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Stability Improvement in Multimachine Power Systems Using Nature Inspired Algorithms

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Abstract:
The major changes in the load, frequency, terminal Voltage, active power, reactive power, fault in the system are the major root causes for the sudden changes. The oscillation due to sudden change in the Power System will causes as unstable condition in the Generating system. This oscillation must be damped out at the earliest. Oscillations are ruled by the Power System Stabilizer. The Power System Stabilizer can be designed with various optimization techniques. The optimized output of the PSS must damp the oscillation in a short duration without disturbance in the generating system. The design was performed with conventional method, Genetic Algorithm and output is evaluated against by Grasshopper Optimization Algorithm output to get fast response from Power System Stabilizer in order to maintain the power system with dynamic stability.

Keywords*: PowerSystemStabilizer,OptimizationTechniques,Genetic Algorithm And Grasshopper Optimization Algorithm.*

I. INTRODUCTION

Stability of power system plays a vital role in the electrical values, under any disturbance like a loss of generator, sudden increase in load or switching out a transmission line during a fault condition. Where the development and interconnection of a large electric power systems, there have been a spontaneous system oscillations at very low frequencies in the order of 0-3Hz. To enhance and improve the power system stability, generators are equipped with the power system stabilizers (PSSs) or power system damping controller(PSDC) that provides a feedback and stabilize the signals in the excitation systems [1].

The several approaches had been done in the recent years, based on the modern control theory have been applied to PSDC design problem. Which includes the optimal control, variable structure control, adaptive control, and intelligent control. Despite of this techniques, the conventional damping controller design using the theory of lead lag compensation can provide a good damping to these oscillations at a particular operation conditions [2,3]. The damping controllers were designed and implemented using concepts of neural networks, fuzzy logic, variable structure control and adaptive algorithms [4, 5]. These controllers had some disadvantage with respect to complex design procedures in fuzzy logic, difficult in training the neural network even though have a effective damping which is suitable for system stability [6, 7].

Recently, as an alternative to these techniques, nature inspired optimization algorithm were extensively implemented in various engineering optimization problems [8, 9]. These include evolutionary programming, harmony search algorithm, honey bee algorithm, genetic algorithm(GA), particle swarm algorithm(PSO), shuffled frog leaping algorithm, cuckoo search (CS)algorithm, grasshopper optimization algorithm(GOA) and differential search algorithm(DSA). These algorithms can be implemented effectively to solve complex power system parameter optimization problems.

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In this paper, the CPSS, GA, and GOA algorithms are implemented for the controller design, so that optimal controller parameters can be computed for better stability of the system. This paper provides the system to damp with the low frequency inertial oscillations experienced in the test IEEE 3-machine 9-bus system to enhance the stability of these systems using various nature-inspired damping controller designs, namely CPSDC, GAPSDC, GOAPSDC. The damping performance is given in the term of time domain –based error minimization, where it is better in the GOAPSDC in comparison with CPSDC, GAPSDC. The GOAPSDC design can be implemented for modern complex interconnected power system networks, so that the experienced low frequency inertial oscillation will be effectively damped to enhance the power system stability.

II. MODELLING OF POWER SYSTEM

A. Multi Machine Power System Modeling

In multi machine model, a synchronous machine or group of synchronous machines connected to a large system through one or more power lines. Figure(1)represents the IEEE 3-machine 9- bus power system [10, 11].

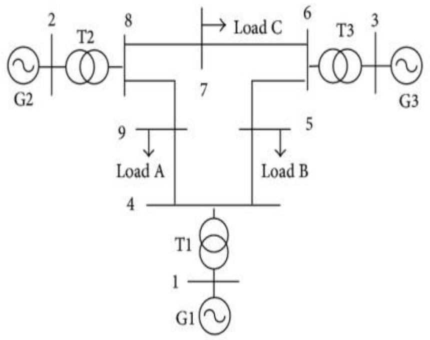

Fig.1. IEEE 3-Machine 9- bus system

$$x = Ax + Bu$$

Where x = vector of state variables.

A,B = state vector matrix and input matrix respectively.

