Tuning of 2DOFPID Controller for Autonomous Hybrid Power system: A Multi objective optimization Approach

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

Abstract: ***This paper explores the design and performance analysis of the Two degree of freedom PID (2DOFPID) controller for Automatic Generation Control (AGC) of an interconnected Autonomous power system. The Autonomous power system comprises of thermal generation unit and Distributed generation (DG) resources. The DG system consists of a Wind turbine generator, Solar PV system, Diesel engine generator, Fuel cell with Aqua electrolyzer and Energy storage like Battery energy storage system. Recently proposed Salp swarm algorithm (SSA), Grasshopper optimization Algorithm (GOA), and Ant lion Optimzer (ALO) algorithm based on Multi objectives are used to obtain an optimal values of the controller and their performances are compared with the most popular swarm intelligent technique like Particle swarm optimization (PSO). Three different case studies with variant set of disturbances are carried out in simulation studies. The comparitive results illustrated the superiority and efficacy of the SSA alogorithm in obatining the objectives of AGC over other algorithms.***

Index Terms: ***Automatic Generation control, Salp swarm algorithm (SSA), Grasshopper optimization algorithm (GOA), Ant lion Optimizer (ALO), Particle swarm Optimization (PSO), 2DOFPID controller.***

I. INTRODUCTION

Due to the rising concerns of global warming and environmental conditions with generation of electrical energy from conventional fossil fuels, it is necessary to integrate renewable energy technology like wind and solar energy into the power grid [1-3]. The wind powers and solar power plants depend on the weather conditions and are stochastic in nature. Due to this situation the electrical load is more than the generation. Therefore Energy storage devices like battery energy device, fly-wheels and ultra capacitor incorporate with the system to meet this unbalance situation. They might also decrease the fluctuations in the grid frequency and improves the power quality [4]. These storage devices store the electrical energy and later release them for a short period, if there occur a surplus power available from these renewable sources to grid when demand load is as more as than the generation. In order to perform these actions properly needs to be a control strategy.

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Lee and Wang[5] presented the new autonomous hybrid power systems consists of a Wind turbine generator, Solar PV unit, Fuel cell with Aqua electrolyzer, Diesel generator and other Energy storage systems in different combinations such as Battery storage system, an Ultra capacitor, Flywheel energy storage system[6].

The scopes of the work are summarized below:

- To design the Two area interconnected Autonomous power system.
- To get the optiml parameters of controllers with SSA, GOA, ALO techniques and to compare their dynamic performances with most popular swarm intelligent technique such as Particle swarm Optimization (PSO).
- To demonstrate the effectiveness found in
  - ➢ Nominal Loading.
  - ➢ Load demand by ± 20% from its nominal value.
  - ➢ Random loading condition.

II. MATHEMATICAL MODELLING OF POWER SYSTEM

The Hybrid distributed generation system considered includes Wind generator, Solar PV system, Aqua electrolyser with a Fuel cell, Diesel engine generator and storage devices like Battery storage system.The output power of Distributed Generation system is given

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

To imitate the dynamic behaviour of the hybrid power system mathematical models of higher order with non-linearities has to be used. In case of simulation of large systems, simplified models such as transfer function models are generally used [9]. Therefore all components are entitled by single order models.

A. Models of Various Generating and Energy storage Units

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 [10]. The simplified and linearized model of various generation systems is represented as single order transfer function model given as

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

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

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

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

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

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

B. Two Degree of Freedom PID (2DOFPID) Controller

2DOFPID was a controller whose serial compensator is a PID element and feedback compensator is a PD element.Degree of freedom of control systems is the number of closedloop transfer function which will be able toadjusted independently. 2DOFPID controller is a two input and single output system. R(s), Y(s) & U(s) represent reference signal, feedback from the measured system output, and output signal respectively. Proportional, integral and derivative gains are represented respectively by Kp, Ki and Kd. PSW and DSW are the set point weights of proportional & derivative respectively. It evaluates a weighted difference signal depending on the propotional and derivative set point weighting for each of the three actions, that is, proportional, integral and derivative. Its generated output signal is determined by the difference in the reference and measured system output [7]. General layout of 2DOFPID controller is shown as

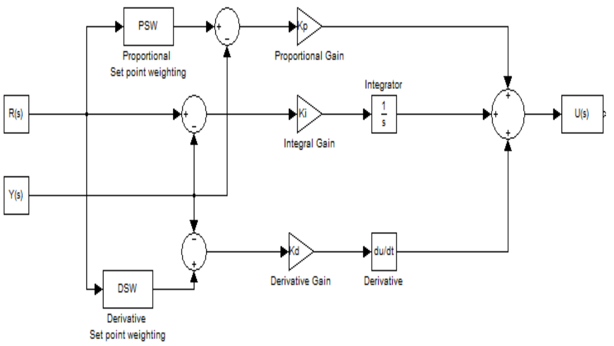


Fig1: Structure of 2DOFPID controller

The simulation diagram with single order function models are shown in fig.3.

