Automatic generation control of a two unequal area thermal power system with PID controller using Differential Evolution Algorithm

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Abstract

The early aim of automatic generation control is to regulate the power output of the electrical generator with in a prescribed area in response to changes in system frequency, tie line loading, so as to maintain the scheduled system frequency and interchange with the other areas with predetermined limits. Automatic generation control of a multi-area power system provides power demand signals for its power generators to control frequency and tie line power flow due to the large load changes or other disturbances. Occurrence of large megawatt imbalance causes large frequency deviations from its nominal value which may result instability in the power system. To avoid such situation emerging control to maintain the system frequency using differential evolution based proportional integral-derivative (PID) controller has been used in this paper. Differential evolution (DE) is one of the most power full stochastic real parameter optimization in current use. Differential evolution based optimization gains give better optimal transient response of frequency and tie line power changes compared toLozi-map based chaotic algorithm (LCOA).

Key words: DE: Differential Algorithm, AGC: Automatic Generation Control, ACE: Area Control Error, SLP: Step Load Perturbation,LFC**:** Load Frequency Control,

I. Introduction

An interconnected power system can generated, transport and distribute the electrical energy with the main objective of these power system is to supply electric energy with its system nominal frequency and terminal voltage. According to the power system control theory the nominal frequency depends upon the balance between the generated power and the consumed real power[1].If the amount of the generated power is less than the amount of demand power, then the speed and frequency of generator units is going to be decreased ,and vice versa .So for that reason the frequency deviation occurred in the power system in order to maintain that balance. For this purpose a megawatt frequency controller or automatic generation control(AGC)concept is used.The early aim of the Automatic generation control(AGC)is to regulate the power output of the electrical generator within a prescribed area in response to changes in system frequency,tie-line loading ,so as to maintain the scheduled system frequency and interchange with the other areas with predetermined limits[2,3]. Generally the load frequency control is accomplished by two different control action of the primary speed control and supplementary speed control in an interconnected power system. The primary speed control performs the initial readjustment of the frequency.By its action, the various generator in the control area track a load variation and share it in proportion to their capacities.The speed of these response is only limited by the natural time lags of the turbine,governor and system it-self.The supple-mentary speed control takes over the fine adjustment of the frequency by the resetting the frequency error to zero through an PI controller[2].The main drawback of this supplementary controller is that the dynamic performance of the system is highly dependent on the selection of its gain.A high gain may deteriorate the system performance having large oscillation and in most cases it causes instability[2,4].Thus the integrator must be set to a level that provides a compromise a desirable transient recovery and low over shoot in the dynamic response of the overall system preventing instability[5,6].For the better performance of PID control optimized constraints have to be adopted.To get the optimized value we are having different optimization techniques such as classical, optimal, genetic algorithm,fuzzy logic,artificial neural network etc, for the design of supplementary controller.Talaq, suggested an adoptive fuzzy gain scheduling method for conventional PI controllerin[11].In[12] Pingkang optimized the gains of the PI and PID controller through real coded genetic algorithm in a two area power system. Abdel-Majid and Abedo purposed a usage of PSO for the same purpose[13].In[14] Yesil suggested the self-tuning fuzzy PID type controller for AGC.In[15]Gozde and Taplamacioglu purposedthe usage of craziness based PSO algorithm for AGC system for an interconnected power system.In[30]M.Farahani, S.Ganjefar, M.Alizadeh suggested a method of using PID controllers for a two area unequal thermal system tuned by Lozi-mape based chaotic optimization algorithm.

In[31]Storn and Price proposed a meta-heuristic evolutionary algorithm non as differential evolution algorithm.In order to solve″ many parameter" based higher order optimization problems; DE can be considered as a power full and well efficient population based stochastic search technique.

2: Proposed methodology

The contribution of this paper is the performance analysis of differential evolution algorithm in tuning of a PID controller applied in AGC.

2.1:PID controller

Basically, different process industries use PID controller as the most popular feedback control mechanism. Till date from half of this century, it is the most popular feedback controller which is being used in the process industries. This can be considered as an excellent controller that can help in providing excellent performance of the process plant. It is due to their easy and simple implementation in various control applications.

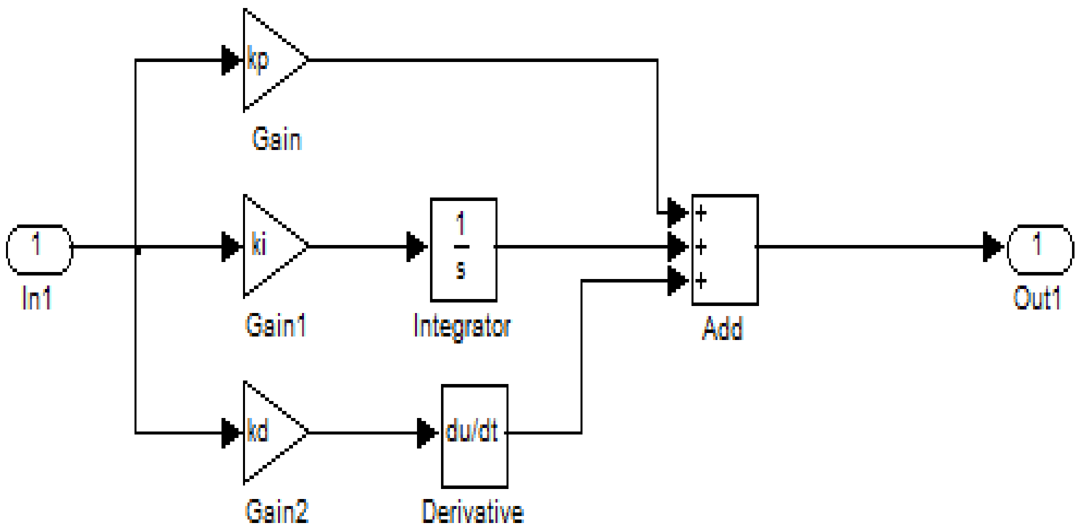

Fig.1. Simulink representation of PID controller

The PID as given in fig. 1 controller consists of three basic modes: proportional, integral, derivative modes respectively. A proportional controller gain (K_p)reduces the rise time but does not eliminate the steady-state error, integral gain (K_i)eliminates the steady state error but resulting a worse transient response, derivative gain (K_d) increases the stability of the system and improves the transient response and reduces overshoot[29]. These values of above gains are obtained by hit and trial method based on the plant behaviour and experiences. The equation below represents the transfer function of PID (Laplace Domain) is given by:

$$TF_{PID} = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

In time domain, the output of PID controller is given by;

$$u\,(t)=K_p.e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \qquad (2)$$

Where *e(t)* is error signal and *u(t)* is control signal.

In the design of PID controllers(two in number) for this work the six gains are selected in such a way that the desired response obtained of the closed loop system which refers that the system should have a minimum settling time and a very less value of overshoot as well as undershoots with less oscillations due to a 20% Step Load Perturbation.

In the PID controllers the control inputs are $ACE_I$and ACE_2whereas u_1 and u_2 are the outputs respectively. On relating the inputs and outputs of the system u_1 and $u_2$are given as;

$$u_1 = ACE_I\left(K_{p_1} + \frac{K_{i_1}}{s} + K_{d_1}s\right) \qquad (3)$$

$$u_2 = ACE_2\left(K_{p_2} + \frac{K_{i_2}}{s} + K_{d_2}s\right) \qquad (4)$$

The value of Area Control Error (ACE) is the sum of Bias Factor and Tie line power deviation. The Area Control Error in both the areas consists of Tie line power error of the intermediate area and the Frequency error, given by;

$$ACE_1 = B_1 + \Delta P_{tie} \qquad (5)$$

$$ACE_2 = B_2 + \Delta P_{tie} \quad (6)$$

In this work, the constraint of setting the gains of PID controller is a major problem. Therefore, the PID gains should be in limits; i.e.

$$K_{p_{min}} \leq K_{p_i} \leq K_{p_{max}}$$
$$K_{i_{min}} \leq K_{i_i} \leq K_{i_{max}}$$
$$K_{d_{min}} \leq K_{d_i} \leq K_{d_{max}}$$

Where i is the number of controller gain (here $i = 2$, due to two controllers). $K_{p_{min}}$, $K_{i_{min}}$, $K_{d_{min}}$ are the minimum values of controller parameters and $K_{p_{max}}$, $K_{i_{max}}$, $K_{d_{max}}$ are the maximum allowable values for the controller parameters. Henceforth, in this work the PID parameters are constrained within [0, 2].

