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Optimized Automatic Generation Control Using Single and Multi-Objective Hybrid Genetic Differential Evolution Technique

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ABSTRACT: This paper presents the optimization of proportional integral derivative (PID) gain parameters through both single and multi objective Hybrid Genetic Differential Evolution (HGDE) technique for automatic generation control scheme. The controls are implemented for 0.1 load disturbance in area1only and computed with sum of absolute value of i^{th} area control error at time t as objective functions. While employing multi objective HGDE optimization techniques, best compromise solution of the corresponding PID parameters are obtained based on fuzzy membership function assignment technique. Furthermore to show the superiority of the suggested method comparison analysis is done with GA-PID and DE-PID optimizing techniques and according the obtained result HGDE is getting better in achieving lesser settling time, undershoot and overshoot

Keywords: Load frequency control, participation factor, single and multi objective HGDE,best compromise solution, frequency response, tie line power response

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I. INTRODUCTION

One of the cause in which frequency oscillation to appear in power system is the increasing in size of interconnected power system as well as poor control strategy, this leads to frequency instability and may result in power disconnection. So to overcome this difficulty, recently, corresponding to the increasing human electric power demand need due to the rapid growing technonology,electrical network interconnection with good control strategy must also required, for this the interest of load frequency control which is one of the function of AGC is growing up [1].Generally frequency control classified in to three catagories,primary control or governor control, secondary control or LFC control and tertiary control sometimes economic dispatch control or also known as in other references emergency control [1,2] and the main aim of this control systems is to maintain balance between consumed power and generated power as well as to hold frequency at its nominal value.

Conventional controller tuning method such as Ziegler Nichols was used to solve the AGC problem. In [3] Ziegler Nichols PID tuning method is applied for load frequency control application and the result is compared with conventional integral controllers, even though these Ziegler Nichols methods coming better here, generally these traditional methods have their own drawback for employing in large interconnected power system, some of the reasons are, they do not perform adequately for non-linearity and uncertainty cases and results in poor transient performance and slow in action with large overshoot and long settling time is mentioned in [4,5].Besides this, these controllers are in effective to meet the standards of LFC under diverse operating circumstances of the system because the gains selection procedure is not based on specific criterion, it is totally depended on the experience of the researcher.

Significant development of evolutionary based optimization methods such as GA and DE for AGC application are shown and reported in literature recently to solve both single and multi objective problems depending on the nature of the problem. Genetic algorithm is one of a heuristic approach optimization technique which was explored its use and introduced by Holland [6].Genetic algorithm (GA) is started with a number of individuals which form population. Solution of new population formed from old population. This motivation creates a hope that new population is considered to be better than old one. In [7] Genetic algorithm along with linear matrix inequality is used to tune PI controller for AGC application having with nine units non reheat multi area thermal power system. Differential evolution developed to optimization problem in 1997 by Rainer StornKenneth Price ,it capable in handling non linear, on differentiable and multi modal objective function, compared to other population based optimization tools like GA and PSO, DE has fewercontrol parameters. The DE‟s control variables, NP, F and CR, are not difficult to choose in order to acquire good results. In DE number of population should not be less than 4, but from experience reasonable NP is taken between 5*D to 10*D where D is dimensional individual vectors or solution's dimension i.e. number of control variables [8].

Recently, to maintain system frequency and tie line power, AGC is playing a great roll, for this researchers are using different types of generating units and controlling techniques to control based on the nature of the problem and the requirement, in [9] the authors' employed AGC application in two area power system with reheat thermal unit using teaching learning based technique of optimization. In [10] GA is applied to improve the stability of power system in two area thermal-thermal power system as the first requirement of AGC is to acquire, secure and economically stable operation of power system in tie line power of interconnected system, since interconnected area is easily sensitive and affected if one of the area is changed so the GA here is used to tune PID controllers and achieved good result in reducing power fluctuations so that to stabilize frequency. According to [11] non reheat type thermal unit is controlled using intelligent and conventional controller method in AGC of single area system.

A suitable linear combination of change in frequency and change in tie line power for i^{th} **area** is known as the **area control error**. The control signals (for each area) are proportional to the change in frequency (Δf_i) as well as change in tie line power ($\Delta P_{tie,i}$) [2,12].In this paper sum of absolute value of ACE of area i at time t ($\sum_{t=0}^{k}\left|ACE_{i,t}\right|$) is used as objective function and the detailed application of this objective function using multiobjective genetic algorithm is clearly described in [13] under which a power system composed of nine units in three area system.

According to [14] multi objective optimization problem is solved by using a combination of Hybrid Sliding Mode Control-Based SMES and genetic algorithm by employing fuzzy-based membership function method to obtain best compromise solution from Pareto set of solution. In [15] genetic algorithm is employed to tune PID for the application AGC in two area non reheat power system using multi objective optimization techniques similarly in [16] fuzzy Sliding Mode Control and genetic algorithm is coordinated to solve multi objective problem

Generally multi objective optimization is used to find different solution in single run.In [17] multi objective DE is employed to solve the load frequency control problem. In [18] the authors' employed DE to tune the PI gain parameter values in AGC of two area non-reheat interconnected thermal system by clearly explaining the procedural steps.

In this paper both single and multi objective GA and DE optimization technique is used to optimize the PID controllers gain parameters for the application of AGC of multi area power system. The following points given below are the contributions in this paper.

- Modeling of two area of AGC having six units using [7,14] as base for parameter data and further reference for the new designed model.
- Identifying the best compromise solution using fuzzy membership function assignment technique among the Pareto set of solution.
- Performing simulation to obtain the optimal gains parameter values of PID through single and multi objective GA and DE which is given in table 1.The simulation is based on 0.1 step load perturbation in area-1 only
- Comparative analysis of GA and DE is done and better performance of LFC controller is achieved through DE technique.

II. POWER SYSTEM MODEL

For the dynamic performance analysis of the AGC using the proposed GA-PID and DE-PID, two area non reheat thermal system having total six units as G1, G2 and G3 in area1, G4, G5 and G6 in area2 are modeled for this paper, as per the share of their participation factor each individual unit will participate in LFC. The nominal parameters are given in appendix A of **7**[7]. According to the rule which is shown in equation (1) for a particular control area total participation factors sum is equal to 1 and a unit having zero participation factor has no any involvement in LFC [2,12].100MW or 0.1pu disturbance in area 1 only is considered for the power system under study here in figure 1.

