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# Automatic Generation Control of Two Area Thermal Power System using Single Objective PSO and DE Optimization Techniques

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***Abstract— Now a days AGC has a great roll in controlling the mismatch between generation and load in interconnected power system, to attain AGC more optimal, tuning the controller using optimization techniques is needed. In this paper PSO and DE optimization techniques are employed for dynamic frequency control analysis. For dynamic analysis, the PID gain parameters obtained through single objective optimization using PSO and DE techniques, the controls are implemented by considering 1% of change in load disturbance in area 1 only and computed with sum of absolute value of $i^{th}$ area control error at time t as objective function and simulation result is obtained by interfacing Matlab (.m file) with Simulink block model under study . Comparison analysis is performed between PSO-PID, without controller and DE-PID. According to the investigations, better dynamic response performance is achieved through DE-PID method than the PSO-PID technique for the measured parameters of time response transient analysis such as maximum overshoot, rise time, maximum undershoot and settling time in AGC of two area system.***

***Keywords: ACE, AGC of two area model, Convergence characteristics, DE, ITAE, PID controller, PSO.***

## I. INTRODUCTION

An interconnected power system consists of several areas and it has many important advantages to make the operation of power systems stable, one of its advantage is making the exchange of tie line power and frequency constant In each area, AGC or Automatic Generation Controller monitors the tie-line flows and the system frequency. One of the functions of AGC is maintaining the balance between load and generation, which is given by the term LFC known as 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. To cope up this problem LFC is one of the function of AGC is growing up and the main role of AGC is not only maintaining the system frequency but also helps to preserve the tie-line power flow exchange of different control areas at their scheduled values[ 1,2].

One the advantage of AGC is to drive ACE to zero and ACE is a linear combination of change in frequency and tie-line power deviations, so that one task of the controlled output of AGC is making the tie-line power and frequency errors to zero [1,3,5]. Ziegler–Nichols is one of the early conventional PID tuning technique [4] ,this method is practical applied for broad range application ,however, 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, large overshoot, more oscillation and long settling time, for this comparison the artificial intelligent methods are better as mentioned in [6].

To enhance the capabilities, PID parameters are tuned using GA and DE for two area multi-unit thermal power plant by applying single and multi-objective optimization and an attractive result was obtained for the case of DE [3,8],the artificial intelligent technique PSO has been applied to improve the PID controller [7] besides this, optimization of nonlinear and linear time-invariant function by PSO is given in [10,13]. Many research work have been done considering AGC of having two or more interconnected areas using both single and multi-objective optimization, in [9,11] single and hybrid optimization methods was applied in AGC of two area having six units in non-reheat thermal power plant to improve the controllability of PID controller. ITAE which is known as Integral of Time multiplied Absolute Error is the most performance criteria or objective function to tune PID controllers, it has the advantage of reducing the settling time because using ITAE better tuning achievement is obtained as compared to other objective functions such as IAE or ISE [12]. For this, in this paper ITAE is chosen as objective function to tune PID controller using PSO and DE. Matlab/Simulink environment is used as simulation tool.

The following points given below are the contributions in this paper:

- Modeling and simulation of two area AGC to obtain the optimal gains parameter values of PID through single objective PSO and DE by considering 0.01 SLP in area 1 only
- Performance comparative analysis of PSO and DE for better LFC controller

***Nomenclature***

$\Delta P_{tie}$ deviation in tie line power.

