# Social Swarm Optimization for Damping Controlling of Multi-machine Power System

Baibhav Bishal, Akash Saxena, Sunil Kumar Goyal

***Abstract* – In this paper simplified swarm optimization technique is used for the designing of power system stabilizers (PSSs). To enhance the small signal stability and system damping PSS is most widely used. This paper represents an optimization technique to calculate the proper set of time constants and gains which provides adequate damping to the system by properly tuning the parameters of PSS and for this swarm based algorithm is used to address the above said optimization process. Speed based objective function is employed to calculate the parameters of PSS of New England System (10 Generators and 39 Buses). Evocative analysis is done by comparing SSO with conventional optimization algorithms namely Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). Stoutness of projected method is veteran over different types of load conditions, perturbations and fault locations.**

***Index Terms* - Particle Swarm Optimization (PSO), Simplified Swarm Optimization (SSO), Automatic Voltage Regulator (AVR), Genetic Algorithm (GA), Power System Stabilizer (PSS), Small Signal Stability.**

## I. INTRODUCTION

Due to stressed operating conditions and multiple grid interconnections the complexity of the modern power system is increasing by leaps and bounds. The major factor responsible for stressed operating conditions is population explosion. With the limited generating capacity it is quite challenging to maintain synchronism between different linked units before fault and post fault conditions. Due to uncertainty in load demand the problem of instability arises for which fast acting automatic voltage regulators were installed to overcome the problem of transient stability.

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High Gain AVRs play major role in improving the system's transient stability but inculcated negative damping in the system which was firstly reported in 1969 by Concordia *et al.* [1].

Power system stabilizers (PSSs) were tied with the AVRs to overcome the problem of negative damping in the system. For the past thirty decades many power researchers came forward to present the robust design of PSS. Abido *et.al.* [2-6] employed bio inspired algorithms like Tabu search (TS), GA, PSO and Simulated Annealing (SA) to design PSS Y. L. Abdel- Magid *et.al.* proposed optimal designing of PSS using genetic algorithm [7-8]. Optimization process was performed in all these approaches so as to obtain the parameters of conventional PSS. In these approaches solution quality and time elapsed were not discussed, which has a paramount importance in offline studies. Modified versions of GA [9] and PSO [10] are available now a days and are proved better than the conventional one as judged on the basis of solution quality and convergence characteristics. Apart from the above many researchers employed Adaptive control schemes [11-14] as the main the advantage with ANN tuned PSS is that they have self-optimized pole-shifting strategy and gives quick response too. But some disadvantage were also noted with the ANN strategy i.e. if any unknown parameters encounters the process model, then it becomes very difficult to construct a continuous parameterized family of candidates controllers.

Studying this Shang Kuan [15] suggested a novel objective function based on Eigen-value and damping ratios and their convergence characteristic was presented. Surprisingly in his analysis the behavior of speed based objective function was depicted. Wang *et.al.* [16] proposed a trajectory based scheme whose objective function was based on speed deviation to find the robust parameters of PSS. Changseok Bae *et.al.* [17] in year 2012 presented a novel swarm based optimization algorithm namely SSO which is the improved version of PSO. Unlike PSO the values of positions and velocity is changed after every iteration. The particle's position value in each dimension will be kept or be updated by its $p_{best}$ value or by the $g_{best}$ value. This paper presents an application of SSO in the design of PSS controller. Different contingencies are created with the help of Simulink replica of New England System to test the robustness of the proposed design.

  

