*International Journal of Engineering Science Invention (IJESI)*
*ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726*
*www.ijesi.org ||Volume 7 Issue 9 Ver II || Sep 2018 || PP 01-18*

# Optimized automatic generation control using single and multi-objective GA and DE techniques

Solomon Feleke, and K.Vaisakh
*Department of electrical engineering, AU College of engineering, Andhra University , Visakhapatnam-530003,AP,India*
*Corresponding Author: Solomon Feleke*

***Abstract:*** *In this paper both single and multi objective genetic algorithm and differential evolution optimization techniques are applied to tune PID parameters for the application of automatic generation control of two area six units non reheat thermal power plant. The controllers are optimized by considering 0.1 step load disturbance for area 1 only and computed with sum of absolute value of $i^{th}$ area control error at time t as objective functions. While employing multi objective GA and DE optimization techniques, best compromise solution of the corresponding PID parameters are obtained based on fuzzy membership function assignment technique. Performance and comparison analysis of GA-PID and DE-PID is done using both single and multi objective optimization techniques and according to the result, the optimized value result obtained by DE is getting better than GA in achieving lesser settling time, undershoot and overshoot in AGC application. Further more, for more realistic and confidential the simulation results obtained from the suggested controllers are compared with that of the simulation obtained from without applying the controller.*

***Keywords:*** *Load frequency control, participation factor, single and multi objective GA-PID and DE-PID,best compromise solution, frequency response, tie line power response.*

---

Date of Submission: 31-08-2018 Date of acceptance: 15-09-2018

---

## I. Introduction

The main target in AGC is to provide balance between generation and load by maintaining the frequency and the power interchange of the neighboring interconnected power system. One of the function of AGC is Load Frequency Control,it plays a very important role in maintaining system frequency as well as power flow in power system. If the variation of demand and generation is not controlled soon and goes to higher deviation it leads the system to breakdown.

One of the role of AGC is, its involvement in energy managementsystem.EMS acquires data from the power system and use computers to process the data, the supervisory control and data acquisition (SCADA) together with security control, load management and AGC are the major units in the application of modern EMS layer. The automatic generation control process task is performed in a control center remote away from the generating plants, for this the intelligent electronics devices (IEDs) for monitoring and controlling of the power system interface can be installed [1].

Conventional controller tuning method such as Ziegler Nichols was used to solve the AGC problem. In [2] 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 [3,4].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 [5].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 [6] different types of GA selection techniques are well described. 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 Storn Kenneth 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 fewer control 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].

In [9] 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 [10] the DE is applied to tune the PI controller for the application of AGC in two area hydro thermal power plants and the result obtained showed that DE, which is a branch of GA algorithm getting better than the conventional techniques. According to [11] DE is applied to tune PI and PID for the control of application of two area AGC of non reheat thermal power system and the result obtained is compared with other research work such as PSO,GA,BFOA and hBFO-PSO reported in the literature to show the superiority of DE-PID.In [12] 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.In [13] GA is applied to improve the performance of power system, here GA is used to tune the PI and the membership function of fuzzy by refined genetic algorithm methods for load frequency control of multi area interconnected 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 ($\Delta f_i$) as well as change in tie line power ($\Delta P_{tie,i}$) [1,14].In this paper sum of absolute value of ACE of area i at time t $(\sum_{t=0}^{k}|ACE_{i,t}|)$ is used as objective function and the detailed application of this objective function using multiobjective genetic algorithm is clearly described in [15] under which a power system composed of nine units in three area system.

According to [16] 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 [17] 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 [18] 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 [19] multi objective DE is employed to solve the load frequency control problem.

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 [7,16] 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 Table **6**[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 [1,14].100MW or 0.1pu disturbance in area 1 only is considered for the power system under study here in figure 1.

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

Where
k is for generator unit k for i[th] area i
$\alpha$ is participation factor

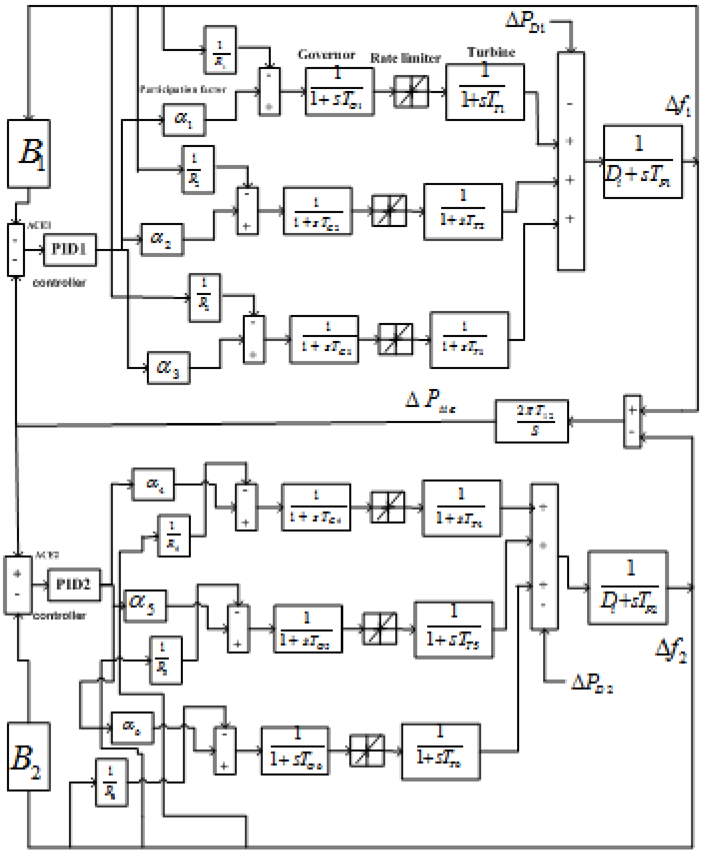


**Figure 1** two area AGC model having six non reheat thermal units

## 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 [1].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 [15].

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

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

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

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

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

$$K_p^{\min} \le K_p \le K_p^{\max}, K_I^{\min} \le K_I \le K_I^{\max}, K_D^{\min} \le K_D \le K_D^{\max} \quad (7)$$

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

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 [6].

i) Roulette wheel selection
ii) Rank selection and
iii) Steady-state selection. After selection process crossover and mutation operation applied to generate offspring. The five phases of genetic algorithms are initializing population, fitness function, selection, crossover and mutation

### 4.1 Steps of Genetic Algorithm

#### 4.1.1. Initializing population

Initializing population by random generation of population, size of the population depends on the inherent features of the problem to be solved

#### 4.1.2. Fitness function

In genetic algorithms fitness is very important concept it determines how chromosomes likely that it will be produced, it is also measured interims of how the chromosome solves some goal of problem, a fitness function in general is a type of objective function which is help full to achieve the set aims, in implementing genetic programming of genetic algorithm, it is a guide of simulation towards optimal solution.