$$\sum_{k=1}^{n}\alpha_{ki}=1,\ 0\le\alpha_{ki}\le1 \qquad (1)$$

Where

k is for generator unit k for i^{th} area i

α is participation factor

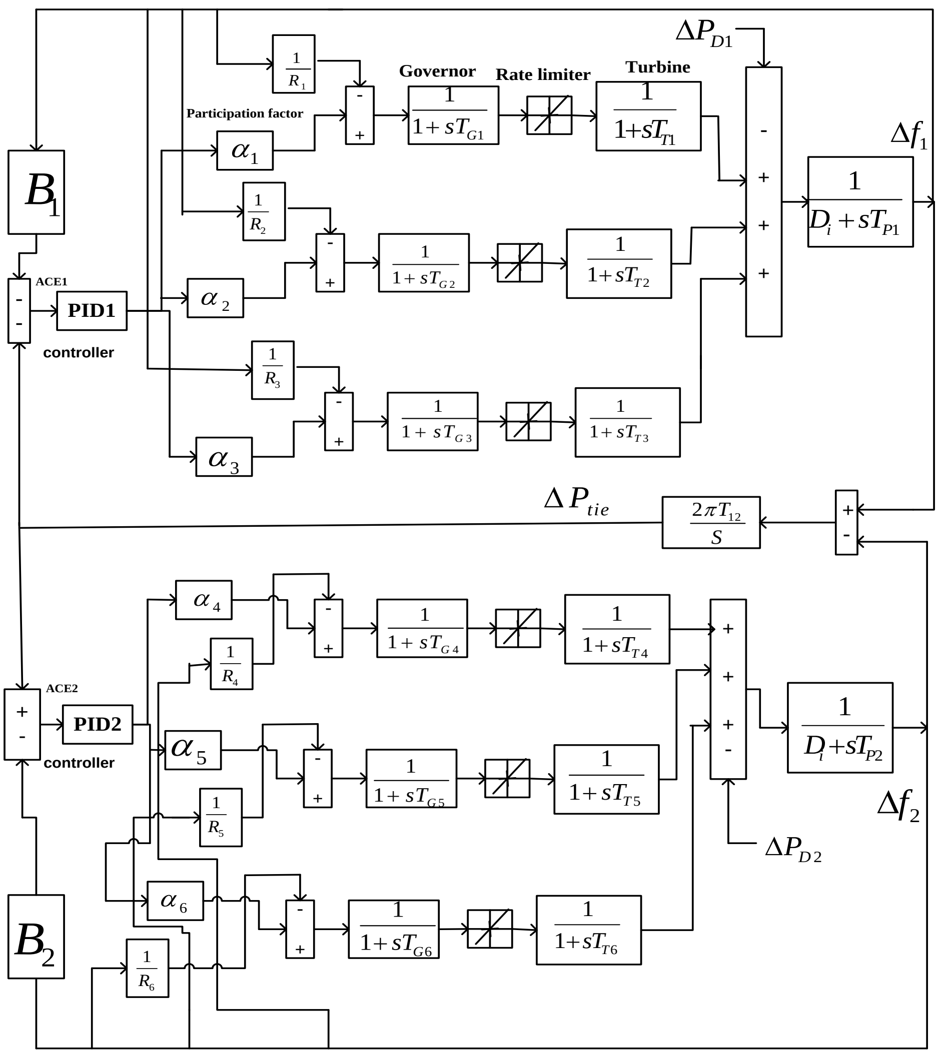

Figure 1 two area AGC model having six non reheat thermal units

III. OPTIMIZATION PROBLEM

The idea behind the optimization technique is in finding the best minimum solution or achieving minimum objective functions, based on the considered model in the present paper the objective functions are formulated on the bases of area control error. The AGC in an interconnected system should control both the interchange power and frequency of local and its neighboring control areas. Disturbance magnitude (P_D) should not be greater than the supplementary (P_C) controller; if such case happens change in tie line power and change in frequency can't converge to zero (0) in steady state [2].From this the main objective of AGC in multi area power system is for converging area control error to zero whenever sudden load disturbance appear, and the single and multi objective optimization techniques using GA and DE are used to tune the PID controller parameters for the application of AGC in this paper. Taking in to account the above consideration in this paper the equations listed in (2) and (3) are taken to be objective functions for single and multi objective optimization respectively [13].

$$J_1 = \left|ACE_{1,t}\right| \quad (2)$$

$$ObjFnc_i = \sum_{t=0}^{K}\left|ACE_{i,t}\right| \quad (3)$$

$$J_1 = \left|ACE_{1,t}\right| \quad (4)$$

$$J_2 = \left|ACE_{2,t}\right| \quad (5)$$

Where $ObjFnc_i$ is the objective functions of power system of area i, K is denoted to be simulation time in (sec.) and $\left|ACE_{i,t}\right|$ is the absolute value of ACE signal of area i at time t.

The problem limitations are the controller parameter bounds. Therefore, the design problem can be described as the following optimization problem:

Minimize, J_1 and J_2 (6)

Subject to

$K_p^{min} \le K_p \le K_p^{max}, K_I^{min} \le K_I \le K_I^{max},$

$K_D^{min} \le K_D \le K_D^{max}$ (7)

Where J_1 in equation (2) for single objective optimization but equation (4) and (5) are for multi objective optimization of under the definition $ObjFnc_i = \sum_{t=0}^{K} \left| ACE_{i,t} \right|$ of the i[th] objective functions and $K_{P\min}$, $K_{P\max}$; $K_{I\min}$, $K_{I\max}$ and $K_{D\min}$, $K_{D\max}$ are the min and max values of control parameters. Based on a report in the literature, the min and max values of controller parameters chosen as -1.0 and 1.0 respectively.

IV. GENETIC ALGORITHM OVERVIEW

Genetic algorithm is one of a heuristic approach optimization technique which was explored its use and introduced by Holland [6].Genetic algorithm (GA) is started with a number of individuals which form population. Solution of new population formed from old population. This motivation creates a hope that new population is considered to be better than old one. In genetic algorithm the first step is randomly creating of population following by evaluating the initial population using fitness function. To select the most fit individual genetic algorithm employs three type of selection process i) roulette wheel selection ii) tournament selection and iii) rank selection. After selection process crossover and mutation operation applied to generate offspring. In this paper the HGDE technique is employed, for that the crossover operation is taken from the GA side and we call it genetic linear crossover and explained in detail in procedure 1 below, linear crossover operator it is applied in HGDE the main objective is generation of new offspring's and substituting their parents with population. In linear crossover in order to substitute parents in the population new offspring will be generated, by assuming p_1 and p_2 as two parent points in the search space, the new generated three points are given in equation (8),(9) and (10),the generated points given in equation (8) are mid points of p_1 and p_2 ,while the generated points in equation (9) and (10) are lying on the line determined by p_1 and p_2 .The main linear crossover procedure is given in procedure 1 [6].

Procedure 1: Linear Crossover (p^1, p^2)

1. Generate three offspring

$c^1 = (c_1^1,...,c_D^1)$, $c^2 = (c_1^2,...,c_D^2)$ and $c^3 = (c_1^3,...,c_D^3)$ are the generated offspring's from parents and the parents are $p^1 = (p_1^1,..., p_D^1)$ and $p^2 = (p_1^2,..., p_D^2)$

$$c_i^1 = \frac{1}{2} p_i^1 + \frac{1}{2} p_i^2, \quad (8)$$

$$c_i^2 = \frac{3}{2} p_i^1 - \frac{1}{2} p_i^2, \quad (9)$$

$$c_i^3 = -\frac{1}{2} p_i^1 + \frac{3}{2} p_i^2, \quad (10)$$

i = 1,…,D.

2. Among the three, choose the best promising offspring in order to substitute their parents in population.

3. Return.

V. DIFFERENTIAL EVOLUTION OVERVIEW

DE technique was proposed by Rainer Storn in 1997, it capable of managing non linear,non differentiable and multi modal objective function, apart from this its main advantages are, simplicity, easy use, real coding, speediness, efficiency and local optimization (searching) property [8]. The four major procedures of differential evolution are described below [18].