The applied variations in components like generated powers (P_W; P_{sol}) are presented in fig.2.

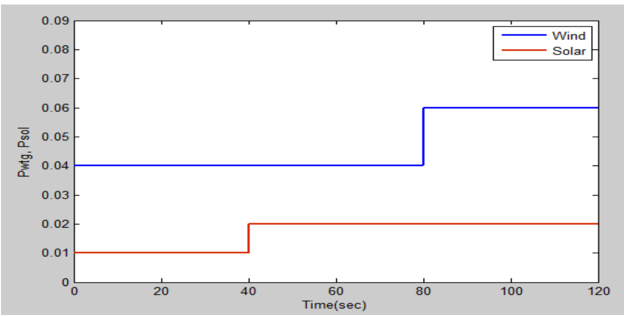


Fig.2. Realization of the renewable power generation

III. Problem Formulation

The Multi Objective (MO) function [8] considered as combination of Integral of so.of squares of Incremental frequency deviation in Area1, Area2, incremental change in Tie line and Area Control errors of respective areas. The final Objective function is given below.

$$Min\ J = Min\ (J1 + J2) \quad (8)$$

Where J1 is given by

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

And J2 is given by

$$J_2 = \min \int_0^T (ACE_1^2 + ACE_2^2)dt \quad (10)$$

Where 'J' is minimized subjected to

$$K_P^{\min} \le K_P \le K_P^{\max}$$

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

$$K_D^{\min} \le K_D \le K_D^{\max}$$

$$PSW^{\min} \le PSW \le PSW^{\max}$$

$$DSW^{\min} \le DSW \le DSW^{\max}$$

IV. Soft Computing Techniques

A. Salp Swarm Algorithm (SSA)

SalpSwarm Algorithm (SSA) is a recent Swarm intelligence algorithm [11] 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

1. Parameter initialization: The algorithm starts by initializing the parameters such as size in population *N*, no.of iterations *t*, and maximum iterations max_{iter}.
2. 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.
3. Individuals Evaluations: Each an individual (solution) on the population are evaluatedby calculating its objective functions value andthe overall the best solution is assigned for F.
4. 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

   $$c_1 = 2e^{-(\frac{4l}{L})^2} \quad (11)$$

   Where l was the present iteration and L was the maximum no.of. Iteration.
5. Position updation of solutions: The position of the leader solution and the other follower solutions are updated as given by

   $$x_j^1 = \begin{cases} F_j + c_1((ub_j - lb_j)c_2 + lb_j) & for c_3 \ge 0 \\ F_j - c_1((ub_j - lb_j)c_2 + lb_j) & for c_3 < 0 \end{cases} \quad (12)$$

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 $x_j^i = \frac{1}{2}(x_j^i + x_j^{i-1})$ (13)

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

6. 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.
7. 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.

B. Grasshopper Optimization Algorithm (GOA)

Grasshopper Optimization Algorithm was a recent Swarm intelligence techniques developed by Mirjalili. GOA is a population based method [12] which explains the mimicking behaviour of grasshoper swarms and their social interaction. Grasshopers are the destructive insects according to their harm to irrigation field. They life has two phases nymph and adulthood. The unique aspect behaviour of grasshoper swarm is found in nymph and adulthood both. Food sources seeking was an important characteristic of grasshoper swarms by dividing the search space in to two tendencies exploration and exploitation. GOA is a population method in which each grasshoper represents solution in population.

Steps followed in GOA

1. Process of Initialization: The algorithm begins by selecting the initial values, maximum and minimum values of decreasing coefficient parameter, C_{max} and C_{min} respectively and the parameters f indicate the attractionintensity and l was the scale of attractive lengths and maximum number of iterations max_{iter}.
2. Initial population and evaluation: The initial population was collected randomly and an each solution in the populations is evaluated by calculating its value by using objective function.
3. Assigning the overall best solution: After evaluating all the solutions in the initial population, the overall (global) best solution is assigned according to its value.
4. Updating the decreasing coefficient parameter: At each iteration, the coefficient parameter c is updating in order to dwindle the comfort, repulsion, attraction zones as given by

$$c = c\max - l\frac{c\max - c\min}{L} \quad (14)$$

Where $cmax$ was the max value, $cmin$ was the min value, $l$indicate the present iteration, and L was the maximum no. of. Iteration.