$\Delta f$ Change in frequency

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| | |
|---|---|
| J | Cost Index |
| $T_{12}$ | synchronizing coefficient of AC tie-line |
| SLP | Step load perturbation |
| R | Governor speed regulation parameter |
| Tsg | Governor Speed time constant |
| Tt | Turbine time constant |
| B | Frequency bias constant |

***Acronyms***

| | |
|---|---|
| ACE | Area Control Error |
| ISE | Integral of Squared Error |
| IAE | Integral of Absolute Error |
| PSO | particle swarm optimization |
| DE | Differential evolution |

## II. SYSTEM MODELING

If generating units are interconnected, they will be in, at better fault tolerant. In control problem the tie- line power creates a tie-line power exchange error. Minimizing ACE using ITAE as a performance index is the major task in this paper. The transfer of power from area1 to area 2 is given by

$$P_{tie12} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1 - \delta_2) \qquad (1)$$

$\delta_1$ *and* $\delta_2$ are angles for voltage magnitude $V_1$ *and* $V_2$ respectively, whenever there is change of load demand in two areas there will exist an incremental change of power angle

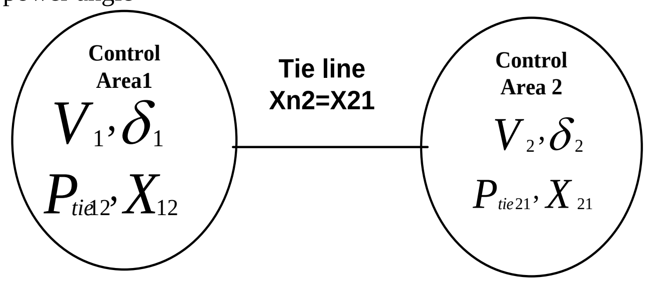


**Fig. 1: block diagram of two area control**

***System representation***

Thermal reheat turbine type of two-area interconnected power system is considered as a test system for this study. The Simulink model without controller and with controller are given in figure 2 and figure 3 respectively [11].The system parameters for the simulation are given in the Appendix A of table A.1.PID controller is optimized with DE and PSO so that the control of tie-line and frequency deviation. ACE is consider here as input to the controllers and the outputs for the model are respective $u_1$ and $u_2$ .

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1 \qquad (2)$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \qquad (3)$$

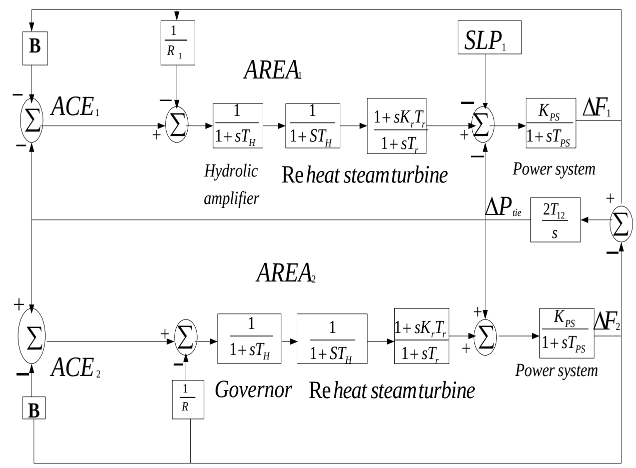


**Fig 2: Power system model under study referring without controller case [11]**

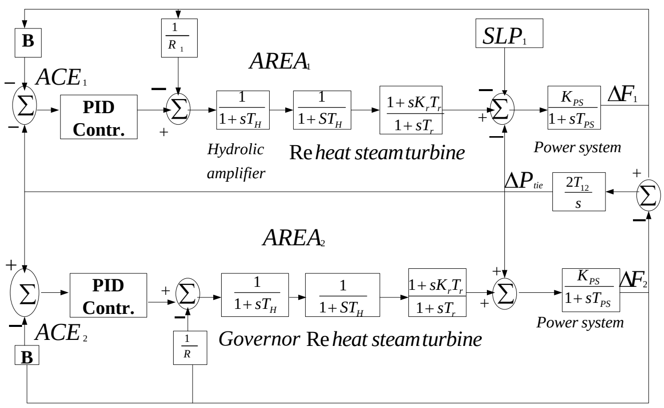


**Fig 3: Power system model under study with controller [11]**

## III. PROBLEM FORMULATION

Main objectives of AGC in power system are sustaining frequency to normal or specified range,mainataining interchange of power at appropriate level and converging ACE to zero, therefore the objective function to be, minimizing the i[th] control area error ( $ACE_i$ ), and mathematically given here in eqn. (4)