In the earlier section, the need for use of PID controller is shown and in order to tune different parameters of the PID controller Evolutionary Algorithms comes into picture. DE can be said as such a meta-heuristic evolutionary algorithm which was developed by Storn and Price[31].In order to solve "many parameter" based higher order optimization problems; DE can be considered as a powerful and well efficient population based stochastic search technique.

The main flow of steps of Differential evolution algorithm in a simple manner is shown in fig.2.The DE algorithm consists of the four basic steps-initialization of a population of search variable vectors, mutation, crossover or recombination, and finally selection.

2.2:Differential Evolution

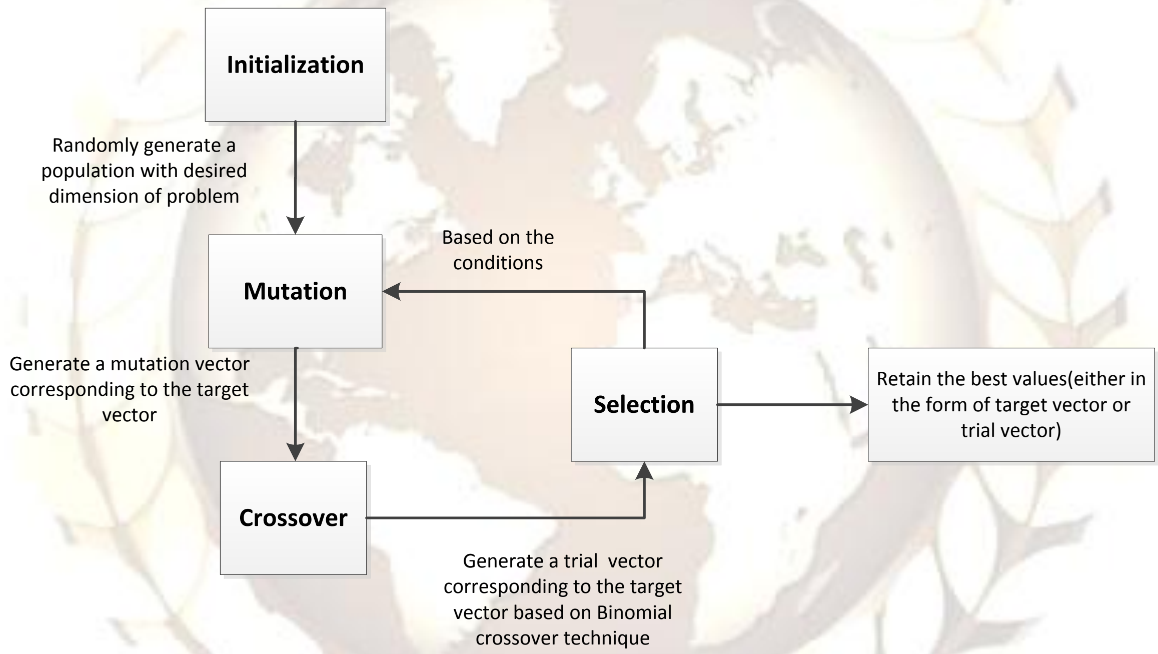

Fig. 2. Stages of Differential Evolution algorithm

2.2.1 Initialization

The values of the control parameters of DE: scale factor *F*, crossover rate *Cr*, and the population size *NP* are initialised. Initially a population of NP individuals is initialized with the generation set given as $G = \{0,1, \ldots \ldots, G_{max}\}$. (7)

For a D dimensional optimization problem, the candidate solutions are taken to be $X_{i,G} = \{x_{i,G}{}^1 \ldots \ldots \ldots \ldots, x_{i,G}{}^D\}$,where the value of $i = [1, NP]$.

$X_{i,G}$ is in a range of $\{X_{min} < X_{i,G} < X_{max}\}$.$X_{min}$ *and* X_{max} have values in the range of $\{x^1{}_{min}, \ldots\ldots, x^D{}_{min}\}$ and $\{x^1{}_{max}, \ldots\ldots, x^D{}_{max}\}$ respectively.

2.2.2 Mutation

Mutation stands for sudden change. In DE-literature, a parent vector from the current generation *G* is called *target* vector, a mutant vector is generated through the mutation operation is known as *donor* vector and finally an offspring formed by recombining the donor with the target vector ($X_{i,G}$) is called *trial* vector. For each target vector, a mutation vector $V_{i,G}$ is generated with the help of following strategy:

Strategy 1 DE/rand/1:

$$V_{i,G} = X_{r_1^i,G} + F.\left(X_{r_2^i,G} - X_{r_3^i,G}\right) \quad (8)$$

$r_1^i, r_2^i, and\ r_3^i$ are generated randomly in between [1,NP] and are mutually exclusive integers are not repeated. F is the scaling factor in the range of [0.1 1.0].

2.2.3 Crossover

The donor vector exchanges its components with the target vector $X_{i,G}$ under this operationto form the trial vector $\overrightarrow{U_{i,G}} = [u_{1,i,G}, u_{2,i,G}, u_{3,i,G} \ldots\ldots, u_{D,i,G}]$ .The DE uses two kinds of cross over methods—*exponential* (or two-point modulo) and *binomial*(or uniform).

Now for each target vector$X_{i,G}$, a trial vector $U_{i,G}$ is generated. Crossover in DE can be binomial or even exponential. Here for the generation of trial vector $U_{i,G}$ binomial crossover is used. The steps for crossover are:

$$U_{i,j,G} = \begin{cases} V_{i,j,G} \text{ if } (j_{rand} \leq CR) \text{ or } (j = j_{rand}) \\ X_{i,j,G} \text{ if } (j_{rand} > CR) \text{ or } (j \neq j_{rand}) \end{cases}$$

j_{rand} is a random number between 0 and 1 multiplied with the dimension of the optimization D. Crossover Rate (CR) is chosen in between [0.1 1.0]. In this work the values of F and CR are 0.8 and 0.5 respectively.

2.2.4 Selection

In order to maintain a constant population size over the length of consistently increasing generations, this step selects the survival of the target or the trial vector based on equations (7) and (8) thus passing it to the next generation, i.e., at $G = G + 1$.The target vector is compared with the trial vector and the better value between these two is used in the further generation.

If $f(U_{i,G}) \leq f(X_{i,G})$ *then* $X_{i,G+1} = U_{i,G}, f(X_{i,G+1}) = f(U_{i,G})$ (9)

If $f(U_{i,G}) > f(X_{i,G})$ *then* $X_{i,G+1} = X_{i,G}$ (10)

The iteration of the DE steps terminates when either the number of generations is exhausted or when the best value of fitness of the objective function does not have an appreciable change.