5. Mapping distance of grasshoppers: The function s as shown in Equation below is required for dividing search space into comfort, repulsion and attraction zones, however its ability decreases to zero when the distance between two grasshoppers is greater than 10. In order to solve this problem the distance between the grasshoppers mapped to the interval 1 and 4.

$$s(r) = fe^{\frac{-r}{l}} - e^{-r}$$

6. Updating solution: Each solution in the population is updated based on the distance between it and the other solutions, the decreasing coefficient parameter c and the global best solution in the population $T_d{}^{\wedge}$ as given by

$$X_i = c\sum_{j=1}^{N} c\left(\frac{ub_d - lb_d}{2} s\left(\left|x_j^d - x_i^d\right|\right)\frac{x_j - x_i}{d_{ij}}\right) + T_d^{\wedge} \quad (16)$$

Where ub_d, & lb_d are the boundaries in thed^{th} dimensions. $T_d{}^{\wedge}$ Shows a target values in the d^{th} dimensions.

7. Solution boundaries violation: After updating the solution, if it violates its upper and lower boundaries, it rests to its domain.
8. Visiting all the solutions in population: The previous three steps are repeated for all the solutions in the populations.
9. Solutions evaluations: The solutions in the population are updated and evaluated and the best global solution is assigned.
10. Termination criteria. The overall operations are repeated until reaching to the max no. of. iterations max_{iter} which was the termination criterion in our work.
11. Returning the best solution: The best globe solution T is returned when the algorithm reaches to its maximum number of iteration.

C. Ant Lion Optimizer (ALO)

Ant Lion Optimizer (ALO) was an new nature inspired algorithms developed by the Mirjalili. ALO algorithm mimics hunting mechanisms of antlions in the nature [13]. This algorithm have been developed to solve as many optimizations problems considering random walks of the ants and building trap and entrapments of ants in the traps, catchingpreysand rebuilding the traps were implemented.

Steps followed in ALO

1. Initializes populations of the Ants and the antlions in random nature.
2. Calculates each fitness value ofeach ant & anlion respectively.
3. Determine its best optimum as best antlion and assume it was elite optimum.
4. Use the Roulette wheel as selection criteria of ant lions and updates the values of c and d with the equation

$$c^t = \frac{c^t}{I} \quad (17)$$

And $d^t = \frac{d^t}{I}$ (18)

Where I was ratio, c^t is minimum of thevariables at thet-th iteration, and d^t indicate vector including the maximum of variable at the t-th iteration.

5. Create the random walks and then normalise it with the equations

$$X(t) = [0, cumsum(2r(t_1)-1), cumsum(2r(t_2)-1).......cumsum(2r(t_n)-1)] \quad (19)$$

And

Where *cumsum* is calculated cumulative sum and n was maximum no.of iterations and t show step of random walk and r(t) is an stochastic functions.

$$X_i^t = \frac{(X_i^t - a_i)\times(d_i - c_i^t)}{(d_i^t - a_i)} + c_i \quad (20)$$

Where a_i was minimums of the randoms walks of the i-thvariable and b_i was maximum of the random walks inthe i-th variable and c_i^t was minimums of the i-th variables at the t^{th} iterations, d_i^t indicate maximums of the i-th variable at t-th iterations.

6. Position updation is carried out with

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (21)$$

Where R_A^t was random walks round the antlions choosed by roulettes wheel at the t t-th iterations and R_E^t was randoms walks round the elite at the t-th iterations, Ant i indicates positions of an i-th ant at its t^{th} iterations.

7. Then Calculate fitness of all the ants and change an antlionswith the corresponding ants as it becomes mostfitter by using

$$Antlion_j^t = Ant_i^t \quad \text{if} \quad f(Ant_i^t) > f(Antlion_j^t) \quad (22)$$

Where't' was current iterations, Antlion $_j^t$ is the positions ofselected j^{th} antlion at the t^{th} iteration, and Ant_i^t indicateposition of i^{th} ant at the t^{th} iterations.