5.1 **Initialization operation**

Random selection of parameter values from pre-specified lower and upper limits (bounds) of x_j^L and x_j^U . For each parameter j random selection is given uniformly in the interval as $\left[X_j^L, X_j^U \right]$

5.2 **Mutation operation**

By considering each target vector $X_{i,G}$ at generation G, a mutant vector $V_{i,G} = \left\{ V_{1i,G}, V_{2i,G,} ...V_{Di,G} \right\}$ is generated by using

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}) \quad (11)$$

Where F is a scaling factor from (0, 2), indices r_1, r_2, r_3 are mutually different integer values randomly generated in the range [1, NP], NP is number of population and D is dimensional individual vector or solution's dimension or in another approach known as number of control variables

5.3 **Crossover operation**

Once mutation phase is accomplished crossover operation is started, the process is generating of trail vector by using mutant vector $V_{i,G}$ and target vector $X_{i,G}$.

$$U_{j,i,G} = \begin{cases} V_{j,i,G}, if\,(rand_j[0,1] \le CR) or (j = j_{rand}) \\ X_{j,i,G}, \quad \text{otherwise} \end{cases},$$

j = 1,2...,D (12)

5.4**Selection operation**

In this phase the comparison of trial vector $f(U_i G)$ and target vector $f(X_i G)$ is performed in the current participant population, so that based on their fitness comparison as given on equation (13), the one which is going to be involve in the next generation from either of the two will be identified.

$$X_{i,G+1} = \begin{cases} U_{i,G}\, iff(U_{i,G}) \le f(X_{i,G}) \\ x_{i,G}\, \text{otherwise} \end{cases} \quad (13)$$

Where $i \in [1, N_P]$

VI. OVERVIEW OF THE PROPOSED HGDE ALGORITHM

Hybrid optimization is designed to get the better and to overcome the drawback of simple or direct evolutionary algorithm, even if simple evolutionary algorithm helps us to achieve desired solution but sometimes this algorithm fails to acquire convenient optimal solution, for this hybrid genetic differential evolution is designed in this paper as a solution.

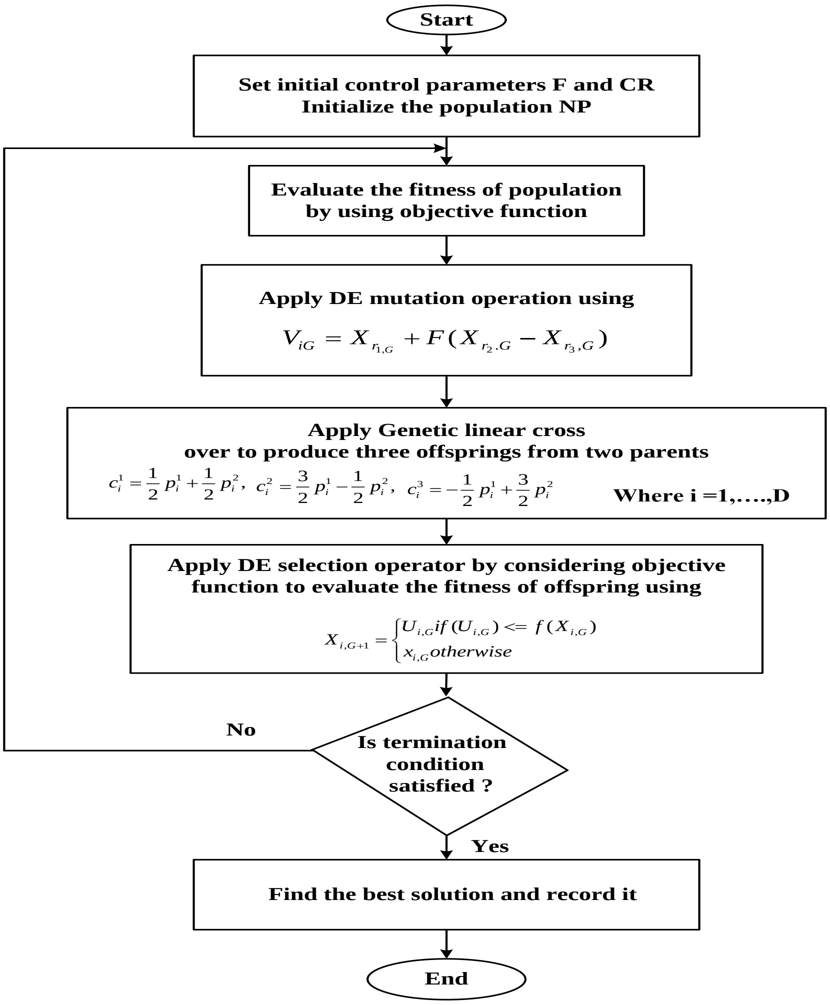

Figure 2 flow chart for the overall over view of HGDE

6.1 Algorithm Steps of HGDE

1.Set generation counter G=0.

2. Set the initialize value of control parameters such as **F, CR** and **NP**

3. Random generation of population P^0

4. Evaluation fitness function for all individuals in P^0

5. **repeat**

6. Set G = G+1 {**Generation (iteration) counter increasing**}

7.**for** (i = 0; i <**NP**; **i++)do**

8. Random selection of indexes r1, r2, r3, where $r_1 \ne r_2 \ne r_3 \ne i$

9. $V_{i,G} = X_{r1,G} + F*(X_{r2,G} - X_{r3,G})$ {**mutation operation using DE**}
10. **end for**
11. **for** (j = 0; j < NP; j++) **do** {**Start linear genetic cross over operation**}
12. Random number r generation from rand ( ) with each $V_{j,G}$ in $P^{(G)}$
13. $c_i^1 = \frac{1}{2}p_i^1 + \frac{1}{2}p_i^2,\ c_i^2 = \frac{3}{2}p_i^1 - \frac{1}{2}p_i^2,$ $c_i^3 = -\frac{1}{2}p_i^1 + \frac{3}{2}p_i^2,$ Where i = 1,…,D.{**creating three offspring's from two parents**}
14. **if** r < CR then apply procedure number 1 to all chosen pairs of $V_{i,G}$ in $P^{(G)}$
15. Update $U_{i,G}$
16. **end if**
17 **end for**
18. **for** (k = 0; k < NP; k++) **do** {**Start DE selection operation**}
19. **if** $f(U_{k,G}) \le f(X_{k,G})$ **then**
20. $X_{k,G+1} = U_{k,G}$
21. **else**
22. $X_{k,G+1} = X_{k,G}$
23. **end if**
24. **end for**
25. Update $P^{(G)}$
26. **Until** iteration no≤ maximum iteration {**until termination condition satisfied**

VII. IMPLEMENTATION OF HGDE ALGORITHM TO AGC

To begin with HGDE algorithm first the parameter to be set are population size (NP), crossover rate (CR) and scaling factor (F), then initial population is randomly generated. The objective functions used to evaluate each individual in a population. All process except crossover including initialization, mutation and greedy selection is operated by DE.The GA is participating in linear crossover operation only, based on a report in the literature many researchers are agreed in the good efficiency of GA in crossover operation.