The state variables used in the modeling for open loops and closed loop system for each machines are given by,

$[X]_{open} = [\Delta\omega_j\ \Delta\delta_j\ \Delta E_{qj}'\ \Delta E_{fdj}]^T$

$[X]_{closed} = [\Delta\omega_j\ \Delta\delta_j\ \Delta E_{qj}''\ \Delta E_{fdj}\ \Delta P_{ij}\ \Delta U_{\delta j}]^T$

Where $\Delta\omega_j$ = Incremental change in rotor speed .

$\Delta\delta_j$ =Incremental change in power angle.

$\Delta E_{qj}'$ = Incremental change in generator volage.

ΔE_{fdj} =incremental change in field voltage.

ΔP_{ij} and $\Delta U_{\delta j}$ represents the PSS model variables. The system data used for simulation are given in Appendix. In equation 2, j=1,2,3 it refers to an machine number. From the equation 2 the state matrices for the three machines will be individually formulated. $[X]_{open}$ and $[X]_{closed}$ refers to the state variables selected for the various machines in the system modeling. The control vector u consists of two inputs to the system namely [ΔT_m and ΔV_{ref}]. ΔT_m represents the mechanical input torque and ΔV_{ref} represents the reference input voltage. Where the input matrices and closed loop state matrices (A_{closed} and B_{closed}) developed in system are given in appendix.

The Heffrons Phillips synchronous generator model taken for the state space modeling and analysis of the system. The PSDC implemented in the generator excitation system feedback loop which represents the PSDC in this model.

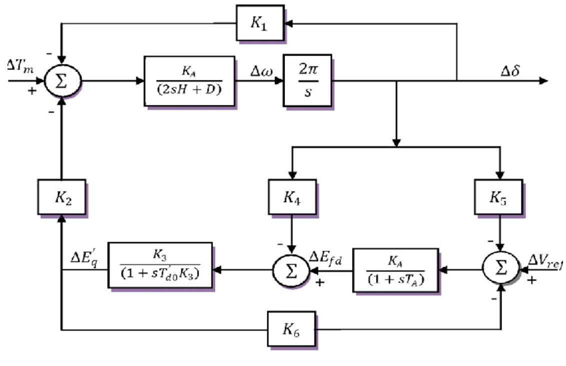

Fig. 2. Heffron –Phillips synchronous generator model

The single machine Heffron -Phillips generator model is extended to perform the modeling of multi machine system. Where in the multi machine system there is interaction among the various generators, and where the branches and loops of the single machine generator model will become multiplied.

In single machine model where the constant K_1 becomes K_{1ij}i=1, 2…n; j=1,2…n I for the instance in multi machine. In this work, n will be equal to 3,

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represents the number of generators in the multi machine system considered. Similarly all the K constants (k1 to k6), damping factor D, inertia M and the state variables used in the single machine model are generalized for n-machine notation.

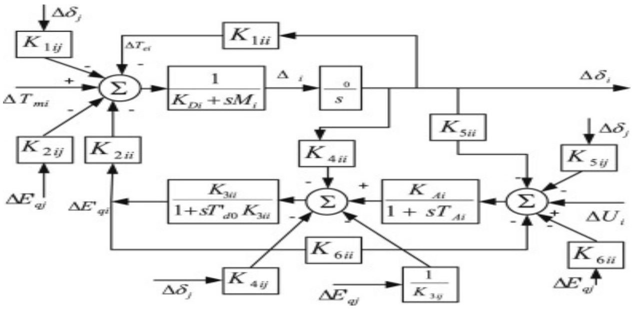

Fig. 3. State space model of multi machine power system

B. CONVENTIONAL POWER SYSTEM STABILIZER:

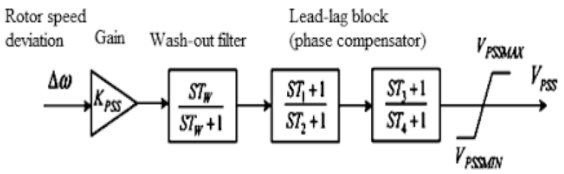

Fig. 4. Conventional Power System Stabilizer

A “lead-lag” PSS structure shown in fig. 4. The output signal of any PSS is voltage signal, noted here as VPSS(s), and added as an input signal to the AVR/exciter. To reduce the over- response of the damping during the severe events, the particular controller structure which contains a washout block sTW/(1+sTW) is used. where the control action, the electric torque and to compensate the lag between PSS output the phase lead blocks are used (lead-lag), and where the component of electrical torque are in phase with the speed deviation must be also produced by PSS. The particular system and the tuning of the PSS is used to find the number of lead-lag locks needed in the system. Where the damping provided by the PSS increase in proportion to increase the gain up to a certain critical gain value, after which the damping begins to reduce and the PSS gain KS is also an important factor. For the each type of generators the PSS variables must be determined separately because of the dependence on the machine parameters. The PSS system values also influenced by the power system dynamics.