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

3:System investigated

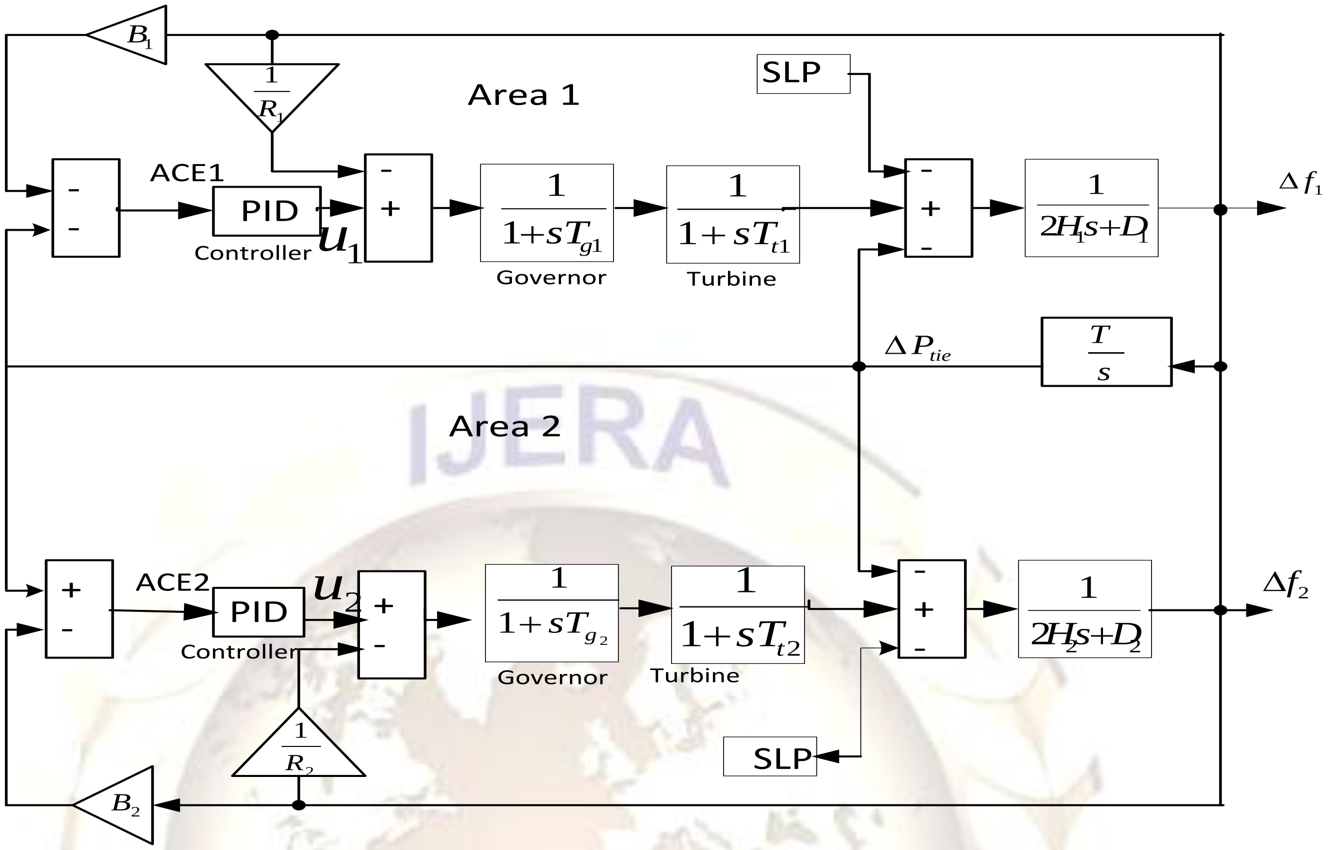

Fig 3. The control diagram of an interconnected unequal thermal system [30]

The Automatic Generation Control system investigated in this work as shown in fig. 3 consists of two generating areas, i.e.; Area 1 and Area 2 both comprising of two unequal thermal systems [30]. The use of both the unequal systems in the interconnected system can be considered as a simple model for general power system around the world which basically consists of thermal as a primary means for the generation of power to cater the demands of the ever-growing consumption. In order to understand the control actions at the power plants for LFC, taking the boiler–turbine–generator combination into consideration of a normal thermal generating unit. Most steam turbo generators (STG) now in service are equipped with turbine speed governors. Moreover, to make the approach more realistic both the areas taken into consideration have different time constants of different control parameters.

4:Results and discussion

As per the Literature and many other past works it has been observed that many researchers have considered to give the disturbance or to provide a small step load perturbation (SLP) only in one area so to optimize the gains of the controller. Similarly in this work a step disturbance of 20% or 0.2 p.u. is provided in Area 1 and thus the parameters of PID controllers are tuned in accordance to it. The PID controller is tuned with meta- heuristic, Differential Evolution algorithms and the results are compared against the past Lozi map-based chaotic optimization algorithm (LCOA) based work [30].

Based on the PID parameters dynamic responses are observed i.e., frequency deviation in Area 1(Δf_1), frequency deviation in Area 2(Δf_2) and the tie line power deviation (ΔP_{tie}). Fig. 4, Fig. 5 and Fig. 6 shows the curves of variations of$\Delta f_1, \Delta f_2$ andΔP_{tie} respectively with optimal controller gains obtained corresponding to the differential evolution algorithms with SLP provided at Area-1.For similar SLP, the variations in the output of the Governor is compared in Fig.7. The settling time (T_s) of $\Delta f_1, \Delta f_2$ andΔP_{tie} corresponding to the differential evolution algorithms used LCOA algorithm are depicted in Table 2. Table3 mentions about the maximum peak overshoot (O_{sh}) of $\Delta f_1, \Delta f_2$ andΔP_{tie} corresponding to the DE algorithms and LCOAalgorithm.The details of the maximum values of undershoot (U_{sh})aredenoted in Table 4.

Results show that the PID controllers' tuned DE algorithm for an AGC system achieves better dynamic performance as compared to LCOA algorithms under normal condition as well as with a step load perturbation of 20%.

Table; 1

Algorithm	**PID controller gains of area 1**			**PID controller gains of area 2**		
	Kp1	**Ki1**	**Kd1**	**Kp2**	**Ki2**	**Kd2**
DE	1.9138	1.8981	0.9063	0.8035	1.6833	0.8820
LCOA	0.939	0.7998	0.5636	0.5208	0.4775	0.7088

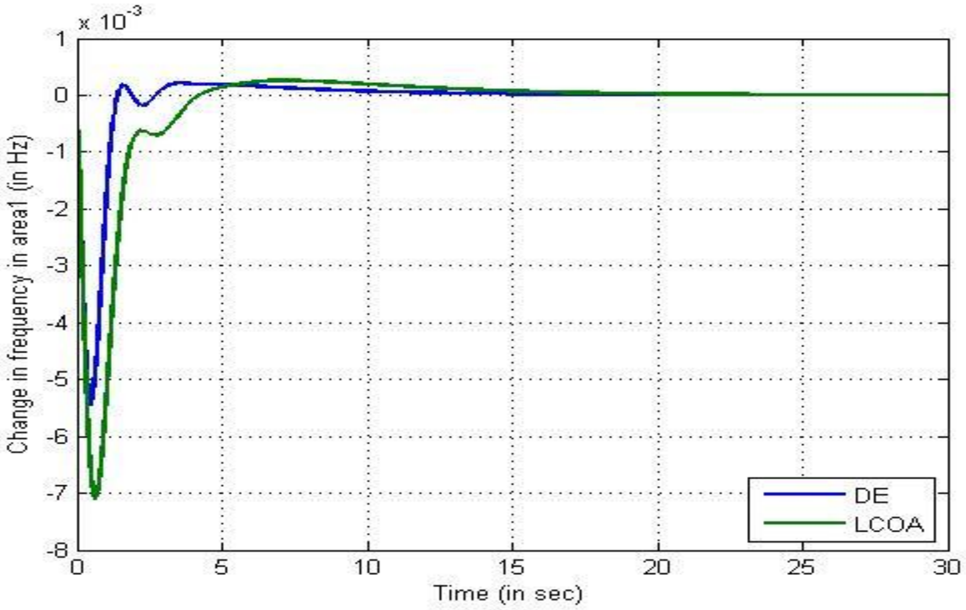

Fig. 4. Comparisons of dynamic responses Frequency deviations (Δf_1) of Area-1.

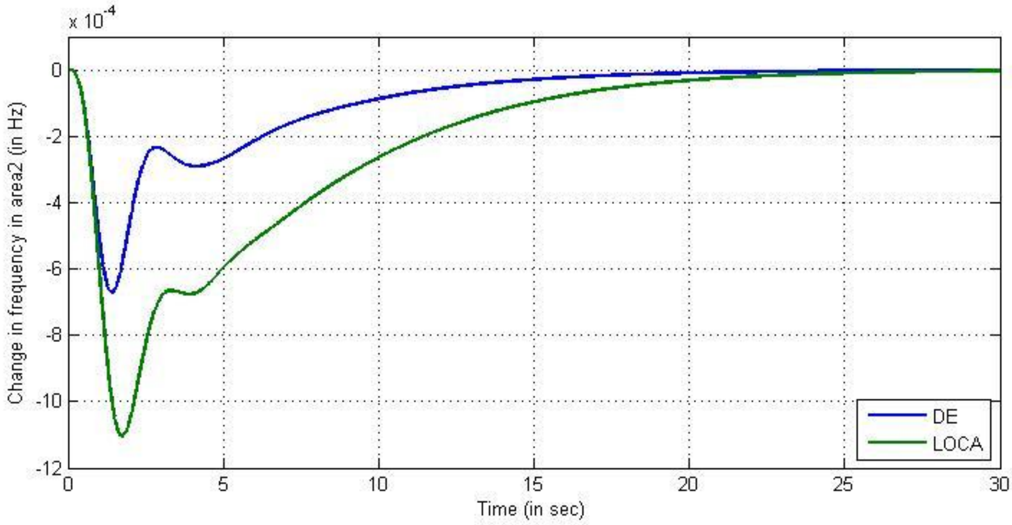

Fig. 5. Comparisons of dynamic responses Frequency deviations (Δf_2) of Area-2.