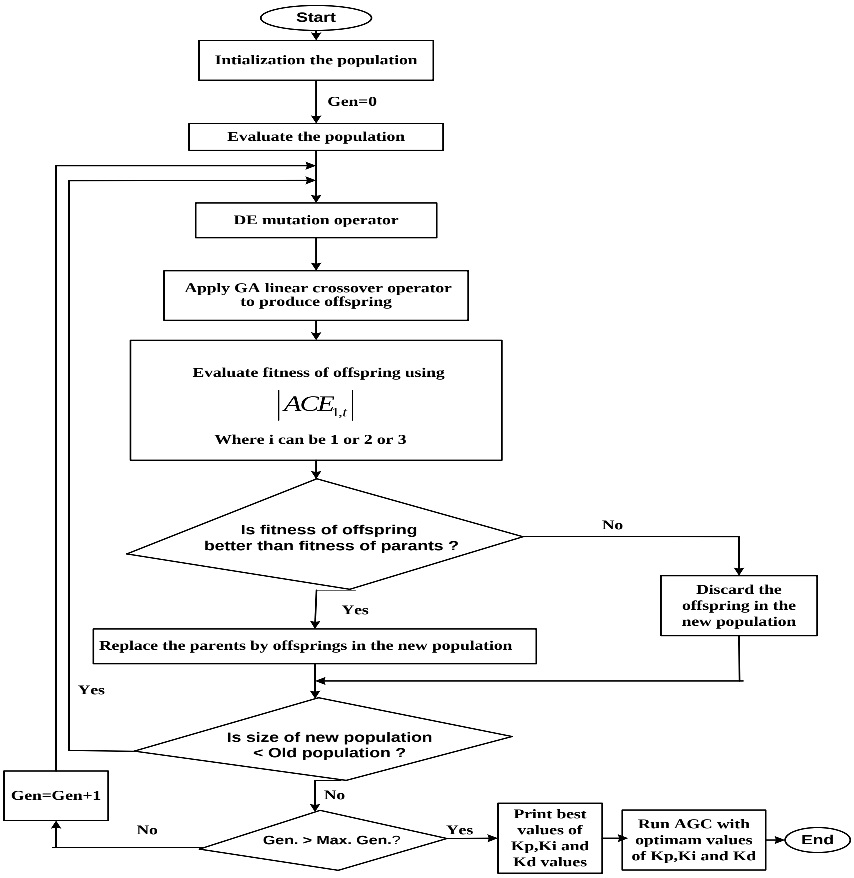

Figure 3 flow chart of single objective HGDE optimization technique

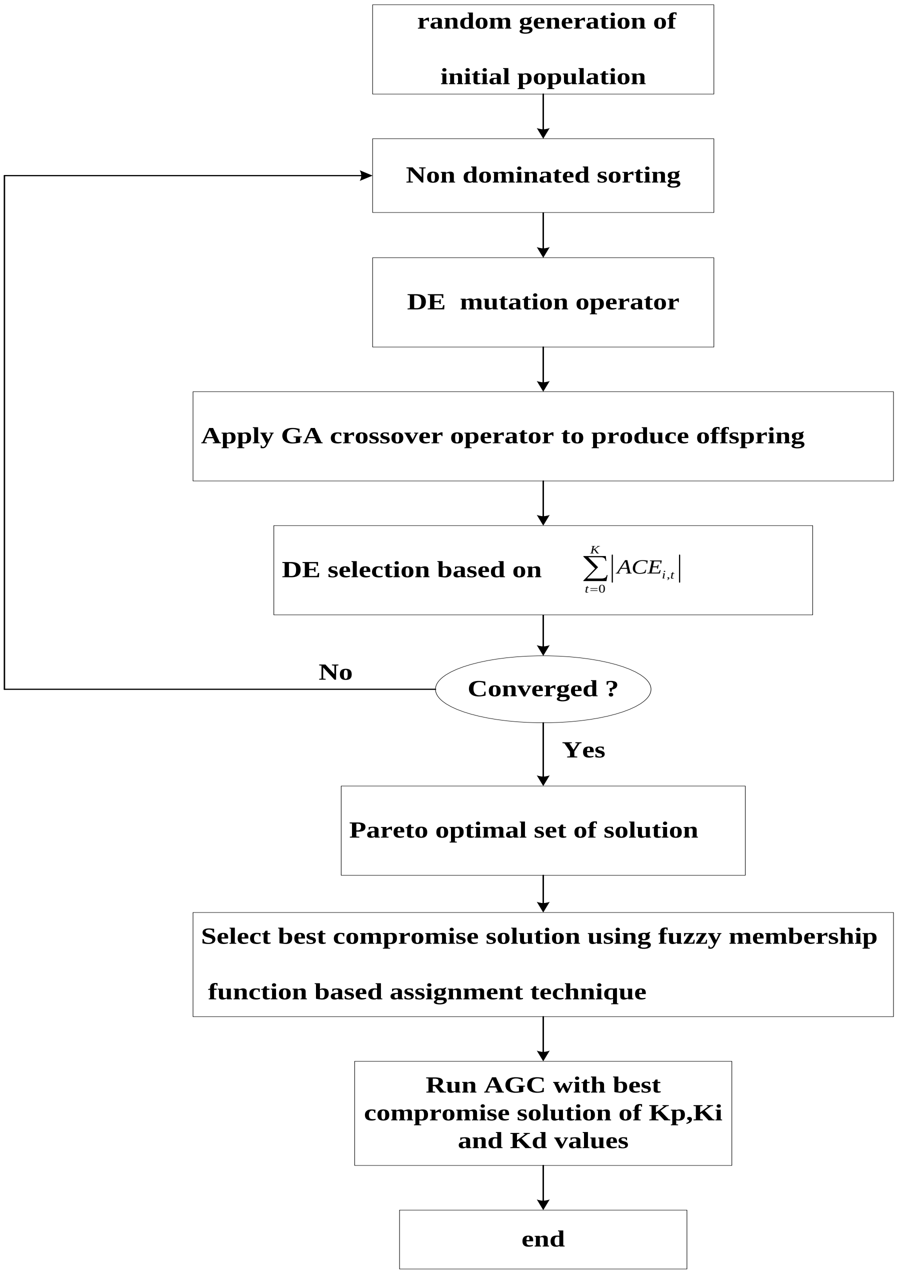

Figure 4 flow chart of multiobjective HGDE optimization technique

7.1 Pseudo code steps for single objective HGDE algorithm

Step 1. Set generation (iteration) counter K=0
Step 2. Input the initial required parameters
Step 3. Random generation of population
Step 4. Evaluate the population
Step 5. Set K=K+1 increasing generation counter
Step 6. Perform DE mutation operation
Step 7. Perform GA linear cross over operation for production of offspring
Step 8. DE selection based on the objective function $|ACE_{1,t}|$.
Step 9. If size of new population less than old population go to step 6 else if go to step 10 to check the next criteria.
Step 10. If generation is not greater than maximum generation go to step 6 else if go to step 11 for output and termination.
Step 11. Out put the optimized (Kp, Ki, K_d)
Step 12. Run AGC with optimal values of (Kp, Ki, K_d)

7.2 Pseudo code steps for multi objective HGDE algorithm

Step 1. Set generation (iteration) counter K=0
Step 2. Input the initial required parameters
Step 3. Random generation of population

Step 4. Sort the initial population using Non dominated sorting
Step 5. Perform DE mutation operation
Step 6. Perform GA linear cross over operation for producing offspring
Step 7. DE selection based using $ObjFnc_i = \sum_{t=0}^{K} \left| ACE_{i,t} \right|$ for two area system
Step 8. Check convergence, if it is converged go to step 9 while a convergence condition not satisfied go to step 4 for non-dominated sorting.
Step 9. Pareto optimal set of solution.
Step 10. Select best compromise solution of Kp, Ki and Kd using fuzzy membership function based assignment technique
Step 11. Run AGC with best compromise solution of Kp, Ki , K_d.

The execution procedure for HGDE-PID is stated in figure 7 and figure 8, While the algorithm is running it is interfacing with the Simulink block of the system under study and it was run repeatedly 20 times and the obtained computed gain values of Kp, K_i and K_d values are listed in table 1.All the required data (parameters) taken for execution of the HGDE algorithm are given in appendix A of table**7**

VIII. BEST COMPROMISE SOLUTION

To select best individual, Pareto based approach is implemented, the objective is identifying non dominated individuals from dominated solution i.e. identifying best turns individual randomly picked, from this set. The desire of Pareto-optimality is a first step for solving a multi objective optimization (MOO) problem. Fuzzy membership function based approach is used in this paper to choose the optimal controller parameters from Pareto optimal set of solution. The membership function is used to represent the j^{th} objective function of a solution [16].

$$\mu_j = \begin{cases} 1, & J_j \le J_j^{min} \\ \frac{J_j^{max} - J_j}{J_j^{max} - J_j^{min}}, & J_j^{min} < J_j < J_j^{max} \\ 0, & J_j \ge J_j^{max} \end{cases} \quad (14)$$

Where J_j^{max} and J_j^{min} are the maximum as well as minimum values of the j^{th} objective function $j_j$for j = 1,2, and n = 3.