$$ITAE = \int_0^T t(|ACE_1| + |ACE_2|) \qquad (4)$$

## IV. TUNING METHODS

### A. Particle Swarm Optimization (PSO)

PSO is developed by Eberhart and Kennedy,it is population based heuristic or stochastic optimization technique based on the social behavior of bird flocking or fish schooling of swarm theory [13].In this method, a swarm consists of a set of individuals which are named as particles and each of them specified by their position as well as by velocity vectors and symbolically represented by (xi(t) and vi(t)) respectively. In PSO fitness values of all of particles is evaluated and optimized by using fitness function which has velocity to direct the flying. The first step in PSO is initializing group of random particles and searching for optima by following updating rules at each generations.

PSO performs searching by using swarm of particles to seek the optimal by updating from one iteration to the next iteration so that to obtain two "best" values, the previously best value so far achieved is (*pbest*) or personal best and the other best value that are obtained by any particle in the population is called (*gbest*) or global nest. The updating of the next iteration of , the velocity $v_{ik}$ and the position $x_{ik}$ for $k^{th}$ dimension of $i^{th}$ particles are given by equation (5) and (6) respectively .

$$v_{ik}^{(t+1)} = w * v_{ik} + c_1 * rand_{1,ik} * \left(pbest_{ik}(t)\right) + c_2 * rand_{2,ik}\left(g_{best,k}(t) - x_{ik}(t)\right)$$

(5)

$$x_{i,k}(t+1) = x_{ik}(t) + v_{ik}(t+1) \qquad (6)$$

where i = 1, 2, …, n is the index of particles, w is the inertia weight, $rand_{1,ik}$ and $rand_{2,ik}$ are random numbers in the interval [0 1], c1 and c2 are learning factors, and t represents the iterations. Here the PSO algorithm was run for 100 iterations with a population size of 50.

**Steps of PSO algorithms are:**

Set control parameters such as pop., number of particles (npar), maximum no.of iterations (maxit),c1,c2.

*Initialization*

*Repeat {*

*Evaluate the fitness values of particles*

*Compare the fitness values to determine the* $p_{best_i}$ *and* $g_{best_i}$

*Update the velocity and position of particle*

*} Until (stopping criteria is met)*

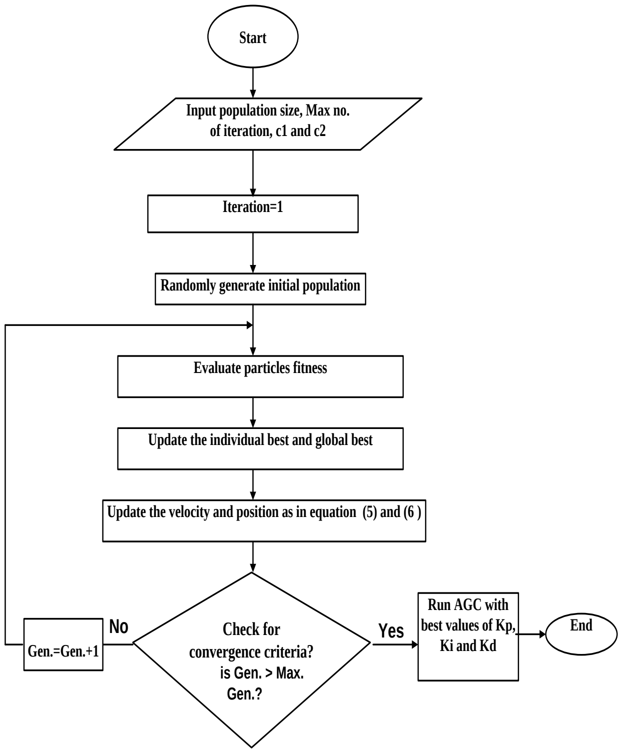


**Figure.4 Flowchart of Particle Swarm Optimization (PSO)**

## B. Differential evolution (DE)

Evolutionary algorithms (EAs) are inspired by their biological evolutionary mechanisms in nature, some disadvantages of the earliest EAs are, stagnation, complex procedure and poor search ability. To overcome such draw backs other related methods are proposed by the researchers such as PSO and DE.

