AGC Of Multi Area Hybrid Power System Based On Multi Objective Optimization

V.S.R.Pavan Kumar.Neeli, Dr.U.Salma

Abstract:— This paper presents Automatic Generation Control (AGC) of a Multi area Hybrid power system. The Hybrid power system considered is the combination of thermal generation unit and Distributed generation (DG) resources. The DG system consists of Wind turbine generator, Solar PV system, Diesel engine generator, Fuel cell with Aqua electrolyzer and Energy storage like Battery energy storage system. A Novel Fuzzy PID plus double integral (FPID-II) controller is treated as secondary controllers in the system. This controller gains are tuned with Novel soft computing techniques such as Salp Swarm Algorithm (SSA) based on Multi objective approach and their performances are compared with three different controllers like PI, PID, Twodegree of freedom PID (TDOFPID) controllers.Further in order to extract the effectivenessof SSA technique,the responses are being compared with other popular swarm intelligence technique such as Grasshopper Optimization Algorithm (GOA), Ant Lion Optimization (ALO), Dragonfly Algorithm (DA) and Particle swarm optimization (PSO) for different loading circumstances. A comparative performance of various algorithms proves that the SSA tuned FPID-II controller shows superior and satisfactory performance over other controllers.

Index Terms:— Power system, Distributed generation, Fuzzy PID plus Double integral (FPID-II) controller, Frequency control, Soft computing techniques, MATLAB/SIMULINK, Salp Swarm Algorithm (SSA), Grasshopper Optimization Algorithm (GOA), Ant Lion Optimization (ALO) , Dragonfly Algorithm(DA)and Particle Swarm Optimization (PSO).

1 INTRODUCTION

The present scenario running in the electricity market is about interconnected power grid. Renewable power sources are more economical to meet the load requirement of consumers and industries that too pollute the enironment. So many markets are looking forward for the inegration of Non-renewable power sources to the interconnection of power grid [4]. Wind and solar energies are being more preferable energy sources.In addition to these sources ther are many more sources such as Bio mass, MHD, tidal energy, wave energy etc., which can be used for integrated but the major drawback is about it can produce only a minimum amout of elecrical energy compared with other sources. The main aim of the AGC is to balance load demand and generation maintaing frequency at an acceptable range. But in the interconnection of power grid there occurs load fluctuations due to many transients etc., which may lead to the frequecny deviations [2]. İn order to regain the power system to the normal operating condition a controller action is necessary.

In this paper a two different hybrid power systems is considered such as

- Two area interconnected thermal power system integrated with DG in area 1
- Three area interconnected thermal power system integrated with DG in area 1

The performance measures such as Integral square error (ISE), minimization of overshoot and minimization of Area control error (ACE) are considered to obtain the controller parameters.

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The main contribution of the work are summarised below:

- To develop the model of Multi area hybrid power system.
- To obtain the parameters of proposed controller using different optimization techniques.
- To examine the effectiveness and robustness of proposed controller when subjected to Step load perturbation.

Deepak kumar and Ajit kumar [1] has established a fuzzy PID controller for a Single area hybrid power system in which the controller parameters are tuned with Moth flame optimization. Similarly pandey et.al [2] has presented a control scheme of linear matrix inequalities (LMI) for the single area hybrid system along with a two area hybrid power system. The LMI approch is developed with the help of Genetic algorithm and Particle swarm optimization algorithms. Sarada prasanna Behera et.al [3-4] demostrates the load frequency control problem for a Two area interconnected Hybrid power system with two types of controllers like Hybrid PIDF controller and a TID controller, Differential evolution (DE) is used for parameter extraction of the respective controllers. Raju et.al [5] presented the frequency control problem of three area interconnected Hybrid power system with secondary controller considered as Two degree of Freedom controller, Symbiotic organisms search (SOS) technique is applied for obtaining the parameters of the controllers. Yogendra arya [6] has proposed a Fuzzy PID with filter plus double integral controller with out scaling factors for AGC of a two area electric power system.

2 MATHEMATICAL MODELLING OF POWER SYSTEM

For simulation of the large scale systems, simplified models such as transfer function models are to be developed. Hence all generating units are developed as first order tranfer funtion models. Therefore the total power obtained is the combination of power from thermal unit and power from the DG resources [12]. The output power of Distributed Generation system is given

$$\Delta P_{DG} = P_{Wg} + P_{Pv} + P_{Dg} + P_{Fc} - P_{Ae} \pm P_{Bss} \quad (1)$$

For small signal stability analysis, the generating units like Wind generator, Solar PV, Fuel cell with electrolyzer and Diesel generator can be modelled by the single order transfer functions with system gains and time constants [14]. The simplified and linearized model of various generation systems is represented as

$$H_{Wg}(s) = \frac{K_{Wg}}{1+T_{Wg}s} \quad (2)$$

$$H_{PV}(s) = \frac{K_{PV}}{1+T_{PV}s} \quad (3)$$

$$H_{Fc}(s) = \frac{K_{Fc}}{1+T_{Fc}s} \quad (4)$$

$$H_{Dg}(s) = \frac{K_{Dg}}{1+T_{Dg}s} \quad (5)$$

$$H_{Ae}(s) = \frac{K_{Ae}}{1+T_{Ae}s} \quad (6)$$

$$H_{Bss}(s) = \frac{K_{Bss}}{1+T_{Bss}s} \quad (7)$$

2.1 Fuzzy PID plus double Integral controller

General layout of FPID-II controller is shown in figure 1. The performance of this controller depends upon five different parameters including the scaling factors. The parameters values are been tuned with the help of SSA optmization technique. Apart from the controller parameters fuzzy logic controller (FLC) ues error and derivative of error as input signals to get the best performance of FPID-II controller.

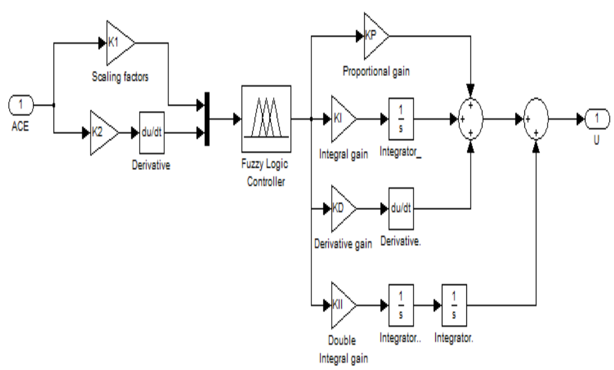

Fig 1: *Structure of FPID-II Controller*

The control signal of proposed controller is given by

$$U = Kp + \frac{Ki}{s} + Kd.s + \frac{Kii}{s^2} \quad (8)$$

Different membership functions such as traingular, trapezoidal and Gaussian shaped functions are employed in fuzzy logic controller design proess.In this view three traingular membership functions are considered with three Linguistic variables namely Negative (N), Zero (Z) and Positive (P) which consists of nine set of fuzzy rules with membership function ranges from [-1 to 1].The two dimensional rule base are listed in table.1

e	e^*		
	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Table.1: *Rule base for error, derivative of error and FLCoutput*

3 Objective Function

The common objective functions available are (i) Integral of absolute error {IAE}(ii) Integral of Square error {ISE} (iii) Integral of time multiplied absolute error {ITAE} (iv)Integral of time multiplied square error {ITSE}.Each and every objective functions are having their own merits and demerits. Therefore in the present study is carried out with Integral of Square error {ISE} is chosen as a desired objective function for the tuning of proposed FPID-II controller. In this paper for the Hybrid power systems considered two objective and three objective functions [13] are employed for the tuning process which are listed below.

For Two area Interconnected system

Two objective Function

$$J_1 = \min \int_0^T (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{Tie12}^2) dt \quad (9)$$

J_2= Minimum Overshoot {(Δf_1) + (Δf_2) + (ΔP_{tie12})} (10)

Three objective Function

$$J_1 = \min \int_0^T (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{Tie12}^2) dt \quad (11)$$

J_2= Minimum Overshoot {(Δf_1) + (Δf_2) + (ΔP_{tie12})} (12)

$$J_3 = \min \int_0^T (ACE_1^2 + ACE_2^2) dt$$

(13)

For Three area Interconnected system

Two objective Function

$$J_1 = \min \int_0^T (\Delta f_1^2 + \Delta f_2^2 + \Delta f_3^2 + \Delta P_{Tie12}^2 + \Delta P_{Tie23}^2 + \Delta P_{Tie13}^2) dt \quad (14)$$

J_2= Minimum Overshoot {(Δf_1)+(Δf_2) + (Δf_3) + (ΔP_{tie12}) + (ΔP_{tie23}) + (ΔP_{tie13})}

(15)

Three objective Function

$$J_1 = \min \int_0^T (\Delta f_1^2 + \Delta f_2^2 + \Delta f_3^2 + \Delta P_{Tie12}^2 + \Delta P_{Tie23}^2 + \Delta P_{Tie13}^2) dt \quad (16)$$

J_2= Minimum Overshoot {(Δf_1)+(Δf_2) +(Δf_3)+(ΔP_{tie12}) + (ΔP_{tie23}) + (ΔP_{tie13})}

(17)

$$J_3 = \min \int_0^T (ACE_1^2 + ACE_2^2 + ACE_3^2) dt \quad (18)$$

Where 'J' is minimized subjected to

$$\left.\begin{array}{ll} K_1^{\min} \le K_1 \le K_1^{\max} & K_2^{\min} \le K_2 \le K_2^{\max} \\ K_P^{\min} \le K_P \le K_P^{\max} & K_I^{\min} \le K_I \le K_I^{\max} \\ K_D^{\min} \le K_D \le K_D^{\max} & K_{II}^{\min} \le K_{II} \le K_{II}^{\max} \end{array}\right\} \quad (19)$$

