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Comparison of Optimized PSS Using Three Different Methods for Single and Multi-Machines Systems

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Oscillations of power systems cause instability in power networks. Power system stabilizer (PSS) is used as a conventional method to damp these oscillations . Finding the optimized gain of PSS is one of the major problems in power system stability issue. In this paper, single machine connected to an infinite bus and 10-machines 39-bus network are considered for study. it's shown that finding the optimal gain by "theory of optimal control" is more better for stability of power networks than the other methods such as "genetic algorithm" , "electromagnetism-like". This claim is proved using system eigenvalues in the analysis of linear system for both networks. Finally, comparison between these algorithms is also provided.

Keywords: Direct Lyapunov Method, Power Swings, UPFC, SMES.

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I INTRODUCTION

Synchronous generators play a highly important role in power networks. Any kind of generator failures cause principle problems in the systems. Low frequency oscillations influence on the networks that may remain in the system for a long time, affect operating conditions and sometimes limiting the transmission of electrical power. Disturbances affecting the systems capability to maintain its synchronism are called small disturbance or small signal. Experiences in power engineering show that low frequency oscillations are related to the lack of adequate damping in a systems mechanical mode. However, adding appropriate damping could stabilize a system to an acceptable level against oscillations. During low frequency oscillations, induced current in the damping windings of the generator could be neglected because of its low value. Hence, the damping windings are eliminated in generator modelling. On the other hand, the natural frequency of the windings in d , q axes of rotor is very high, and its eigenvalues have no particular effects on low frequency oscillations study [1]. The important role here will be from the machine excitation winding, since its frequency is low and this winding is directly connected to the excitation system, where the complementary controller is applied [2-4]. At present, the most common and widely used method to increase damping of system against low frequency oscillation (LFO) is power system stabilizer (PSS). PSS uses an auxiliary stabilizing signal to increase damping. There are several methods in the literatures for tuning the PSS parameters. References [5-7] deals with designing a PSS by the particles swarm optimization (PSO) algorithm. In reference [8], the optimized PSS design of a 10-machines and 39-bus system is made by using two methods : the simulated annealing (SA) and particle swarm optimization (PSO) and the results were compared. In this paper, theory of optimal control is used for PSS parameters tuning [9]. This method was investigated in several different applications. Furthermore, the results are compared with other methods such as Genetic, Electromagnetism-Like , Simulated Annealing and Particle Swarm Optimization algorithms.

II PROBLEM FORMULATION

In this section, the eigenvalue based objective function is used for optimal selection of PSS parameters [2], and the optimization problem is solved with using of "genetic algorithm" ,"simulated annealing method", "electromagnetism-like method", "particle swarm optimization algorithm", and Theory of Optimal Control Method (TOCM). For the stabilization of a system, the system eigenvalues must be on the left hand side of y axis. For single machine connected to infinite bus system, the parameters of PSS should be selected such that the following objective function is minimized:

$$F = max\{\mathrm{Re}(\lambda_t) + \beta\} \tag{1}$$

Where λ_t is closed loop eigenvalue and β is relative stability factor which could be $-2 \leq \beta \leq -2.5$. It is clear, if a solution is found such that $F < 0$, then the resulting parameters simultaneously stabilize the entire of the systems [2]. It should be noted that just the system electromechanical modes are used in the objective function. Also the bounds on the stabilizer gain is chosen as [0.01, 10] and for time constants are selected as [0.02, 1].