For each solution i, the membership function μ^i is calculated as

$$\mu^i = \frac{\sum_{j=1}^{n} \mu_j^i}{\sum_{i=1}^{m} \sum_{j=1}^{n} \mu_j^i} \quad (15)$$

Where n and m are the number of objective functions and the number of solutions respectively. The solution having the maximum value of μ^i is best compromise solution. As per rule of best compromise solution for the optimal gain parameter values of PID obtained by the applied method of multi objective GA and DE algorithm techniques are given in table 2 with bold mark.

IX. RESULT ANALYSIS

A two area interconnected power system having non reheat thermal turbines having total six generating units in all the areas are used for the investigation and analysis. The model of the system under study for i^{th} area is shown in **Figure 1** which is developed in Matlab/Simulink environment and its corresponding parameter is also given in table 7 of appendix. Simulations were conducted on an Intel (R) Core (TM) i-3 CPU of 2.4 GHz, 4 GB, 64-bit operating system processor laptop computer in the MATLAB '9.2.0.538062 (R2017a)' environment. At first 0.1 p.u. load disturbance in area-1 only, is applied and the effective gains of PID obtained through both single and multi objective GA-PID,DE-PID and HGDE optimization techniques are given in table 1. The performance of GA-PID,DE-PID and HGDE design is evaluated on the basis of sum of absolute value of i^{th} area control error at time t as objective functions ($\sum_{t=0}^{K} \left| ACE_{i,t} \right|$) and comparative analysis of GA-PID,DE-PID and HGDE based settling time, overshoot, undershoot and some more additional simulation graphs are clearly described and depicted in from figure 5 to figure 16 for both single and multi objective techniques cases, besides this the comparison is also tabulated for both optimization techniques in table 5 and table 6, it can be seen in table 1 that minimum area control error cost function (J_1=0.1007) value is obtained in AGC for HGDEcase than both GA-PID which is (J_1=0.1074) and DE-PID which is (J_1 =0.1009,similarly in multi objective optimization the cost function area control error of HGDE which is (J_1= **0.10167**, J_2 =**0.035963**) is smaller than from both DE-PIDwhich is (J_1= **0.14165**, J_2 =**0.053738**) and GA-PID (J_1= **0.18304**, J_2 =**0.083142**) which supports the superiority of HGDE in greatly reducing peak overshoots, undershoot and settling time in frequency as well as tie-line power deviations than the corresponding GA-PID and DE-PID methods. The settling trend is smooth with lesser overshoot and undershoot and it also shown that settling time reduced to less than 20 seconds in AGC of all the applied optimization cases of DE-PID, GA-PID and HGDE here.

Table 1Computed gains parameters of PID for the considered power system model

PID parameters	$K_{P1}=K_{P2}$	$K_{i1}=K_{i2}$	$K_{d1}=K_{d2}$	Cost functions
single-objective DE-PID tuned values	0.9996	1	0.3180	J1 = 0.1009
single-objective GA-PID tuned values	0.9825	0.9559	0.2540	J1 = 0.1074
single-objective HGDE tuned values	1	1	0.3413	J1 = 0.1007
multi-objective DE-PID tuned values	0.7070	0.7083	0.2301	J1 = 0.14165
				J2 = 0.053738
multi-objective GA-PID tuned values	0.8558	0.5639	0.1229	J1 = 0.18304
				J2 = 0.083142
multi-objective HGDE tuned values	1	0.9920	0.3333	J1 =0.10167
				J2 =0.035963

Table 2 multi objective DE-PID optimized set of solution, the bold value here depicts best compromise solution

solution	J1	J2	μ^i	Kp	Ki	Kd
Soln_1	0.1485	0.051658	0.079158	0.70837	0.7199	0.26019
Soln_2	0.13942	0.057749	0.079158	0.71502	0.77849	0.41138
Soln_3	0.1399	0.055772	0.10066	0.7132	0.76218	0.36934
Soln_4	0.14027	0.055167	0.10529	0.71835	0.80778	0.48698
Soln_5	0.14117	0.054254	0.10933	0.71154	0.74754	0.33154
Soln_6	0.14165	0.053738	**0.11183**	0.70698	0.70826	0.23006
Soln_7	0.14397	0.052365	0.10945	0.70698	0.70826	0.23006
Soln_8	0.14278	0.052994	0.11161	0.72076	0.82892	0.54155
Soln_9	0.14579	0.051842	0.10043	0.7194	0.81669	0.51002
Soln_10	0.14686	0.051692	0.093078	0.70752	0.71242	0.24088

Table 3 multi objective GA-PID optimized set of solution, the bold value here depicts best compromise solution

solution	J1	J2	μ^i	Kp	Ki	Kd
Soln_1	0.16853	0.096593	0.073256	0.86484	0.54581	0.12432
Soln_2	0.23371	0.79484	0.073256	0.8484	0.57935	0.12168
Soln_3	0.17145	0.088603	0.10419	0.92612	0.42321	0.1342
Soln_4	0.2082	0.07988	0.10024	0.90908	0.45652	0.13145
Soln_5	0.1906	0.081548	0.11287	0.90086	0.47329	0.13013
Soln_6	0.21746	0.079502	0.091441	0.88599	0.50412	0.12773
Soln_7	0.17366	0.086893	0.10902	0.84272	0.59045	0.12076
Soln_8	0.18304	0.083142	**0.11454**	0.85584	0.56394	0.12287
Soln_9	0.17723	0.085013	0.11306	0.89802	0.47884	0.12967
Soln_10	0.19801	0.080709	0.10813	0.93062	0.41415	0.13492

Table 4 multi objective HGDE optimized set of solution, the bold value here depicts best compromise solution

solution	J1	J2	μ^i	Kp	Ki	Kd
Soln_1	0.10147	0.036224	0.099371	1	0.99108	0.33552
Soln_2	0.10183	0.035781	0.099371	1	0.98925	0.33972
Soln_3	0.10153	0.036138	0.10052	1	0.99121	0.33522
Soln_4	0.10147	0.036221	0.099401	1	0.992	0.3334
Soln_5	0.10164	0.03601	0.10116	1	0.98918	0.33988
Soln_6	0.10179	0.035831	0.099964	1	0.99068	0.33642
Soln_7	0.10167	0.035963	**0.10133**	1	0.99203	0.33334
Soln_8	0.10174	0.035882	0.10088	1	0.98998	0.33803
Soln_9	0.10155	0.036124	0.097813	1	0.98826	0.34198
Soln_10	0.10178	0.035844	0.10018	1	0.98777	0.3431

9.1 Performance comparison using single objective optimization

Table 5 performance comparison considering GA-PID,DE-PID and HGDE using single objective optimization.