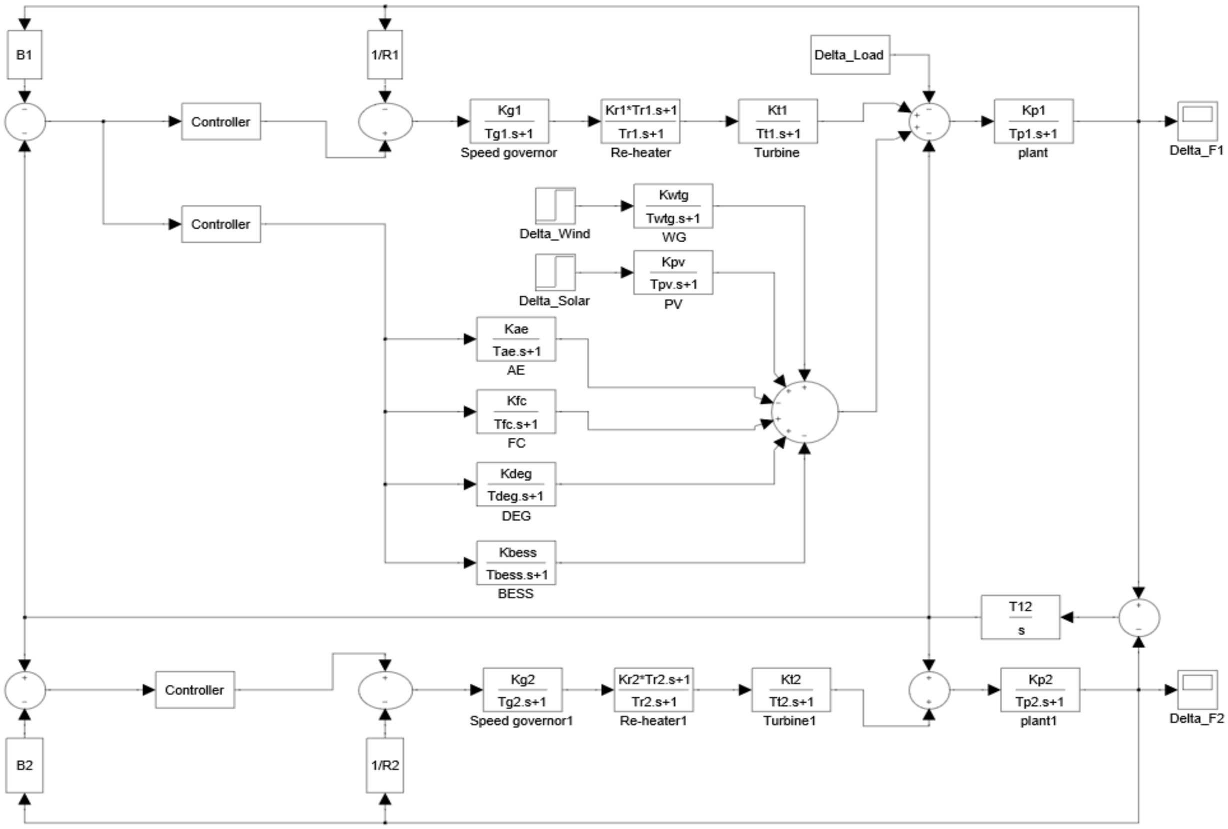

***Fig 2.** Two area Interconnected thermal Power system Integrated with DG in area1*

4 OVERVIEW OF SALP SWARM ALGORITHM

SalpSwarm Algorithm (SSA) is a recent Swarm intelligence algorithm [7] developed in 2017 by Mirjalili. SSA is a population based method which explains the mimicking behaviour of Salp Swarms and their social interaction. The group of Salps called salp chains mathematically divide in to two groups: head salp is a leader and other arefollowers. Till now, the behaviour of salp swarm is not well conveyed, hence the researcher scholars consider the behavior of it to intensify their movement in seeking for food.

Steps followed in SSA

- Parameter initialization: The algorithm starts by initializing the parameters such as size in population N, no.of iterations t, and maximum iterations max_{iter}.
- Initial Population: We generate initial population x_i, i={1…..n} randomly in the range of [u,l] where u,l are upper and lower boundaries respectively.
- Individuals Evaluations: Each individual (solution) in the population are evaluated by calculating its objective function value and the overall the best solution is assigned for F.
- Exploration and exploitation: In order to balance between the Explorations and exploitations of the algorithm, we update the value of parameter c_1 given in the equation

$$c_1 = 2e^{-(\frac{4l}{L})^2}$$

(20)

Where l is the present iteration and L is the maximum no.of. Iterations.

- Position updation of solutions: The position of the leader solution and the other follower solutions are updated as given by

$$x_j^1 = \begin{cases} F_j + c_1((ub_j - lb_j)c_2 + lb_j & for c_3 \geq 0 \\ F_j - c_1((ub_j - lb_j)c_2 + lb_j & for c_3 < 0 \end{cases}$$

(21)

- Where x_j^1 is the leader position in j^{th} dimension and ub_j & lb_j are the max and min boundaries for j^{th} dimension and F_j is the food source position.

And $x_j^i = \frac{1}{2}(x_j^i + x_j^{i-1})$

(22)

Where $i \geq 2$; x_j^i depicts the position of i^{th} follower Salp in the j^{th} dimension

- Boundaries violations: If any solution violates the range of the search space during the update process, it returned back in the range of the problem.
- Termination criteria: The number of iterations t is increased gradually untill it reaches to maximum iterations max_{iter} then the algorithm terminates search process and produces the overall best solution found so far.

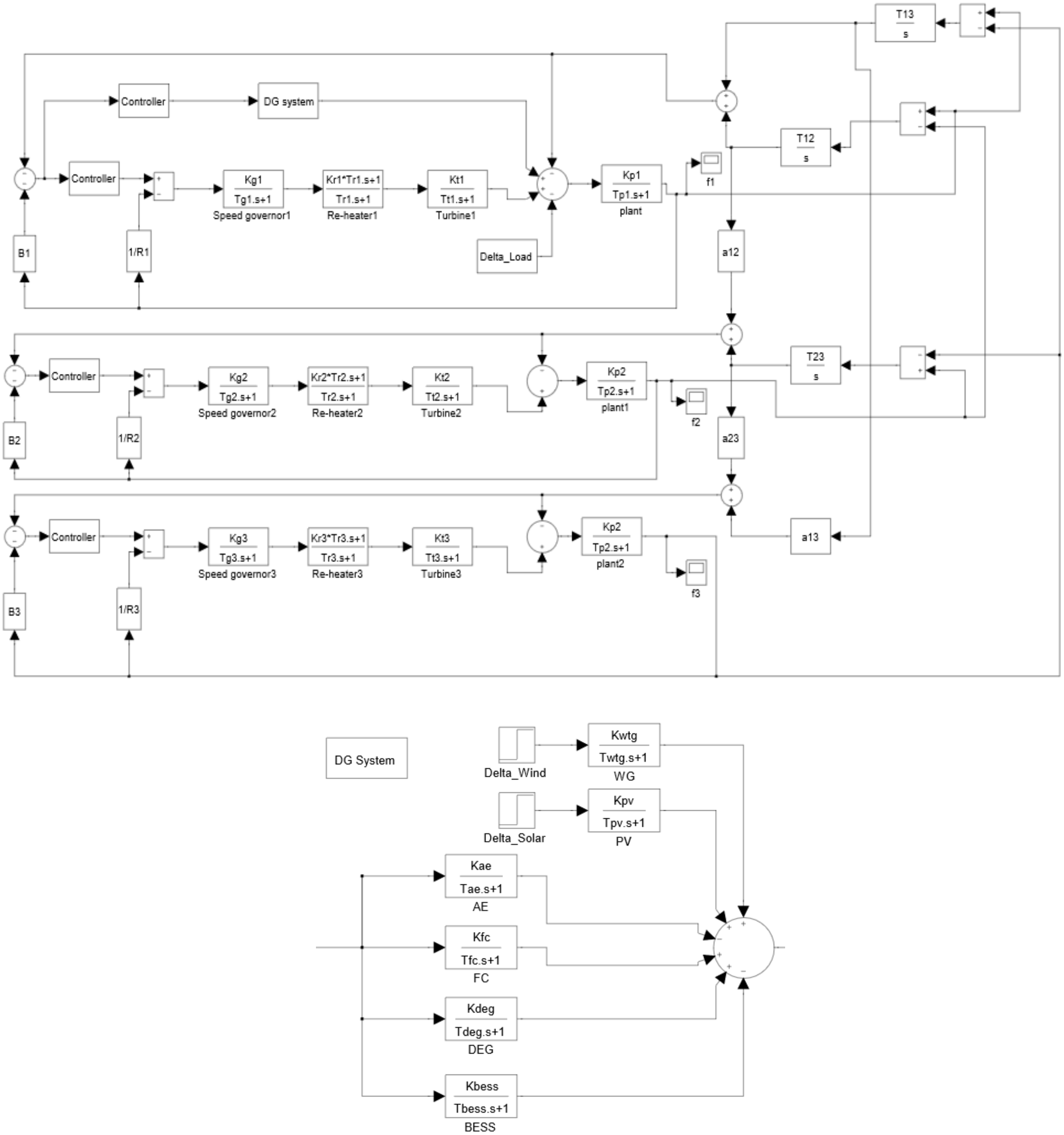

Fig 3. *Three area Interconnected Thermal Power system Integrated with DG in area 1*

5 RESULTS AND DISCUSSIONS

The Dynamic behaviour of the choosen power system is analyzed in two different scenarios.Simulations were conducted on an Intel, Core i-3 and 4 GB RAM computers in the MATLAB (R2010a) software environment. The wind power and solar power variations applied to the power system are considered as ΔP_{wtg} =0.5 p.u and ΔP_{pv}=0.18 p.u Initially the comparison of dynamic responses of PI, PID, TDOFPID and FPID-II controller is carried out with the SSA technique. The results depicts that the FPID-II controller performs better controlling action compared to PI, PID and TDOFPID. Furthermore the comparison of dynamic responses of SSA, GOA, ALO, DA and PSO [8-11] are carried out with FPID-II controller for different loading conditions.

