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# Hybrid PSO-GSA Algorithm for the Static Synchronous Series Compensator based Single Machine Infinite Bus

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***Abstract*: In modern power system, stability problem plays an important role. We can improve the dynamic stability of the power system by simultaneously tuning the SSSC based damping controller set with hybrid PSO-GSA algorithm (HPSOGSA). HPSOGSA technique is applied to search the optimal parameters of the controller. The optimization of the particle swarm optimization (PSO) is motivated by the social results of the flocks of birds, the gravity search algorithm (GSA) is based upon the intersection of gravity and mass. To realize and observe the performance of SSSC based damping controller, SMIB system is developed based on Phillips Haffron model. The given controller is employed in the model in the platform provided by MATLAB/ Simulink. Then, its analysis was carried out. Further, the performance of the SSSC based controller is improved with the uses of newly developed HPSO-GSA technique. The system developed was analyzed with two different cases of change in mechanical torque input and reference voltage setting with different parameters values. Observations have been tabulated in each case with different steps of variations for speed deviation, power angle deviation and electrical power deviation respectively. Finally, it is detected that the optimized HPSO-GSA parameters provide reduces the settling time and superior performance of the power system. Various simulation results can be obtained under various disturbances and operating conditions.**

***Keywords*: Power System, Single Machine Infinite Machine System, particle swarm optimization (PSO), Gravity Search Algorithm (GSA), Hybrid PSO-GSA Algorithm (HPSOGSA).**

## 1. Introduction

Power system is a large interconnected network comprising of generation, transmission and distribution network. Power is generated at generating station and is forwarded via transmission network to the various substations. From there onwards it supplies powers to different users and at last to end consumers via distribution network. It's a long and complicated mesh of network accomplishing this vital task [3].

To keep all this vital in sequence and proper order without any flaw, it needed to be take care of the conditions affecting its operations. It has to be stable in all conditions or must be capable of returning to stable condition after being disturbed. Mainly, its stability is very important for low load losses with desired output. Therefore, damping has to be proper in power system to eliminate all sorts of disturbances or the situation causing it. But as it is a large interconnected network it is very possible to have frequent disturbances in it. Before knowing how it can be damped or eliminate disturbance causing events it is more important to know the structure of power system and different stabilities of it [4].

There are two types of stability i.e. large and small signal stability. Large signal stability is also known as transient stability. In case of small signal stability when there is no proper damping it occurs. While when power system encounters the serious transient disturbance like short circuit or the tripping of line it is the case of large signal stability. Starting Operating state and severity of disturbances influences the stability. The configuration of the system is so set in order to be in the stable state following set of chosen contingencies.

The power system stability problem can be a concerning issue due to its insufficiency of damping such oscillations. Therefore, generator excitation system is provided with conventional lead lag power system stabilizer (CPSS). It damps out these low frequency oscillations by introducing a damping torque into generator rotor torque oscillations. It is derived from its speed, power or frequency. There have been many researches on PSS design and methods to tune it's parameters. Some of the optimization approaches are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy logic and Teacher learner based optimization (TLBO) etc.

This kind of problem in single machine Infinite bus (SMIB) system can be solved with much ease as compared to the system where more than one machine is involved i.e. a multi machine system. It is more practical system where observation of such problems can lead to practical solution. Although, SMIB study did give the idea of characteristics of machine subjected to different conditions.

### *A. Objective Function*

The main objective of the thesis is to reduce the disturbance causing oscillation with use of SSSC controller. Employment of this increases the stability in terms of the settling time via the controlling of variation in rotor angle and speed. The problem is given as an integral time absolute error of the speed deviations, i.e.

$$J= \int_0^{t1} |\Delta\omega|.\,t.\,dt \quad (1)$$

In equation (1) Δw is speed change.

Minimize J subjected to

$$K^{min} \leq K \leq K^{max} \quad (2)$$
$$T_1^{min} \leq T_1 \leq T_1^{max} \quad (3)$$
$$T_2^{min} \leq T_2 \leq T_2^{max} \quad (4)$$

## 2. System model

### *A. SMIB System with SSSC*

The system here is SMIB which is connected to the controller name SSSC as fig.1 depicted below. The system comprises a generator connected to an infinite bus. The generator presented by SG and generator terminal voltage is presented by $V_t$ & infinite bus voltage presented by $V_b$. The SSSC containing a transformer, voltage source inverter & dc-storage capacitor. The SSSC injected voltage to transformer is $V_{bt}$ . The voltage source converter have two control variables as modulation index m & phase angle Ψ [2].