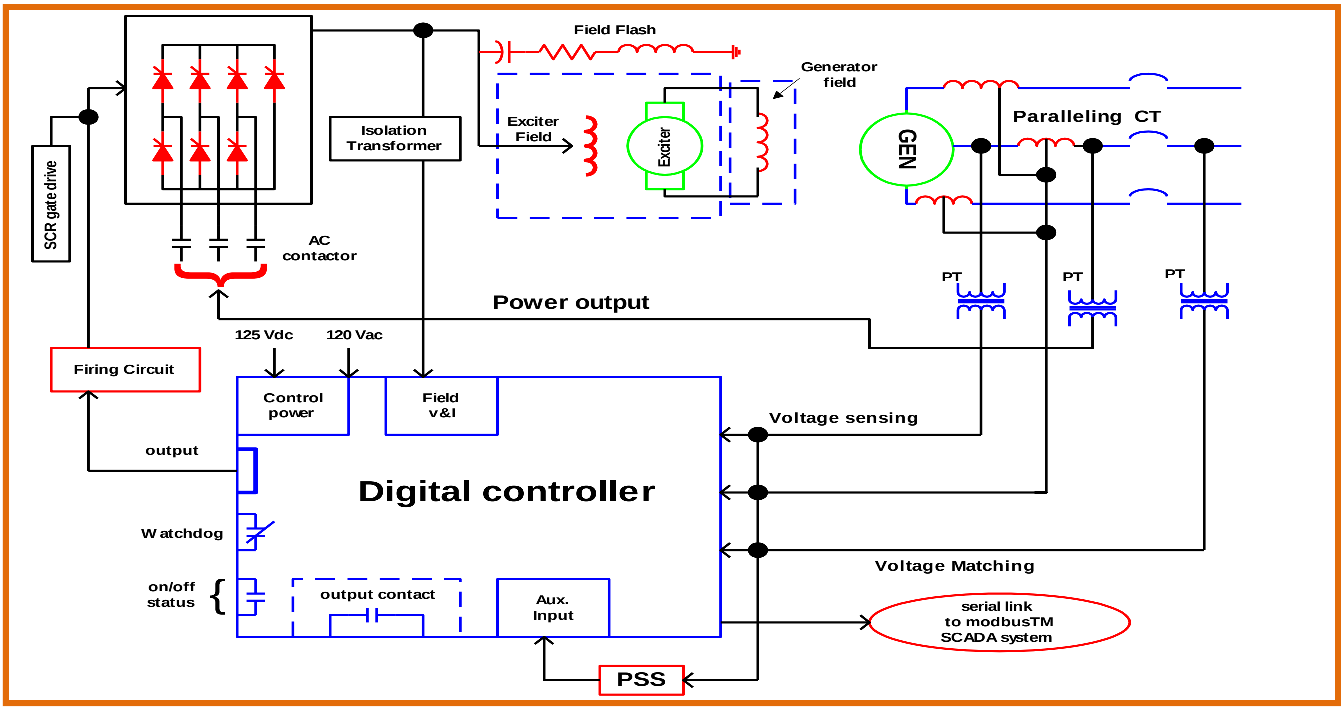


*Fig.1 Modern excitation system with AVR & PSS*

Above fig.1 represents how AVR and PSS are tied in the modern power system to avoid the effect of negative damping in the system.

## II. Problem Statement

### A. Power System Modeling

Formulation of the power system can be concluded and understand by following set of equations.

$$\dot{X} = f(X,U) \tag{1}$$

Where x is the state variables, u is the vector of input variable. To carry out the small signal stability studies the power system is usually linearize near an operating point. Equation (1) can further be transformed as

$$\dot{X} = A\Delta X + B\Delta U \tag{2}$$

If $n$ is the total no. of machines, size of $A$ will be $4n\times4n$, $\Delta X$ is $4n\times1$ state vector, while $U$ vector is $N_{pss}\times1$.

In literature conventional lead lag structure is used [2-6] & [15-16]. In this work speed based objective function is used to solve the PSS parameter optimization problem. Fig. 1 shows the modern excitation system with AVR and PSS.

The objective function employed to solve PSS estimation problem is expressed as equation (3).

$$U_i = K_i \frac{sT_w}{1+sT_w} \cdot \frac{(1+sT_{1i})}{(1+sT_2)} \cdot \frac{(1+sT_{3i})}{(1+sT_4)} \cdot \Delta\omega_i \tag{3}$$

The objective function J is to be minimized with the constraints. Where $i$ is the total no. of generators.

$$J = \min \sum_{i=1}^{i=n} \int_0^{tsim} (\Delta\omega_i)^2 \tag{4}$$

Where

equation (4) is subject to

$$\begin{Bmatrix} K_i^{\min} \le K_i \le K_i^{\max} \\ T_{1i}^{\min} \le T_{1i} \le T_{1i}^{\max} \\ T_{3i}^{\min} \le T_{3i} \le T_{3i}^{\max} \end{Bmatrix} \tag{5}$$

The proposed approach will solve the optimization for the variables $\{K_i, T_{1i}, T_{3i}, for\ i = 1, 2 \ldots m\}$ where $m$ is the size of network or total no. of generator machines incorporated with PSSs. This work washout time constant $T_w = 10\ s$ and $T_2$ & $T_4$ are considered as 0.05s. The left over parameters K, $T_1$ and $T_3$ are assumed to be the modifiable parameters; hence from here we can shape the size of the parameters that for 10 machines; there will be 30 parameters. Generators speed deviation under different fault conditions, time settings and for different fault locations is calculated using Integral Square Error (ISE).