5.1. Two area Interconnected thermal Power system Integrated with DG in area1

Two objective results

Case 1: Step Load perturbation of 0.03 p.u in area 1

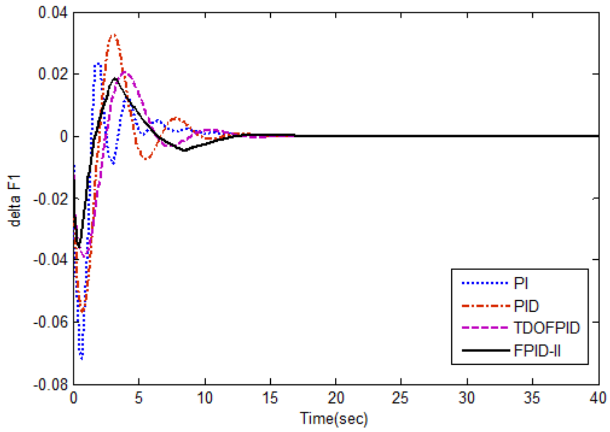

Fig 4*.Deviation in frequency in area 1*

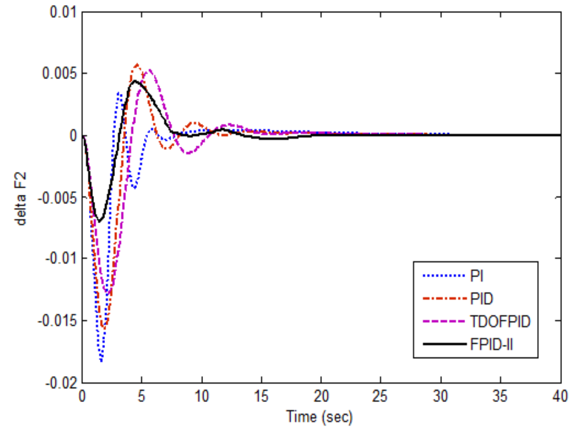

Fig 5.*Deviation in frequency in area 2*

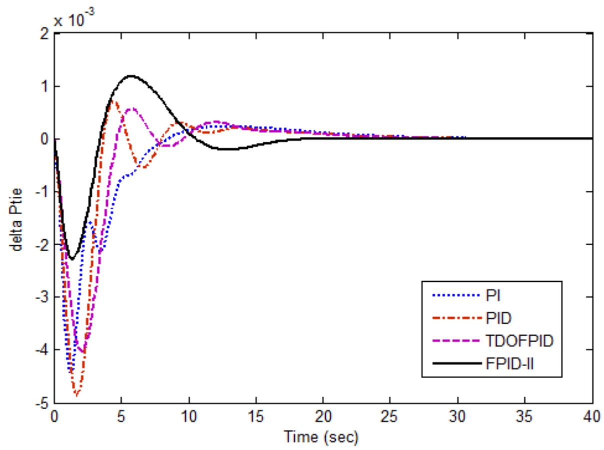

Fig 6.*Deviation in Tie-line power*

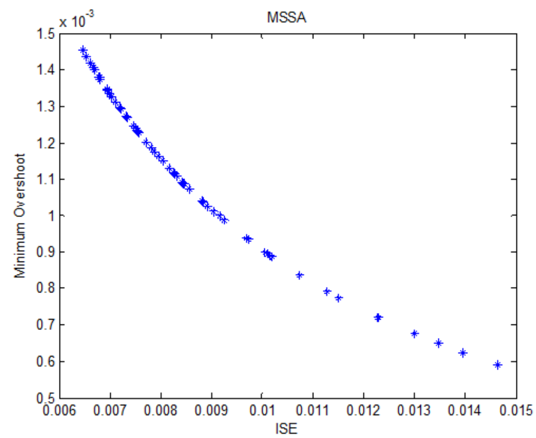

Fig 7.*Optimal response for Two objective function*

Case 2: Step Load perturbation of 0.045 p.u in area 1

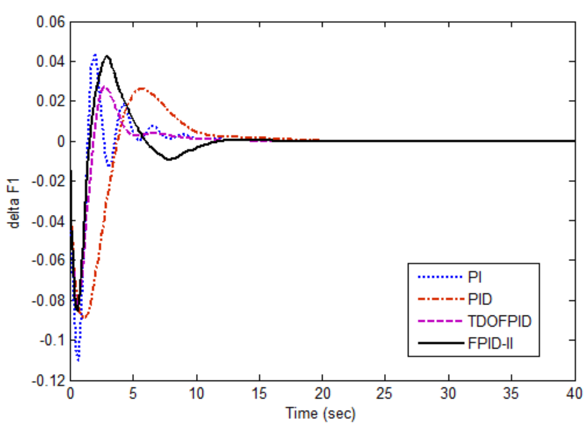

Fig 8.*Deviation in frequency in area 1*

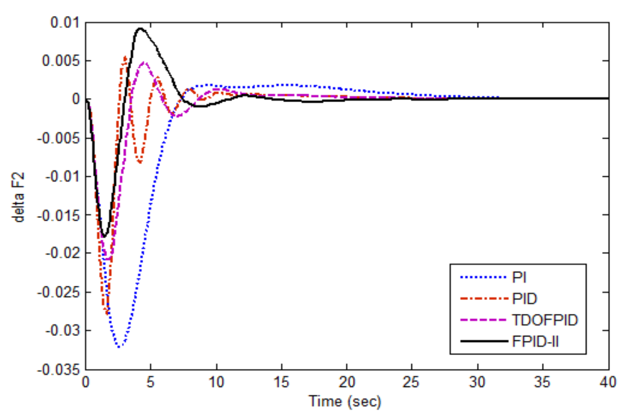

Fig 9*.Deviation in frequency in area 2*

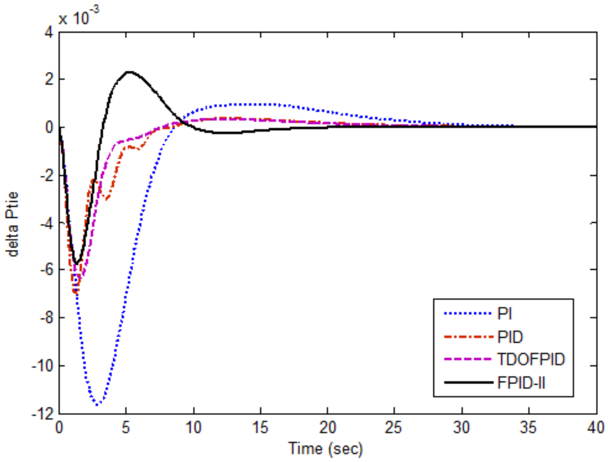

Fig 10.*Deviation in Tie-line power*

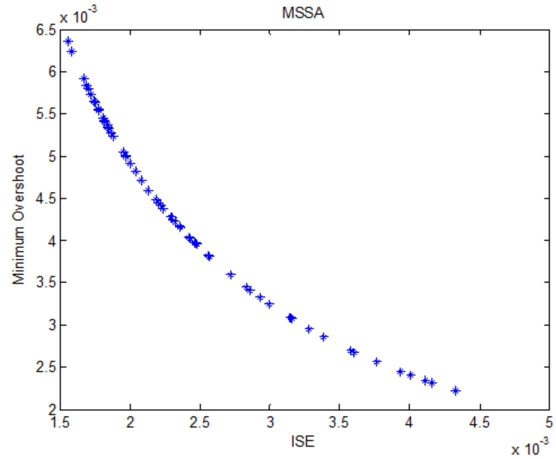

Fig 11.*Optimal response for Two objective function*

Three objective results

Case 1: Step Load perturbation of 0.03 p.u in area 1

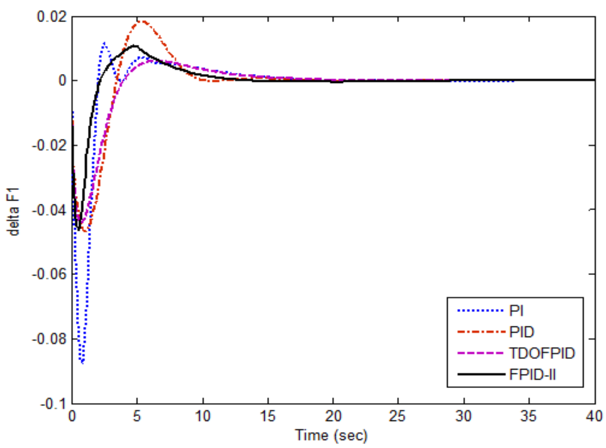

Fig 12.*Deviation in frequency in area 1*

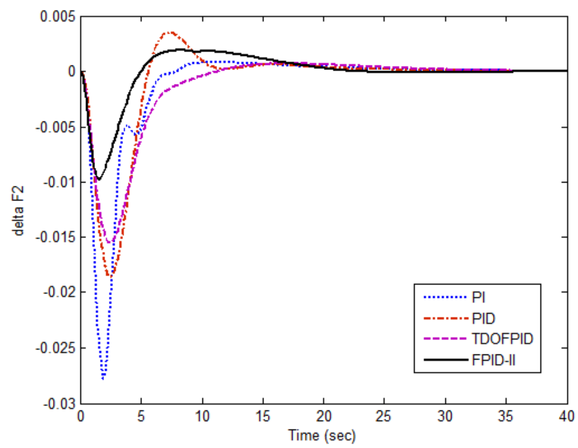

Fig 13.*Deviation in frequency in area2*

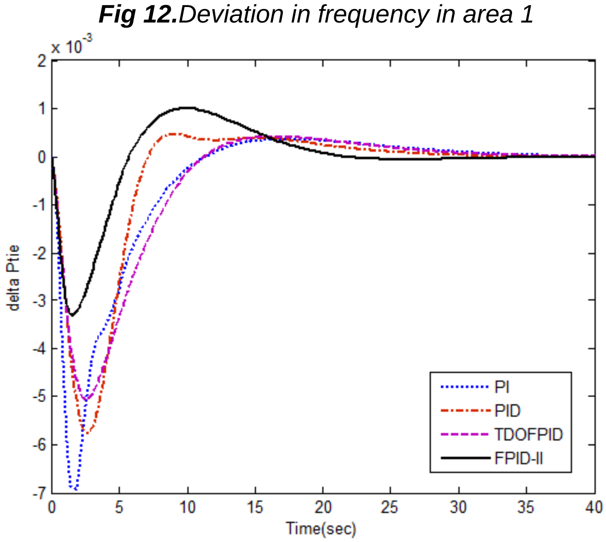