#### 4.1.3. Selection

It is an important function of genetic algorithm by considering evaluation criteria, the idea is selection of the fittest individuals in order to pass their genes for the next generation, for this individuals or parents having two pairs are selected in refer to on their fitness outcomes. Those individuals having high fitness have a better chance for to be selected in reproduction, The most common techniques of chromosome selection are roulette wheel, rank selection and steady state selection.

4.1.3.1 **Roulette wheel selection**

This method of selection is based on their fitness, better chromosomes have more chance of getting selection as a parent, the method is based on roulette wheel which each individual assigned as a slice of circular wheel, being the size of each slice is proportional to the fitness of chromosomes in the individual i.e. the bigger the value, the larger the size of the slice.

4.1.3.2 **Rank selection**

In rank selection the population will be given ranks based on their fitness and then ranking is given for every chromosome. Based on the worst rank the first worst will take fitness 1on similar fashion the second worst will take fitness 2 and the best one will have a fitness value n, where n is the number of chromosomes in the population

4.1.3.3 **Steady-state selection**

The main idea of steady state selection is a chromosome having a big part should survive to the next generation. This technique replaces few individuals in each generation, and is not a particular method for selecting the parents. Only a small number of newly created offspring's are put in place of least fit individual.

4.1.4. **Cross over**

In genetic algorithm the most important phase is cross over, it is chosen at randomly from within the genes. It is also called recombination, cross over is a means of genetic operation used to combine two parents of the genetic information to generate new offspring.

**4.1.5. Mutation**

In mutation genetic diversity is maintained from one generation to the next generation of a population by altering one or more genes value in a chromosome starting from initial state

**4.2. Implementation steps of single objective genetic algorithm in AGC**

nGen = Number of generation
NP = number of population
$P_m$ = mutation probability
CR = cross over probability
Set maximum iteration number
Initialize cross over probability (CR) and mutation $P_m$
Step 1.Set the generation counter t = 0.
Step 2.Random generation of initial population Kp, Ki and Kd and assign it as $P^0$
Step 3. Evaluate the fitness function of all individuals in $P^0$ using objective function
Step 4. repeat
Step 5. Set t = t + 1.{Generation counter increasing}
Step 6. Select an intermediate population $P^t$ from $P^{t-1}$ {Perform roulette wheel selection}
Step 7. Associate a random number r from (0, 1) with each row in $P^t$
Step 8. if r < CR then
Step 9. Perform cross over operation to all selected pairs of $P^t$.
Step 10. Update $P^t$.
Step 11. end if {Crossover operator}
Step 12. Associate a random number r1 from (0, 1) with each gene in each individual in $P^t$
Step 13. if r1 < $P_m$ then
Step 14. Mutate the gene by generating a new random value for the selected gene with its domain.
Step 15. Update $P^t$
Step 16. end if {mutation operation}
Step 17. Evaluate the fitness function of all individuals in $P^t$
Step 18. if stopping criteria satisfied go to step 19 otherwise go to step 3
Step 19. Get optimal output values of Kp,Ki and Kd
Step 20. Apply the printed out values of Kp,Ki and Kd to AGC

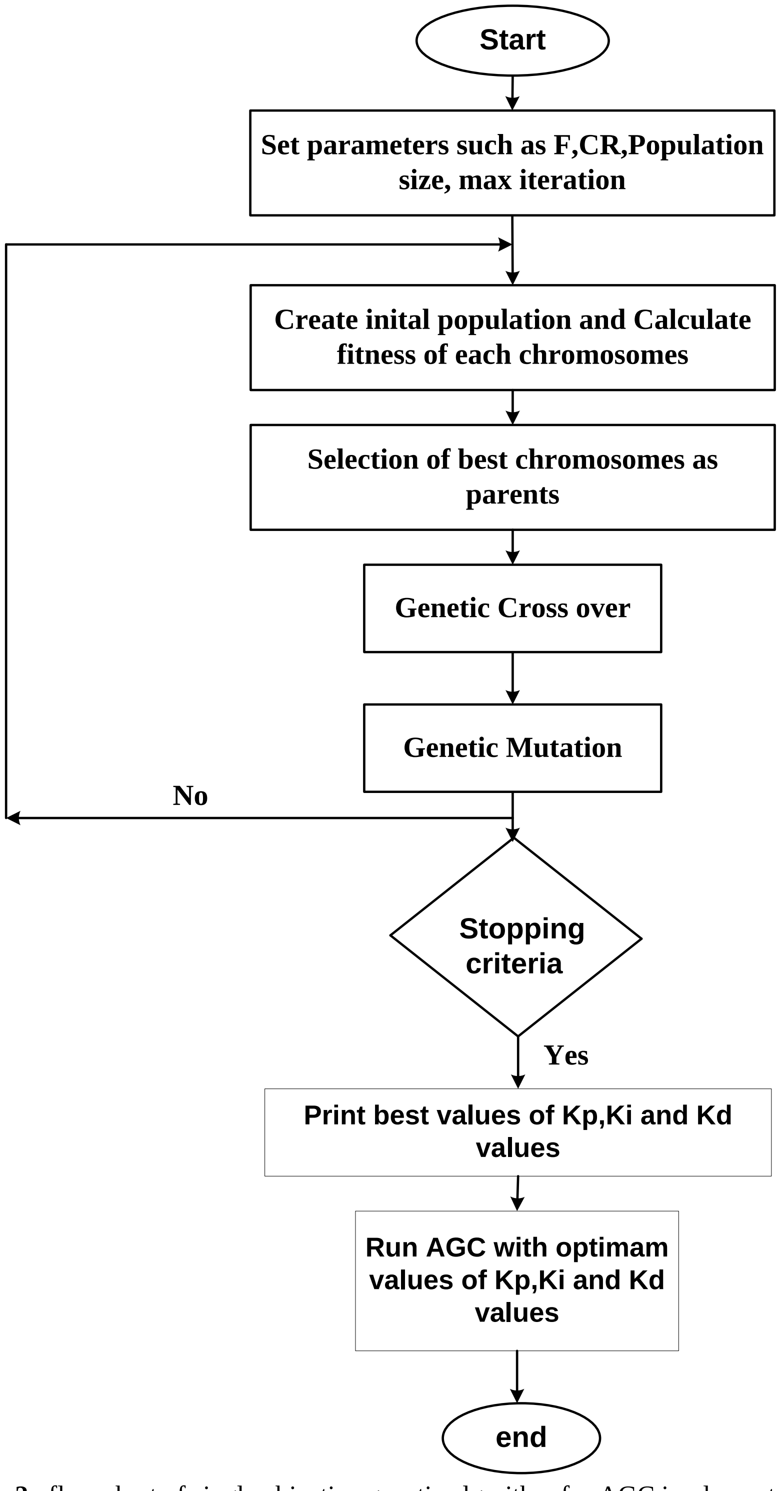


**Figure2.** flow chart of single objective genetic algorithm for AGC implementation

**4.3 Implementation steps of multi objective genetic algorithm in AGC**

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 GA cross over operation to generate new offspring.
Step 6. Perform GA mutation operation to maintain genetic diversity

