.2822376
K_{DD3}	0.4424953
N_1	457.8377
N_2	50.29273
N_3	477.4545
C_1	0.9903223
C_2	0.2698537
C_3	0.1333892

5.CONCLUSIONS

In this paper a LFC of three unequal areas thermal power system is proposed. Every area is consideration of Generation Rate Constraint (GRC) of 3%/min. Controller (2DOF-IDD) is optimized by Gray Wolf Optimization (GWO) technique. The result compared with the cuckoo search (CS) algorithm for same interconnected power system. The simulation result is analyzed with various condition and sensitivity analysis. The different loading and parameter variation is applied in the system but every condition system shows superior response when controller parameters tuned with GWO technique. The various controller parameters are presents in tabular form and it is observed that, the dynamic performance of proposed controller is improved. Moreover, it is also seen that the designed system is tough and is not affected by changes in the loading condition. The entire conditions GWO tuned 2DOF-PID controller based system shows best performance and improves the stability of the system.

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