$$J = ISE = \int_0^{tsim} \left(\Delta\omega_1^2 + \Delta\omega_2^2 + \ldots\ldots + \Delta\omega_{10}^2\right) dt \tag{6}$$

## III. Simplified Swarm Optimization

PSO is a kind of heuristic optimization algorithms. It is motivated from simulating certain simplified animal social behaviors such as bird flocking, and is first proposed by Kennedy and Eberhart in (R.ebehart,1995) [18] which is an iterative, population based process. Via two instinct properties: position and velocity the particles are described.

The position of each particle represents a point in the parameter space, which a possible solution of the optimization problem and the velocity is used to change the arrangement. Modification of PSO is SSO algorithm. Initially, the number of swarm population size, the number of maximum generation, and three pre specified parameters are determined. In every generation, and the particle position value in each dimension will be kept or be updated by its $p_{best}$ value or by the $g_{best}$ value or be replaced by new random value according to this procedure.

$$x_{id}^{t} = \begin{cases} x_{id}^{t-1}, & \text{if } \operatorname{rand}(\,)\,\varepsilon[0, C_w] \\ p_{id}^{t-1} & \text{if } \operatorname{rand}(\,)\,\varepsilon[C_w, C_p] \\ g_{id}^{t-1} & \text{if } \operatorname{rand}(\,)\,\varepsilon[C_P, C_g] \\ x, & \text{if } \operatorname{rand}(\,)\,\varepsilon[C_g, 1] \end{cases} \quad (7)$$

In this equation, $i = 1,2\ldots m$ where $m$ is the swarm population. $X_i = (x_{i1}, x_{i2}\ldots x_{iD})$, where $x_{iD}$ is the positive value of the $i^{th}$ particle with respect to the $D^{th}$ dimension of the feature space. $C_w, C_p, C_g$ three predetermined position constants with $C_w < C_p < C_g$, $P_i = (P_{i1}, P_{i2}\ldots P_{iD})$ denotes the best solution achieved so far by itself $(p_{best})$, and the best solution achieved so far by the whole swarm $(g_{best})$, is represented by $G_i = (g_{i1}, g_{i2}\ldots g_{iD})$. The $x$ represent the new value for the particle in every dimension which are randomly generated from random function rand (), where the random number is between 0 and 1. The flowchart of SSO algorithm is shown in Figure 2.

## IV. Simulation Result

The system considered for the verification of the PSS design scheme is New England system. The modeling of the system and simulation studies are performed over Intel ® core ™, i7, 2.9 GHz 4.00 GB ram processor unit. Different types of fault are presented with the calculation of integral square speed error (ISE) using equation (6).

The realization of the objective function with the interpolation analysis is carried out with the presence of three phase faults for six cycles.