C. DUAL- INPUT POWER SYSTEM STABILIZER

The system is also a point of debate for PSSs in the input signals. The signals that have been identified as valuable include deviations in the rotor speed (Δω =ωmech –ωo), the frequency (Δf) , the electric power (ΔPe) and the accelerating power (ΔPa).

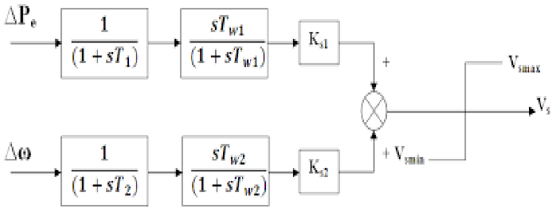

Fig .5. IEEE type of PSS3B structure

Since the main action of the PSS is to control the rotor oscillations, the input signal of the rotor speed has been the most frequently advocated in the literature. A different- type of regulation and a high gain would ideally used on speed deviation based controllers. Where the lead-lag structure is commonly used which is mentioned previously, since it impractical in reality. However, one of the limitation of the speed in pu PSS is that it may excite torsional oscillatory modes. The torsional interaction problem which is suffered by the speed-input PSS has solved by the solution where a power/speed (ΔPe-ω, or delta-P-omega) PSS design has proposed. The power signal used is the generator electrical power, Which has high torsional attenuation the use of a power signal as input, where due to its low level of torsional interaction either electrical power (ΔPe) or the accelerating power (ΔPa= Pmech - Pelec), are been considered. Where the tuning method is related to this design approach which is valid for the other input signals where the Pa signal is one of the two involved in the “4 -loop” PSS controller [12, 13].

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III. OPTIMIZATION CRITERION

OBJECTIVE FUNCTION (TIME DOMAIN SIMULATION-BASED)

$$[j] = {}^{T}{}_{0}\int[e^2(t)]dt$$

Here, e(t) represents the error deviations in generator speed and power angle. The time of simulation is represented by T.

The objective here is to Minimize[j], so that the integral of the squared error deviation is minimized, thus enhancing the damping of electromechanical oscillations for better system stability.

The optimization problems including the constraints are given as follows:

Optimize j[minimize j]

Subject to:

$k_s^{min} \leq k_s \leq k_s^{max}$

$T_1^{min} \leq T_1 \leq T_1^{max}$

$T_2^{min} \leq T_2 \leq T_2^{max}$

The following are the various minimum and maximum values selected for the controller parameters for simulation of the system model. For the gain [1.0 to 50], for time constant T_1[0.1 to 1.0] and for time constant T_2[0.1 to 1.0].

IV. PROPOSED NATURE INSPIRED OPTIMIZATION ALGORITHMS

A. Overview of Genetic Algorithm

The natural selection and genetics are inspired to the nature inspired algorithms like genetic algorithm [14, 15]. The following 4 operators are essential in the GA to create the fittest individuals:

- Selection
- Crossover
- mutation and
- Replacement

- In initial population for reproduction where the identifying the two parent chromosomes, and this process is selection. Where in this paper the roulette wheel selection process is implemented. For recombination compared to other selection methods the useful solution and the selecting potentially is the roulette wheel selection for genetic selection.

- Crossover is the process of taking 2 selected parent chromosomes to produce better offspring. The uniform crossover method is implemented in this work. After the crossover, the strings are subjected to the phenomenon of mutation.

- The lost genetic materials involved in the genetic process are recovered by mutation. The flipping a bit, i.e Changing 0 to 1 and vice versa where it is involved in the mutation.

- The last stage in the genetic cycle is the replacement stage. The generation gap of 0.8 involving the weak parent replacement is implemented in this paper.