Step 7. GA roulette wheel 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 , $K_{d.}$

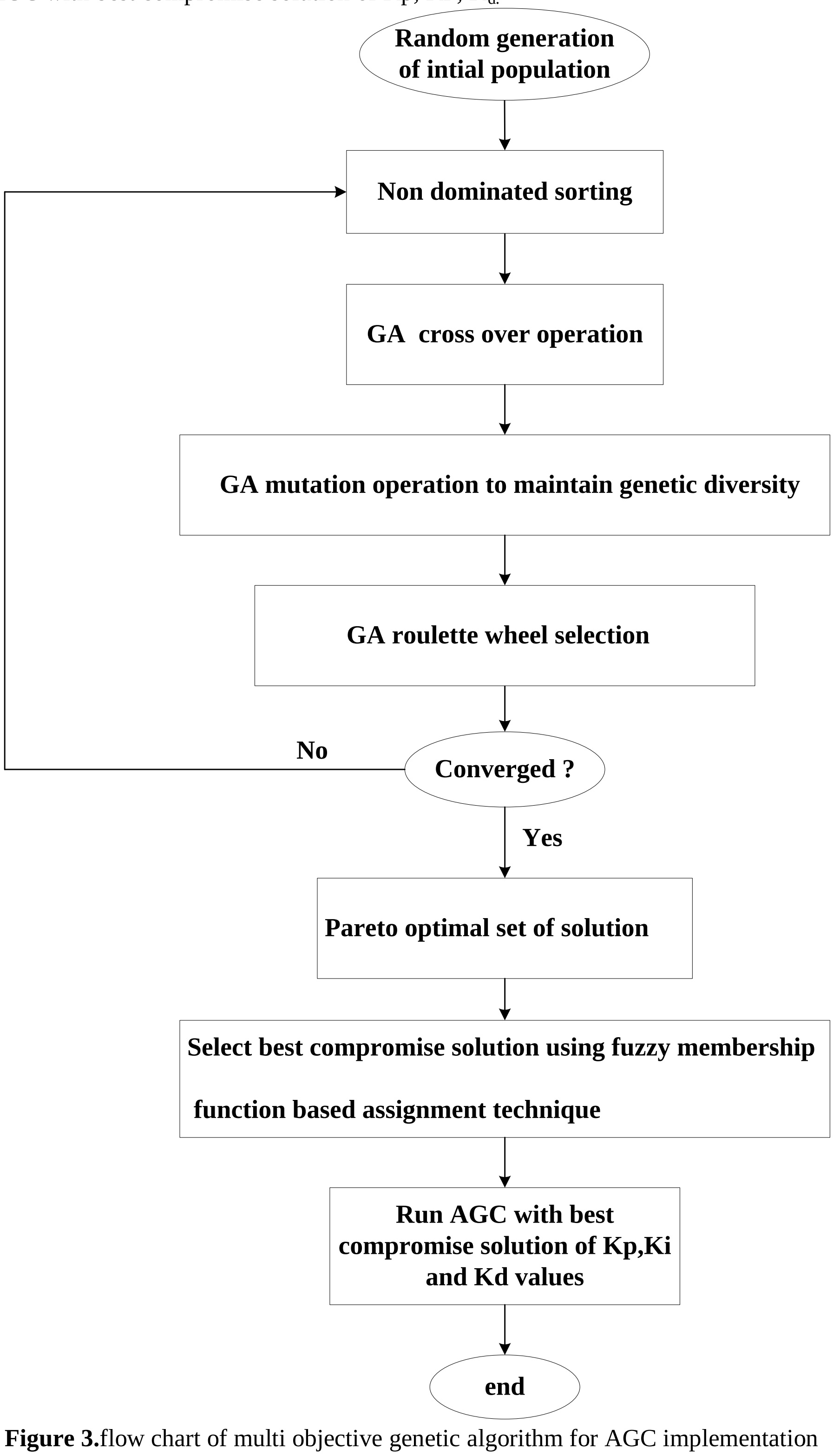


**Figure 3.**flow chart of multi objective genetic algorithm for AGC implementation

## V. Differential Evolution Overview

Differential evolution is one of the optimization technique and based on 1997 report of Storn and Price,DE is effective and efficient than, from both genetic algorithm and simulated annealing [8]. The four major procedures of differential evolution are described below [9].

**5.1 Steps of Differential Evolution**

**5.1.1 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 $\left[X_j^L, X_j^U\right]$

**5.1.2 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

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}) \tag{8}$$

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

**5.1.3 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 $X_{i,G}$ .

$$U_{j,i,G} = \begin{cases} V_{j,i,G}, if\,(rand_j[0,1] \le CR) or (j = j_{rand}) \\ X_{j,i,G,} \quad \text{otherwise} \end{cases}, \text{ j = 1,2...,D} \tag{9}$$

**5.1.4 Selection operation:** In this phase the comparison of trial vector $f(U_iG)$ and target vector $f(X_iG)$ is performed in the current participant population, so that based on their fitness comparison as given on equation (10), the one which is going to be involve in the next generation from either of the two will be identified.

$$X_{i,G+1} = \begin{cases} U_{i,G} iff(U_{i,G}) \le f(X_{i,G}) \\ x_{i,G} otherwise \end{cases} \tag{10}$$

Where $i \in [1, N_P]$

**5.2 Implementation steps of single objective differential evolution in AGC**

nGen = Number of generation

NP = number of population

$P_m$ = mutation probability

CR = cross over probability

Set maximum iteration number

Initialize cross over probability (CR) and mutation $P_m$

Setting input data of scaling factor F ∈ [0, 2], cross over CR ∈ (0, 1), population size NP and maximum iteration number

Step 1.Set generation counter G = 0

Step 2. Set the initial value of F and CR

Step 3.Random generation of initial population Kp, Ki and Kd and assign it as $P^0$

Step 4. Evaluate the fitness function of all individuals in $P^0$ using objective function