Measured parameters	GA-PID			DE-PID			HGDE		
	Δf1	Δf2	$\Delta P_{tie\ 12}$	Δf1	Δf2	$\Delta P_{tie\ 12}$	Δf1	Δf2	$\Delta P_{tie\ 12}$
Settling time	7.4871	8.6059	7.0839	7.2153	6.6750	7.0120	7.0913	6.6540	7.0120
Over shoot	0.0141	0.0007	0.0022	0.0090	0.0001	0.0014	0.0073	0	0.0014
Under shoot	-0.0608	-0.0324	-0.0471	-0.0573	-0.0297	-0.0435	-0.0562	-0.0288	-0.0425

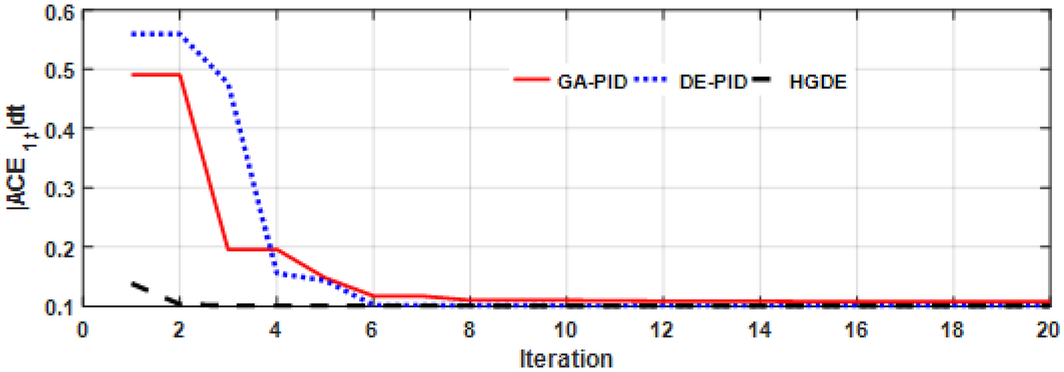

Figure 5comparison of DE-PID and GA-PID single objective optimized convergence graph.

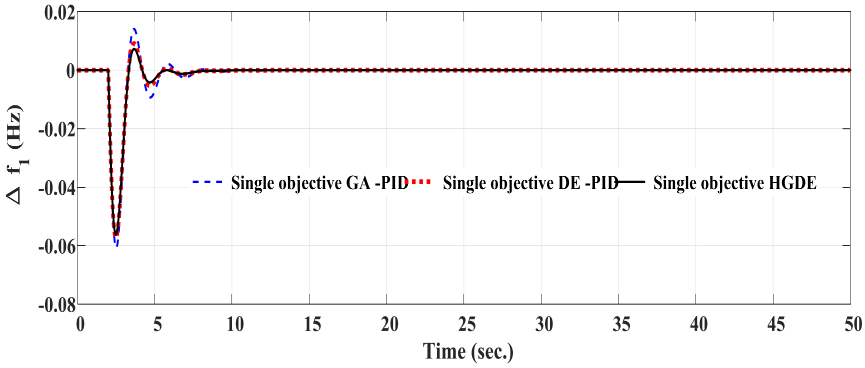

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Figure 6 change in frequency (Δf_1) response in area 1 using single objective optimizing methods.

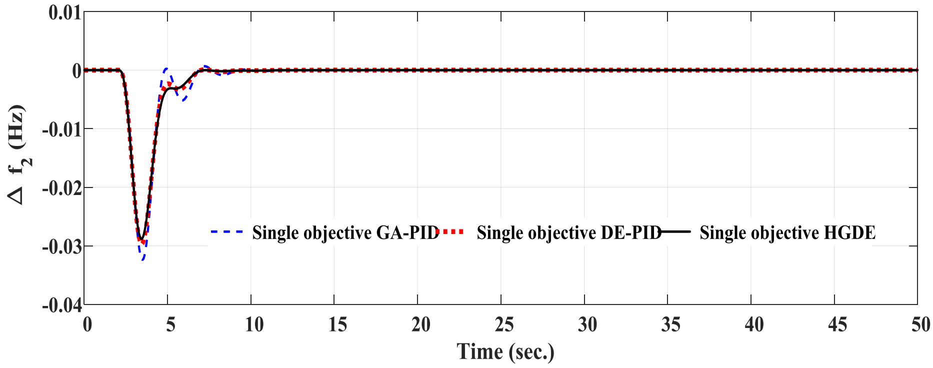

Figure 7 change in frequency (Δf_2) response in area 2 using single objective optimizing methods

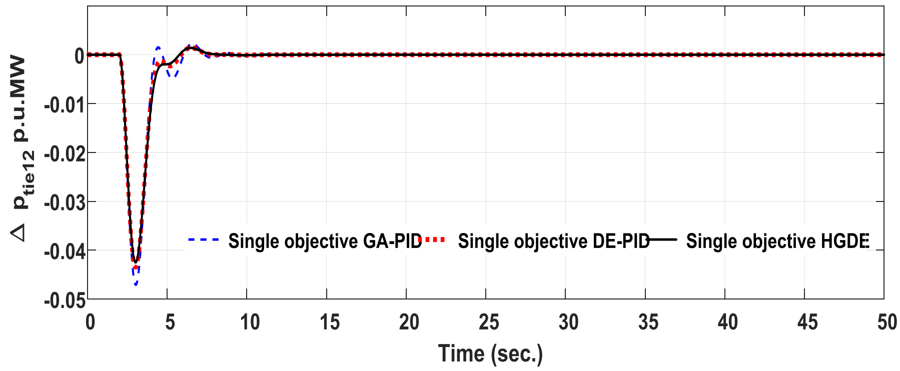

Figure 8 change in tie-line power ($\Delta P_{1\text{-}2}$) response using single objective optimizing methods

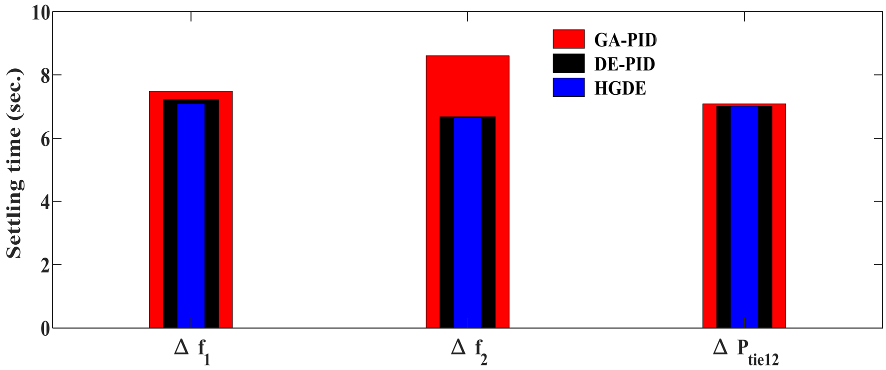

Figure 9 Performance comparison of DE–PID, GA-PID and HGDE using single objective optimization based settling time measure.

9.2 Performance comparison using multi objective optimization

Table 6 performance comparison considering GA-PID,DE-PID and HGDE using multi objective optimization.

Measured parameters	GA-PID			DE-PID			HGDE		
	Δf1	Δf2	$\Delta P_{tie\ 12}$	Δf1	Δf2	$\Delta P_{tie\ 12}$	Δf1	Δf2	$\Delta P_{tie\ 12}$
Settling time	10.2595	11.7225	9.4059	8.1481	7.3777	7.6011	7.1528	6.6857	7.0290
Over shoot	0.0169	0.0002	0.0032	0.0099	0	0.002	0.0077	0	0.0014
Under shoot	-0.0714	-0.0398	-0.0616	-0.0661	-0.0353	-0.0574	-0.0566	-0.0291	-0.0429