8. Update its elite if antlions become morefitter than the elite.

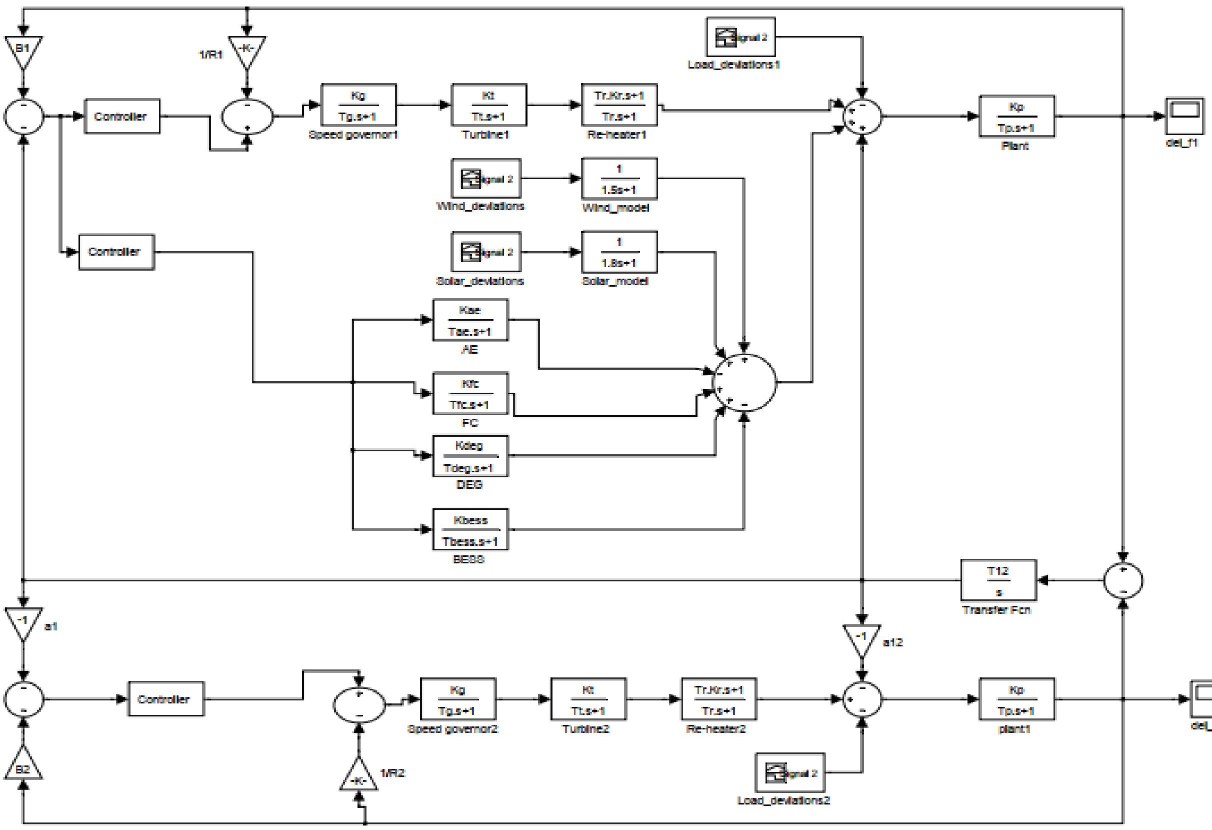


Fig.3. Simulation Structure of Two areaThermal-thermal Interconnected Power system inegrated with DG

V. Results and Discussions

Simulations are conducted on an Intel, Core i-3 and 4 GB RAM computers in the MATLAB (R2010a) software environment. Initially the comparisons of dynamic responses of PI, PID and 2DOFPID controllers is carried out with the SSA technique. The results depicts that the 2DOFPID controller performs better controlling action compared to PI and PID. Furthermore the comparison of dynamic responses of SSA, GOA, ALO and PSO are carried out with 2DOFPID controller for different loading conditions.

A. Case1: *Nominal Loading condition*

Here, the dynamic performances of the choosen system was investigated when subjected to the disturbance in Wind, Solar and Load as shown in Fig. 4