III SYSTEM MODEL

The main role of the power stabilizer is to increase the damping of the system by auxiliary stabilizing signals. The action of a

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PSS is to extend the angular stability limits of a power system by providing supplemental damping through the generator excitation [4].The conventional lead-lag power system stabilizer is shown in Fig. 1. The first block is stabilizer gain. The second block is washout filter with a time lag T_W. The third block is a lead compensation to improve the phase lag through the system [4]. Also the subscript "i" in PSS block, indicates the values for i-th machine. The PSS transfer function is obtained according to equation 2.

$$\frac{\Delta\nu_s}{\Delta\omega_r} = K_{STAB}\frac{sT_{wi}}{1+sT_{wi}}\frac{1+sT_{1i}}{1+sT_{2i}} \quad (2)$$

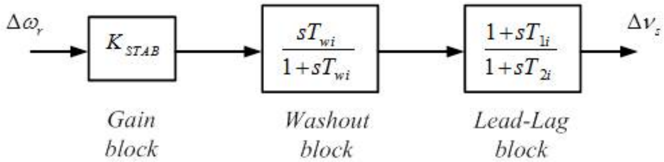

Figure 1: Structure of power system stabilizer

The values of T_2 and T_w are given in section IX. T_1 and K_STAB are assumed to be adjustable parameters. In this paper, the single machine connected to infinite bus system as well as 10- machines, 39-bus system are considered. The optimization problem is the selection of these PSS parameters. Five optimization methods are simulated to solve this problem (genetic algorithm, simulated annealing approach, "electromagnetism- like method", "particle swarm optimization algorithm" and TOCM). For a given operating point, the power system is linearized around the operating point, the eigenvalues of the closed-loop system are computed, and the objective function is then evaluated. The block diagrams of AVR with PSS are shown in Fig. 2. In this figure, the constants $K1$, $K2$, $K4$, $K5$ and $K6$ are dependent on the actual real power (P) and reactive power (Q) loading as well as the excitation levels in the machine. K3 is a function of of impedances. Single line diagram of 10-machines 39-bus system is shown in Fig. 3. The system data can be found in [2].

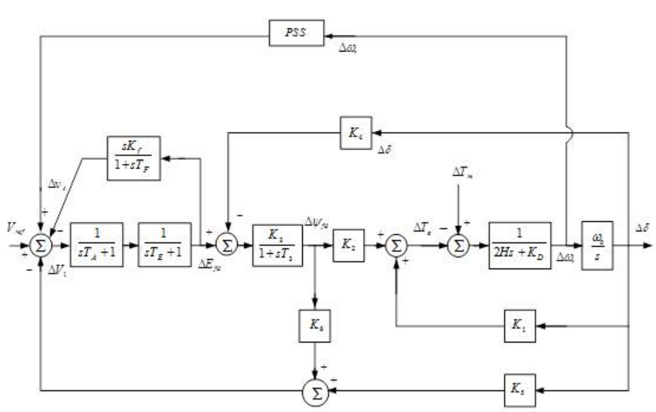

Figure 2: Small-signal block diagram of the system with Excitation System, AVR and PSS

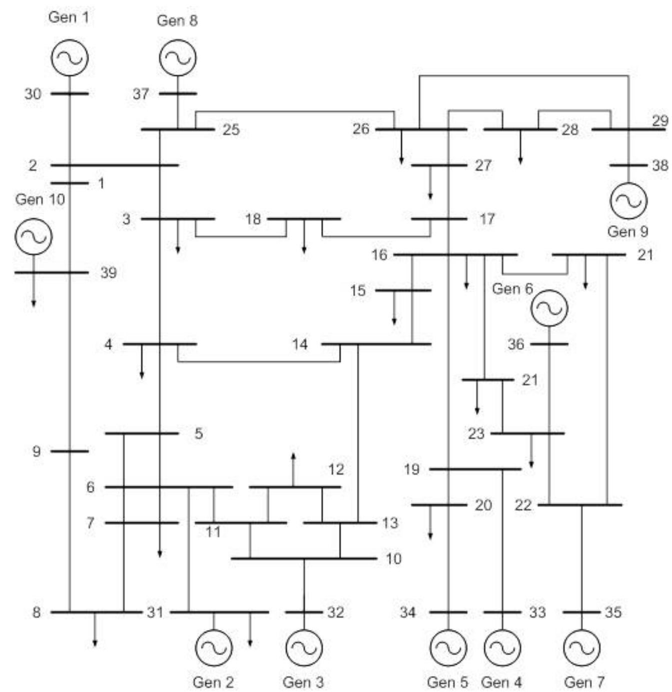

Figure 3: One-line diagram of 10-machines, 39-bus system

IV GENETIC ALGORITHM

This algorithm is based on the evolution theory of Darwin. The only part of the population generated in this algorithm is that which has the best characteristics.To determine the optimized parameters of PSS, the relevant coefficients are considered as chromosomes by using the genetic algorithm. The structure of the genetic algorithm is shown in Fig. 4.