DE is population-based stochastic global search method ,which is proposed and developed by Storn and Price [14].Since DE is the most recent EAs,it has the following advantages such as simplicity, reliability, robustness ,efficiency, speediness, real coding and helps to solve problems in real type optimization parameters, in DE the sequences of the optimization processes are, initialization of the population,mutation,recombination or cross over and the last one is selection, the number of population size and iteration number applied here using DE method in this paper are 50 and 100 respectively. The steps of DE operations are described below [3].

***Initialization***

By considering parameter j having lower bound $X_j^L$ and upper bound $X_j^U$ the initial parameter values are randomly and uniformly selected in the interval [ $X_j^L$ , $X_j^U$ ]

***Mutation operation:*** By considering each target vector $X_{i,G}$ a mutant vector , $V_{i,G} = \{V_{1i,G}, V_{2i,G,} .. V_{Di,G}\}$ is obtained by using

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}) \qquad (7)$$

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

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

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

, j = 1,2...,D (8)

***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 (9), the one which is going to be involve in the next generation from either of the two will be identified.

$$X_{i,G+1} = \begin{cases} U_{i,G} & if\ f(U_{i,G}) \le f(X_{i,G}) \\ x_{i,G} & otherwise \end{cases} \qquad (9)$$

Where $i \in [1, N_P]$

**Steps of DE algorithms are:**

Set control parameters such as NP, F, CR, Gen., number of particles (npar)

*Initialization*

*Evaluate the fitness values of each particle*
*Repeat {*
*Mutation*
*Crossover*
*Selection*
*Evaluate the new individuals.*
*} Until (convergence criterion is met*

**Table 1 PID gain values**

| Optimization methods | *Area* | *Kp* | *Ki* | *Kd* |
|---|---|---|---|---|
| PSO-PID | Area1 | 0.9043 | 0.4704 | 0.1204 |
| | Area2 | 0.9591 | 0.6021 | 0.1530 |
| DE-PID | Area1 | 1 | 1 | 0.1401 |
| | Area2 | 1 | 1 | 1 |