Fig 14.*Deviation in Tie-line power*

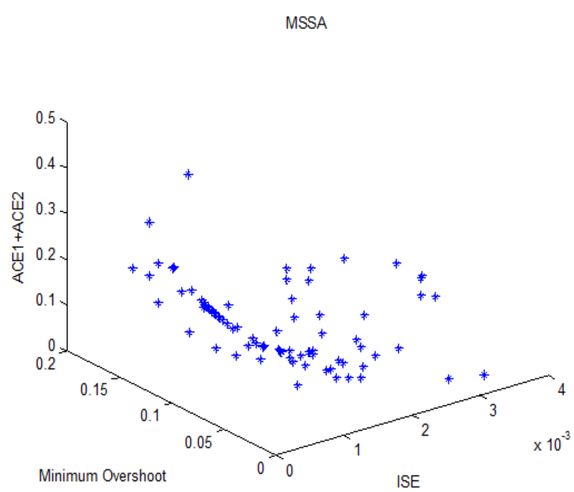

Fig 15.*Optimal response for Three objective function*

Case 2: Step Load perturbation of 0.045 p.u in area 1

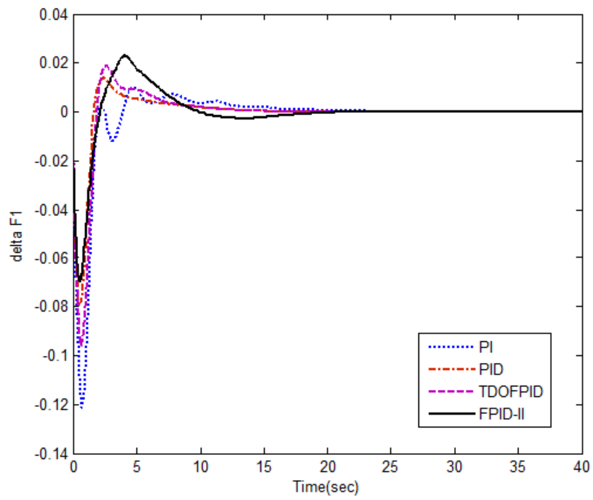

Fig 16.*Deviation in frequency in area 1*

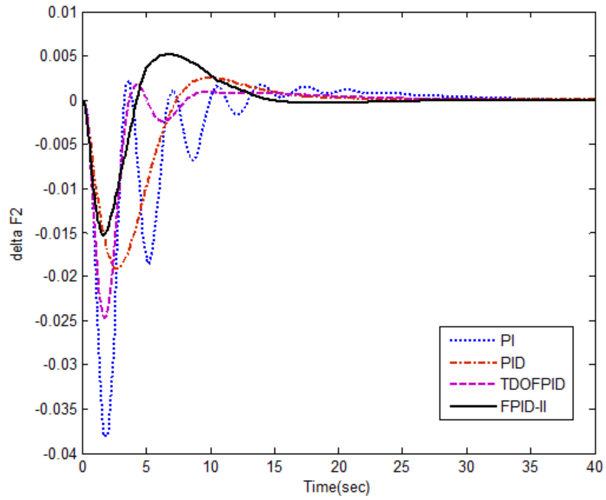

Fig 17.*Deviation in frequency in area2*

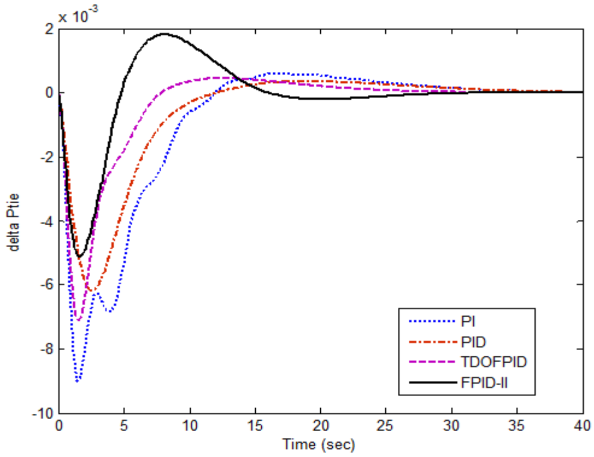

Fig 18.*Deviation in Tie-line power*

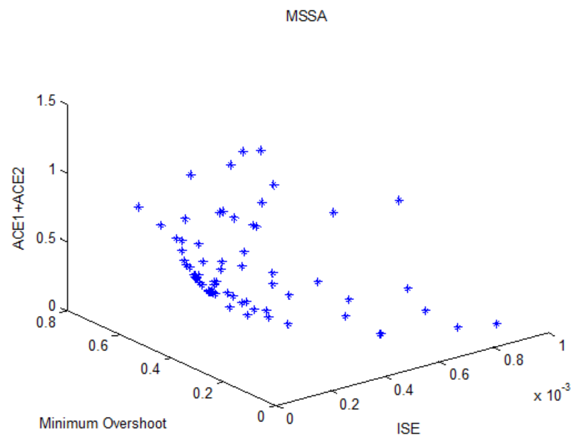

Fig 19.*Optimal response for Three objective function*

Case 3 : Comparison of SSA respone with different optimization techniques under case-1 of Two objective function

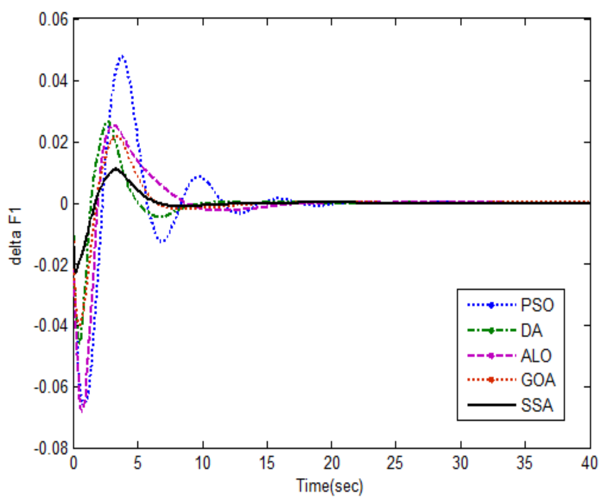

Fig 20.*Deviation in frequency in area 1*

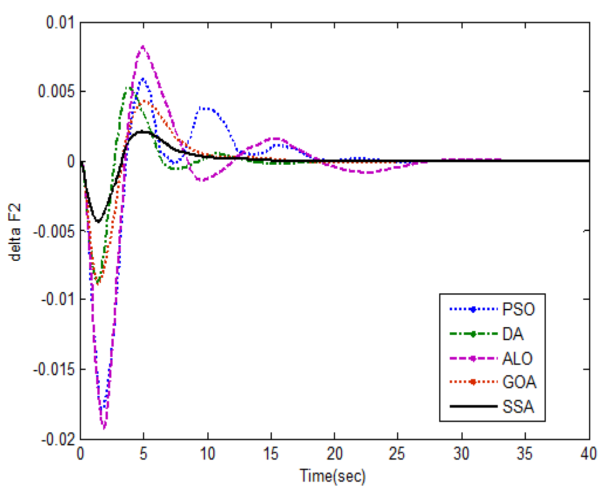

Fig 21.*Deviation in frequency in area2*

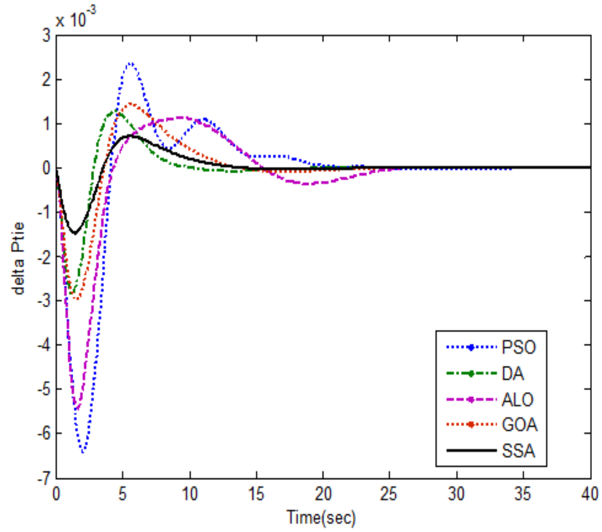

Fig 22.*Deviation in Tie-line power*

The results depicts the capability of proposed FPID-II controller compared with rest of the controllers. Similarly the dynamic performance of the system is significantly improved with proposed SSA optimization technique under the considered load varaiations.