V ELECTROMAGNETISM-LIKE ALGORITHM

This algorithm, abbreviated by EM, is known to be one of the new methods in ultra-revelation optimization, based on collective intelligence. One of the strong points of this algorithm is its few parameters, which allows its suitable amount to be determined by trial and error most of the time. In each iteration, the best obtained article is transferred to the next repetition. The procedures and stages of this algorithm can be described in four main parts.

The following parameters must be identified and defined before using the algorithm. m is the number of used particles that is often some 10 digits; $Maxiter$ is the maximum number of iterations needed to finish the execution of the algorithm, according to Reference [11]; $Maxiter = 25n$; n is equal to the variables in the case and is clearly dominant in different trial and error problems, on the content of the case; $LSIter$ is Number of local search iterations, and δ is the parameter of the local numerical search in [0,1] time. The general form of the EM algorithm is expressed as follows:

1: Initialize ()
2: iteration 1

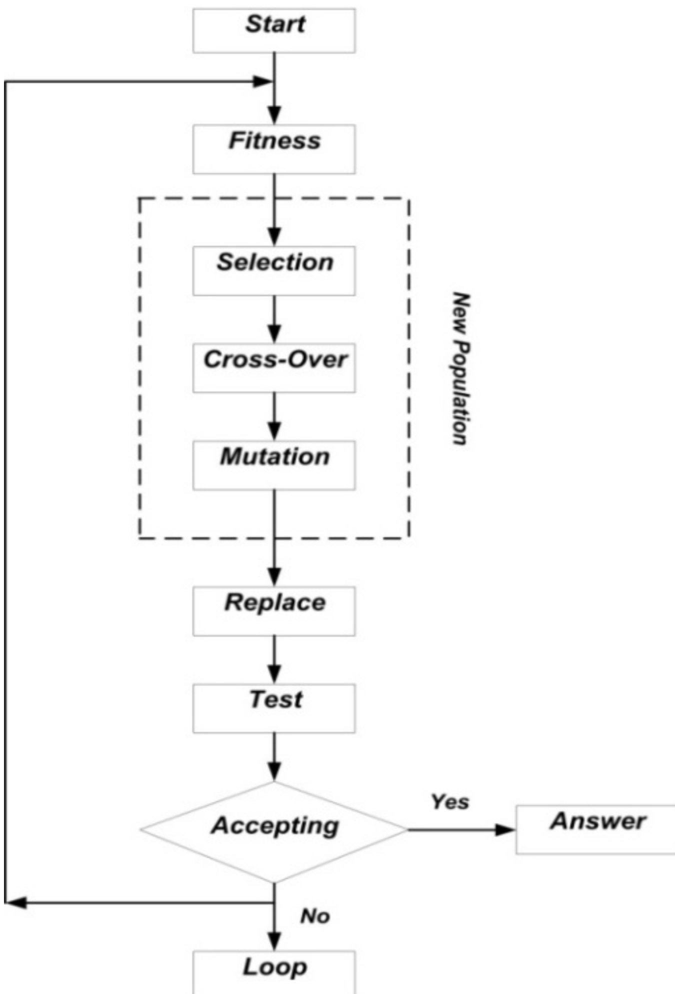

Figure 4: genetic algorithm

3: while iteration $< MaxIter$ do
4: Local ($LSIter$, δ)
5: Calc (F)
6: Move (F)
7: iteration = iteration + 1
8: end While

The vector of the random response in line 1 is dispersed in the domination of the case. In lines 3 to 8 of the local search procedures (Local), calculation of the general force on each of the particles (CalcF) and displacement of the particles for the imposed force (Move) are done continually and a definite number of times [11].