B. Proposed Grasshopper Optimization Algorithm (GOA)

Where the behaviour has been derived from the majority of heuristic algorithms which has a powerful simulated annealing and particle swarm optimization which gives to a meta heuristic algorithm in the nature of physical and biological systems. Where the annealing process of metals are based by the simulated annealing and for example where the swarm behaviour of birds and fish are developed as the particle swarm optimization[16].

Grasshopper optimization algorithm (GOA) is a population based single objective and stochastic and heuristic optimization technique proposed by saremi et al, it imitates the behaviour of grasshopper swarms in the nature and models where it is used mathematically for solving optimization problems with an contentious variables. Where GOA can solve many optimization problems effectively. Where grasshoppers are insects, they cause damage to crop production and agriculture, and it consider as a pest, they are seen individually in nature, where in creatures they join a one of the largest swarm of all creatures. Where the swarming behaviour found in

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both nymph and childhood are the unique aspect of the grasshopper swarm. Where the millions of nymph grasshopper jump and move like a rolling cylinder, they eat almost all vegetation. And when they become adult they form a swarm in the air. This is how the grasshopper migrate over the large distances.

The main characteristics of the swarm in the larval phase is slow movement and small steps of the grasshoppers. In contrast, long range and abrupt movement is the essential feature of the swarm in adulthood. Food source seeking is another important characteristic of the swarming of grasshoppers. Nature inspired algorithms logically divide the search process into two tendencies: exploration and exploitation. Where in exploitation they tend to move locally, and in exploration the search agents are encouraged to move abruptly. These two functions as well as target seeking, are performed by grasshoppers naturally [17, 18].

The mathematical model employed to simulate the swarming behavior of grasshoppers is presented as:

$$X_i=S_i + G_i + A_i \tag{1}$$

Where X_i defines the position of the i-th grasshopper, S_i is the social interaction, G_i is the gravity force on the i-th grasshopper, and A_i shows the wind advection. Note that to provide random behavior the equation can be written as $X_i= r_1 S_i + r_2 G_i + r_3 A_i$ Where r_1,r_2, and r_3 are random numbers in [0,1].

$$S_i=\sum_{\substack{j=1 \\ j\neq i}}^{N} s(d_{ij})\hat{d}_{ij} \tag{2}$$

Where d_{ij} is the distance between the i-th and the j-th grasshopper, calculated as $d_{ij}=|x_j-x_i|$, s is a function to define the strength of social forces, and $d_{ij} = x_j-x_i \div d_{ij}$ is a unit vector from the ith grasshopper to the jth grasshopper.

The social forces where the s function is calculated as follows:

$$S(r)= f e^{-r/l} - e^{-r} \tag{3}$$

Where the l is the attractive length scale and the f indicates the intensity of attraction.

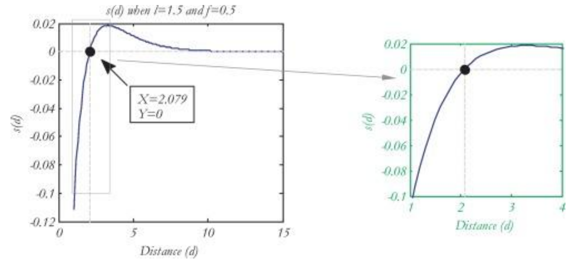

Fig. 6. social forces function s when l=1.5 and f=0.5 range of function s when x is in [1,4].

The function s shows how it impacts on the social interaction (attraction and repulsion) of grasshoppers. It may be seen in this figure that distances from 0 to 15 are considered. Repulsion occurs in the interval [0 02.079], when a grasshopper is 2.079 units away from another grasshopper, there is neither attraction nor repulsion. This is called the comfort zone or comfort distance. The attraction can be increase from 2.079 unit of distance to nearly 4 and then gradually decreases. Changing the parameters l and f in (3) equation results in different social behaviours in artificial grasshoppers. To see the effects of these parameters, the function s is redrawn with varying l and f independently. The parameter l and f change comfort zone, attraction region and repulsion region significantly. It should be noted that the attraction or repulsion regions are very small foe some values (l=1.0 and f=1.0 for instance). Where the l=1.5 and f=0.5 are the values chosen.