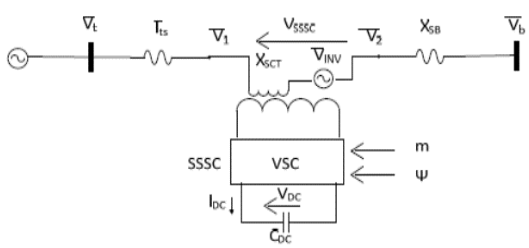


Fig. 1. SMIB System with SSSC

### *B. Power System with SSSC Linear Dynamic Model*

The linearization of nonlinear model gives the linear Heffron-Philips model of a SMIB system including SSSC around a nominal Operating point. Fig. 2, shows the Modified Phillips Heffron Model of SMIB System [1].

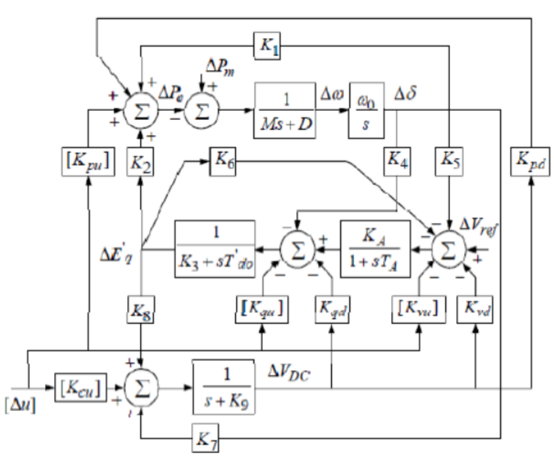


Fig. 2. Modified Phillips Heffron Model of SMIB System [1]

## 3. HPSOGSA tuned SSSC controller

This algorithm uses the concept of both PSO and GSA algorithm. It is proposed by Mirjalili and Hashimor (2010). This algorithm can deal with ability of social thinking of PSO and local search ability of GSA algorithm.

Combination of PSO and GSA algorithms could be summarized as follows:

$$V_i(t+1) = w * V_i(t) + C_1'\text{*rand*}ac_i(t) + C_2'\text{*rand*}(g_{best} - X_i(t)) \quad (5)$$

Where $V_i(t)$ represented i agent velocity at t iteration
w = weighting function
$C_j'$ = weighting factor
$ac_i(t)$ = acceleration of agent i at iteration t, rand is a random number between 0 and 1
$G_{best}$ = Best solution

Following expressions should be used to update the positions of each individual particle:

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (6)$$

First step of HPSO-GSA has a random initialization of all agents and all agents are treated as a candidate solution. Calculation of different forces and constants among the agents is carried out by calculate gravitational constant, gravitational force, resultant forces etc. For each particle acceleration is evaluated using GSA algorithm and best solution is achieved for each iteration. All agents would be calculated for its velocity and position by above equations. Updating process will stop after the criteria for the velocities and position satisfy and end criterion. Some assumptions should be carried out to improve efficiency of HPSO-GSA algorithm. Fitness is taking into account to update the process. Agents which are near to the good solution attract the other agents it moves very slowly to a good solution. At any moment of time $g_{best}$ is a memory which is used to save the best solution. Equilibrium can be obtained by adjusting the values of $C_1'$and $C_2'$ between the global search and the local search ability. Main objective of hybridization is to overcome the weakness of one approach during its application with the strengths of other by appropriately integrating them. To attain much better results in comparison to a single one lot of hybrid methodologies are used. But out of all hybrid technologies PSO and GSA is more siplest and easiest.

PSO and GSA kept some similarity to each other based on their formulation unlike of other population based approaches like simulated annealing (SA), genetic algorithm (GA) and differential evolution (DE). GSA having better strength towards exploitation while PSO is more effective for exploring agents. To obtain best optimal results hybridized co evolutionary method is used. By both PSO velocity and GSA acceleration performance of respective algorithm is improved. Precaution must be carried out if any particle violates in equality constraint then position of that particle is adjusted to maximum or

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minimum operating limit. If minimum point is not satisfying lower limit and at upper point is exceeding from maximum limit.