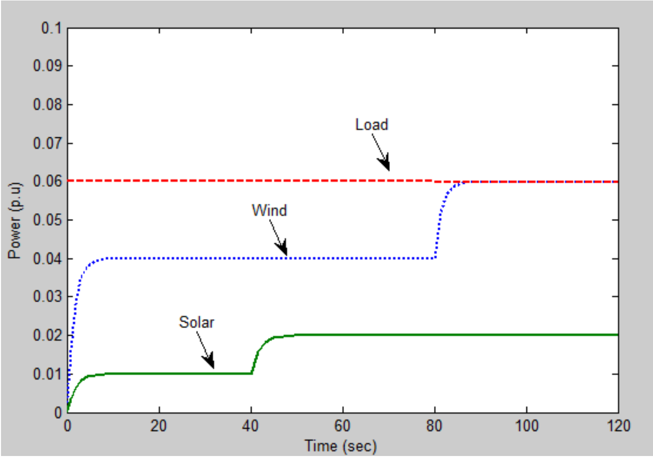


Fig.4 Variations of Wind, Solar and Load under Case 1

B. Case 2: ***Change in loading condition by ± 20% from its Nominal value***

In this case the robustness of different controllers is investigated under sensitivity analysis with ± 20% change in load in both areas and variations of Wind and Solar will remain same. The following figure shows the respective variations.

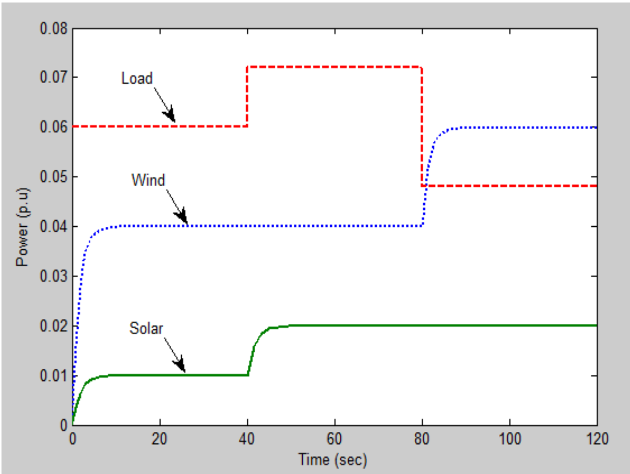


Fig.5 Variations of Wind, Solar and Load under Case 2

C. Case 3: Random Loading condition

The superiority of the controller is clearly examined under the effects of random loadings condition applied for both areas. The patterns of loading condition was demonstrated in the following figure.

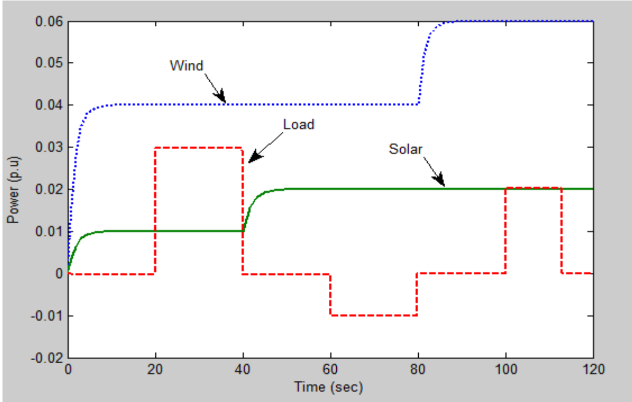


Fig.6 Variations of Wind, Solar and Load under Case 3

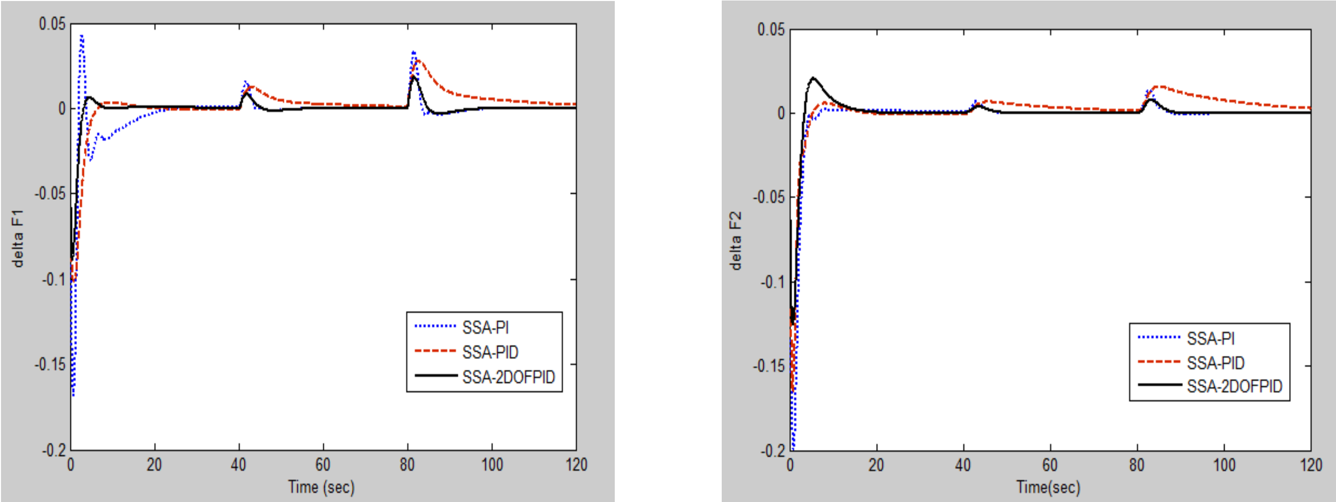
The following figures 7,8,9,10,11&12 illustrates the comaparitive performance analysis of frequency deviations of choosen system. The responses clearly reveals that SSA optimized Controller outperforms as comapared with other controllers.