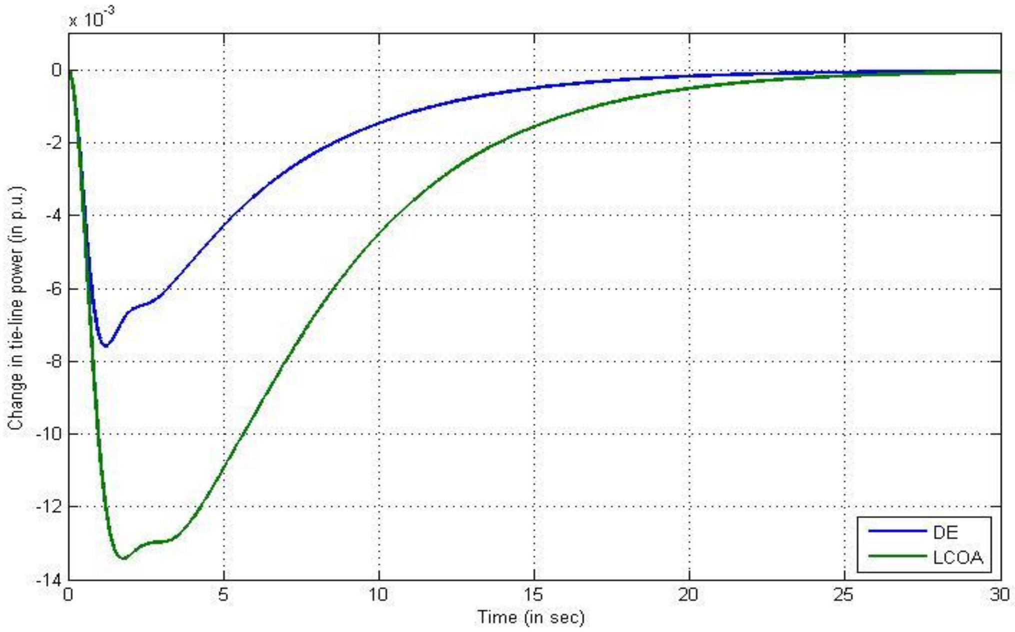

Fig.6. Comparisons of dynamic responses Tie-line power deviations (ΔP_{tie}).

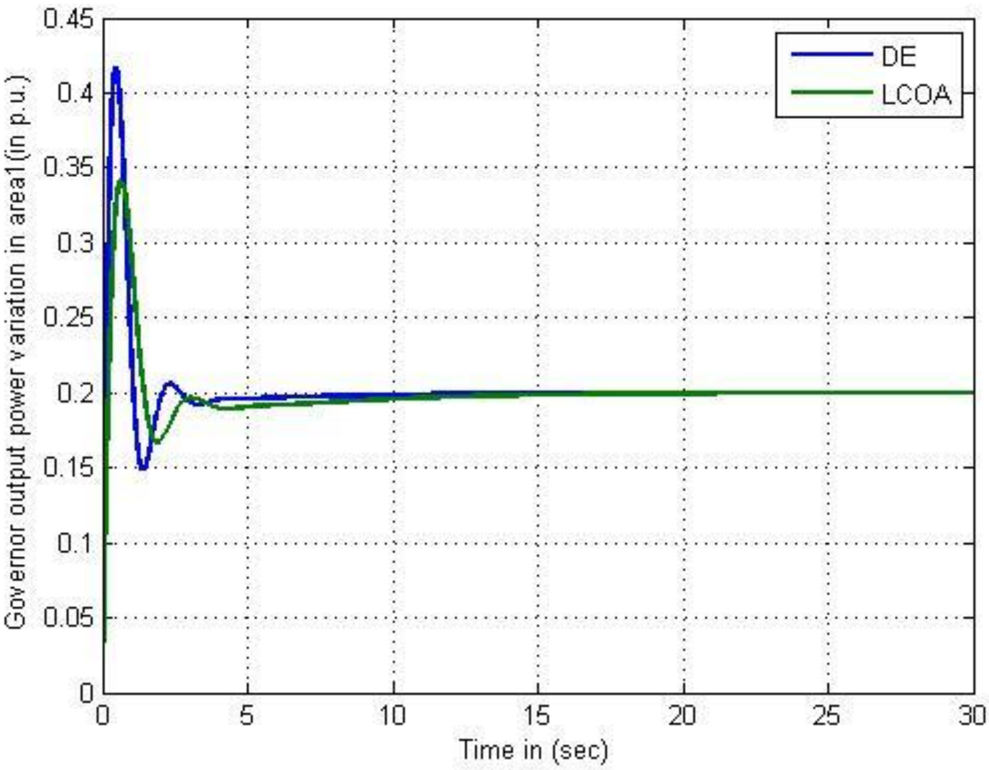

Fig.7. Comparisons of dynamic responses of Governor output variations due to DE & LCOA.

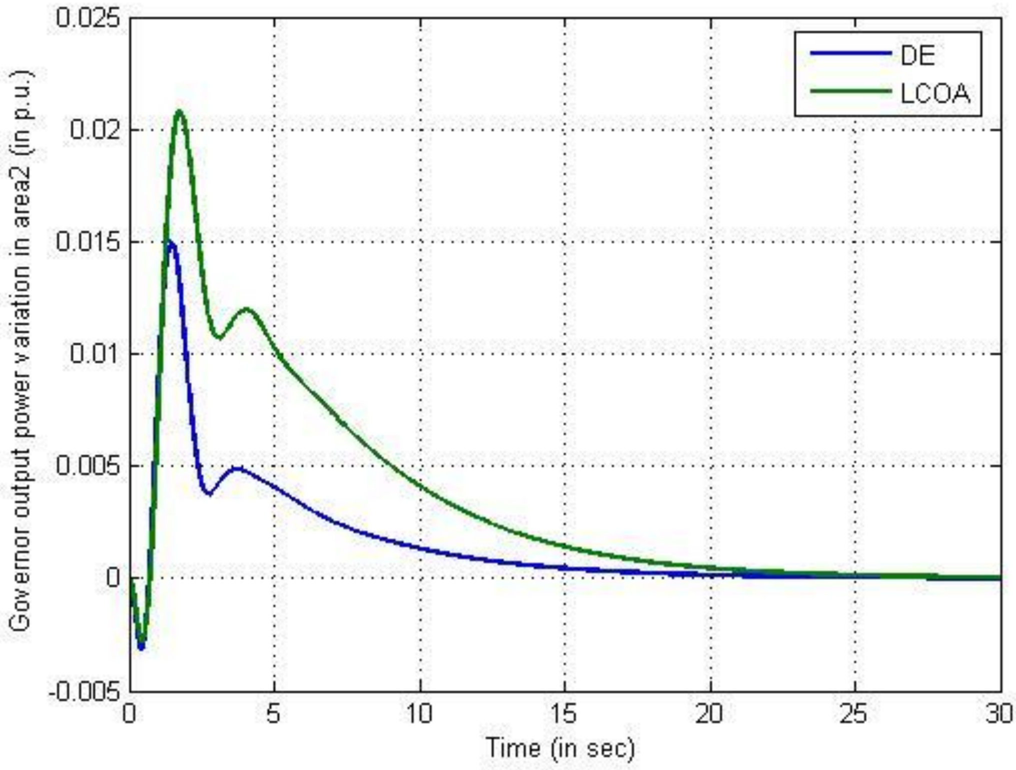

Fig.8. Comparisons of dynamic responses of Governor output variations due to DE & LCOA.

4.1 Analysis of settling time

Table 2

Settling times (0.02% band) corresponding DE and LCOA algorithms.