A Generation of random vectors

Equation (3) is used to generate random vectors:

$$x_k^i = l_k + \alpha(u_k - l_k) \tag{3}$$

where $(k = 1, ...n)$,$(i = 1, ...n)$,$\alpha = U(0, 1)$ This relation determines the best function value at each point and finds the best place of the vector that leads to the best state for the objective function.

B Local Search

After distributing the vectors randomly in the problem domain, the local function deals with the local search adjacent to each response by applying random variations to each component of the vector x^i. In this search, the δ and $LSIter$ parameters, respectively, determine the vicinity of the local search. By defining the term (4), we will let the x^i components change to the maximum amount.

$$\delta(\max_k\{u_k - l_k\}) \tag{4}$$

Thus each of the x^i components will remain in the case of domain. Now, we should temporarily store x^i in a variable, such as y, and then simultaneously change one of the y components randomly and equal to the obtained step in the maximum repetition of $LSIter$. If applying the changes leads to a value less than $f(x^i)$ for $f(y)$, then $f(y) < f(x^i)$ replaces the vector y to vector x^i, and the local search will be performed for the place adjacent to vector x^{i+1}. After the local search in the neighborhood of all the responding vectors, x^{best} will be determined [11].

C Calculation of the force vector

According to Coulombs law, the imposed force on each of the two loaded particles in an electrostatic system is equivalent to the multiplication of the load and also equivalent to the inverse square of the distance between two particles. In the EM algorithm, as stated, a virtual load is related to each particle, but the relation for the particles varies during the program. Hence after relating a virtual load to each particle, we can calculate total force using a law similar to Coulombs law. The function "Calc (F) is used in the general form of the EM algorithm in line 5 to calculate the imposed force on each virtual particle by other particles in the group. We first relate the virtual load q^i to the nth particles in function Calc (F). The value of q^i is defined versus to x^i as follows:

$$q^i = \exp\left(-n\frac{f(x^i) - f(x^{best})}{\sum_{k=1}^{m}(f(x^i) - f(x^{best}))}\right) \tag{5}$$

Equation (5) shows the optimized related virtual load to each particle. To calculate the total imposed force on the ith particle, F^i , that is equal to the total force from other particles on this particle, it is necessary to first determine the force from jth particles $(F_j)^i$ by equation (6) [11].

$$F_j^i = \begin{cases} (x^j - x^i)\frac{q^i q^j}{\|x^j - x^i\|^2} & f(x^j) < f(x^i) \\ \\ (x^i - x^j)\frac{q^i q^j}{\|x^j - x^i\|^2} & f(x^i) \le f(x^j) \end{cases} \tag{6}$$

consequently, F^i can be determined by:

$$F^i = \sum_{j \neq i}^{m} F_j^i \qquad i = 1, ..., m \tag{7}$$

The overall results of the above equations show that particles that are less optimized are always observed by the particles with higher optimization states.

D Displacemente of the particles using force vectors

The function Move () in the EM algorithm expresses the displacement of particles in the case. If the domain is shown by α it will be equal to a random variable with homogeneous distribution in time [0,1]. It can be calculated by equation (8).

$$x^i \leftarrow x^i + \alpha \frac{F^i}{\|F^i\|} \overrightarrow{R} \tag{8}$$

Where R is a vector defining the permissible limit of variation of each variable. In other words, this vector guarantees that the obtained result (8) is always in the permissible interval $[l_k - u_k]$.