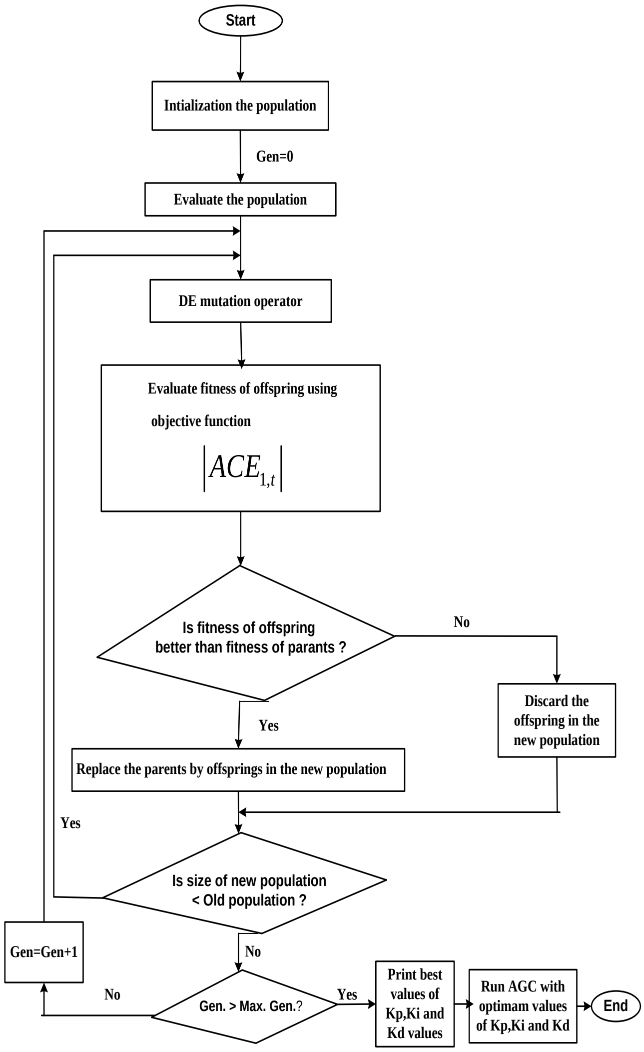


**Figure 5: Flow chart of DE [8]**

## V. RESULTS AND DISCUSSION

Thermal-thermal, two equal area power system model is developed using Matlab/Simulink as given in figure 2 and figure 3 without controller and with controller respectively and simulation is carried out using PSO and DE methods, in case of PSO total number of particles are given 6, cognitive ($c_1$) and social ($c_2$) learning parameters are 2 and regulation factor (R) and constant ($c_3$) are given respectively as 30 and 1.For DE, number of particles are 6, 0.98 and 0.5 are crossover rate (CR) and scaling factor (F) respectively. The optimal gain parameter values of PID using these techniques for both areas are given in table 1 .The task has been done by interfacing (.m file) written program with Simulink block using ITAE as a performance index and best simulation result is obtained after running the program for 20 times by considering 50 populations and 100 maximum generations using Intel core i7 desk top computer, by considering 1% step load change in area 1.Figure 6 shows the convergence characteristics of PSO-PID with DE-PID, and according to the result DE-PID has better convergence than PSO-PID.Similarly the comparison of PSO-PID,DE-PID and without controller is given from figure 7 to figure 11, for the time response parameters such as undershoot, overshoot and settling time, to measure the change in frequency, change in tie-line deviation and change in area control error and according to the investigation result, it reveals that with DE-PID controller rise time,overshoot,undershoot and oscillation decreases, besides this faster settling time is also achieved better than PSO PID,the numerical comparative analysis is also given in table 2

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**Table 2.Time response transient analysis performance comparison analysis for PSO-PID, DE-PID and without controller cases**

| Measured parameters | Without controller | | | | | PSO-PID | | | | | DE-PID | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta ACE\ 1$ | $\Delta ACE\ 2$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta ACE\ 1$ | $\Delta ACE\ 2$ | $\Delta f1$ | $\Delta f2$ | $\Delta P_{tie\ 12}$ | $\Delta ACE\ 1$ | $ACE\ 2$ |
| Rise time | 0.0792 | 0.3168 | 0.2799 | 0.1454 | 6.5427e-04 | 8.5592e-05 | 2.9392e-05 | 0.0091 | 5.3693e-05 | 0.0092 | 2.2694e-05 | 4.5043e-05 | 2.0898e-04 | 3.5724e-05 | 6.0889e-04 |
| Settling time | 27.9243 | 28.7290 | 33.6246 | 29.7489 | 33.2074 | 16.5433 | 17.3441 | 25.7324 | 21.2969 | 20.1005 | 11.1892 | 13.1448 | 18.2450 | 14.9611 | 17.2586 |
| Under shoot | -0.0216 | -0.0205 | -0.0055 | 0.0038 | -0.0025 | -0.0047 | -0.0017 | -0.0050 | -4.0847e-04 | -0.0021 | -0.0047 | 1.8869e-07 | -0.0046 | -0.000452 | -9.4966e-04 |
| Over shoot | -0.0031 | -0.0025 | -9.7162e-04 | 0.0131 | 0.0054 | 0.001 | 6.8610e-04 | 2.2109e-04 | 0.0124 | 0.0046 | 0.001 | -0.000827 | 2.1868e-04 | -4.6207e-08 | 0.0025 |
| ITAE error value at without controller | | | | 6.5992 | | | | | | | | | | | |
| ITAE error value at DE PID controller | | | | 0.1145 | | | | | | | | | | | |
| ITAE error value at PSO PID controller | | | | 0.2424 | | | | | | | | | | | |