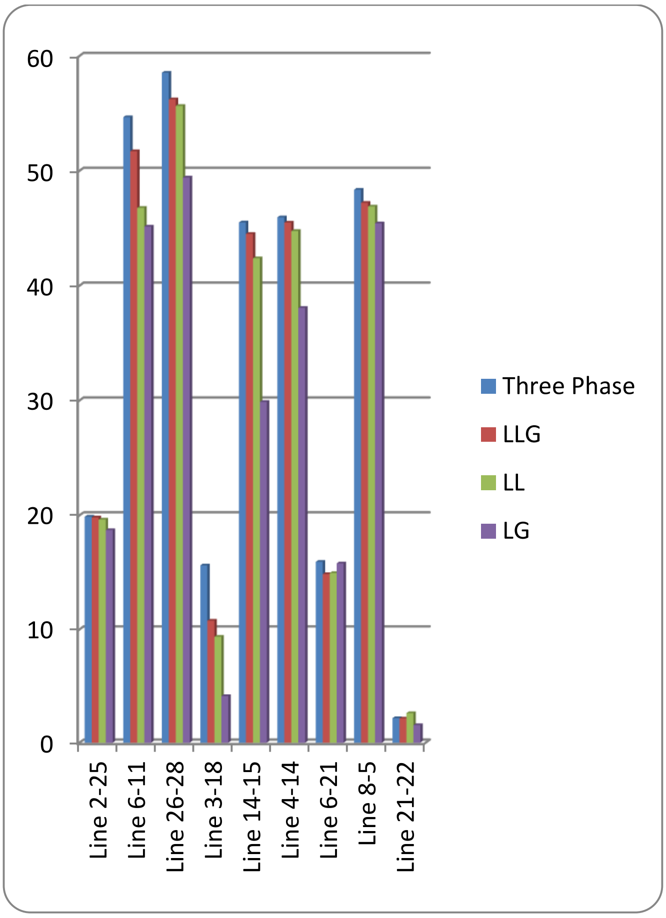


*Fig.3 Vertical bar Graph representation of $\Delta\omega^2$ for different faults.*

Excel plot show in fig.3 depict that for the same duration of the fault the three phase fault is more severe and creates more impact on the speed deviation of the generators. So to realize the objective function, the generators perturbation with three phase fault is considered and the interpolation between PSS parameters and generator's speed deviation is carried out with the help of cf tool in MATLAB.

On the basis of different designs the PSS parameters for linear, quadratic and cubic polynomials are considered and the values of ISE after incorporating the PSS are shown in figure 4. It is observed that the values of speed deviations are minimum with the quadratic realized based objective function.