Settling time	DE	LCOA [30]
For frequency deviation in area1	3.9300	9.23
For frequency deviation in area2	6.2600	11.44
For tie line power deviation	19.0900	23.97

Based on Table 2, it can be made clear that the system tuned with DE algorithm has a settling time (T_s) for $\Delta f_1, \Delta f_2$ andΔP_{tie} lesser than that of the system tuned with LCOA algorithms. The settling time for frequency deviation in Area 1 for DE algorithm is about 57.4% lesser than that LCOA algorithm tuned system. Similarly, the settling time for frequency deviation in Area 2 for DE algorithm is about 45.3% lesser than that LCOA algorithm tuned system. For the deviation in tie line power the settling time for DE algorithm is 20% lesser than that of LCOA tuned system[30]. Thus; in all respects and all cases the settling time of the dynamic responses of the deviations of $\Delta f_1, \Delta f_2$ andΔP_{tie} for the system tuned with DE algorithm are quite lesser in comparison to the LCOA algorithm. In order to give a clear pictorial representation fig.9 shows the comparison of the settling times for the DE and LCOA algorithms for the deviations in frequencies and tie line power deviations.

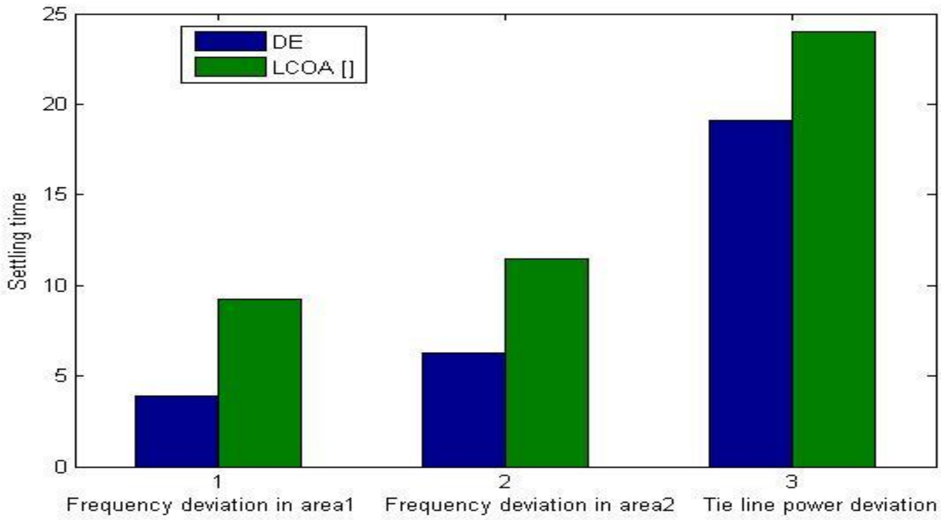

Fig. 9..Comparison of settling times for DE and LCOA algorithm.

4.2Analysis of maximum peak overshoot

Table 3
Maximum Peak overshoots corresponding to DE and LCOA algorithms ($*10^{-4}$).

Overshoot x10^{-4}	DE	LCOA [30]
For frequency deviation in area1	2.1377	2.5766
For frequency deviation in area2	0	0
For tie line power deviation	0	0

From Table 3, it can be seen that the frequency deviation in area 2 and the tie line power deviation do not have any peak overshoot or positive value of peak. Mainly the peak overshoot is present for the frequency deviation in Area 1 which has a lower value for the system tuned with DE algorithm. The maximum overshoots for frequency deviation in Area 1 for DE algorithm is about 17% lesser than that of LCOAalgorithm tuned system. To verify this analysis a column graph is depicted in fig 10.In this it is clear that the system tuned with DE gives a lesser value of peak overshoot as compared to LCOA algorithms.

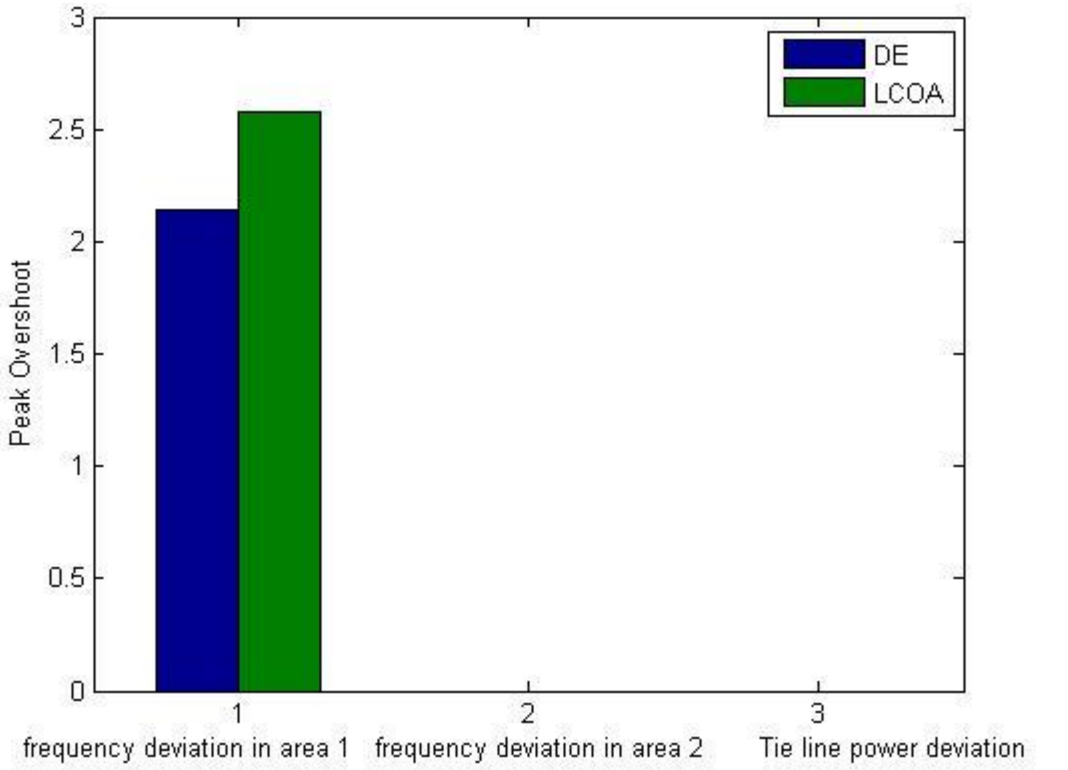

Fig. 10. Comparison of peak overshoots for DE and LCOA algorithm.

4.3 Analysis of maximum peak undershoot

Table 4

Maximum Peak undershoots corresponding to DE and LCOA algorithms ($*10^{-4}$).

Undershoot x10^{-4}	DE	LCOA [30]
For frequency deviation in area1	-54.3827	-70.9301
For frequency deviation in area2	-6.7042	-11.0361
For tie line power deviation	-75.8542	-134.2559

Table 4 specifies the values of maximum values of peak undershoot for the dynamic responses corresponding to DE and LCOA algorithms. In all the responses i.e.,Δf_1, Δf_2 andΔP_{tie} the values of peak undershoots are minimum in case of DE tuned system. The values obtained with the DE system are quite lesser in compared to LCOA algorithms. The peak undershoot $(\boldsymbol{U_{sh}})$ for frequency deviation in Area 1 for DE algorithm is about 23.3% lesser than that LCOA algorithm tuned system. Similarly,$(\boldsymbol{U_{sh}})$ for frequency deviation in Area 2 for DE algorithm is about39.25% lesser than LCOA algorithm tuned system. For the deviation in tie line power the undershoot$(\boldsymbol{U_{sh}})$ for DE algorithm is about43.5%lesser than that of LCOA tuned system . Fig. 11 shows the comparisons for the values of undershoots for the system