		PSO	ALO	GOA	**SSA**
Fitness function value **Case1**	J	0.0585	0.0498	0.0450	**0.0413**
	J_1	0.0486	0.0417	0.0375	**0.0345**
	J_2	0.0098	0.0081	0.0075	**0.0068**
Fitness function value **Case2**	J	0.1014	0.0836	0.0753	**0.0644**
	J_1	0.0841	0.0701	0.0632	**0.0538**
	J_2	0.0173	0.0134	0.0121	**0.0105**
Fitness function value **Case3**	J	0.0749	0.0703	0.0677	**0.0583**
	J_1	0.0631	0.0589	0.0565	**0.0489**
	J_2	0.0119	0.0114	0.0113	**0.0094**

Table.1: Simulation results

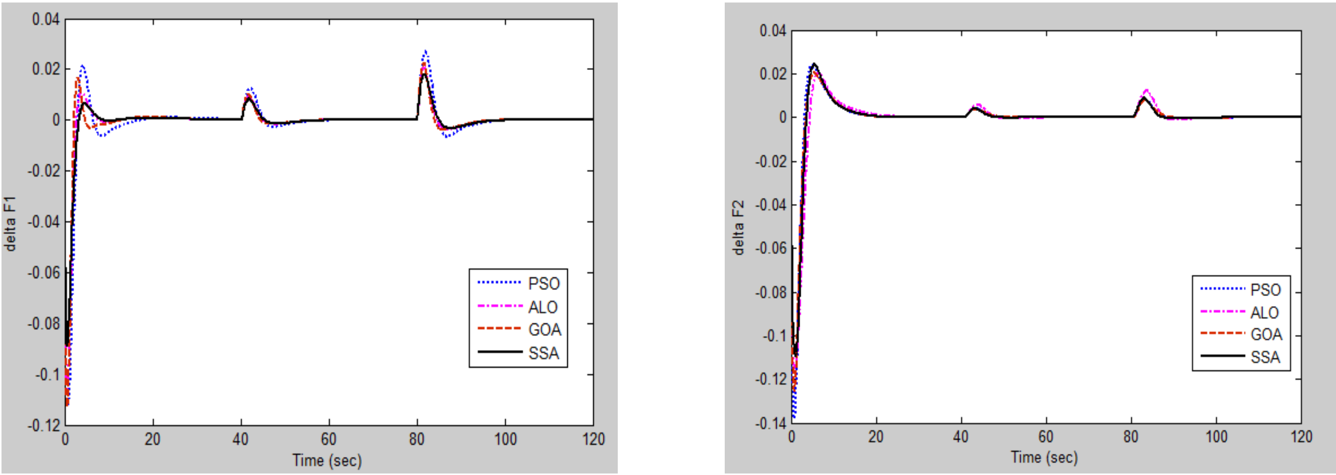
	Fitness value	SSA tuned 2DOFPID Controller		
		IAE	**ISE**	ITAE
Case1	J	8.6057	**0.0413**	40.9669
	J1	5.8231	**0.0345**	29.8427
	J2	2.7827	**0.0068**	11.1241
Case2	J	2.1033	**0.0644**	67.1662
	J1	1.4856	**0.0538**	47.6725
	J2	0.6177	**0.0105**	19.4938