Step 5. repeat

Step 6. Set G= G+1.{Generation counter increasing}

Step 7. for i=0;i<NP;i++ do

Step 8. Select random indexes $r_1, r_2, r_3$ where $r_1 \ne r_2 \ne r_3 \ne i$

Step 9. $v_i^{(G)} = x_{r1}^{(G)} + F*(x_{r2}^{(G)} - x_{r3}^{(G)})$ .{mutation operator}

Step 10.j=rand (1,D)

Step 11.for (k=0;k<D;K++)do

Step 12.if (rand (0,1)≤ CR k=j then

Step 13. $u_{ik}^{(G)} = v_i^{(G)}$ {cross over operator}

Step 14. else
Step 15. end if
Step 16. $u_{ik}^{(G)} = x_{ik}^{(G)}$
Step 17. end for
Step 18. $if\,(f(u_i^{(G)}) \le f(x_i^{(G)}))$ then
Step 19. $x_i^{(G+1)} = u_i^{(G)}$
Step 20. $x_i^{(G+1)} = u_i^{(G)}$
Step 21. else
Step 22. $x_i^{(G+1)} = x_i^{(G)}$
Step 23.end if
Step 24. end for
Step 25. if stopping criteria satisfied go to step 26 otherwise go to step 4
Step 26. Get optimal output values of Kp,Ki and Kd
Step 27. Apply the printed out values of Kp,Ki and Kd to AGC

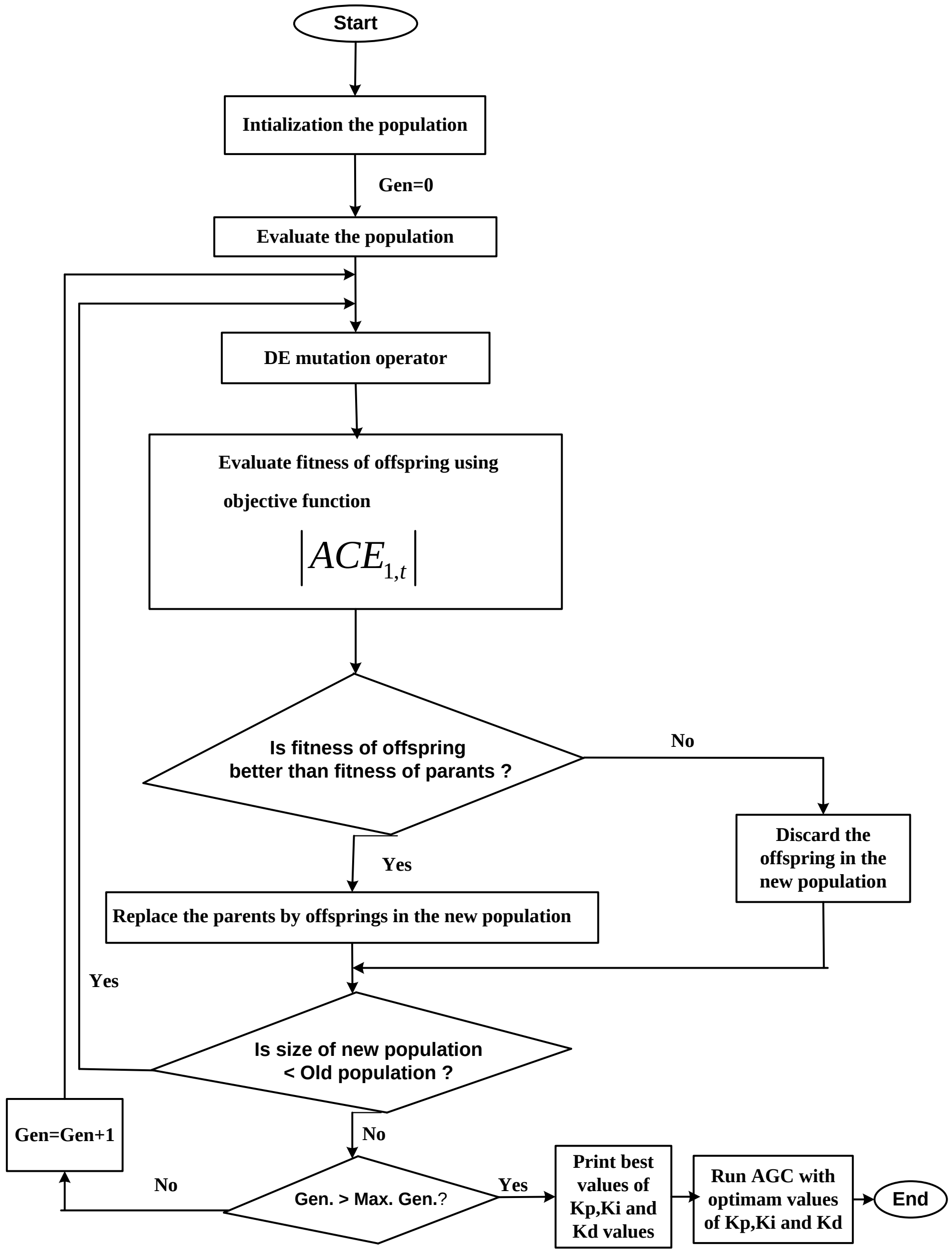

**Figure 4.**flow chart of single objective differential evolution for AGC implementation

**5.3 Implementation steps of multi objective differential evolution in AGC**

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 DE 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 , $K_{d.}$