The oscillatory condition will sustain for less duration with the implementation of FPID-II controller, making the system stable. The proposed optimization performance can be evident from the table mentioned below.

	Comparison of different optimization techniques				
Objectives	*SSA*	*GOA*	*ALO*	*DA*	*PSO*
J1	*0.0065*	*0.0084*	*0.0098*	*0.0158*	*0.0194*
J2	*0.0010*	*0.0016*	*0.0025*	*0.0031*	*0.0049*

Table.2*: Comparison of objective fuction values under case-1 of Two objective function*

Controllers	*Two area Interconnected Thermal power system integrated with DG in area-1*									
	Two objective				*Three Objective*					
	Case1		*Case 2*		*Case 1*			*Case 2*		
	J1	*J2*	*J1*	*J2*	*J1*	*J2*	*J3*	*J1*	*J2*	*J3*
PI	*0.0086*	*0.0021*	*0.0042*	*0.0062*	*0.0077*	*0.6521*	*1.8665*	*0.0042*	*0.6632*	*3.8689*
PID	*0.0074*	*0.0016*	*0.0023*	*0.0052*	*0.0060*	*0.4633*	*0.8244*	*0.0034*	*0.6591*	*2.9707*
TDOFPID	*0.0070*	*0.0014*	*0.0019*	*0.0043*	*0.0045*	*0.3432*	*0.3538*	*0.0030*	*0.5563*	*2.6835*
FPID-II	*0.0065*	*0.0010*	*0.0014*	*0.0024*	*0.0008*	*0.1115*	*0.0709*	*0.0003*	*0.3462*	*1.0328*