Table.2: Sensitivity Analysis with different Performance Index



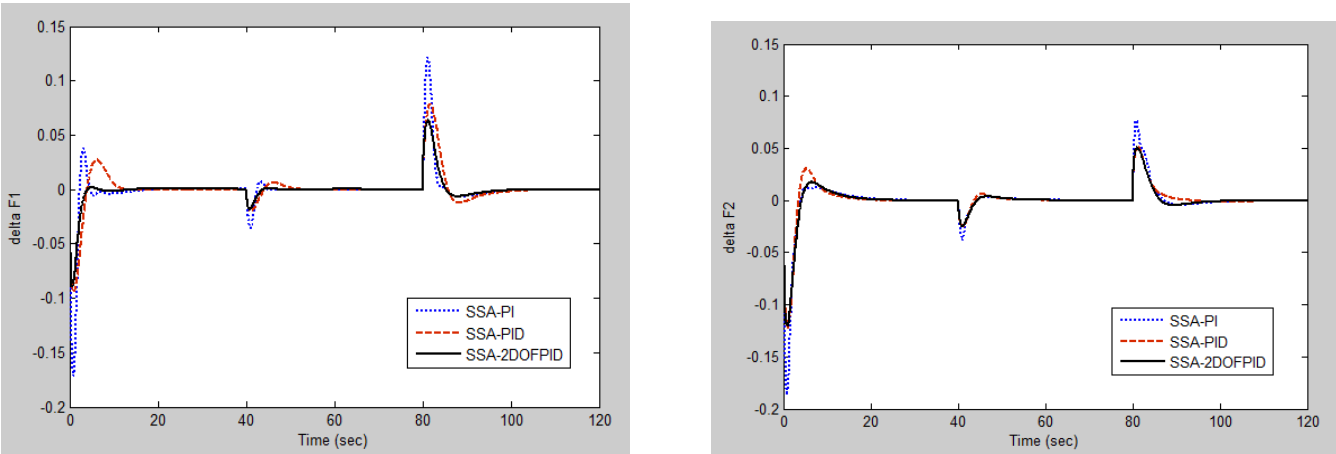
(a) (b)

Fig.7 (a&b) Frequency deviatons in area1, area2 under case1 condition



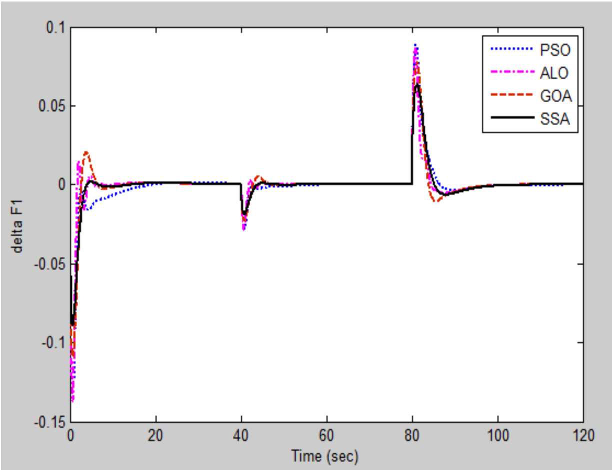
(a) (b)

Fig.8 (a&b) Comparitive respose of SSA, GOA, ALO, PSO in area1, area2 under case1 condition

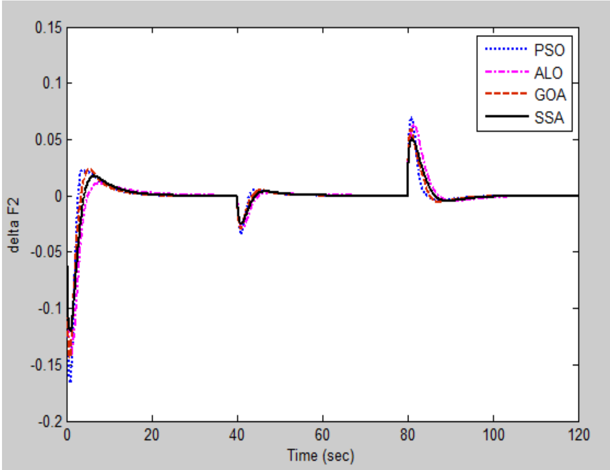


(a) (b)

Fig.9 (a&b) Frequency deviatons in area1, area2 under case2 condition

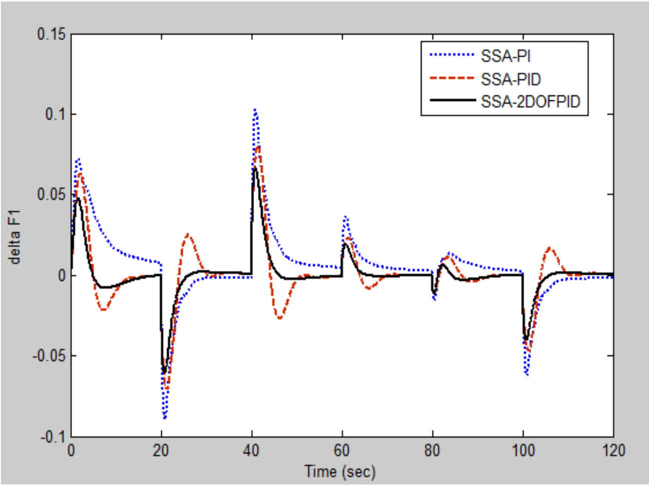


(a)