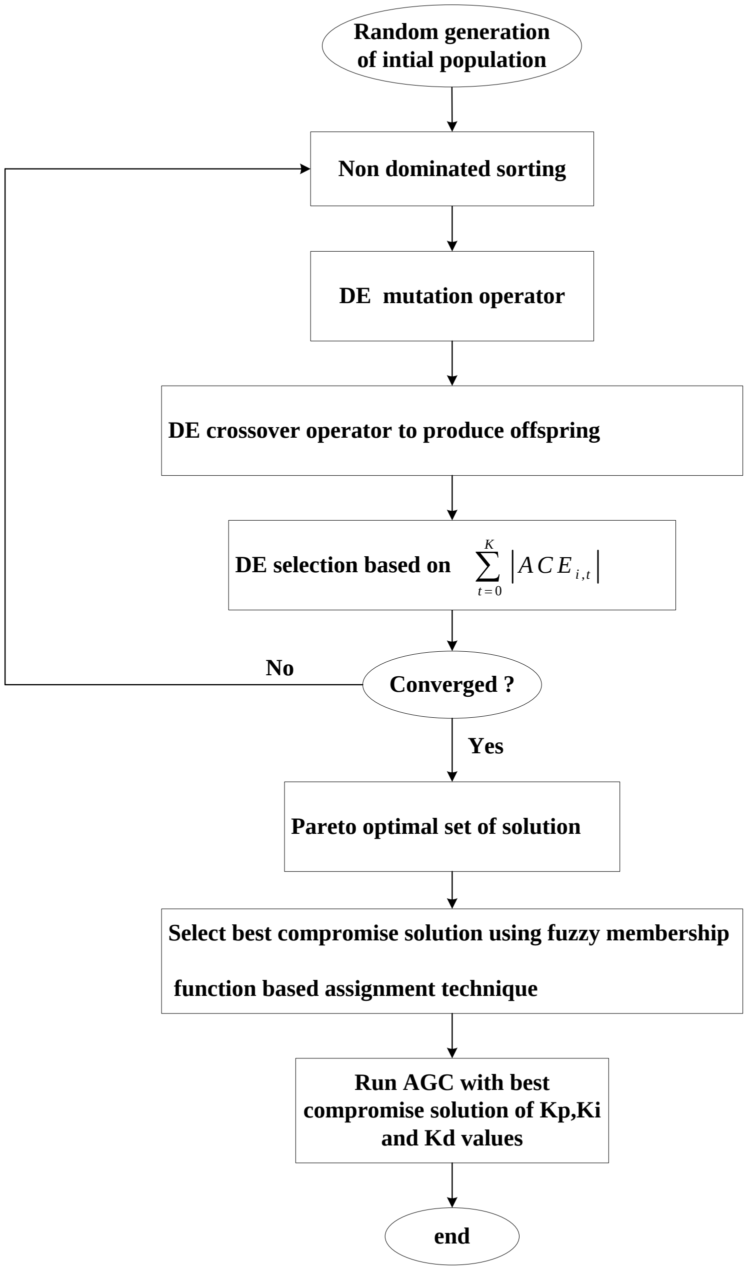

**Figure 5.**flow chart of multi objective differential evolution for AGC implementation

## 6. **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].

$$\mu_j = \begin{cases} 1, & J_j \leq J_j^{min} \\ \frac{J_j^{max} - J_j}{J_j^{max} - J_j^{min}}, & J_j^{min} < J_j < J_j^{max} \\ 0, & J_j \geq J_j^{max} \end{cases} \quad (11)$$

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 $\mu^i$ is calculated as

$$\mu^i = \frac{\sum_{j=1}^{n} \mu_j^i}{\sum_{i=1}^{m} \sum_{j=1}^{n} \mu_j^i} \quad (12)$$

Where *n and m are* the number of objective functions and the number of solutions respectively. The solution having the maximum value of $\mu^i$ 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.

## 7. 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 data is also given in table 6 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 and DE-PID optimization techniques are given in table 1. The performance of GA-PID and DE-PID 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 without controller,DE-PID and GA-PID based settling time, overshoot, undershoot and some more additional simulation graphs are clearly described and depicted in from figure 6 to figure 16 for both single and multi objective techniques cases, besides this the comparison is also tabulated for both optimization techniques in table 4 and table 5, it can be seen in table 1 that minimum area control error cost function ( $J_1$ =0.1009) value is obtained in AGC for DE-PID case than GA-PIDwhich is ( $J_1$ =0.1074),similarly in multi objective optimization the cost function area control error of DE-PID which is ( $J_1$ = **0.14165**, $J_2$ =**0.053738**) is smaller than GA-PID ( $J_1$ = **0.18304**, $J_2$ =**0.083142**) which supports the superiority of DE-PID in greatly reducing peak overshoots, undershoot and settling time in frequency as well as tie-line power deviations than the corresponding GA-PID method. 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 and GA-PID here.

**Table 1 Computed** 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 |
| 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 |

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

| solution | J1 | J2 | $\mu^i$ | 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 | $\mu^i$ | 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 | 0.91441 | 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 |

### 7.1 Performance comparison using single objective optimization

**Table 4** performance comparison considering with controllers and without controllers using single objective optimization.

| Measured parameters | Without controller | | | GA-PID | | | DE-PID | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ |
| Settling time | 16.3962 | 19.9936 | 16.9966 | 7.4871 | 8.6059 | 7.0839 | 7.2153 | 6.6750 | 7.0120 |
| Over shoot | 0.0090 | -0.0068 | -0.0281 | 0.0141 | 0.0007 | 0.0022 | 0.0090 | 0.0001 | 0.0014 |
| Under shoot | -0.0804 | -0.0441 | -0.0735 | -0.0608 | -0.0324 | -0.0471 | -0.0573 | -0.0297 | -0.0435 |

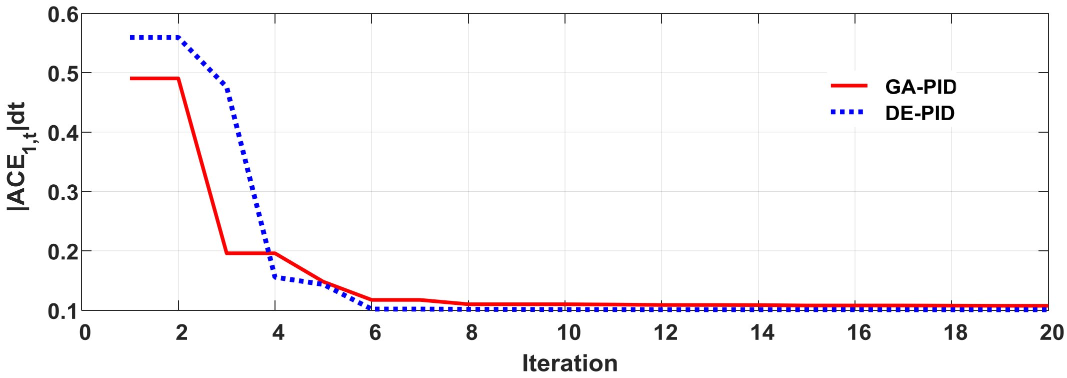


**Figure 6** comparison of DE-PID and GA-PID single objective optimized convergence graph.

.