Table.3*: Comparison of objective fuction values of considered controllers*

5.2. Three area Interconnected thermal Power system Integrated with DG in area1

Two objective results

Case 1: Step Load perturbation of 0.03 p.u in area 1

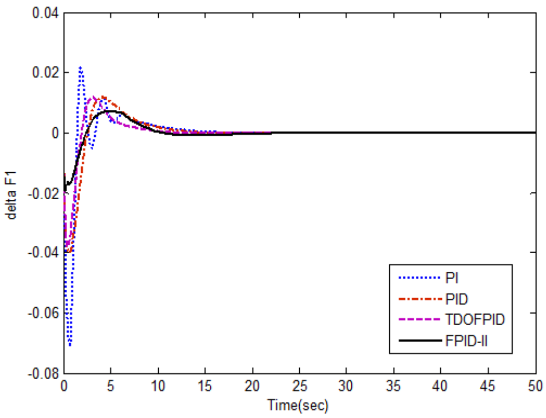

Fig 23.*Deviation in frequency in area 1*

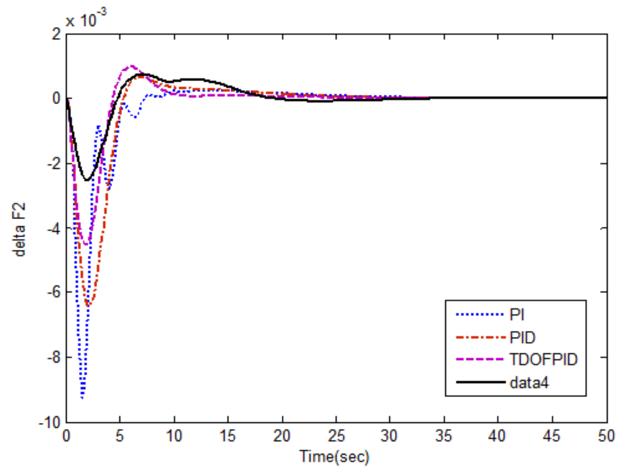

Fig 24.Deviation in frequency in area 2

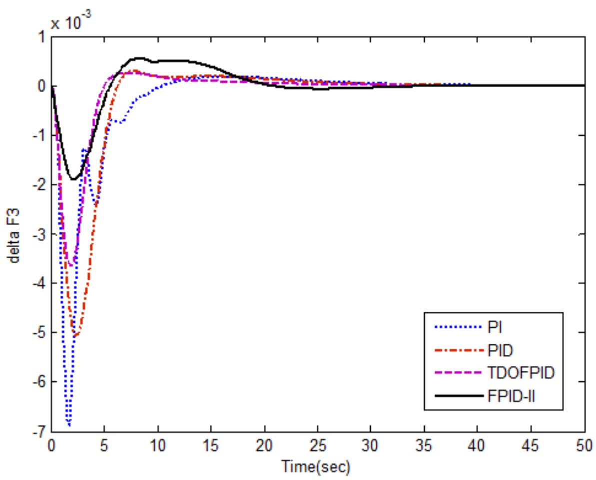

Fig 25.*Deviation in frequency in area 3*

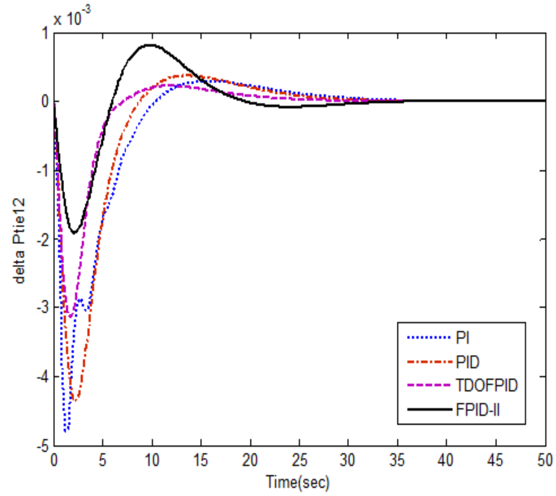

Fig 26.*Deviation in Tie-line power for area 1&2*

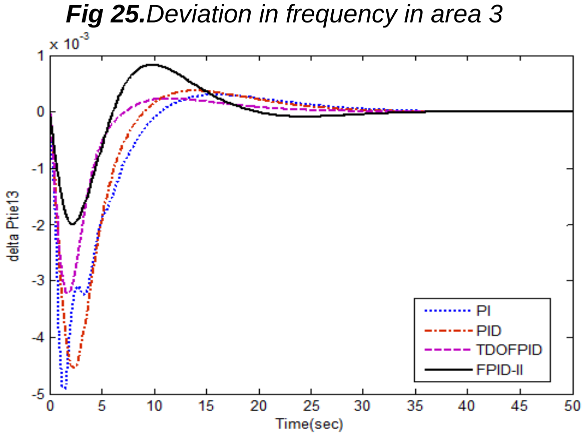

Fig 27.*Deviation in Tie-line power for area 1&3*

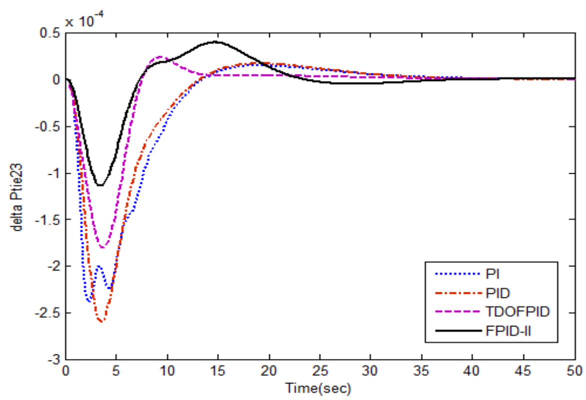

Fig 28.*Deviation in Tie-line power for area 2&3*

Case 2: Step Load perturbation of 0.045 p.u in area 1

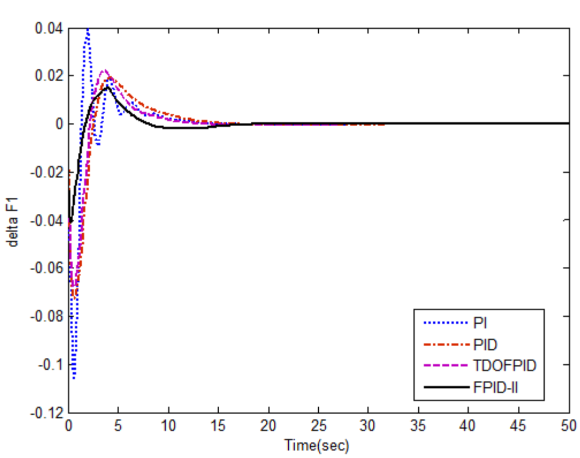

Fig 29.*Deviation in frequency in area 1*

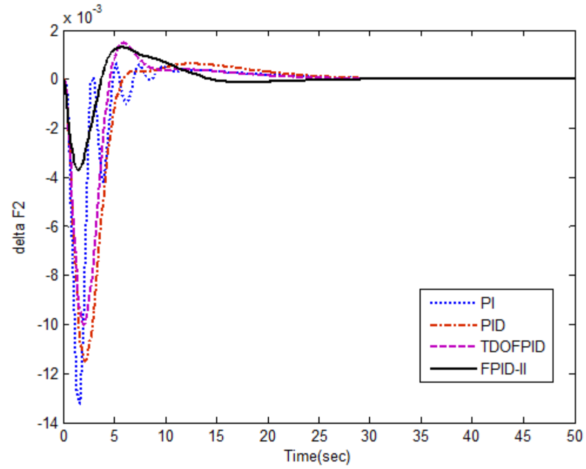

Fig 30.*Deviation in frequency in area 2*

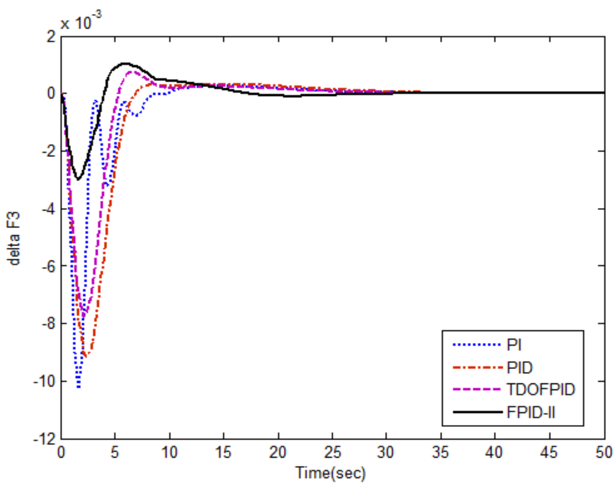

Fig 31*.Deviation in frequency in area 3*

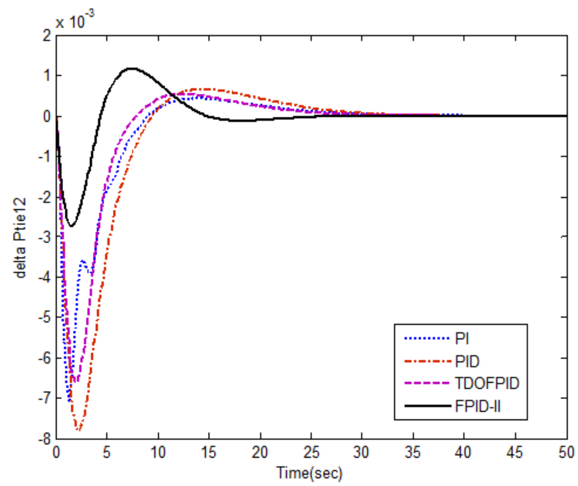

Fig 32.*Deviation in Tie-line power for area 1&2*

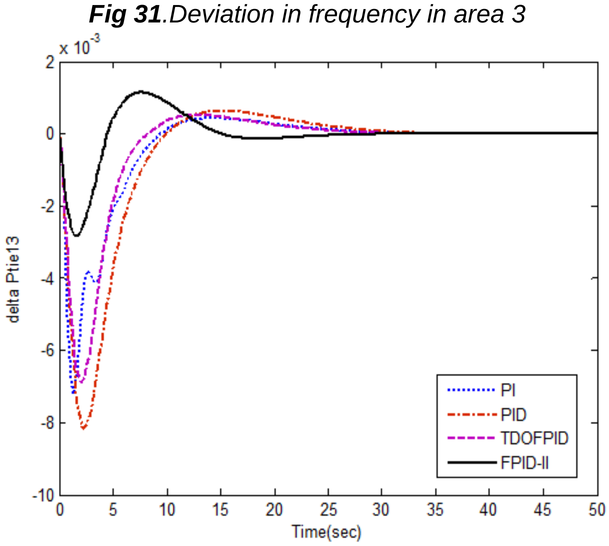

Fig 33*.Deviation in Tie-line power for area 1&3*

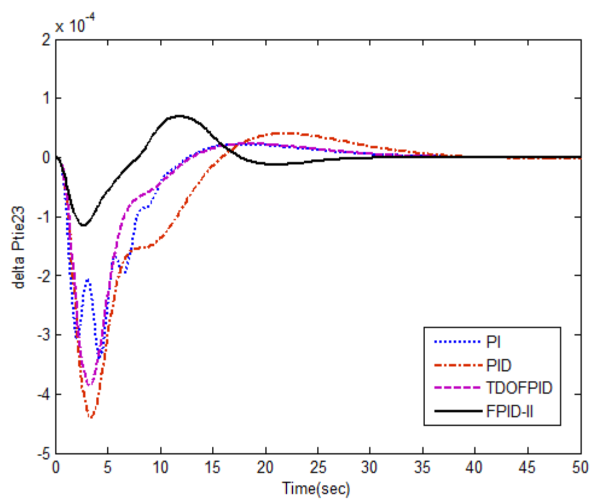

Fig 34.*Deviation in Tie-line power for area 2&3*

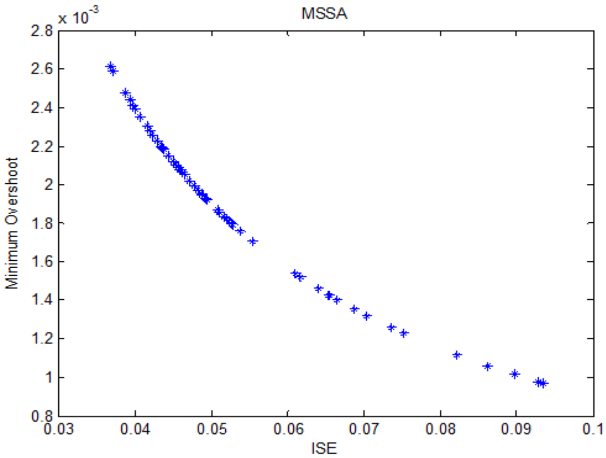

Fig 35.*Optimal response for Two objective function under* case 1

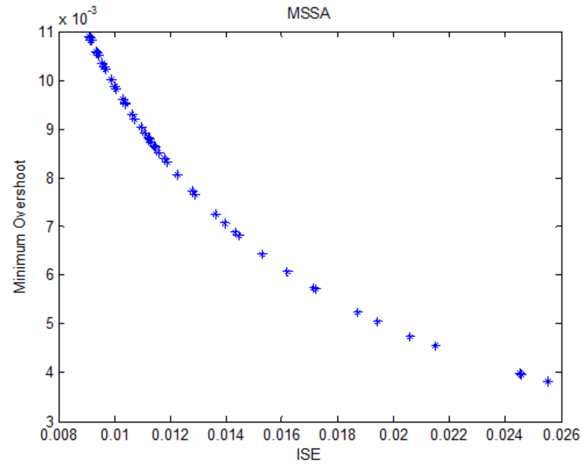

Fig 36.*Optimal response for Two objective function under* case 2

Three objective results

Case 1: Step Load perturbation of 0.03 p.u in area 1

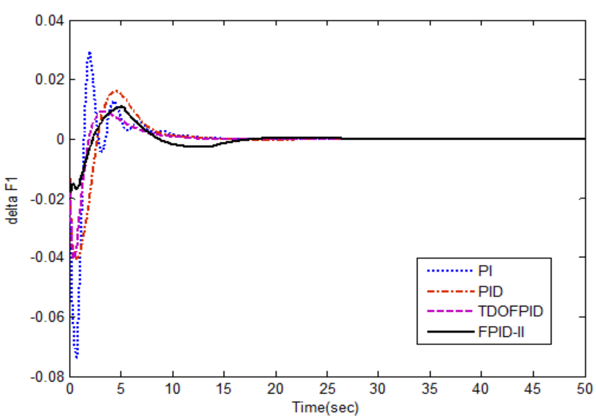

Fig 37.*Deviation in frequency in area 1*

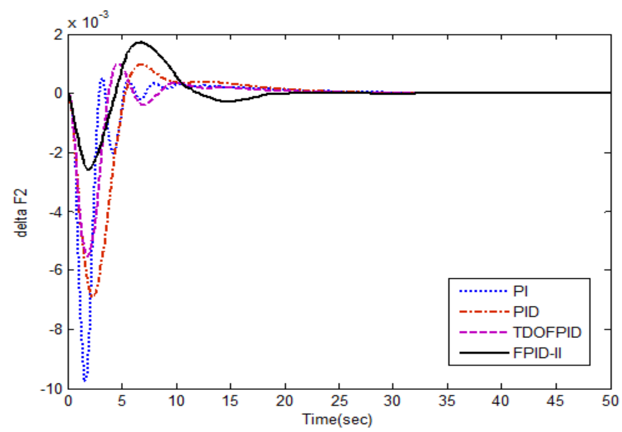

Fig 38.*Deviation in frequency in area 2*

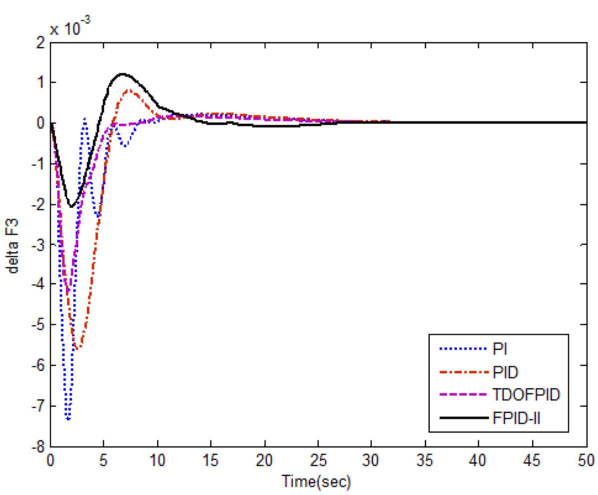

Fig 39.*Deviation in frequency in area 3*

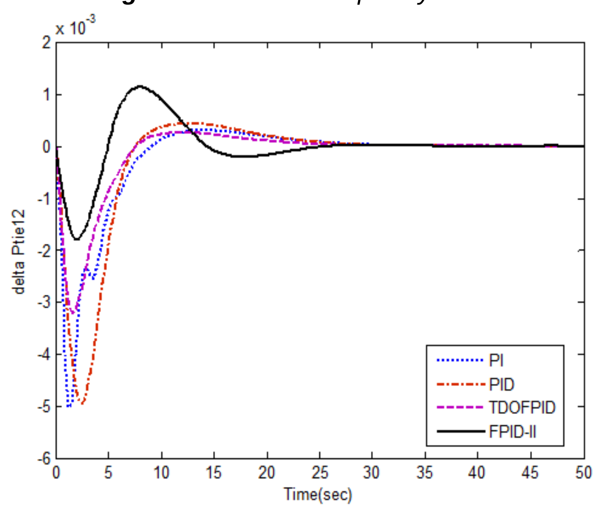

Fig 40*.Deviation in Tie-line power for area 1&2*