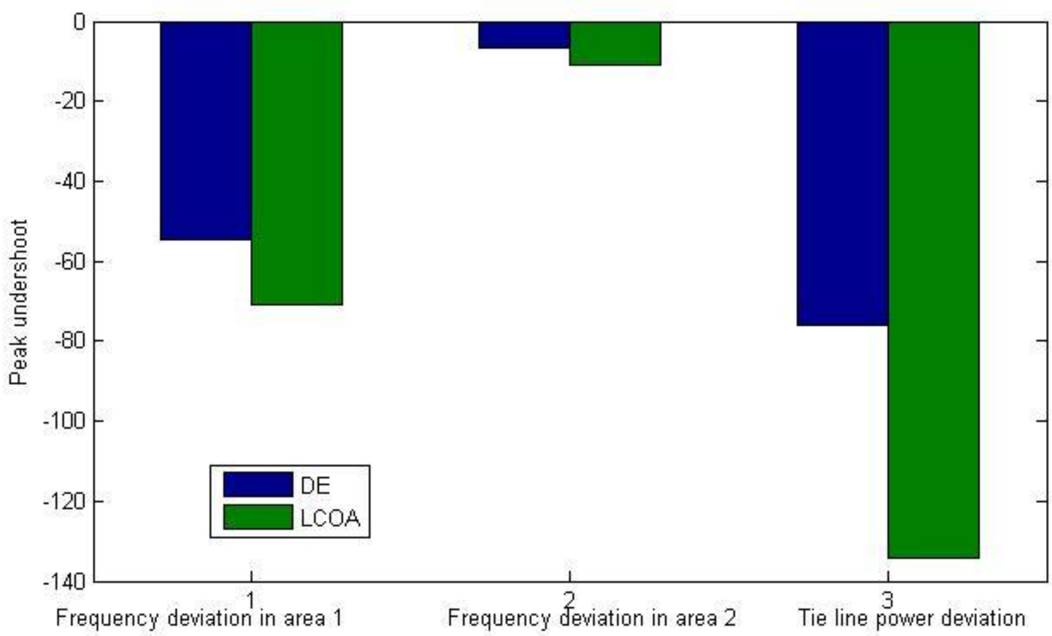

Fig.11. Comparison of peak undershoots for DE and LCOA algorithm.

From all the above analysis, facts and figures it is cleared that the DE tuning approach gives better dynamic responses as compared to LCOA tuning algorithm Thus, keeping all other factors, analysis and comparison it can be well said that this system when tuned by DE approach gives the best dynamic response.

5.VARIATION IN THE STEP LOAD PERTURBATION (SLP)

The nominal value of Step Load Perturbation used in this work is 20% or 0.2 p.u. The value of SLP is varied in the ranges of $\pm$ 50% in steps of 20% in order to estimate the response of the interconnected power system to different values and types of disturbances i.e., SLP. The settling time along with the values of maximum peak overshoot and undershoot of the transient responses due to the variation of SLP applied in areas 1and as far as in all possible cases is given in Table 5,Table 6 and Table 7. From the analysis, it can be depicted that the transient response of the curve takes a time of about 21sec,s to completely zero itself even if the disturbance of 30% or 0.3 p.u. is provided at both the areas simultaneously. Fig 12-17 shows the curves for SLP variation in area 1, the variation of the curves from the normal value of response when SLP is varied in the areas 1. Also, from Table 7and Table 8; it can be clearly analysed that the values of overshoots as well as undershoot lies within a allowable range. Thus, it can be said that irrespective of variation in the values of SLP the system does not show any undesirable results.

5.1.SLP Variation applied to Area 1

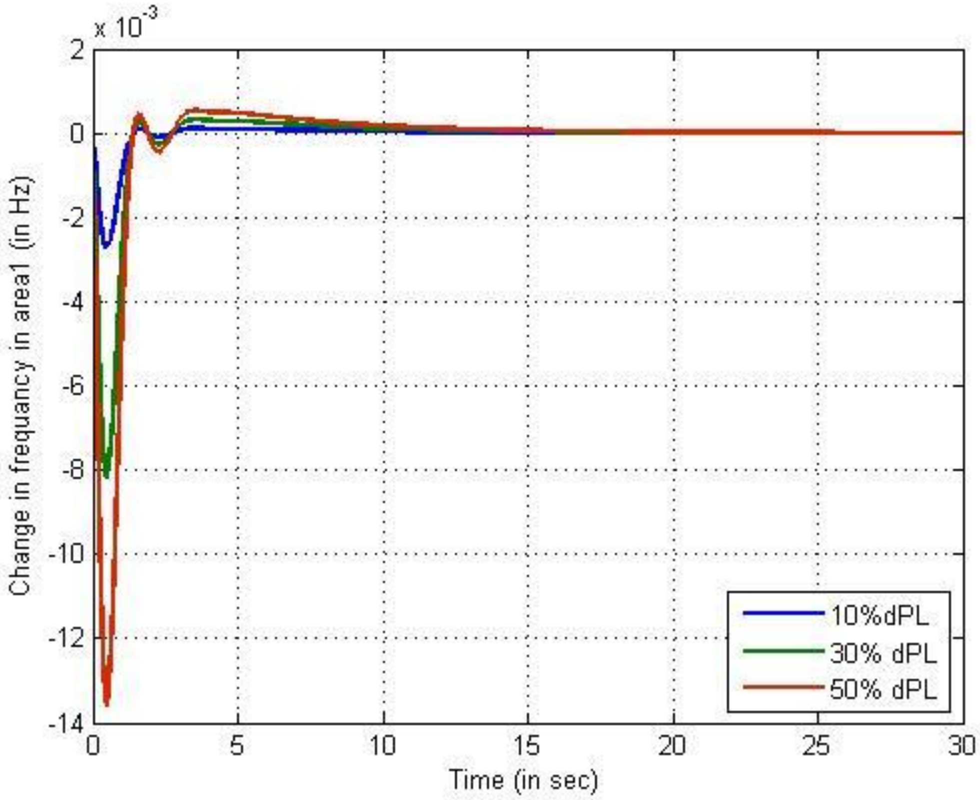

Fig.12. Frequency Deviation in Area 1 due to SLP in area 1.

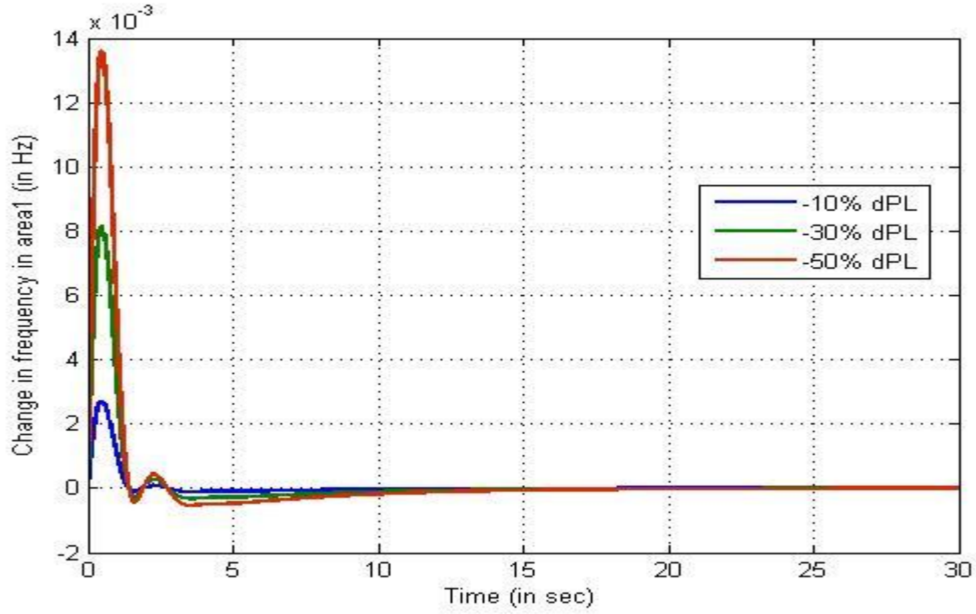

Fig.13. Frequency Deviation in Area 1 due to SLP in area 1.