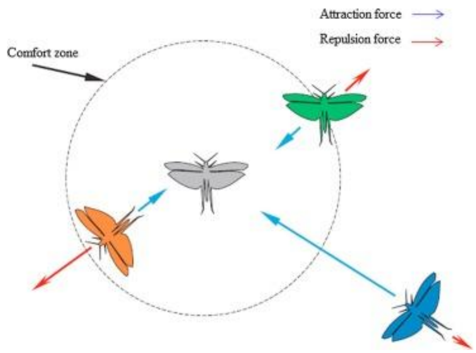

Fig.7. primitive corrective patterns between individuals in a swarm of grasshoppers

A conceptual model for the interactions between grasshoppers and the comfort zone using function s is illustrated in Fig. 7, It may be noted

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that, in simplified form, this social interaction was the motivating force in some earlier locust swarming models. The function s able to divide the space between two grasshoppers into repulsion region, comfort region, and attraction region, this function returns the values close to zero with distances greater than 10. Therefore, this function is not able to apply strong forces between grasshoppers with large distances between them. To resolve this issue, we have mapped the distance of grasshoppers in the interval of [1.4].

The G component in equation (1) is calculated as:

$$G_i = -g e_g \qquad (4)$$

Where g is the gravitational constant and e_g shows a unity vector towards the center of earth.

The A component in equation (1) is calculated as:

$$A_i = u\, e_w \qquad (5)$$

Where u is a constant drift and e_w is a unity vector in the direction of wind.

Nymph grasshoppers have no wings, so their movements are highly correlated with wind direction. Substituting S,G and A in Equation (1), this equation can be expanded as follows:

$$X_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} s(|x_j - x_i|)\, x_j - x_i/d_{ij} - g e_g + u\, e_w \qquad (6)$$

Where $S(r)= f e^{-r/l} - e^{-r}$ and N is the number of grasshoppers. Since nymph grasshoppers land on ground, their position should not go below threshold. This equation is not utilize in swarm simulation and optimization algorithm because it prevent algorithm from exploring and exploiting, the model utilized for the swarm is in free space. Therefore "(6)" is used to simulate the interaction between grasshoppers in swarm.

However, the mathematical model cannot be used directly to solve optimization problems, mainly because the grasshoppers quickly reach the comfort zone and the swarm does not converge to a specific point. A modified version of this equation is proposes as follows to solve optimization problems:

$$X_i^d = c\left(\sum_{\substack{j=1 \\ j \neq i}}^{N} c \;\; ub_d - lb_d/2s\, (|x_j - x_i|)\, x_j - x_i / d_{ij}\right) + T_d \qquad (7)$$

Where ub_d is the upper bound in the D th dimension, lb_d is the lower bound in th Dth dimension $S(r)= f e^{-r/l} - e^{-r}$, T_d is the value of the Dth dimension in the target and c is a decreasing coefficient to shrink the comfort zone, repulsion zone, and attraction zone. S is almost similar to the S component in equation (1). We do not consider gravity (G component) and assume that the wind direction (A component) is always towards a target (T_d).

Equation (7) shows that the next position of a grasshopper is based on its current position, the position of target, and the position of all other grasshoppers. The first component of this equation is the location of the current grasshopper with respect to other grasshoppers, We have considered the status of all grasshoppers to define the location of search agents around the target. This is different to PSO as the well –regarded swarm intelligence technique in the literature. In PSO, there are two vectors for each particle: position and velocity vector, However there is only one position vector for every search agent in GOA. The other main difference between these two algorithms is that PSO updates the position of the particles with respect to current position, personal best, and global best. However, GOA updates the position of a search agent based on its current position, global best, and the position of all other search agents. This means that in PSO none of the other particles contribute to updating the position of a particle, whereas GOA requires all search agents to get involved in defining the next position of each search agents. It is also worth mentioning here that the adaptive parameter c has been used twice in " (7)", for the following reasons:

- The first c from the left is very similar to the inertial weight (w) in PSO. It reduces the movements of grasshoppers around the target. In other words, this parameter balances exploration and exploitation of the entire swarm around the target.
- The second c decreases the attraction zone, comfort zone, and repulsion zone between grasshoppers. Considering the component c $ub_d - lb_d/2s$ ($|x_j - x_i|$) in the " (7)" c $ub_d - lb_d/2$

linearly decreases the space that the grasshoppers should explore and exploit. The component s ($|x_j - x_i|$) indicates if a grasshopper should be repelled from or attracted to the target.