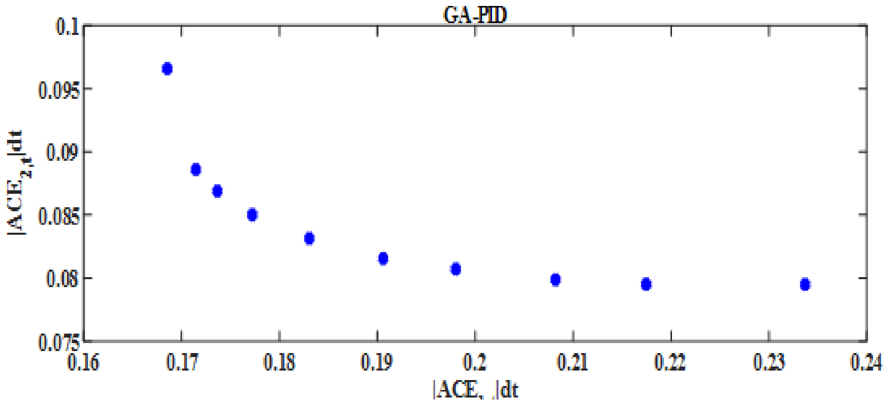

Figure 10 the obtained Pareto set of solution using multi objective GA-PID optimization methods

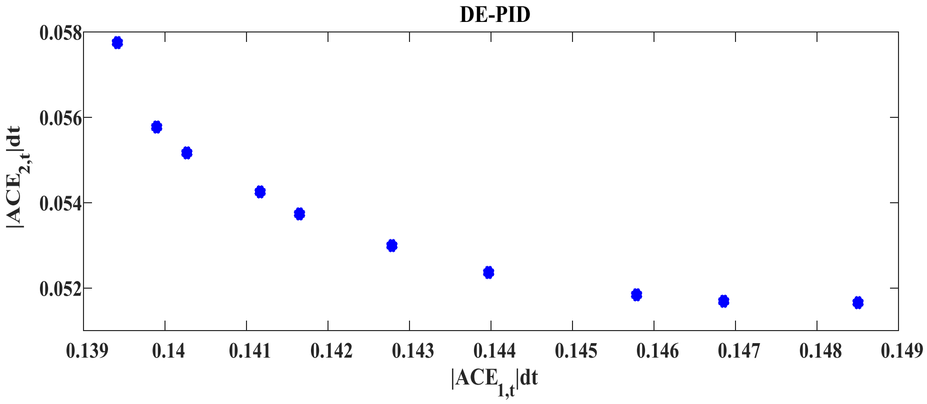

Figure 11 the obtained Pareto set of solution using multi objective DE-PID optimization methods

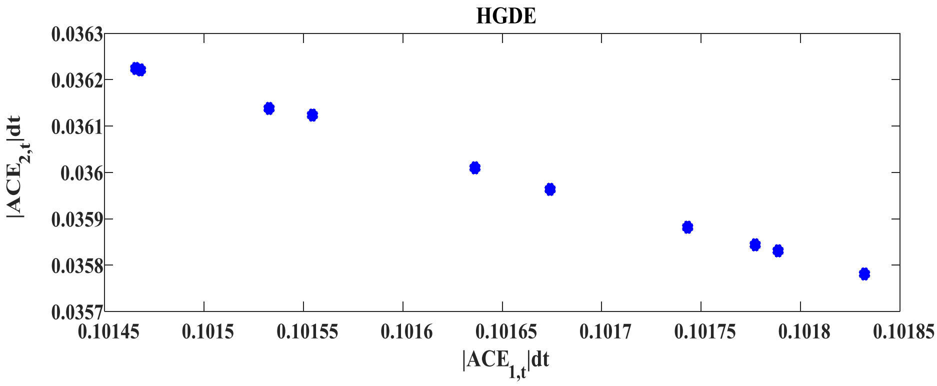

Figure 12 the obtained Pareto set of solution using multi objective HGDE optimization methods

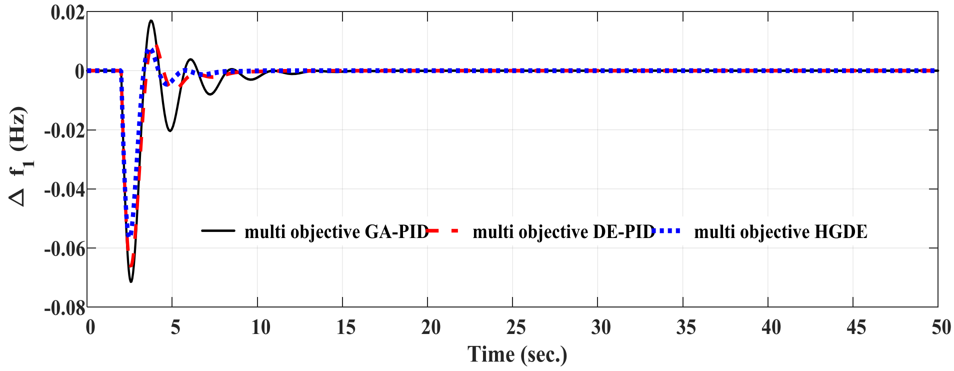

Figure 13 change in frequency (Δf_1) response in area 1 using multi objective optimizing methods.

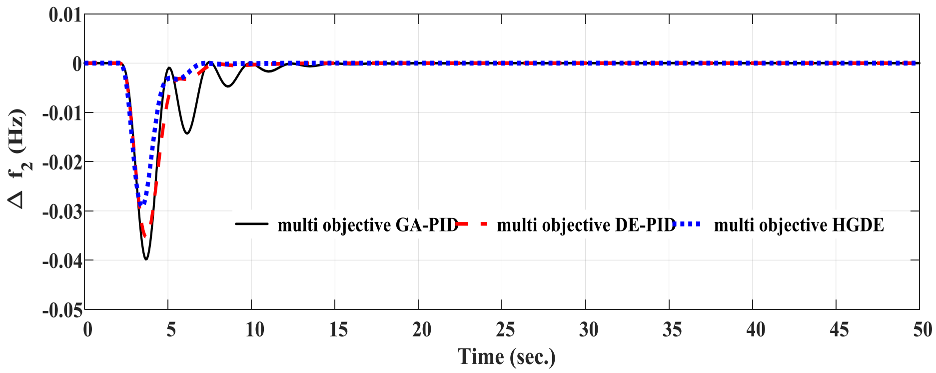

Figure 14 change in frequency (Δf_2) response in area 2 using multi objective optimizing methods

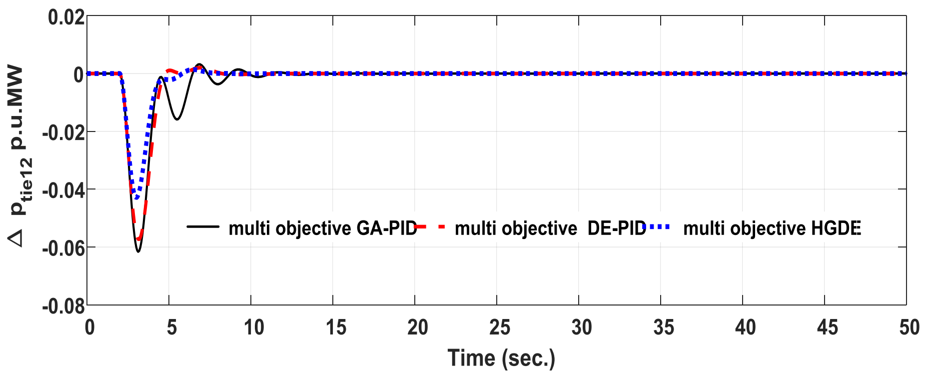

Figure 15 change in tie-line power ($\Delta P_{1\text{-}2}$) response using multi objective optimizing methods