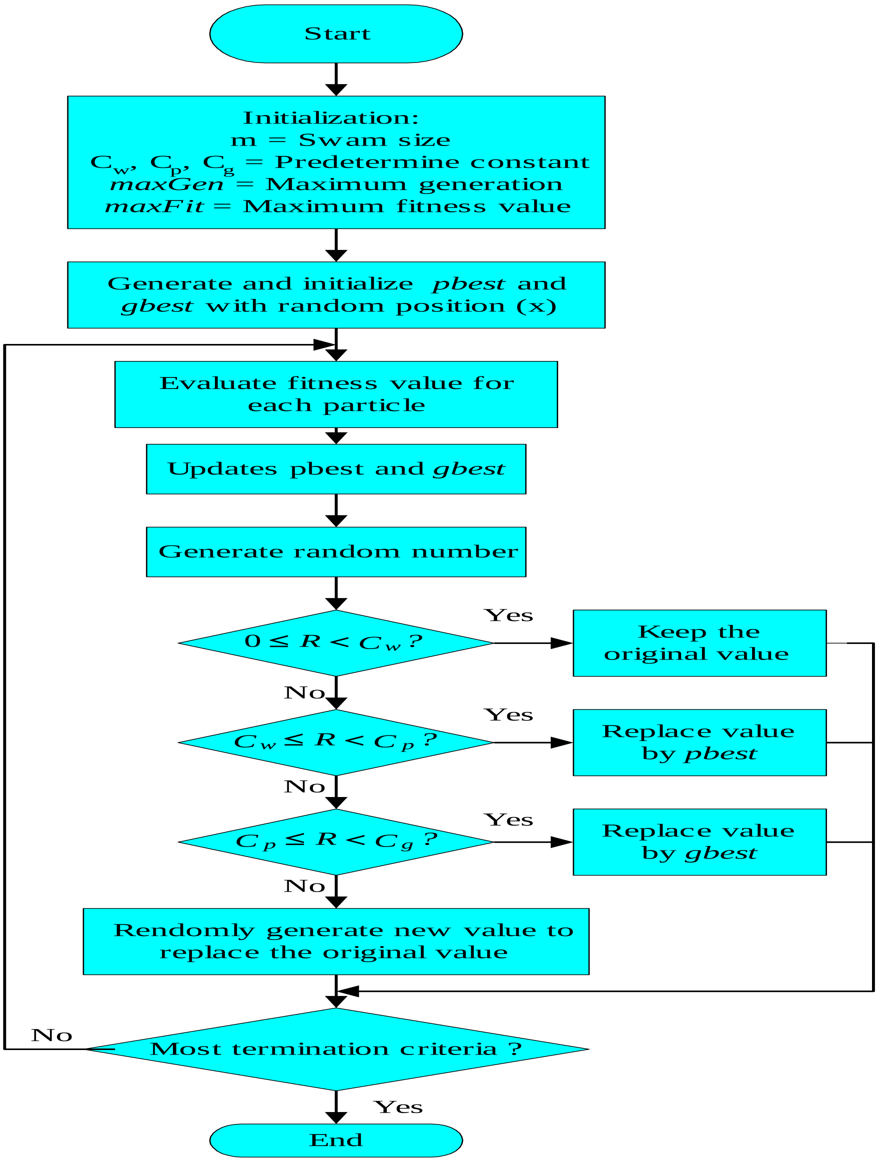


*Fig.2 Flow chart of SSO Algorithm*

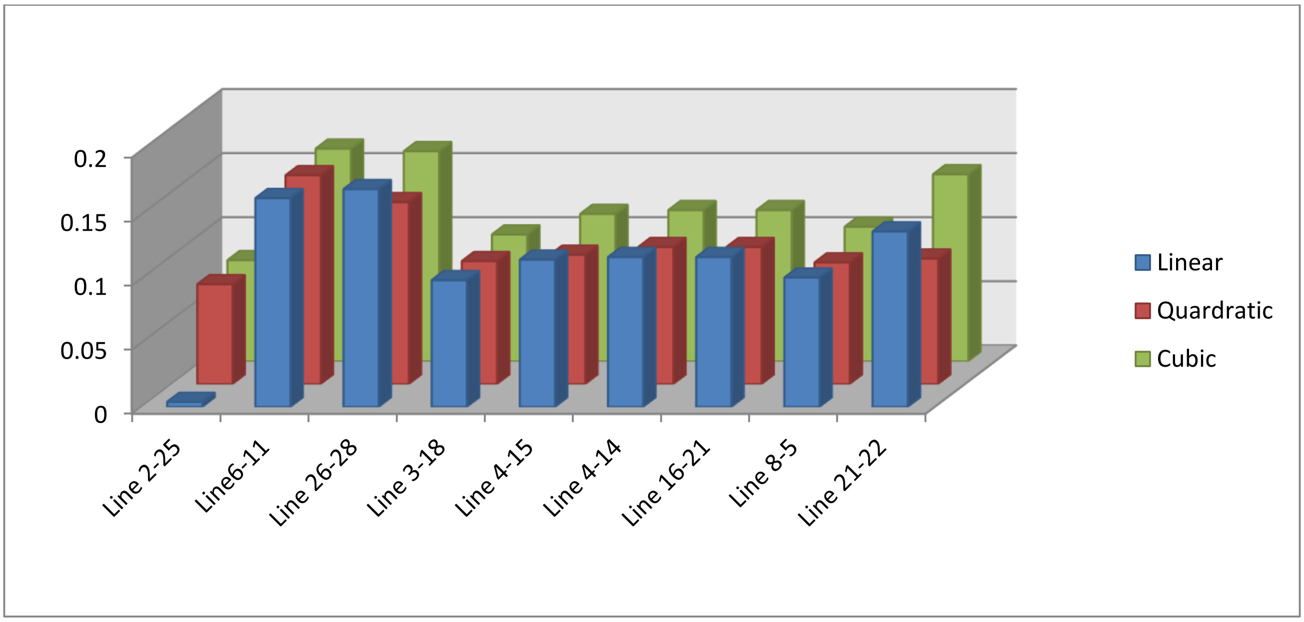


*Fig. 4 Comparison between three Objective Functions*

Above figure 4 shows the excel plot for three types of equation viz. linear, quadratic and cubic.

Table I shows the Eigen values of New England system. It can be observed that system is in bad health and some of Eigen value possess positive real part. Due to high gains of AVRs the system is observing negative damping. The Eigen property analysis is carried out by using PST. It is found that some of modes are very poorly damped. After successful employment of PSS the damping of system is improved.

It can be observed from the responses of various generators that PSS tuned through GA and PSO gives less dynamic response in comparison to SSO-PSS. Figure 5 to 12 shows the speed deviation curves of different generators under different perturbations and fault locations.

Table I: Eigen Property Analysis of New England System

| Without PSS | | With SSO-PSS | |
|---|---|---|---|
| Eigen Values | Damping Ratio | Eigen Values | Damping Ratio |
| 0.2848-i6.6998 | -0.0424 | -1.2415-i 6.0180 | 0.202 |
| 0.2848+i6.6998 | -0.0424 | -1.2415+i 6.0180 | 0.202 |
| 0.5729-i7.220 | -0.079 | -1.2496-i 6.3805 | 0.1922 |
| 0.5729+i7.220 | -0.079 | -8.0145 | 1 |
| 0.1351-i7.7029 | -0.0175 | -8.2664 | 1 |
| 0.1351+i7.7029 | -0.0175 | -1.8780 - i8.2486 | 0.2219 |
| 0.0358-i8.2562 | -0.0043 | -8.7423+i 0.5205 | 0.9982 |
| 0.0358+i8.2562 | -0.0043 | -1.5857 -i 8.7701 | 0.1779 |
| 0.0194-i9.0723 | -0.0021 | -12.5383 | 1 |
| 0.0194+i9.0723 | -0.0021 | -27.4636-i16.465 | 0.8576 |

To extend the analysis in a more pragmatic manner three operating cases are taken here to justify the efficacy of the proposed design.