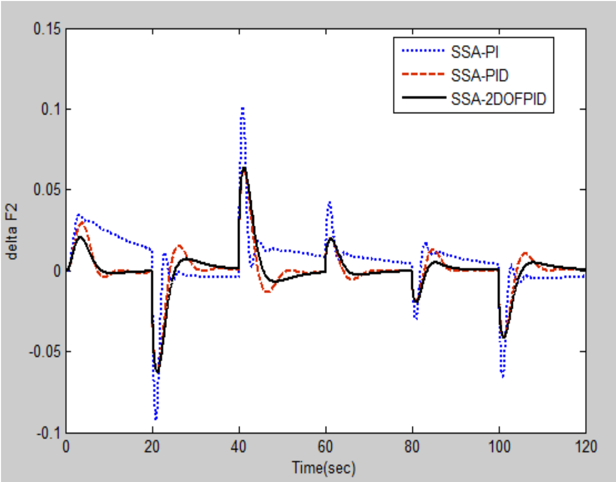


(b)

Fig.10 (a&b) Comparitive respose of SSA, GOA, ALO, PSO in area1, area2 under case2 condition

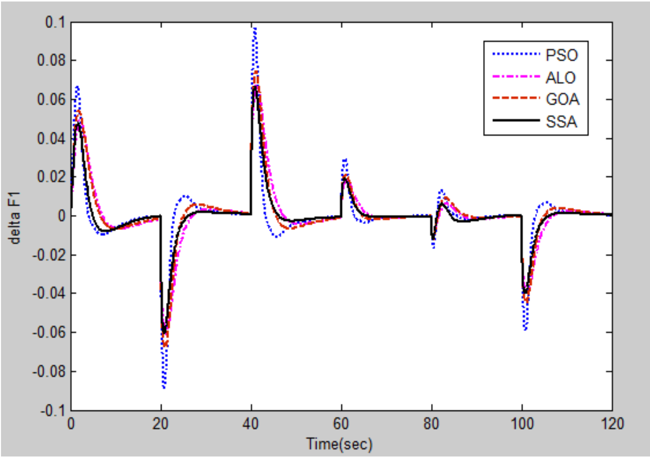


(a)

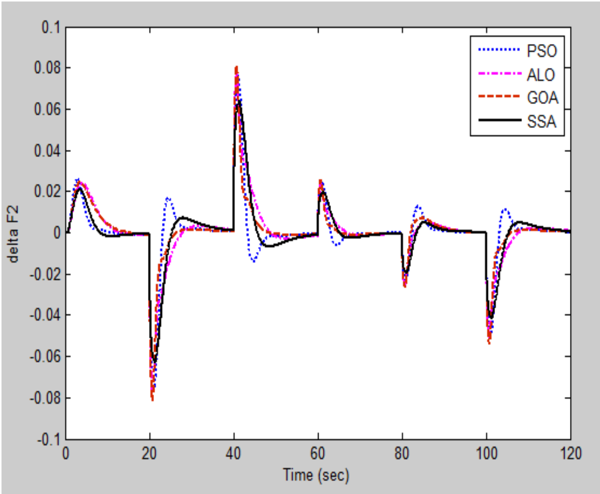


(b)

Fig.11 (a&b) Frequency deviatons in area1, area2 under case3 condition



(a)



(b)

Fig.12 (a&b) Comparitive respose of SSA, GOA, ALO, PSO in area1, area2 under case3 condition

VI. CONCLUSION

The proposed work consist of an two area Autonomous Hyrid power systems in which area1 consists of a Thermal generating unit along with Distributed generation resources. Two degrees of freedom PID (2DOFPID) controller is employed as a secondary controller. To test the robustness of proposed controller it is compared with PI and PID contro-llers. Four different optimization techniques are used with Multiobjective function to obtain the parameters of the controller. A comparative Time-domain simulation result reveals that the SSA tuned 2DOFPID controller provides better controlling action. The comparative analysis is carried out under three different loading conditions.

The result and the analysis done clearly depicts that SSA tuned 2DOFPID controller is very much effective and superior at minimising the frequency of deviation in respective areas.

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