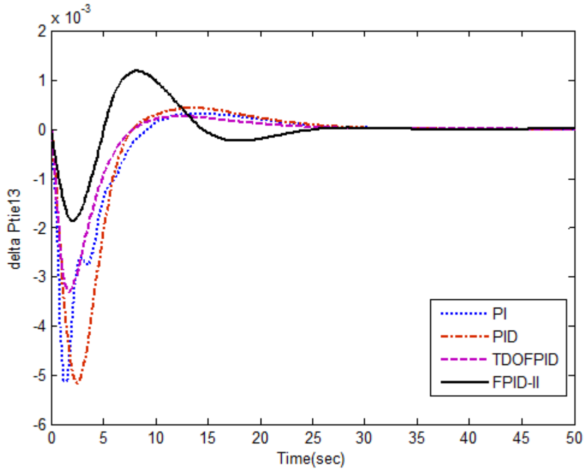

Fig 41. *Deviation in Tie-line power for area 1&3*

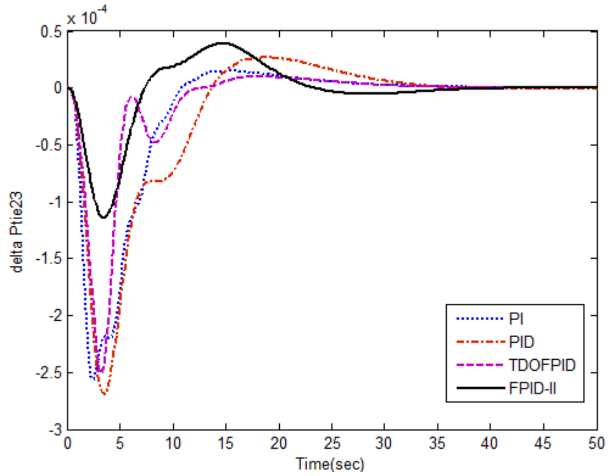

Fig 42. *Deviation in Tie-line power for area 2&3*

Case 2: Step Load perturbation of 0.045 p.u in area 1

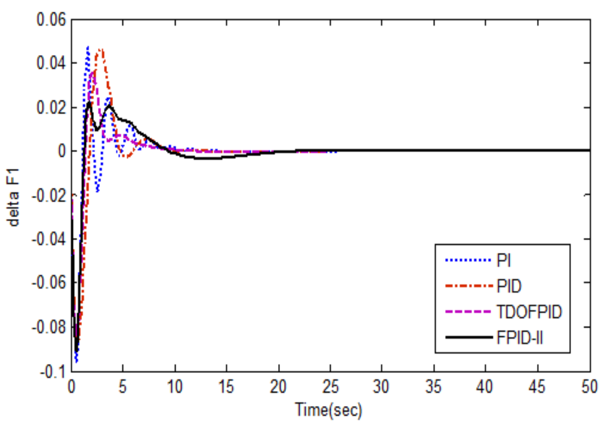

Fig 43. *Deviation in frequency in area 1*

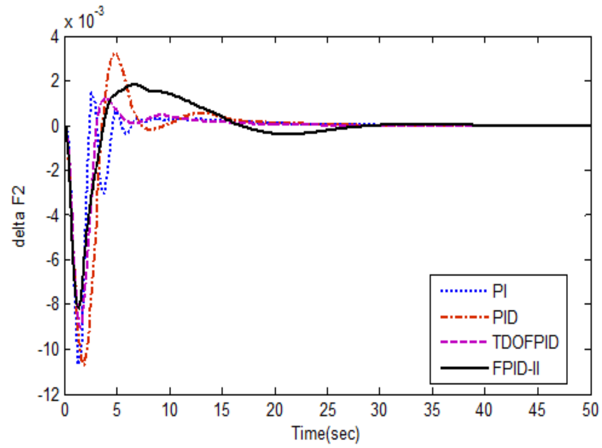

Fig 44. *Deviation in frequency in area 2*

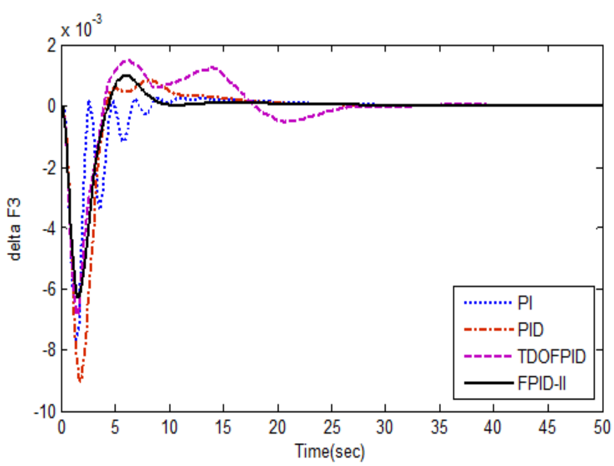

Fig 45. *Deviation in frequency in area 3*

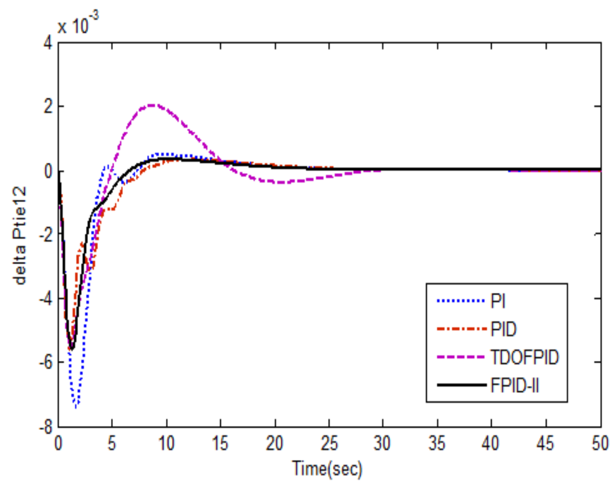

Fig 46. *Deviation in Tie-line power for area 1&2*

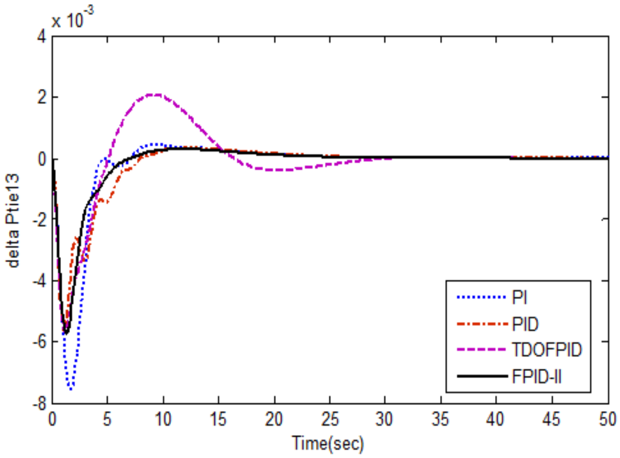

Fig 47.*Deviation in Tie-line power for area 1&3*

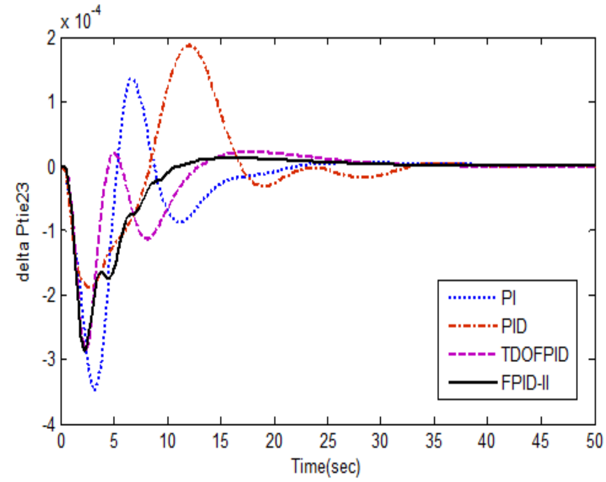

Fig 48.*Deviation in Tie-line power for area 2&3*

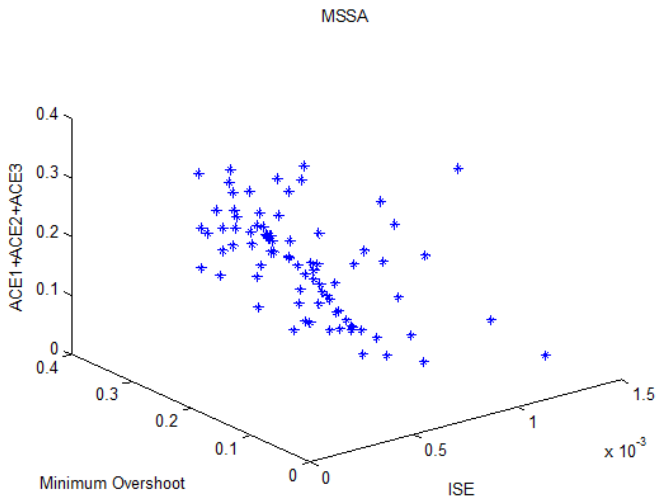

Fig 49. *Optimal response for Three objective function* under case 1

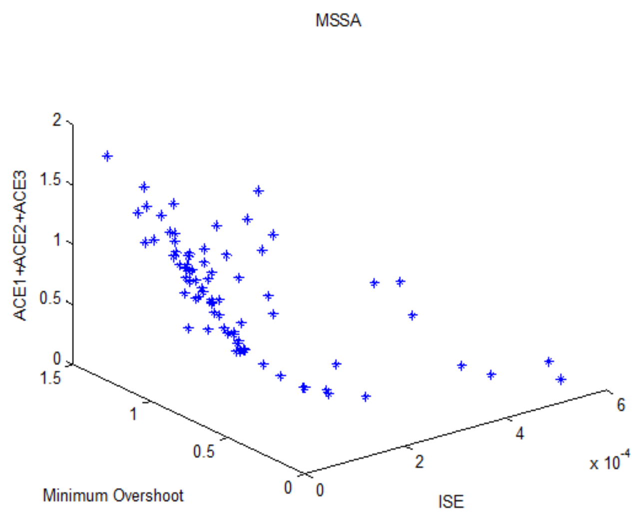

Fig 50. *Optimal response for Three objective function* under case 2

Case 3 : Comparison of SSA respone with different optimization techniques

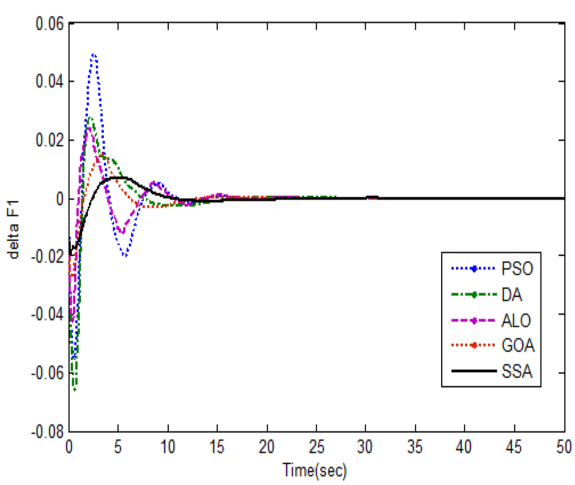

Fig 51.*Deviation in frequency in area 1*

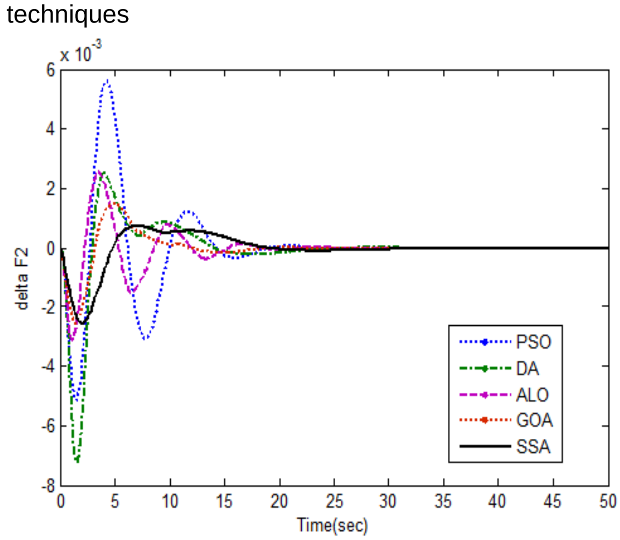

Fig 52*.Deviation in frequency in area 2*

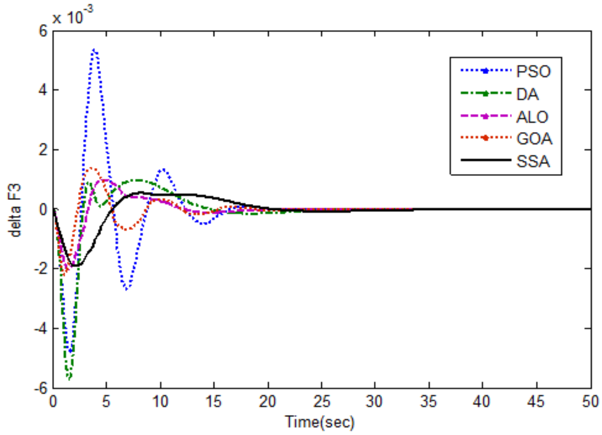

Fig 53.*Deviation in frequency in area 3*

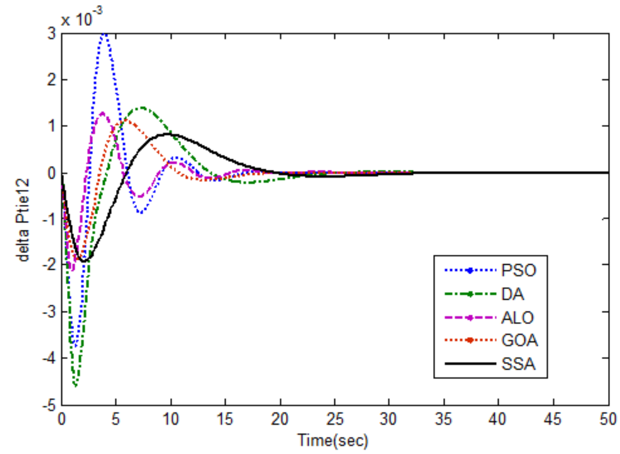

Fig 54.*Deviation in Tie-line power for area 1&2*

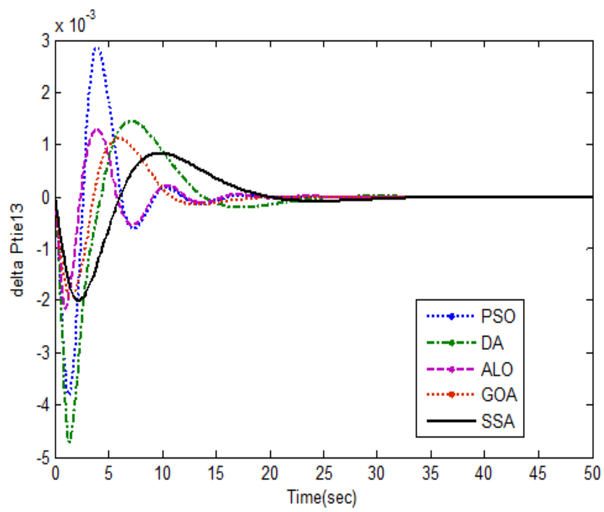

Fig 55.*Deviation in Tie-line power for area 1&3*

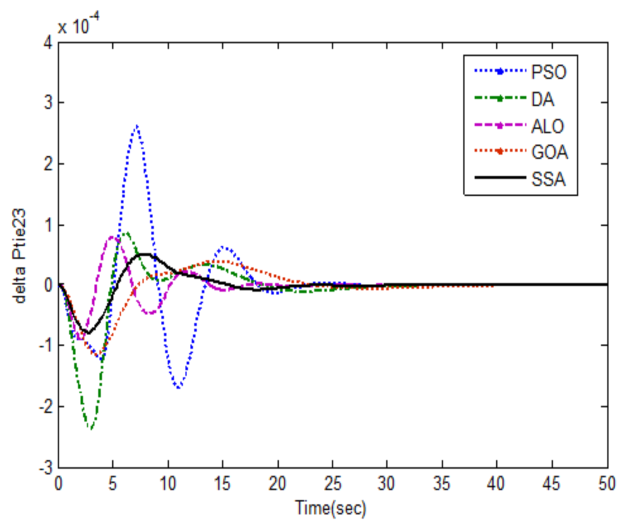

Fig 56.*Deviation in Tie-line power for area 2&3*

Controllers	*Three area Interconnected Thermal power system integrated with DG in area-1*									
	Two objective				*Three Objective*					
	Case1		*Case 2*		*Case 1*			*Case 2*		
	J1	*J2*	*J1*	*J2*	*J1*	*J2*	*J3*	*J1*	*J2*	*J3*
PI	*0.0758*	*0.0024*	*0.0136*	*0.0097*	*0.0087*	*0.5261*	*0.6717*	*0.0024*	*0.8744*	*1.3221*
PID	*0.0689*	*0.0021*	*0.0117*	*0.0088*	*0.0082*	*0.3783*	*0.5117*	*0.0022*	*0.7431*	*1.2666*