VI OPTIMAL CONTROL THEORY

In this section, linear optimal control based on Lyapunov theorem is used for obtaining PSS parameters. It is assumed that $t \rightarrow \infty$ and the starting time is zero. The method can be briefly described in equations 9 to 13 [12] :

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{9}$$

Defining the performance index with the aim of minimizing:

$$\int_0^\infty \left[xT(t)Px(t) + x^T(4)Ru(t) \right] dt \tag{10}$$

System input will have the following relation:

$$u(t) = -Kx(t) \tag{11}$$

The matrix K will be:

$$K = R^{-1}B^TP \tag{12}$$

P in this equation is an unknown symmetrical positive definite real matrix that is obtained from the following algebraic equation:

$$PA + A^TP - PBR^{-1}B^TP + Q = 0 \tag{13}$$

R and Q are also symmetrical real positive definite matrixes.

VII SIMULATION RESULTS

In this section, system response without PSS is first presented and then the effect of adding "GA PSS", "EM PSS" and "TOCM PSS" is studied. Furthermore the results are compared with two other different method, Simulated Annealing ("SA PSS") and Particle Swarm Optimization ("PSO PSS) that are obtained from [9].The network comprises a single machine connected to an infinite bus through a transmission line. Five different loading conditions are assumed. The operating conditions were selected randomly and are given in section IX.

A Simulation results without PSS

The eigenvalues are found from system state space model matrix for the five operating conditions and given in Table (1).

From Table (1), it is clear that in some loading conditions the system is unstable, because its eigenvalues are on the right half side of $j\omega$ axis.

Table 1: Eigenvalues of single machine system in different loading conditions without PSS

Operating Conditions	Eigenvalues		
a	0.49±6.63i	-33.68	-17.36
b	0.75±7.37i	-11.55	-39.99
c	0.028±5.36i	-25.05+9.18i	-25.05 -9.18i
d	0.19± 6.92i	-10.78	-39.65
e	0.54±612i	-21.63	-29.49

B Genetic algorithm results

In the simulation, the number of pairing strings is chosen as 20, elite children are selected 2, and the percentage of produced strings in the interesting method is 80

Table 2: Eigenvalues of single machine system in different loading conditions with GA-PSS

O.C.	Eigenvalues			
a	-44.32	-16.22±40.02i	-0.18±2.81i	-0.71
b	-44.38	-16.34±28.2i	-0.83±3.71i	-0.73
c	-34.44	-21.44±13.8i	-0.56±4.74i	-0.72
d	-44.13	-16.04±18.05i	-1.61±4.22i	-0.75
e	-44.01	-17.09±39.4i	-0.14±4.492i	-0.7

C Electromagnetism-like method results

In the simulation, parameters δ and $LSIter$" are chosen to be 0.01 and 10, respectively. Simulations are done by 40 particles.After applying electromagnetism-like method to the linear model of the single-machine system, according to the objective function "F" for five different loading conditions, unstable poles transfer to left half side and system become stable (Table 3).The EM-PSS parameters are: K_STAB=14.2479, T_1=0.11713 Sec , T_2= 0. 0378Sec , T_W=1.0113 Sec.

Table 3: Eigenvalues of single machine system in different loading conditions with EM-PSS

O.C.	Eigenvalues				
a	-36.2±4.1i	-4.3	-0.3±5.6i		-0.7
b	-32.04	-27.6	-0.3±10i	-5.03	-0.7
c	-25.03±6i	-19.7	-0.86±6.1i		-0.7
d	-32.6±0.63i	-1±7.8i	-3.3		-0.8
e	-29±7i	-10	-0.7±8i		-0.74

D Optimal control method results

In the simulation, the values of parameters Q and R have been chosen by trial and error.After replacements and required calculations according to the equations of (9 to 13), the stabilizer matrixes K are obtained. By using matrix K_i in the equation $(A_i - B_iK_i), i = 1, ..., 5$, the eigenvalues of the resultant system matrix, for the five operating conditions are obtained which are shown in Table (4), according to Table VII. From this Table, it is obvious that, the obtained eigenvalues are more better than the other methods for system stability.