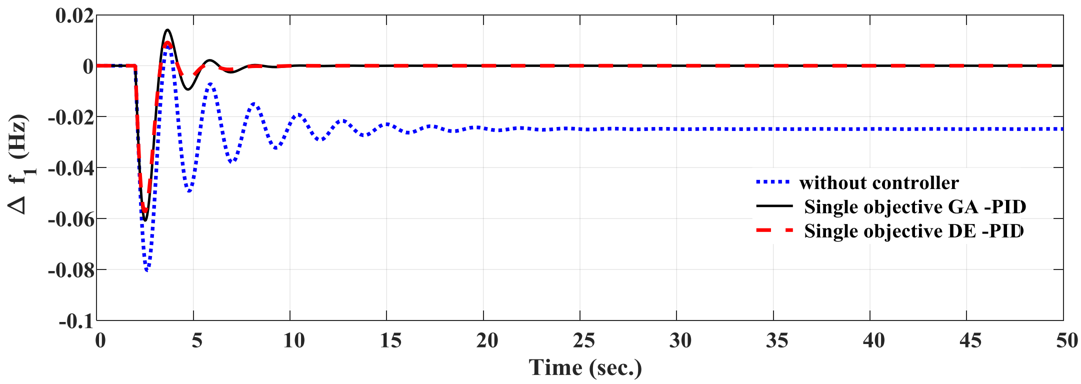


**Figure 7** change in frequency ($\Delta f_1$) response in area 1 using single objective optimizing methods.

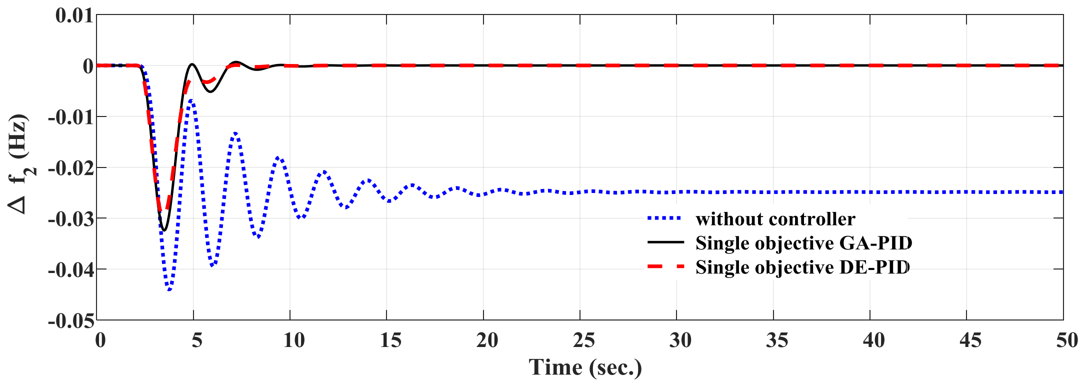


**Figure 8** change in frequency ($\Delta f_2$) response in area 2 using single objective optimizing methods

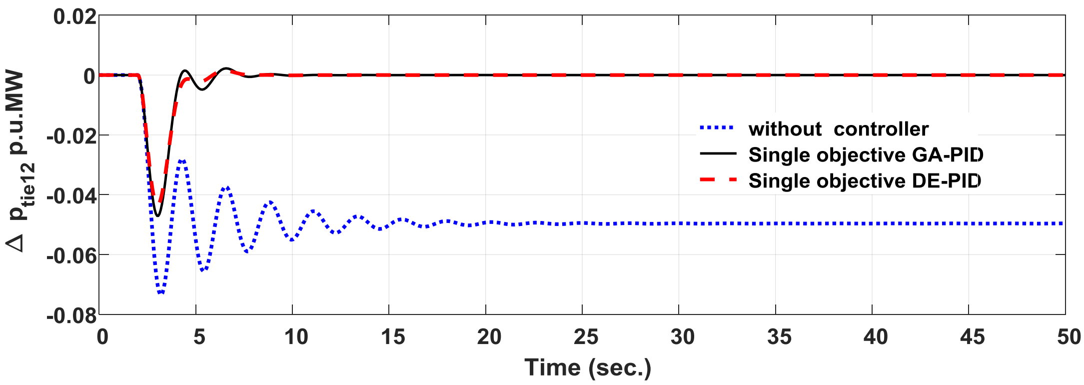


**Figure 9** change in tie-line power ($\Delta P_{1\text{-}2}$) response using single objective optimizing methods

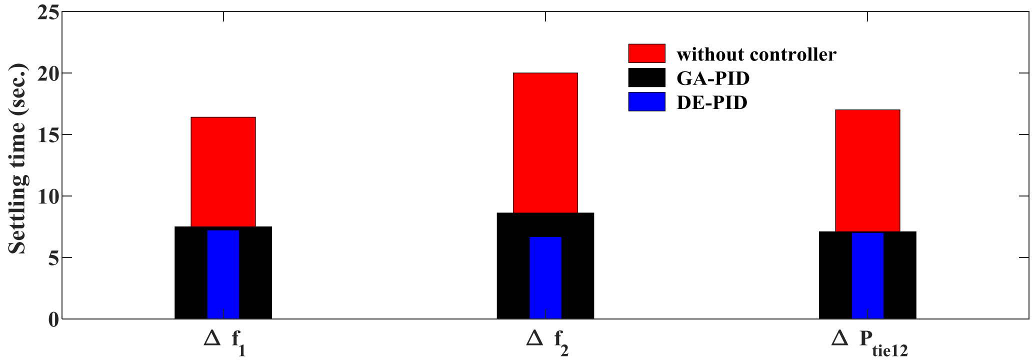


**Figure 10** Performance comparison of without controller, GA-PID and DE –PID using single objective optimization based settling time measure.

### 7.2 Performance comparison using multi objective optimization

**Table 5** performance comparison considering with controllers and without controllers using multi objective optimization.

| Measured parameters | Without controller | | | GA-PID | | | DE-PID | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ |
| Settling time | 16.3962 | 19.9936 | 16.9966 | 10.2595 | 11.7225 | 9.4059 | 8.1481 | 7.3777 | 7.6011 |
| Over shoot | 0.0090 | -0.0068 | -0.0281 | 0.0169 | 0.0002 | 0.0032 | 0.0099 | 0 | 0.002 |
| Under shoot | -0.0804 | -0.0441 | -0.0735 | -0.0714 | -0.0398 | -0.0616 | -0.0661 | -0.0353 | -0.0574 |