The inner c contributes to the reduction of repulsion/attraction forces between grasshoppers proportional to the number of iterations, While the outer c reduces the search coverage around the target as the iteration count increases. The first term of equation (7), the sum consider the position of other grasshoppers and implements the interaction of grasshopper in nature. The second term, T_d, simulate their tendency to move towards the source of food. Also, the parameter c simulates the deceleration of grasshoppers approaching the source of food and eventually consuming it. T provide more random behavior, and as an alternative, both terms in equation (7) can be multiplied with random values. Also individual terms can be multiplied with random values to provide random behavior in either interaction of grasshoppers or tendency towards the food source.

The explore and exploit of the search space is proposed by the mathematical formulation. However, there should be a mechanism to require the search agents to tune the level of exploration to exploitation. In nature, grasshoppers first move an search for foods locally because in larvae they have no wigs, then move freely in air and explore a much larger scale region. In stochastic optimization algorithms, however, exploration comes first due to the need for finding promising regions of the search space. After finding promising regions, exploitation obliges search agents to search locally to find an accurate approximation of the global optimum.

For balancing exploration and exploitation, the parameter c is required to be decreased proportional to the number of iteration. This mechanisms promotes exploitation as the iteration count increases. The coefficient c reduces the comfort zone proportional to the number of iterations and is calculated as follows:

$$C = cmax - l\,\frac{cmax - cmin}{L} \qquad (8)$$

Where cmax is the maximum value, cmin is the minimum value, l indicates the current iteration, and L is the maximum number of iterations. In this work 1 and 0.00001 for cmax and cmin respectively.

Steps of Grasshopper Optimization Algorithm

The steps of GOA are summarized as follows:

Step 1: choose the objective functions f(x), $x=(x_1,x_2,\ldots\ldots x_{dim})$, dim= no of dimensions

Step 2: Generate initial population of n grasshoppers $x_i=(i=1,2,\ldots\ldots.,n)$

Step 3: calculate fitness of each grasshopper

Step 4: T= the best search agent

Step 5: **while** stopping criteria not met **do**

Step 6: update c_1 using Eq. (8)

Step 7: update c_2 using Eq. (8)

Step 8: **for each** grasshopper gh in population **do**

Step 9: Normalize the distances between grasshoppers in [1,4]

Step 10: Update the position of the gh by Eq.(7)

Step 11: If required, update bounds of gh

Step 12: **end for**

Step 13: If there is a better solution, update T

Step 14: **end while**

Step 15: output the T.

V. SIMULATION AND RESULTS

DEVELOPMENT OF THE SIMULINK MODEL

Where for all the modeling and simulation, MATLAB tool was used. In this work where the Power System Stabilizers are installed in the generator 2 and generator 3, the generator 1 bus is treated as infinite bus system.

The designed Grasshopper Optimization Algorithm based PSS is exerted to damp low frequency oscillation in the system study. In order to study and analysis the system performance, a disturbance is created in the system. The simulation results under disturbances for various operating conditions are presented in figure 8 to 14

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Also, where the open loop without PSS in speed deviation in figure (10), indicates the deviations are more oscillating in nature and is need of suitable damping controller for the effective damping and stability enhancement.

Where the time domain deviation responses for the various controllers can be provided to analyze the non linear time domain simulation. Figure 9 and 10 represents the speed and power angle response for P=0.9, Q=0.01,pd=0.01pu condition of G2. From these response it is clear that the GOAPSS which provides an effective damping to the system by damping the deviation overshoots and also making the oscillation deviation to settle at quick stage compared to a CPSS and GAPSS.

Similarly, figure11and12indicates the speed and power angle deviation response for P=0.9, Q=0.01, pd=0.01 pu condition of G3. Where these response indicate the damping action of proposed GOAPSS is damped with the low frequency oscillations effectively, thus satisfying the objective formulated for an stability enhancement. The figure 9 to 14 shows the speed and power angle deviation response ofgenerator2and3,forcondition1P=0.9,Q=0.01,Pd=0. 01,condition2 P=0.95,Q=0.03,Pd=0.02. The results show that the GOA optimization algorithm is more robust and enough damping controller when compared to the CPSS and GA based PSS.