Table 4: Eigenvalues of single machine system in different loading conditions with TOCM-PSS

O.C.	Eigenvalues			
a	-40.18	-16.35±12.72i	-3.55±11.66i	-1.58
b	-44	-16.35±12.72i	-4.21±15.43i	-1.77
c	-43.61	-16.29±12.98i	-4.04±15.46i	-1.85
d	-44.27	-16.62±13.72i	-3.54±8.12i	-1.43
e	-44.17	-16.71±13.7i	-2.95±7.45i	-1.17

E Comparison of optimization methods

In this section, comparison between the optimization methods for five different loading conditions are carried out in Figures 5 to 9. Simulated Annealing and Particle Swarm Optimization algorithms results which are obtained from [9] are also shown for more clarity. The figures show damping rate of the system for the five loading conditions due to the different optimization methods and clearly indicate that TOCM-PSS is more optimal than the other methods.

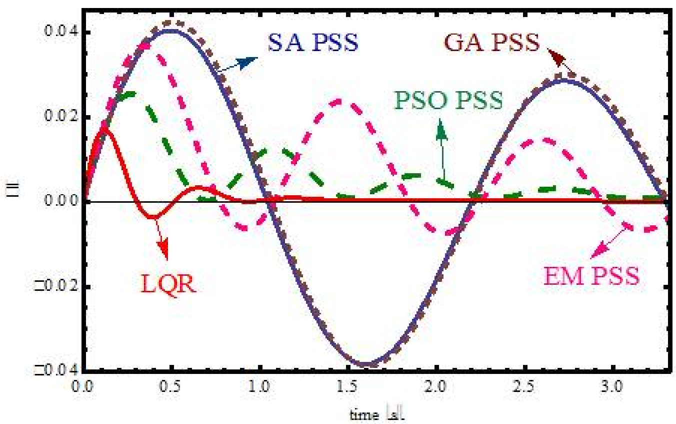

Figure 5: Single machine system response with different types of PSS for operating conditions "a"

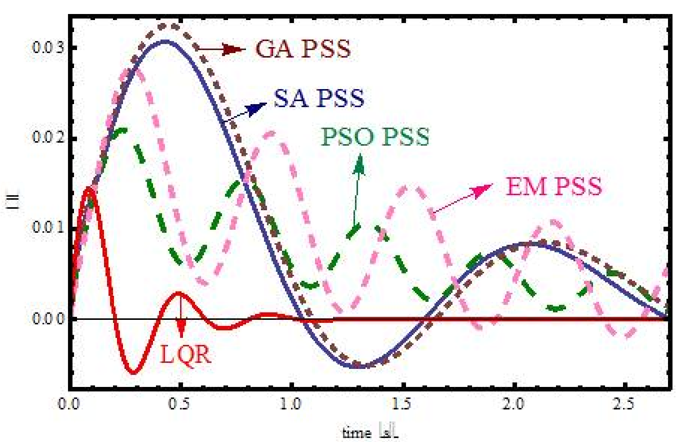

Figure 6: Single machine system response with different types of PSS for operating conditions "b"

To justify the stated results stability of the 10-machines 39-bus system is also studied. For showing the effectiveness of the pro-

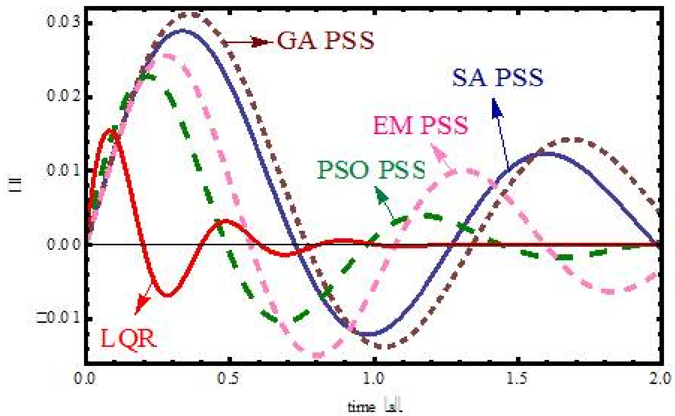

Figure 7: Single machine system response with different types of PSS for operating conditions "d"