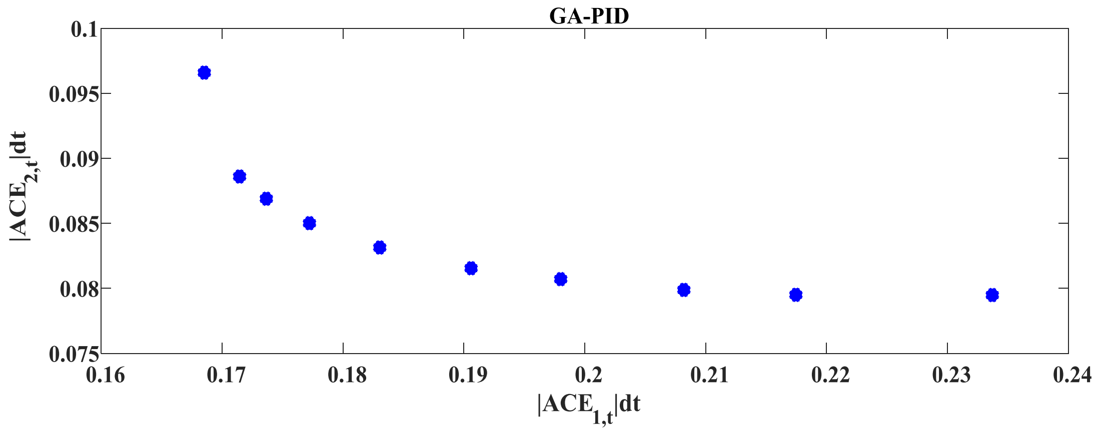


**Figure11** Pareto set of solutions graph obtained from multi objective GA-PID optimization methods

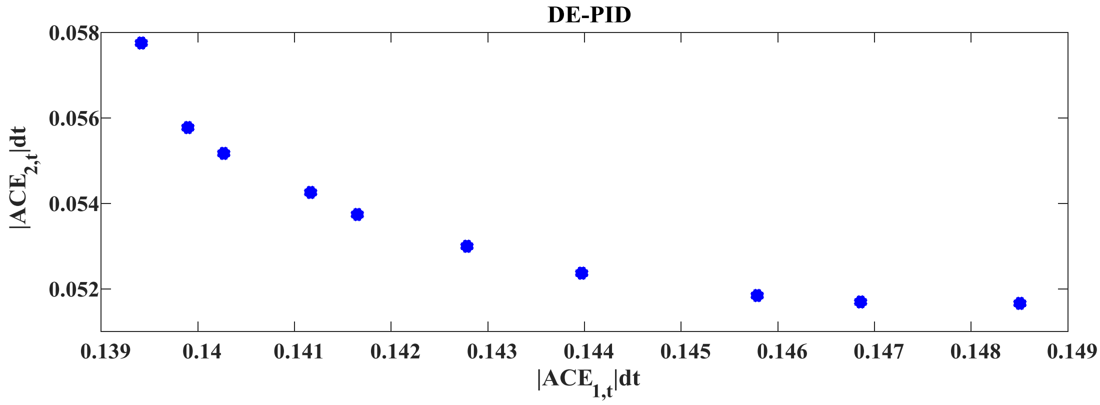


**Figure12** Pareto set of solutions graph obtained from multi objective DE-PID optimization methods

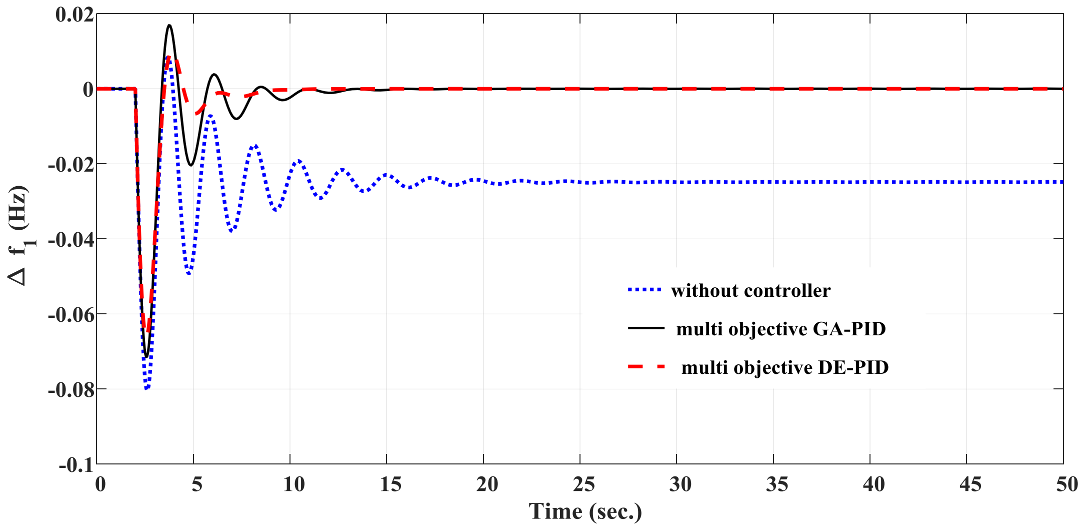


**Figure 13** change in frequency ($\Delta f_1$) response in area 1 using multi objective optimizing methods.

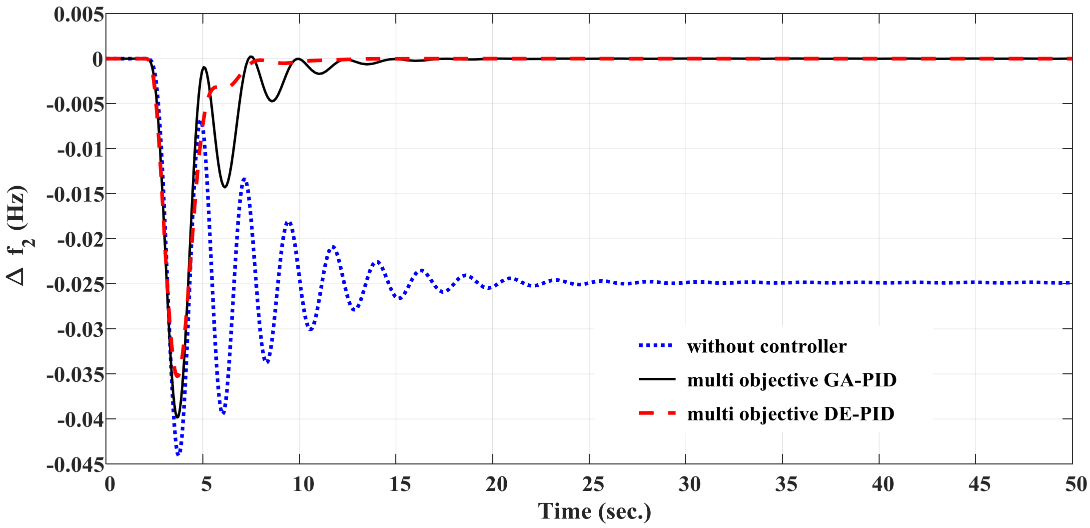


**Figure 14** change in frequency ($\Delta f_2$) response in area 2 using multi objective optimizing methods

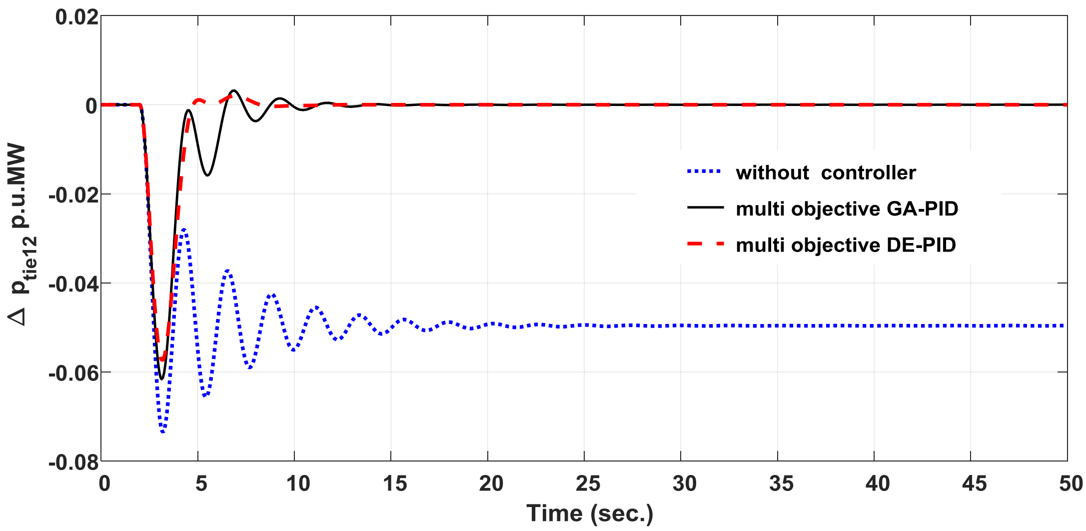


**Figure 15** change in tie-line power ($\Delta P_{1\text{-}2}$) response using multi objective optimizing methods

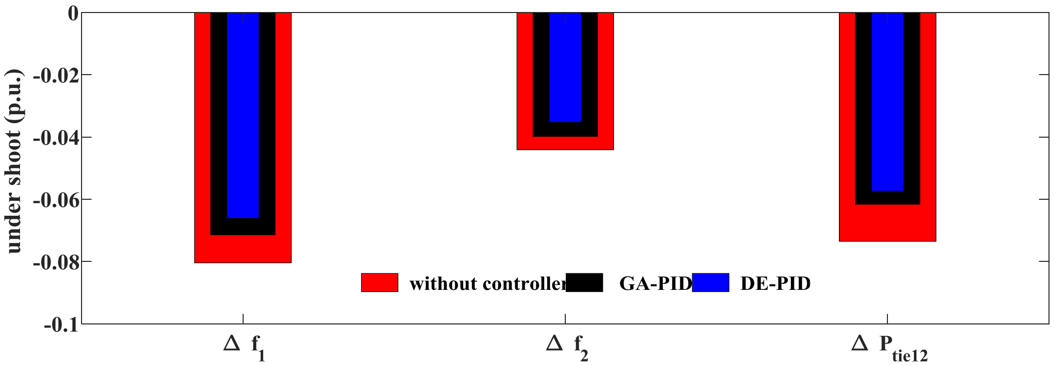


**Figure 16** Performance comparison of without controller, GA-PID and DE-PID using multi objective optimization based under shoot measure

## 8.Conclusion

This paper proposes the optimization of proportional integral derivative (PID) gain parameters through single and multi objective GA-PID and DE-PID 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 advantages of AGC proposed controllers are clearly observed by performing comparison between with controller and without controller, the proposed controllers outshined more by damping the oscillation in achieving zero steady state value.
- Both the algorithms GA-PID and DE-PID tuning methods are 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 and GA-PID reveal that DE-PID is getting relatively better by acquiring lower cost functions, overshoot/undershoot and settling time than the corresponding GA-PID.It is also reveal that both controllers are better than the AGC result under the case in without controller.
- Different area control error cost functions are obtained in both single and multi objective optimization simulation cases while applying for AGC using DE-PID and GA-PID and in comparison lower area control error cost functions in both cases is obtained for DE-PID cases that supports and strengthening the superiority of the proposed objective functions and controllers besides this DE-PID converges at 18 second while GA-PID converges at 19 second in case of single optimization.

## References

[1] Bevrani H. Robust Power System Frequency Control, 2nd ed. New York: Springer; 2016
[2] 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
[3] ekhasreer 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
[4] Ibraheem, Kumar P, Kothari D,Recent Philosophies of Automatic Generation Control Strategies In Power Systems. IEEE Transactions on Power Systems. 2005;20:346–57.