- **Base Case.** Constant impedance on all load buses.
- **Case a.** Outage of line 21-22, along with the base case.
- **Case b.** increase in load on bus on 16 & 21 by 25 %.

Disturbances are considered as 3-phase 6-cycles at different locations mentioned in sub heading of the Fig. (5-8).

Data for the New England system is taken from standard bench mark system IEEE [19] & [21]. Non-linear simulation and Eigen property analysis is done on Matlab Simulink [20] with Power System Toolbox (PST) [22].

It can be observed from the responses of various generators that PSS tuned through GA and PSO give less dynamic response in compare with SSO-PSS. Fig. 5 to Fig.8 are the speed deviation curves of different generators under different perturbations and fault locations.

  

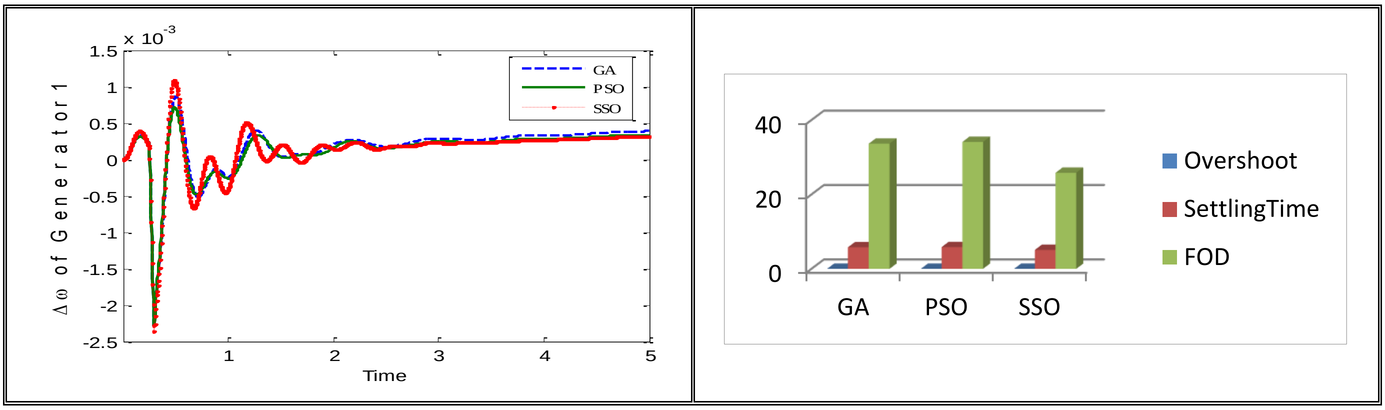


*Fig.5 Speed deviation of generator 1 for a 6 cycle fault at line 2-25*

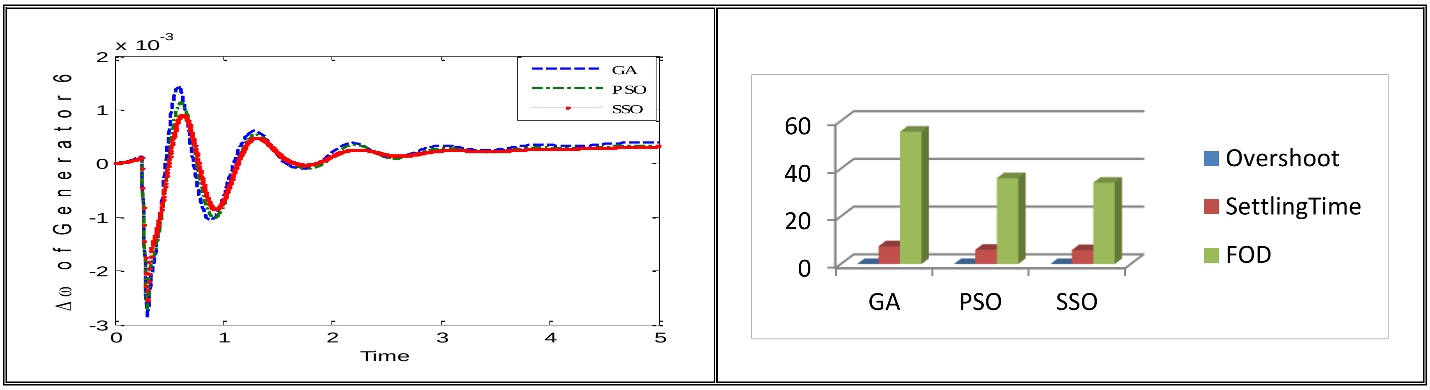


*Fig.6 Speed deviation of generator 6 for a 6 cycle fault at line 2-25*

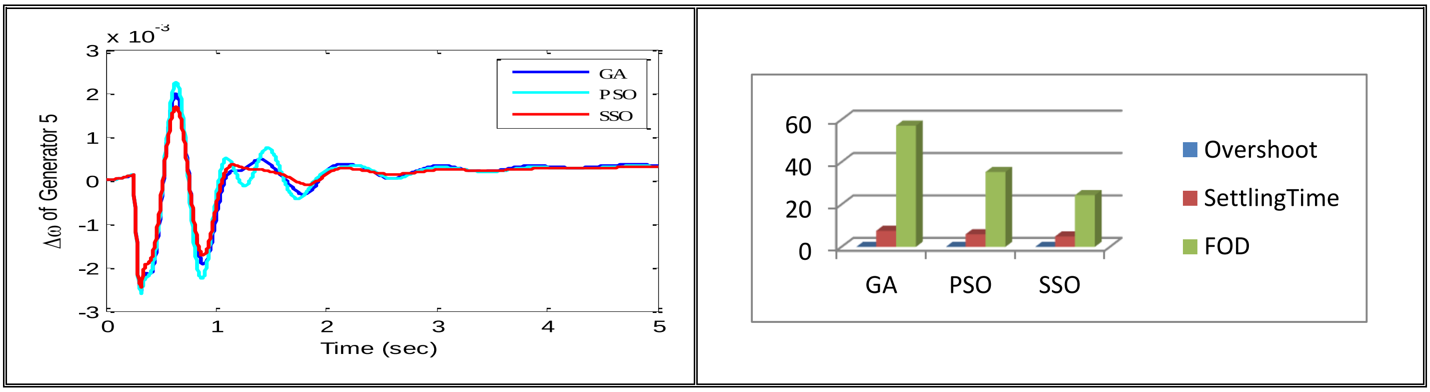


*Fig.7 Speed deviation of generator 5 for a 6 cycle fault at line 6-11(Case b)*

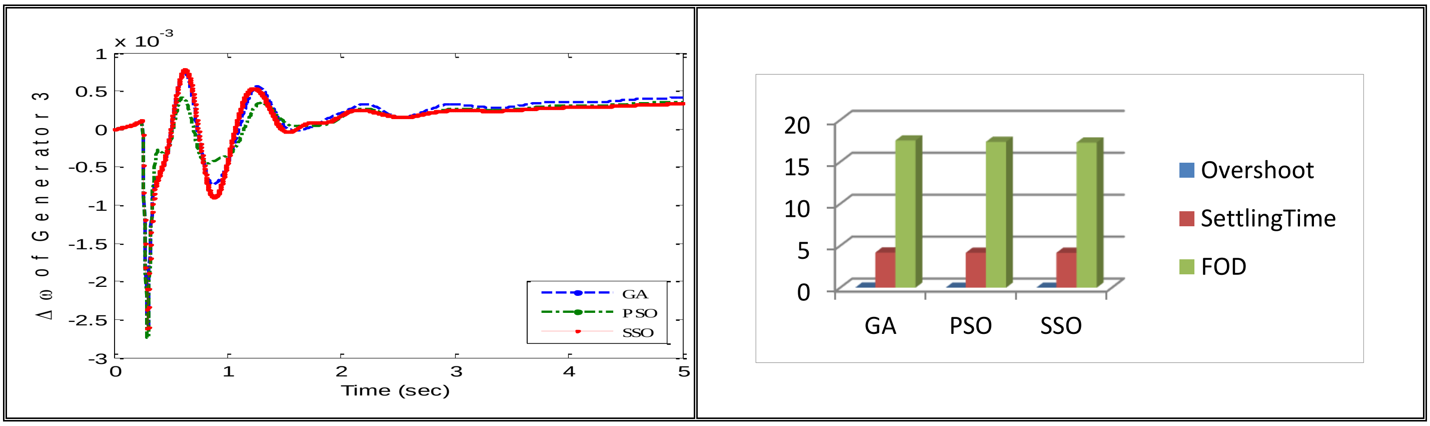


*Fig.8 Speed deviation of generator 3 for a 6 cycle fault at line 2-25( Case c)*

Table II: Comparative analysis of Speed deviation curve of generator 1

| Fault on Line 2-25 with base case | | | |
|---|---|---|---|
| G1 | % Overshoot | Settling Time | FOD |
| GA | 0.0008676 | 5.8 | 33.64 |
| PSO | 0.00024 | 5.84 | 34.1056 |
| SSO | 0.0001807 | 5.08 | 25.8064 |