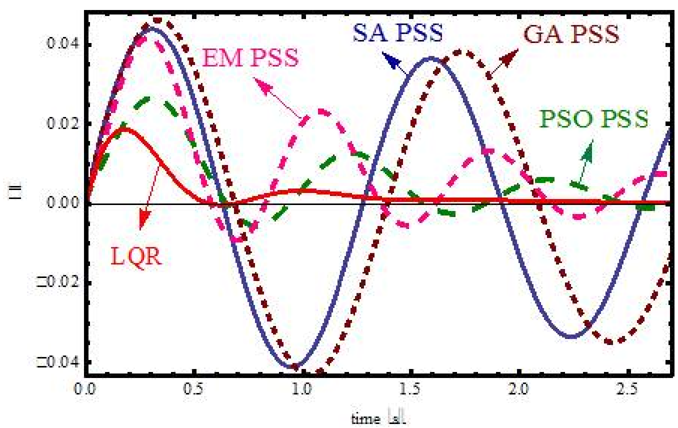

Figure 8: Single machine system response with different types of PSS for operating conditions "e"

posed PSSs over a wide range of operating conditions, we will create two three-phase faults at bus 29 at the end of line 26-29 and at bus 14 at the end of line 14-15. These faults will give more affected the speed deviation of Generator 9 and Generator 3 than the other generators [9]. For showing the effectiveness of the optimization methods and compare them, the behavior of these methods against the faults occupance are illustrated in Figs 10 and 11. From this comparison, it is clear that damping rate of the system with TOCM-PSS is more optimal than the other methods.

VIII CONCLUSION

In this paper, different PSS design optimization methods have been presented for a single machine connected to infinite bus system and 10-machine 39-bus system. Genetic algorithm, Electromagnetism-Like method and Linear optimal control theory were simulated and compared. Five loading conditions were selected and a three-phase fault was applied to the systems with optimised PSS. Simulation results show that the PSS designed based on optimal control theory has the best response and damping.

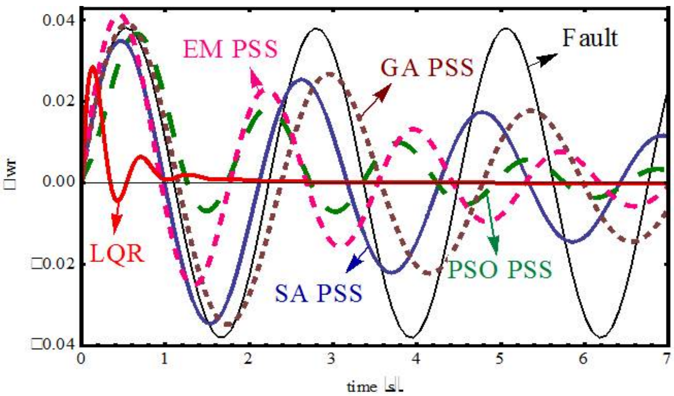

Figure 9: 10-machines system,G9 Response with different types of PSS

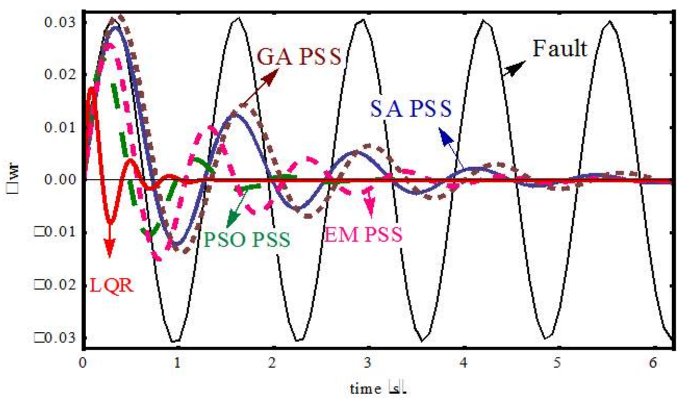

Figure 10: 10-machines system,G3 Response with different types of PSS

IX APPENDIX

Loading conditions:
a: P=0.9, Q=0.3
b: P=0.8, Q= -0.1
c: P=0.5, Q=0.5
d: P=0.6, Q= -0.2
e: P=1, Q=0.6