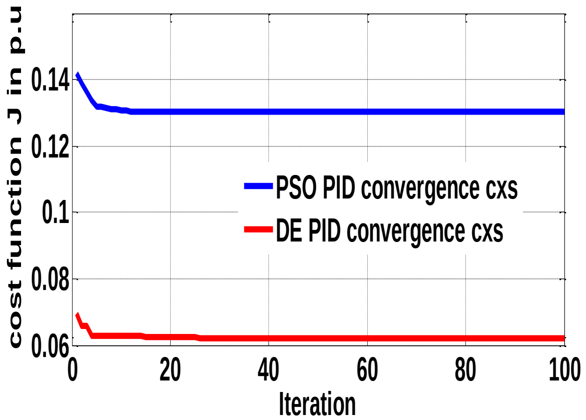


**Fig 6. Convergence characteristics of PSO and DE**

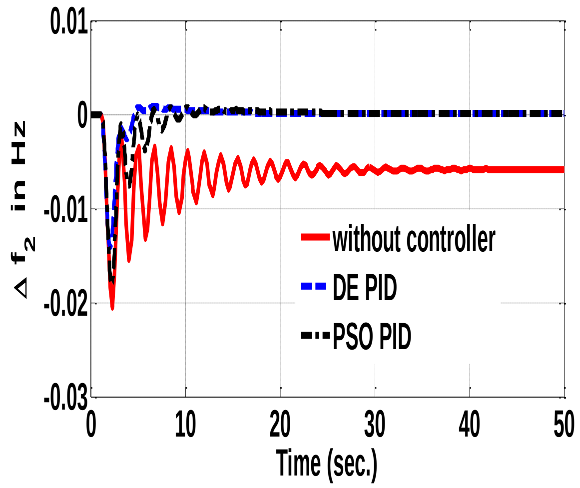


**Fig 8. Dynamic frequency response of $\Delta f2$ in area 2**

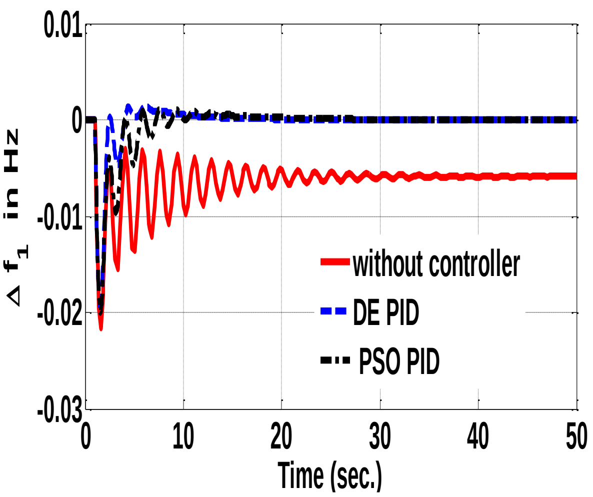


**Fig 7. Dynamic frequency response of $\Delta f1$ in area 1**

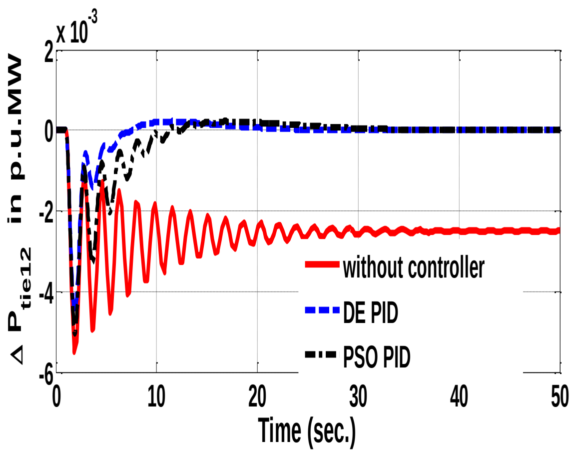


**Fig 9. Tie line power p12 response**

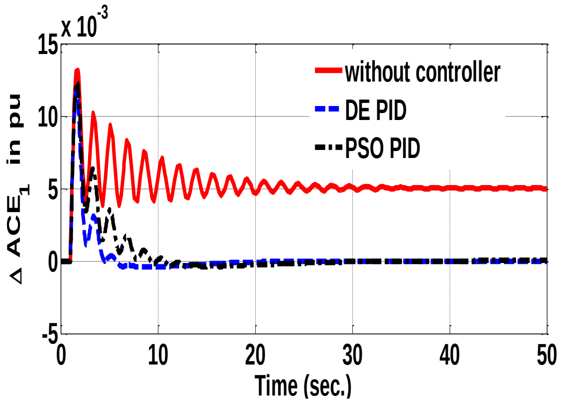


**Fig 10.** $\Delta ACE1$ **response**

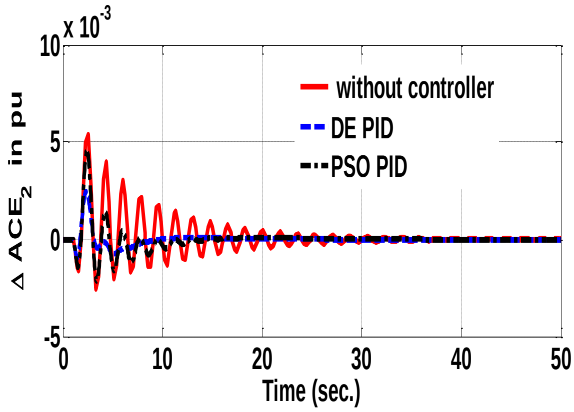


**Fig 11.** $\Delta ACE2$ **response**

## VI. CONCLUSION

To study the roll of AGC in power system control, two area system is considered.DE tuned PID controller is proposed to improve the AGC performance. Using the developed AGC model, performance of the proposed DE-PID is compared with without controller and PSO-PID, since the proposed method is also advanced instead of the usual governor control system of LFC.The following points are main conclusion from the task carried out.

- Power system model is developed for the system under study
- DE-PID and PSO-PID algorithms are developed and interface with the Matlab/Simulink model of the system under study.
- Comparative study for DE-PID, PSO-PID and without controller is performed and investigation inferred the superiority of the proposed DE-PID over PSO-PID.
- Moreover less settling time, less under shoot and low oscillation is obtained through the method of DE-PID.

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## APPENDIX A

**Table A.1**

| Symbols | Value |
|---|---|
| $T_H$ | 0.08 s |
| $T_T$ | 0.3 s |
| $T_r$ | 10.0 s |
| $K_r$ | 0.5 |
| $T_P$ | 20 s |
| $K_P$ | 120 |
| $R$ | 2.4 Hz/MW |
| $B$ | 0.425 MW/Hz |
| $T_{21}$ | 0.086 |

## AUTHOR'S PROFILE

**Dr.Solomon Feleke Aklilu,** received the B.Tech degree in Electrical and Electronics Engineering from Bahir Dar University,Bahir Dar,Ethiopia in 2008,MSc.degree from Arba Minch University,Arba Minch, Ethiopia in 2012 and Ph.D degree from Andhra University,Visaknapatnam,India in 2019, he has more than two publications on international journals .He is now, currently working as an Assistant Professor in Electrical and Computer Engineering Department in Debre Berhan University, Debre Berhan,Ethiopia.