Table III: Comparative analysis of Speed deviation curve of generator 6

| Fault on Line 2-25 with base case | | | |
|---|---|---|---|
| G6 | % Overshoot | Settling Time | FOD |
| GA | 0.001418 | 7.45 | 55.5025 |
| PSO | 0.001141 | 6 | 36 |
| SSO | 0.0009035 | 5.84 | 34.1056 |

Table II to V represents shows the comparison between the three algorithms viz. GA, PSO, SSO in terms of their maximum peak overshoot, settling time and FOD .FOD is nothing but a linear combination of settling time and overshoot of the swing curve which is a close replica of swing curve response.

$$FOD = Os^2 + Ts^2 \quad (8)$$

Where Os is overshoot of curve and Ts is settling time of the curve.

The response is said to be poor if the value of this FOD is more. So in most cases high values of FOD is observed in GA and PSO. Significantly less values of FOD by SSO validates the efficacy of the proposed approach.

Table IV: Comparative analysis of Speed deviation curve of generator 5

| Fault on Line 6-11 with outage of line 21-22 | | | |
|---|---|---|---|
| G5 | % Overshoot | Settling Time | FOD |
| GA | 0.001994 | 7.56 | 57.1536 |
| PSO | 0.002264 | 5.94 | 35.28361 |
| SSO | 0.001685 | 4.94 | 24.4036 |

Table V: Comparative analysis of Speed deviation curve of generator 3

| Fault on Line 2-25 with increase in bus load | | | |
|---|---|---|---|
| G3 | % Overshoot | Settling Time | FOD |
| GA | 0.0007483 | 7.63 | 58.2169 |
| PSO | 0.0004189 | 6.03 | 36.3609 |
| SSO | 0.0007783 | 5.9 | 34.81 |