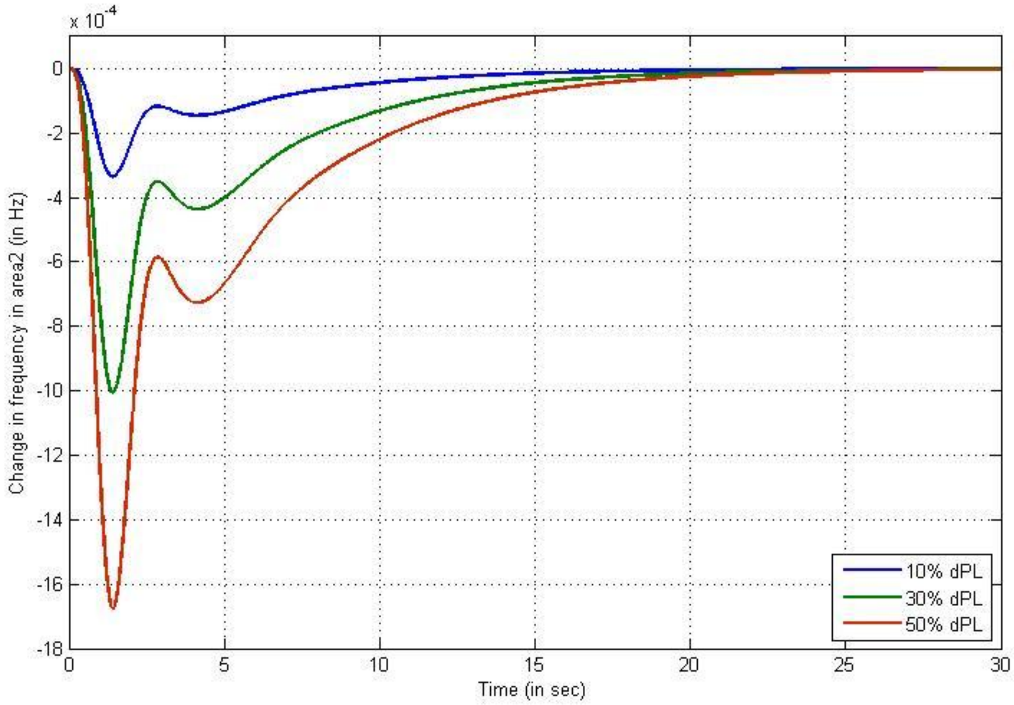

Fig.14. Frequency Deviation in Area 2 due to SLP in area 1.

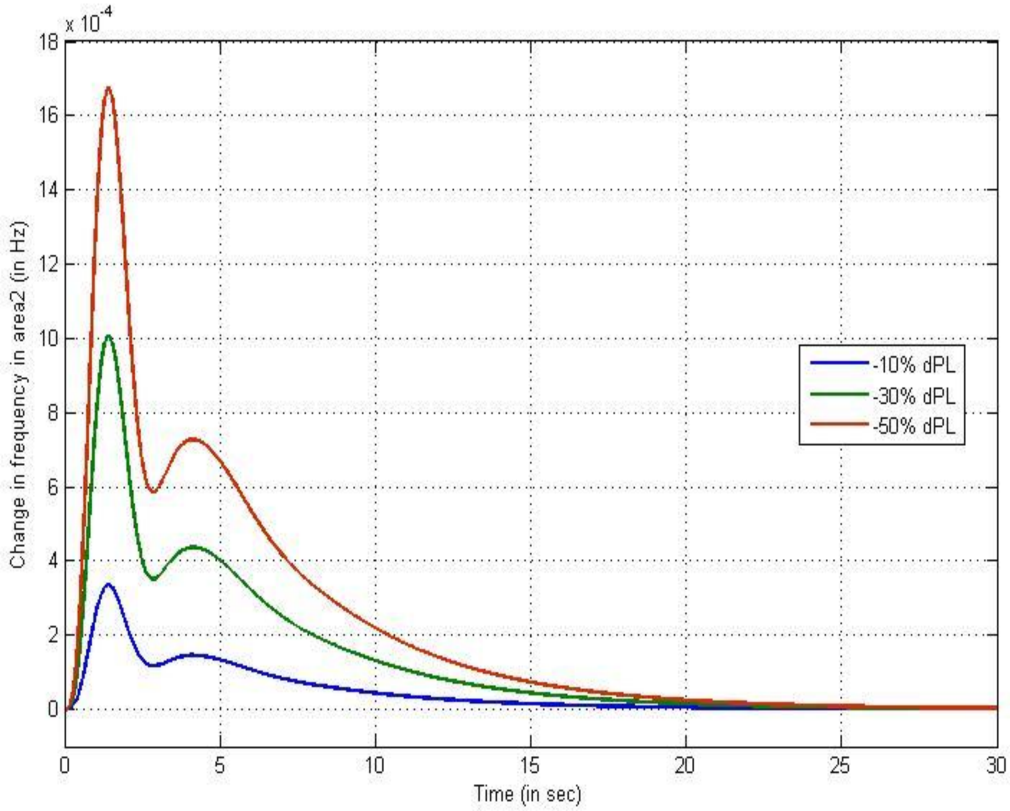

Fig.15. Frequency Deviation in Area 2 due to SLP in area 1.

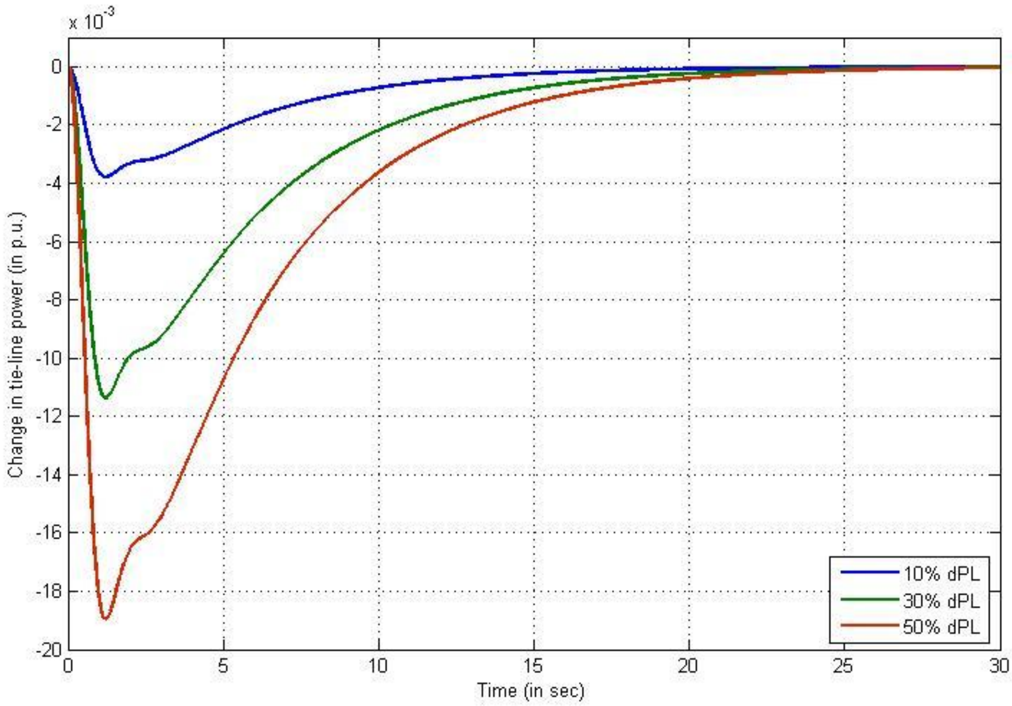

Fig.16. Tie-line power deviation due to SLP in area 1.

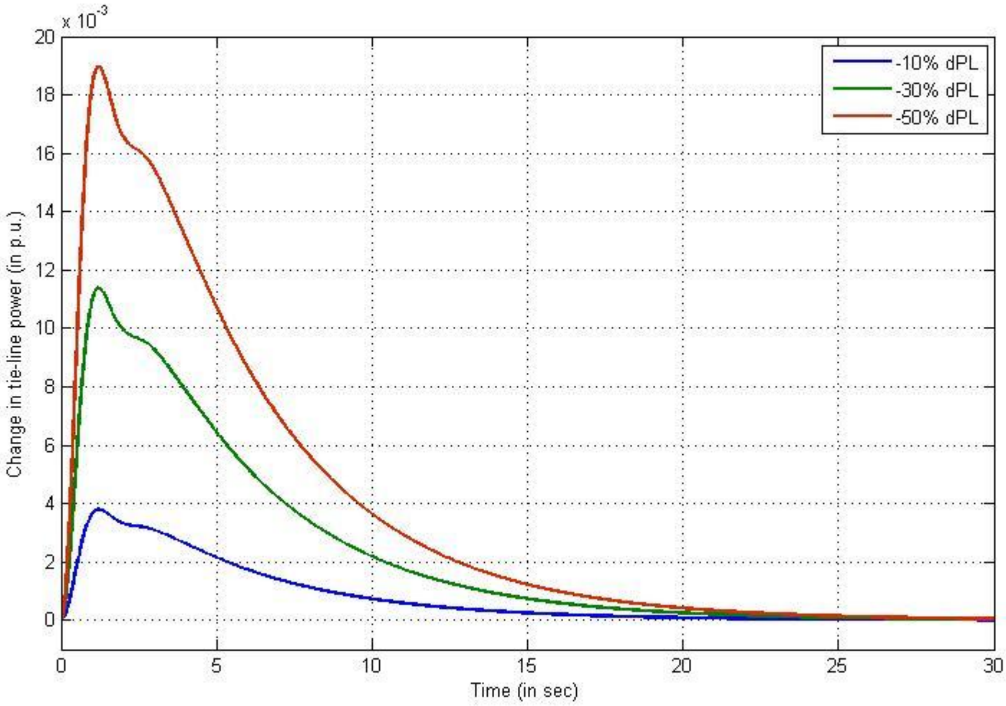

Fig.17. Tie-line power deviation due to SLP in area 1.