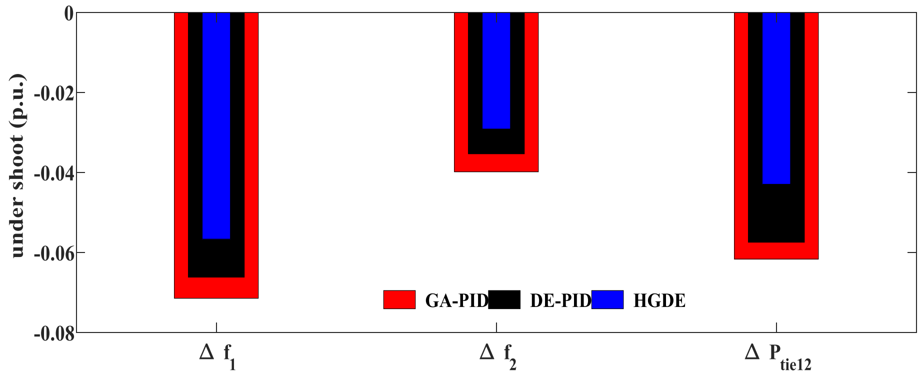

Figure 16 Performance comparison of GA-PID,DE-PID and HGDE using multi objective optimization based under shoot measure

X. CONCLUSION

This paper proposes the optimization of proportional integral derivative (PID) gain parameters through single and multi objective HGDE techniques for automatic generation control (AGC) scheme. The controls are implemented by applying 0.1 p.u. step load disturbance in area 1 only and the following conclusions are drawn from the work carried out:

- Successful modeling of two area non reheat thermal system with six unit is accomplished.
- The advantage of hybrid optimization controller method (HGDE) is clearly observed by performing comparison with DE-PID and GA-PID and the proposed controllers outshined more by damping the oscillation in achieving zero steady state value.
- The proposed HGDE methodis seen to deliver advantages in improving time domain response by reducing settling time, overshoot and undershoot of the measured power system

parameters such as change in frequency, change in tie-line power deviation.

- The comparison between DE-PID ,HGDE and GA-PID reveal that HGDE is getting relatively better by acquiring lower area control error cost functions, overshoot/undershoot and settling time than the corresponding GA-PID and DE-PID
- Different area control error cost functions are obtained in both single and multi objective optimization simulation cases while applying for AGC using DE-PID, GA-PID and HGDE methods and in comparison lower area control error cost functions in both cases are obtained for HGDE cases that supports and strengthening the superiority of the proposed objective functions and controller, besides this DE-PID converges at 18 second, GA-PID converges at 19 second and HGDE converges at 9 second in case of single optimization.

REFERENCES

[1]. Kouba Y 'A New Optimal Load Frequency Control Based on Hybrid Genetic Algorithm and Particle Swarm Optimization' International Journal on Electrical Engineering and Informatics – Volume 9, Number 3, September 2017

[2]. Bevrani H. Robust Power System Frequency Control, 2nd ed. New York: Springer; 2016.

[3]. Khan A, et al.,Comparative Analysis of Different Methods of Tuning Load Frequency Control Problem, International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 3 Issue IX, September 2015 ISSN: 2321-9653

[4]. Rekhasreer L, and J.Abdul Jaleel, Automatic Generation control of complex power system using Genetic Algorithm,International Journal of engineering Research and Technology, 10, October-2013

[5]. Ibraheem, Kumar P, Kothari D,Recent Philosophies of Automatic Generation Control Strategies In Power Systems. IEEE Transactions on Power Systems. 2005;20:346–57.

[6]. Fouad A. A novel hybrid genetic differential evolution algorithm for constrained optimization problems. International Journal of Advanced Research in Artificial Intelligence. 2014;3.

[7]. Rerkpreedapong D, Hasanovic A, Feliachi A (2003) Robust load frequency control using genetic algorithms and linear matrix inequalities. IEEE Transactions on Power Systems 18:855–861. doi: 10.1109/tpwrs.2003.811005

[8]. Storn R, Price K Differential Evolution – A Simple and Efficient Heuristic for global Optimization Over Continuous Spaces. In: Springer Link. https://link.springer.com/article/10.1023/A:1008202821328. Accessed 23 Nov 2017

[9]. Anita Pritam et,al, Automatic Generation Control Study in Two Area Reheat Thermal Power System, IOP Conf. Ser.: Mater. Sci. Eng. **225** 012223, 2017

[10]. Regar R and Jangid R,load frequency control of two area system using genetic algorthim,International Journal of Engineering Research and Technology Vol. 6 Issue 04,April-2017

[11]. Dhamanda A and A.K. Bhardwaj**,**Automatic generation control of thermal generating unit by using conventional and intelligent controller, **International journal of electrical engineering and technology (IJEET),10, October (2014), pp. 56-64**

[12]. H. Bevrani and T. Hiyama, Intelligent Automatic Generation Control, 1st ed. Boca Raton, FL: CRC Press, Apr. 2011.

[13]. Daneshfar F, Bevrani H. Multiobjective design of load frequency control using genetic algorithms. International Journal of Electrical Power & Energy Systems. 2012;42:257–63

[14]. Khosraviani M, Jahanshahi M, Farahani M, Bidaki ARZ. Load–Frequency Control Using Multi- objective Genetic Algorithm and Hybrid Sliding Mode Control-Based SMES. International Journal of Fuzzy Systems. 2017;

[15]. Panda, Sidhartha, and Narendra Kumar Yegireddy. "Automatic Generation Control of Multi-area Power System Using Multi-objective Non-dominated Sorting Genetic Algorithm-II." International Journal of Electrical Power & Energy Systems 53 (2013): 54- 63. doi:10.1016/j.ijepes.2013.04.003.

[16]. Khosraviani M, et al.,Load Frequency Control in Power Systems Using Multi Objective Genetic Algorithm & Fuzzy Sliding Mode Control,International Journal of Smart Electrical Engineering, Vol.5, No.1,Winter2016

[17]. Tejaswini M and Salma U,Load Frequency Control in Two-Area Interconnected Power System Using Multi-Objective Differential Evolution, International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE) Vol 3, Issue 3, March 2017

[18]. Rout UK, Sahu RK, Panda S. Design and analysis of differential evolution algorithm based automatic generation control for interconnected power system. Ain Shams Engineering Journal. 2013;4:409–21.

Abbreviation and mathematical notations

NP	: Number of population (population size)
DE	:Differential evolution
GA	: Genetic algorithm
CR	: Cross over rate
AGC	: Automatic Generation Control
IEEE	: Institute of Electrical Electronics Engineering
PID	: Proportional Integral Derivative controller
SLP	: Step load perturbation
Kp	: Proportional gain
Ki	: Integral gain
Kd	: Derivative gain
T_t	: Turbine time constant (sec.)
T_g	: Governor time constant (sec.)
ACE_i	: Area control error of i^{th} area (pu)
α_i	: Generating unit's Participation factor
B_i	: Frequency bias constant (p.u.MW/Hz)
R_i	: Speed regulation parameter (Hz/p.u.MW)
Δ	: Deviation from nominal values
Δf	: Deviation in frequency
D	: Area load governing characteristic
η_i	: The area interface
P_{tie_i}	: Net tie-line flow
T_{ij}	: Tie-line synchronizing coefficient between area i and j
P_V	: Governor valve
P_T	:Turbine power
P_D	: Power demand
T_P	: Area aggregate inertia
k	: Generator unit k for i^{th} area i
P_C	: Governor load set point
u_i	: Control input of power system
$[x_j^L, x_j^U]$	: Upper and lower bound
$X_{i,G}$	: Target vector
$V_{i,G}$	: Mutant vector
F	: Scaling factor
r_1, r_2, r_3	: Mutually randomly generated integers
$J_j^{\max}$, $J_j^{\min}$	: The maximum and minimum values of the j^{th} objective functions
μ^i	: Membership function
n	: Number of objectives
m	: Number of solutions

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