Table VI: Optimal parameters of proposed PSS for 10 Machine 39 Bus System

| Generator No. | $K_{stab}$ | $T_1$ | $T_3$ |
|---|---|---|---|
| 1 | 20.53 | 0.203 | 0.22 |
| 2 | 19.76 | 0.44 | 0.49 |
| 3 | 30.01 | 0.49 | 0.36 |
| 4 | 24.33 | 0.30 | 0.04 |
| 5 | 14.04 | 0.49 | 0.50 |
| 6 | 26.85 | 0.50 | 0.27 |
| 7 | 13.45 | 0.49 | 0.49 |
| 8 | 20.53 | 0.45 | 0.22 |
| 9 | 23.57 | 0.405 | 0.02 |
| 10 | 20.53 | 0.203 | 0.22 |

  

Table VI shows the parameters of all 10 PSSs obtained from the optimization process solved by SSO.

## V CONCLUSION

This paper is an effort to apply SSO algorithm in PSS parameter estimation problem. The application of swarm algorithm is compared with the conventional GA and PSO. From the speed deviation curve and dynamic responses following points can be concluded:

*a)* Successful implementation of SSO algorithm is exhibited for designing PSS for New England System. 30 Parameters including gain of PSS and time constants are calculated by the algorithm. Table VI shows the parameter calculated by optimization process

*b)* Overall dynamic response is better for SSO as compared with GA and PSO. Overall Dynamic response is judged by figure of demerit.

*c)* Different loading combination and operating conditions which are considered as hard [14] is applied to achieve a robust design.

*d)* Eigen property analysis ascertains the proposed approach that SSO tuned PSS is able to provide positive damping in the system. This analysis is shown in Table-I.

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