Table 5

Settling time (0.02% band) of frequency deviations and tie-line power changes due to variation in parameters in the areas 1 in the range on -50% to +50% with SLP given only at Area 1.

Parameters	% age deviation	T_s for frequency deviation in area1	T_s for frequency deviation in area2	T_s for tie line power deviation (in pu)
T_{g1}	-50%	4.7200	6.3700	19.2000
	-30%	4.5900	6.3200	19.1600
	-10%	3.8500	6.2800	19.1100
	10%	3.9700	6.2400	19.0700
	30%	4.0800	6.1900	19.0200
	50%	5.8600	6.1800	18.9700
T_{t1}	-50%	4.9700	6.5200	19.3900
	-30%	4.6900	6.4200	19.2700
	-10%	2.2700	6.3100	19.1500
	10%	4.1900	6.2100	19.0300
	30%	4.5200	6.1300	18.900
	50%	4.8200	5.9700	18.7700

Table 6

Maximum overshoots of frequency deviations and tie-line power changes due to variation in parameters in areas1 in the range on -50% to +50% with SLP given only at Area 1.

Parameters	% age deviation	O_{sh} for frequency deviation in area1	O_{sh} for frequency deviation in area2	O_{sh} for tie line power deviation (in pu)
T_{g1}	-50%	2.0495	0	0
	-30%	2.0312	0	0
	-10%	2.0017	0	0
	10%	4.1254	0	0
	30%	9.2868	0	0
	50%	14.7803	0	0
T_{t1}	-50%	2.0355	0	0
	-30%	2.0165	0	0
	-10%	1.9900	0	0
	10%	5.2863	0	0
	30%	12.3728	0	0
	50%	19.4919	0	0

Table 7

Maximum undershoots of frequency deviations and tie-line power changes due to variation in parameters in areas 1 in the range on -50% to +50% with SLP given only at Area 1.

Parameters	% age deviation	U_{sh} for frequency deviation in area1	U_{sh} for frequency deviation in area2	U_{sh} for tie line power deviation (in pu)
T_{g1}	-50%	-45.0130	-5.9597	-70.3897
	-30%	-48.9729	-6.2091	-71.3591
	-10%	-56.0471	-6.5256	-73.9870
	10%	-56.0471	-6.8932	-77.9570
	30%	-59.1938	-7.2932	-82.5994
	50%	-62.1271	-7.7108	-87.5517
T_{t1}	-50%	-40.5065	-5.1529	-66.6938
	-30%	-46.6195	-5.6688	-67.1584
	-10%	-51.9414	-6.3423	-71.7302
	10%	-56.7024	-7.0730	-80.1779
	30%	-61.0409	-7.8158	-89.0313
	50%	-65.0412	-8.5532	-97.9099

5.2.ROBUSTNESS ANALYSIS

The system tuned by Differential Evolution algorithm was analysed for robustness by varying the Time Constants of the control parameters of both the unequal areas in the steps of 25% in the range of -50% to +50%.The variation of the parameters are basically carried out on the Governor and Turbine time constants of both the thermal areas.

Table:8

Settling time (0.02% band) of frequency deviations and tie-line power changes due to variation in parameters in both the areas in the range on -50% to +50% with SLP given only at Area 1& 2.

Parameters	% age deviation	T_s for frequency deviation in area1	T_s for frequency deviation in area2	T_s for tie line power deviation (in pu)
T_{g1}	-50%	4.7200	6.3700	19.2000
	-25%	4.5500	6.3100	19.1500
	25%	4.0500	6.2000	19.0300
	50%	5.8600	6.1800	18.9700
T_{t1}	-50%	4.9700	6.5200	19.3900
	-25%	4.6400	6.3900	19.2400
	25%	4.4400	6.1500	18.9300
	50%	4.8200	5.9700	18.7700
T_{g2}	-50%	3.8200	6.2700	19.1100
	-25%	3.8600	6.2800	19.1000
	25%	4.0300	6.1600	19.0800
	50%	4.1900	5.9500	19.0700
T_{t2}	-50%	3.7700	6.1600	19.1300
	-25%	3.8300	6.2300	19.1100
	25%	4.1200	6.1800	19.0700
	50%	4.6600	6.1800	19.0500

Table:9

Maximum overshoots of frequency deviations and tie-line power changes due to variation in parameters in both the areas in the range on -50% to +50% with SLP given only at Area 1& 2.

Parameters	% age deviation	O_{sh} for frequency deviation in area1	O_{sh} for frequency deviation in area2	O_{sh} for tie line power deviation (in pu)
T_{g1}	-50%	2.0495	0	0
	-25%	2.0247	0	0
	25%	7.9526	0	0
	50%	14.7803	0	0
T_{t1}	-50%	2.0355	0	0
	-25%	2.0159	0	0
	25%	10.5942	0	0
	50%	19.4919	0	0
T_{g2}	-50%	2.0850	0	0
	-25%	2.1073	0	0
	25%	2.1725	0	0
	50%	2.2061	0	0
T_{t2}	-50%	2.0702	0	0
	-25%	2.0990	0	0
	25%	2.1716	0	0
	50%	2.1924	0	0

Table:10
Maximum undershoots of frequency deviations and tie-line power changes due to variation in parameters in both the areas in the range on -50% to +50% with SLP given only at Area 1& 2.

Parameters	% age deviation	U_{sh} for frequency deviation in area1	U_{sh} for frequency deviation in area2	U_{sh} for tie line power deviation (in pu)
T_{g1}	-50%	-45.0130	-5.9597	-70.3897
	-25%	-49.9150	-6.2824	-71.8483
	25%	-58.4228	-7.1911	-81.3999
	50%	-62.1271	-7.7108	-87.5517
T_{t1}	-50%	-40.5065	-5.1529	-66.6938
	-25%	-48.0125	-5.8273	-67.1849
	25%	-59.9892	-7.6304	-86.8079
	50%	-65.0412	-8.5532	-97.9099
T_{g2}	-50%	-54.3831	-5.9824	-75.9023
	-25%	-54.3829	-6.3570	-75.8557
	25%	-54.3826	-7.0123	-75.8750
	50%	-54.3826	-7.2844	-75.9064
T_{t2}	-50%	-54.3832	-5.7041	-75.8746
	-25%	-54.3829	-6.2529	-75.8297
	25%	-54.3826 -	-7.0793	-75.9001
	50%	-54.3826	-7.3988	-75.9507

Therefore, by considering all above analysis the system it can beseen that the rate of deviations is quite less such that the system tuned with DE algorithm can be said as a robust one.

Conclusion

The DE optimization algorithm is used in this paper to obtained the optimum gains of the PID controller for the LFC problem. At first, the optimization algorithm is explained in detail. Then, a two areapower system is investigated. The simulation results emphasise the effectiveness of the DE. It is found that the frequency after a disturbance have minimum overshoot and oscillation. Also, simulation results demonstrated that the PID controllers capable to guarantee the robust stability and performance under a wide range of uncertaintiesand load changes.A comparative study is carried out between the DE & LCOA algorithms. The comparison results show that the DE PID can provide a better performance than LCOA PID.

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Appendix

The system parameters are as follows (frequency=60 Hz, MVA base =1000) [2]:

Area 1: H=5, D=0.6, Tg=0.2, Tt=o.5, =0.05,B1=20.6,
Area 2: H=4, D=0.9, Tg=0.3, Tt=0.6, R=0.0625, B2=16.9,