Steps used for proposed HPSO-GSA:

a) Set the parameters $P_{best}$ & $g_{best}$ to generate initial population.
b) For all particles evaluate fitness function.
c) Best and worst for the population update the $P_{best}$ & $g_{best}$.
d) Calculate w and G for each iteration, calculate M and a for all particles.
e) For all particles update velocity and position.
f) *Termination:* If stopping criterion is satisfied then iteration will be stopped. Maximum generation of 150 and tolerance of 1X $10^{-6}$ is used for this algorithm as stopping criterion. Step 2-5 will repeat till best solution nit obtained otherwise it will stop when criteria is met.

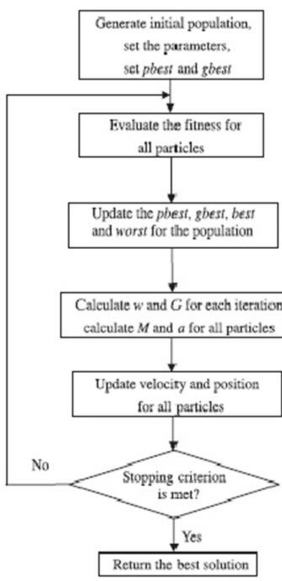


Fig. 3. Flow Chart of Hybrid PSO-GSA Algorithm

## 4. Result Analysis & Discussion of HPSO-GSA Tuned SSSC Controller

They so far discussed model is designed without SSSC controller and with it along HPSO-GSA granted. Results confirm that SSSC implementation is useful to given system. It can cover the operation of system to the extended limits considering all such error causing variations in operating points. When SSSC HPSO-GSA controller is tested under different operating conditions i.e. as reference voltage setting, mechanical torque and parameter variations input at various at speed deviations, power angle deviations, and electrical power deviations.

Table 1
SSSC Parameters Tuned by HPSOGSA

| S. No. | System | HPSO-GSA Optimized SSSC Controller Parameters | | |
|---|---|---|---|---|
| | | K | $T_1$ | $T_2$ |
| 1. | SMIB System | 72.3712 | 1e-04 | 0.0433 |

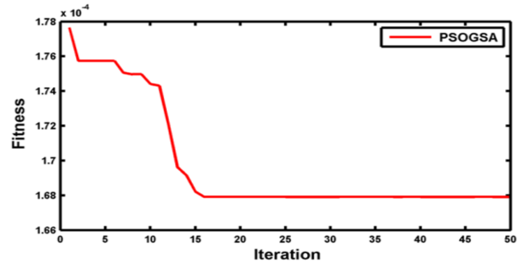


Fig. 4. Convergence of Objective Function for Best Cost in SMIB System

Fig. 4 shows the convergence rate of objective functions of SMIB system.

### A. *Case-1: 10% Step Increase in Mechanical Torque Input & 5% Increase in Reference Voltage Setting*

Initially, SSSC has no controller for damping then GSA & hybrid particle swarm optimization & GSA tuned SSSC controller is used when the system applies a 10% step increase in mechanical torque input & 5 % increase in reference voltage setting. For these cases, speed deviation, power angle deviation &electrical power deviation with time are shown in Fig.5 to 7. So HPSOGSA tuned SSSC controller shows better response than GSA tuned SSSC controller and the system shows with less overshoot and settling time. Finally, uncontrolled response is poorly damped and controlled response settle down very quickly. Table 2 shows a comparison table of the different controller.

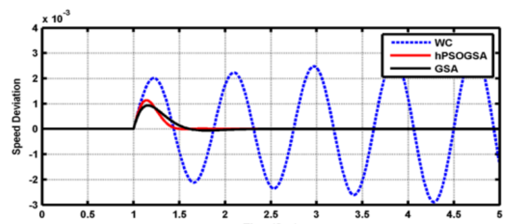


Fig. 5. Speed Deviation in SMIB System for Mechanical Torque Input

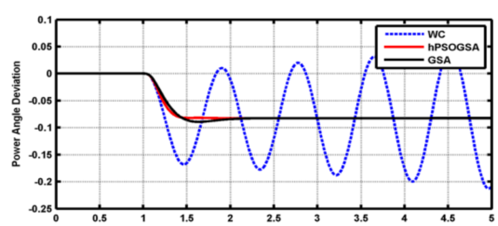


Fig. 6. Power Angle Deviation in SMIB System for Reference Voltage Setting

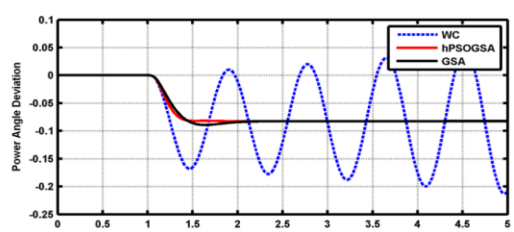


Fig. 7. Electrical Power Deviation in SMIB System for Reference Voltage Setting

Table 2
Comparison of Different controller at 10 % Step increase in Mechanical Torque Input & 5% Step Increase in Reference Voltage Setting