[5] Fouad A. A novel hybrid genetic differential evolution algorithm for constrained optimization problems. International Journal of Advanced Research in Artificial Intelligence. 2014;3.
[6] Malhotra, Rahul, Narinder Singh, and Yaduvir Singh. "Genetic Algorithms: Concepts, Design for Optimization of Process Controllers." Computer and Information Science 4, no. 2 (2011). doi:10.5539/cis.v4n2p39.
[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] 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.
[10] M.A. Zamee, K.K. Islam, A. Ahmed, K.R. Zafreen, Differential evolution algorithm based load frequency control in a two-area conventional and renewable energy based nonlinear power system, 2016 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET). (2016). doi:10.1109/icdret.2016.7421476.
[11] Kumari S, et al., Study of Load Frequency Control by using Differential Evolution Algorithm, 1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES-2016)
[12] 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
[13] Chang, C. S., Weihul Fu, and Fushuan Wen. "Load Frequency Control Using Genetic-Algorithm Based Fuzzy Gain Scheduling Of Pi Controllers." Electric Machines & Power Systems 26, no. 1 (1998): 39-52. doi:10.1080/07313569808955806.
[14] H. Bevrani and T. Hiyama, Intelligent Automatic Generation Control, 1st ed. Boca Raton, FL: CRC Press, Apr. 2011.

[15] Daneshfar F, Bevrani H. Multiobjective design of load frequency control using genetic algorithms. International Journal of Electrical Power & Energy Systems. 2012;42:257–63
[16] 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;
[17] 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.
[18] 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
[19] 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

**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)
$\alpha_i$ : Generating unit's Participation factor
$B_i$ : Frequency bias constant (p.u.MW/Hz)
$R_i$ : Speed regulation parameter (Hz/p.u.MW)
$\Delta$ : Deviation from nominal values
$\Delta f$ : Deviation in frequency
D : Area load governing characteristic
$\eta_i$ : 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

| | |
|---|---|
| $\mu^i$ | : Membership function |
| $n$ | : Number of objectives |
| $m$ | : Number of solutions |

Solomon Feleke and K.Vaisakh" Optimized automatic generation control using single and multi-objective GA and DE techniques' International Journal of Engineering Science Invention(IJESI), vol. 7, no. 9, 2018, pp. 01-18