The simulation results shows that applying Grasshopper Optimization Algorithm based PSS signal, it greatly enhances the damping of low frequency oscillations and therefore the systems becomes stable as shown in the results.

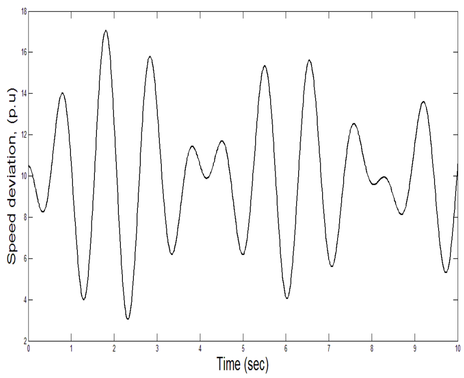

Fig. 8. Open Loop Without PSS In Speed Deviation

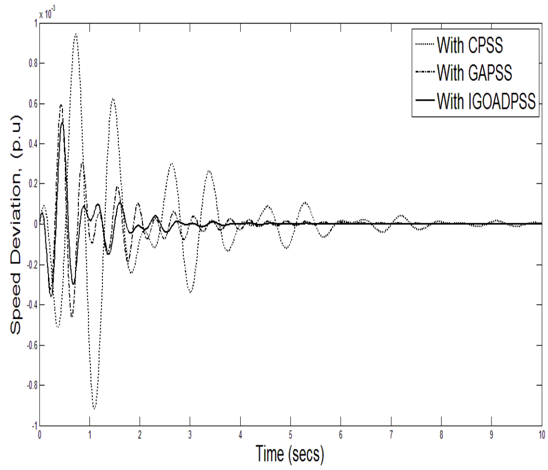

Fig. 9. Speed Deviation Response Of G2, For Condition P=0.95, Q=0.03, Pd=0.02 Per Unit

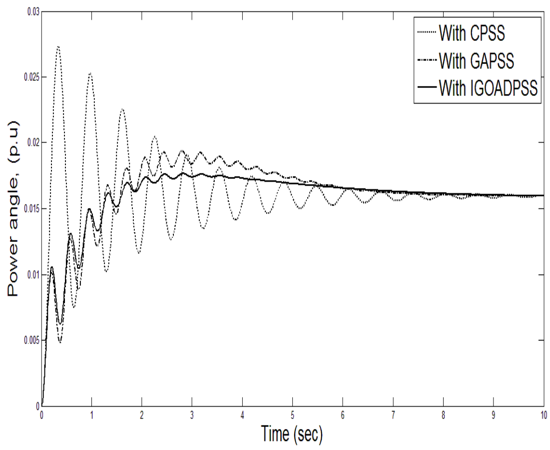

Fig. 10. Power Angle Response Of G2, For Condition P=0.95, Q=0.03, Pd=0.02 Per Unit

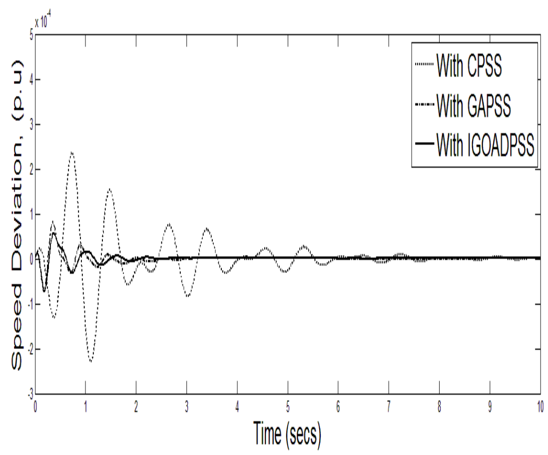

Fig.11. Speed Deviation Response Of G3, For Condition P=0.93, Q=0.05, Pd=0.005 Per Unit