Machine (p.u)
$X_d = 1.7$ $X'_d = 0.254$ $X_q = 0.164$
$f_b = 60Hz$ $T'_{do} = 1.7Sec$ $H = 2.36Sec$
$K_D = 0$
Transmission line (p.u)
r_e=0.02 x_e=0.4
Exciter and Stabilizer
K_A=400 K_E= -0.176 K_F=0.026 T_A=0.060s
T_E=0.95s T_F=1.0s T_W=1-1.20s T_1=0.1 - 1.5 s
T_2=0.02 - 0.15s

Table 5: List of Parameters

F	Objective function
λ	Closed loop eigenvalues
β	Relative stability
P	Active power
Q	Reactive power
K_D	Damping torque factor
K_s	Synchronised torque factor
H	Inertia Constant
ω_0	Synchronous angular speed
$\Delta\omega_r$	rotor speed
$\Delta\delta$	load angle
ΔT_m	Mechanical input torque
$\Delta\psi_{fd}$	Excitation winding flux linkage
E_{fd}	Excitation output voltage
ΔT_e	Electrical torque
$MaxIter$	Maximum number of iterations
$LSIter$	Number of local search iterations
u_k	The upper limit
l_k	The lower limit
q^i	The virtual load
F^i	The total imposed force on the i-th particle
$u(t)$	System input

REFERENCES

[1] J. Nazarzadeh, M. Razzaghi, K.Y. Nikravesh, *"Solution of the matrix riccati equation for the linear quadratic control problems,,"*, Mathematical and Computer Modelling, vol. 27, pp. 51-55, 1998.

[2] MA. Abido, YL Abdel-Magid, AH Mantawy, *"Robust tuning of power system stabilizers in multi machine power systems,."*,IEEE Transaction on Power Systems, vol. 15, pp. 735-740, 2000.

[3] P. Kundur, *"Power systems stability and control,"*, New York, McGraw, Hill Press, 1994.

[4] MA. Abido , *"Robust design of multi machine power system stabilizers using simulated annealing,"* IEEE Transactions on Energy Conversion, vol. 15, pp. 297-304, 2000.

[5] AD. Falehi, M. Rostami, A. Doroudi *"Optimization and coordination of SVC-based supplementary controllers and PSSs to improve power system stability using a genetic algorithm,"*, Turk J Elec Eng and Comp Sci, vol. 20, pp. 1010-838, 2012.

[6] E. Babaei, S. Galvani, M. Ahmadi Jirdehi *"Design of robust power system stabilizer based on PSO,,"*, IEEE Symposium on Industrial Electronics and Applications, vol. 1, pp. 325-330, 2009.

[7] S. Panda, NP. Padhy, *"Robust power system stabilizer design using particle swarm optimization,"*,Technique Int J Electrical and Electronics Engineering, vol. 1, pp. 1-8, 2008.

[8] Sh. Gui, Y Takagi, H. Ukai, *"Design of power system stabilizer based on robust gain scheduling control theory,"* ,IEEE Power System Technology, vol. 3, pp. 1191-1196, 2000.

[9] A. Jeevanandham, K. Gowder Thanushkodi, *"Robust design of decentralized power system stabilizers using meta-heuristic optimization techniques for multimachine systems,"*,Serbian Journal of Electrical Engineering, vol. 6, pp. 89-103, 2009.

[10] RL. Haupt, SE Haupt , *"Practical genetic algorithms,"*,2nd ed, published by John Wiley and Sons, Inc, Hoboken, New Jersey, 2004.

[11] SI. Birbil, SC. Fang , *"An electromagnetism-like mechanism for global optimization,"*,Journal of Global Optimization, vol. 25, pp. 263-282. 2003.

[12] Chen CT , *"Introduction to linear system theory,"*,Holt Rinehart and Winston, 1984.