| S. No. | Types of Deviation | Without SSSC (Settling Time) Seconds | With GSA SSSC (Settling Time) Seconds | With HPSOGSA SSSC (Settling Time) Seconds |
|---|---|---|---|---|
| 1. | Speed Deviation | Highly Oscillatory | 2.1069 | 1.4671 |
| | Power Angle Deviation | Highly Oscillatory | 2.0165 | 1.4268 |
| | Electrical Power Deviation | Highly Oscillatory | 1.7480 | 1.5336 |

Table 3
10% Step Increase in Mechanical Torque Input & 5% Step Increase in Reference Voltage Setting at with GSA & HPSO-GSA based SSSC Controller

| S. No. | Parameter Variation | Deviation | With GSA SSSC (Settling Time) | With HPSO-GSA SSSC (Settling Time) |
|---|---|---|---|---|
| 1 | 25% Increase in open circuit direct axis transient time constant at Mechanical Torque Input | Speed | 2.10228 | 1.4585 |
| | 25% decrease in open circuit direct axis transient time constant at Reference Voltage Setting | Power Angle | 2.0133 | 1.4292 |
| | 25% decrease in machine inertia constant at Reference Voltage Setting | Electrical Power | 2.2042 | 1.8589 |

*B. Parameter Variations at 10% Increase in Mechanical Torque Input & 5% Increase in Reference Voltage Setting*

Fig. 8 to 10 shows various response & system is tested with parameter variation in 25% increase & decrease in open circuit direct axis time constant & 25% Increase in Machine Inertia Constant as without SSSC controller, with GSA & with HPSOGSA. Without controller system unstable and show high oscillatory response but when SSC parameter tuned by GSA & HPSOGSA both condition system maintain stability but HPSOGSA tuned system shows better response and settle very fast than GSA. Table 3 shows various performances at different controller.

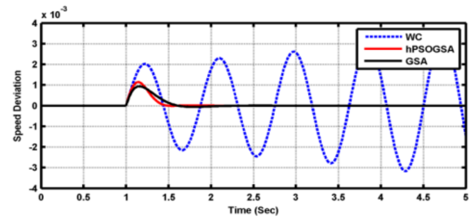


Fig. 8. Speed Deviation for 25% Increase in Open Circuit Direct Axis Transient Time Constant at Mechanical Torque Input

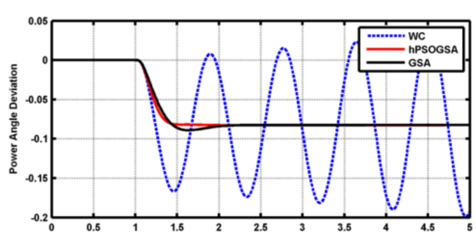


Fig. 9. Power Angle Deviation Response for a 25% Decrease in Open Circuit Direct Axis Transient Time Constant at Reference Voltage Setting

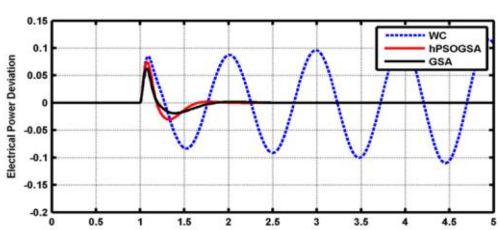


Fig. 10. Electrical Power Deviation for a 25% Increase in Machine Inertia Constant at Reference Voltage Setting

## 5. Conclusion

In this paper we designed and developed SSSC based modified Heffron Phillips model of a SMIB by HPSO-GSA and implement it for optimizing SSSC parameters for SMIB systems. We examined simulation results of SMIB systems for various operating conditions like at reference voltage setting, mechanical torque input & parameter variations without and with GSA & HPSO-GSA tuned SSSC controller. We reduced the settling time of speed deviation, power angle deviation and electrical power deviation when HPSO-GSA tuned SSSC controller is used. We obtained result from the proposed technique when its compare with other optimization result it's found more accurate and efficient.

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