TDOF	*0.0432*	*0.0014*	*0.0113*	*0.0085*	*0.0056*	*0.2820*	*0.3824*	*0.0015*	*0.6983*	*0.9297*
FPID-II	*0.0406*	*0.0012*	*0.0102*	*0.0073*	*0.0004*	*0.2378*	*0.2245*	*0.0001*	*0.6776*	*0.7522*

Table. 4: *Comparison of objective fuction values of considered controllers*

	Comparison of different optimization techniques				
Objectives	*SSA*	*GOA*	*ALO*	*DA*	*PSO*
J1	*0.0406*	*0.0694*	*0.0710*	*0.0769*	*0.0778*
J2	*0.0012*	*0.0018*	*0.0023*	*0.0032*	*0.0041*

Table.5: *Comparison of objective fuction values under case-1 of Two objective function*

A critical inspection from above results, unveils that the proposed FPID-II controller exhibits the robustness and authority for Step load perturbations applied in area-1.The dynamic responses also reveals the superiority of the SSA optimization technique based FPID-II controller in minimising the frequency deviations that occurred due to certain load disturbances.

6 Conclusion

Salp swarm Algorithm (SSA) based Fuzzy PID plus double integral (FPID-II) controller is presented for the AGC problem of Interconneted Hybrid power systems.The test systems considered are Two area interconnected Thermal power system integrated with (Distributed Generation) DG in area-1and Three area interconnected Thermal power system integrated with DG in area-1.The simulation results are carried out with Step load perturbation of 0.03 p.u and 0.045 p.u in area-1.The controller parameters are obtained with SSA technique based on two objective and three objective functions.The dynamic performance of FPID-II controller are being compared with PI,PID and TDOF controllers. Further more, the responses obtained from SSA techniques are been compared with other techniques like GOA, ALO, DA and PSO. With the comparison of the results, it can be concluded that the proposed SSA optimized FPID-II controller provides appreciative results via minimising the oscillations in the system frequency and tie-line power flow.

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