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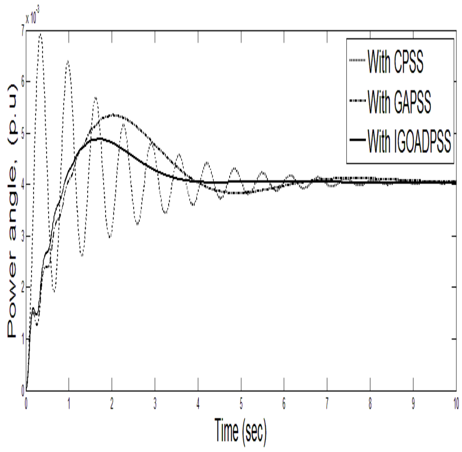

Fig.12. Power angle response of G3, for condition P=0.93, Q=0.05, Pd=0.005Per Unit

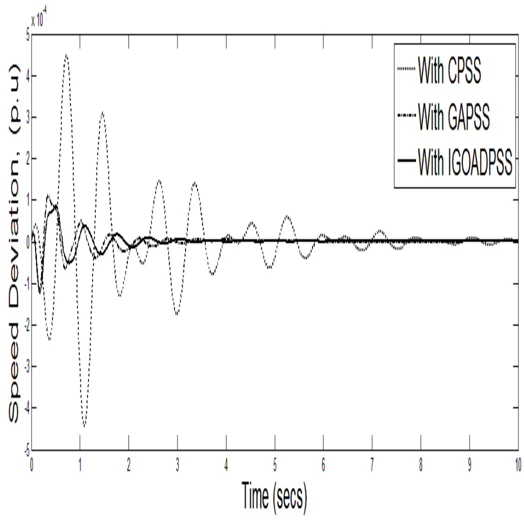

Fig.13. Speed Deviation Response Of G2, For Condition P=0.98, Q=0.07, Pd=0.009 Per Unit

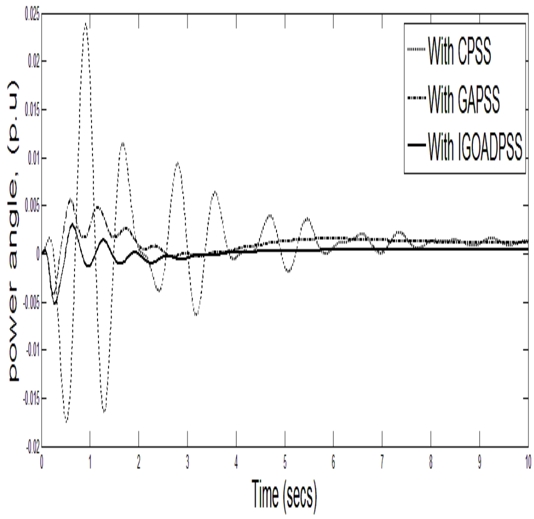

Fig.14. Power Angle Response Of G3, For Condition P=0.98, Q=0.07, Pd=0.009 Per Unit

VI. CONCLUSION

In this work, a dual input power system stabilizer is designed and developed with conventional Algorithm, Genetic Algorithm and Grasshopper Optimization Algorithm. The proposed Grasshopper optimization algorithm was applied to a Multi Machine IEEE 9 bus with Dual input. Power system containing parametric uncertainties and various load condition. The simulation demonstrated that the dual input PSS is capable of sustain various disturbance under wide range of system uncertainties. The oscillation frequency and small signal stability was improved by using Grasshopper optimization Algorithm compared to conventional power system stabilizer and Genetic Algorithm undergo to stable and to control the poor damping occurred.

Appendix

Test multi machine power system data

Generator 1: 125 MVA, 13.8 KV. Rated power factor =0.9, Xd=1.05, Xd'=0.3, Xq=0.686, Xq'=0.686, Tdo'=6.170, D=0, M= 10.
Generator 2: 31 MVA, 13.8 KV. Rated power factor =0.9,Xd=1.010,Xd'=0.36, Xq=0.570, Xq'=0.570, Tdo'=7.600, D=0, M=12.
Generator 3: 145 MVA, 14.4 KV. Rated power factor =0.9, Xd=0.953, Xd' =0.312, Xq = 0.573, Xq'=0.573, Tdo'=7.070, D=0, M=10.
Excitation system: IEEE ST1A type, for speed input damping controller
K_A =180, TA=0.05, $K_{F=0.025,}$T $_F$=1.0, Ke=0.15,T_e=0.025

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