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Design of Coordinated PSS and SVC Damping Stabilizer for Low Frequency Oscillations Enhancement

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Abstract: This paper presents the application of PSS with based damping controller FACTS device and describes a coordinated tuning of parameters. The FACTS device considered here is Static Var Compensator (SVC). The method proposed to optimize the controller parameters is Particle Swarm Optimization (PSO) algorithm. The Single Machine Infinite Bus (SMIB) with PSS and SVC-based damping controller is selected as a case study system. In order to evaluate the effectiveness of these controllers, eigenvalues analysis and nonlinear simulation of this system are carried out under different loading conditions. The simulation results shows that PSS coordinated with SVC based stabilizer have outstanding fast damping of low frequency power system oscillations.

Keywords: SMIB, PSS, FACTS, SVC, PSO.

1. INTRODUCTION

The phenomenon of low frequency oscillations in power systems is considered one of the most complexes in recent years. Continuous growth of demand and weak tie-lines of large interconnected areas are among the reasons which led to the increase of this problem. Once started, the oscillations can continue for a while and then disappear, or continues to grow to cause a partially or total collapse of the system [1]. Satisfactory damping of electromechanical low frequency oscillations in power system plays an important role not only in increasing the reliability and transmission capability of the transferred power but also in enhancing the stability of overall power system [2].

Although a number of ways are available for mitigating the electromechanical modes (EM) of oscillations in power systems, the Power System Stabilizers (PSSs) is considered the most commonly used to enhance the system damping [3,4]. Several approaches have recently been applied to design the Conventional Power System Stabilizers (CPSS), based on the linear control theory. These include phase compensation method, residue and eigenvalue sensitivity.

Despite of these methods, the design of CPSS presented on this approach can be tuned to an operating condition and will provide excellent damping over a certain range around the design point but may not be optimal for the whole set of possible operating conditions and configurations [5,6]. Recent advances in power electronics technology have enabled the development of a variety of sophisticated

Controllers which were used to solve long-standing technical and economic problems found in electrical power systems at both the transmission and distribution levels. These emerging

Controllers are grouped under the headings FACTS and Custom power technology, respectively [7].Among various FACTS controllers, the Static Var Compensator (SVC) is one of the most promising FACTS devices: having many practical installations around the world and has attracted a lot of attention for designing effective control systems to enhance the system stability [8, 9].

In this paper. PSO technique is proposed for computing the optimal parameters of CPSS and SVC based stabilizer and coordinate between them in order to enhance the damping of power system electromechanical low frequency oscillations. PSO is a novel population based met a heuristics approach which utilizes the swarm intelligence generated by the cooperation and competition between the particles in a swarm and has emerged as a useful tool for engineering optimization [10].

2. Power System Model

A. Generator:

This study assumes a Single Machine Infinite Bus (SMIB). The generator is a third order generator equipped with a PSS and the system has a SVC installed at the **m-th** point in transmission line as shown in figure 1.

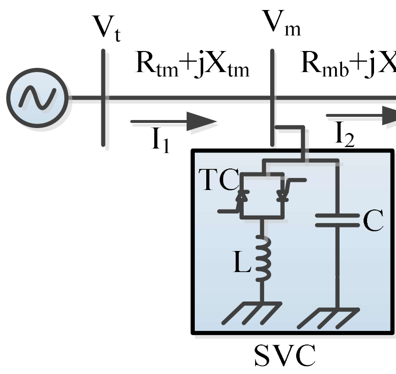

Fig.1: SMIB equipped with SVC.

The following differential equations define the system:

$$\frac{d\delta}{dt} = \omega_b(\omega - \omega_s) \tag{1}$$

$$\frac{d\omega}{dt} = \frac{1}{M}\left[P_m - P_t - D(\omega - \omega_s)\right] \tag{2}$$

$$\frac{d\acute{E}_q}{dt} = \frac{1}{T\acute{}_{do}}\left[-\acute{E}_q - (x_d - \acute{x}_d)i_d + E_{fd}\right] \tag{3}$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_A}\left[-E_{fd} + K_A(V_{ref} - V_t + V_s)\right] \tag{4}$$

Where

$$P_t = \frac{\acute{E}_q V_b}{c_{svc}\acute{x}_d}\sin\delta - \frac{V_b^2(x_q - \acute{x}_d)}{2c_{svc}^2\acute{x}_d x_q}\sin 2\delta$$

$$V_{td} = \frac{x_q V_b \sin\delta}{c_{svc}x_q},, V_{tq} = \frac{x_1\acute{E}_q}{\acute{x}_d} + \frac{V_b\acute{x}_d\,\mathrm{co}}{c_{svc}\acute{x}_d}$$

$$V_t = \sqrt{{V_{td}}^2 + {V_{tq}}^2}$$

And

δ: Rotor angle

ω: Speed at any time t

ω_s: synchronous speed

M: inertia constant

P_M: mechanical power

P_t: electrical power

D: damping constant

X_d: direct axis reactance

X_q: direct axis reactance

X'_d: transient reactance

E'q: quadrature axis emf

E_{fd}: field emf

Id: direct axis current

T_A and T'_{do}: time constants

V_{ref}, V_t, V_b and V_s: reference, terminal, infinite-bus and system voltages respectively.

V_{td} and V_{tq}: direct and quadrature axis voltages

C_{SVC}: SVC constant

2.2 Power System Stabilizer PSS:

As shown in Figure (2), a conventional lead lag PSS is installed in the feedback loop to generate a stabilizing signal u_{pss}.

2.3 Static Var Compensator SVC:

Figure (3) shows the SVC stabilizer controller with PI controller which is installed at **m-th** point to generate or absorb the reactive power to enhance the voltage at its terminal bus.

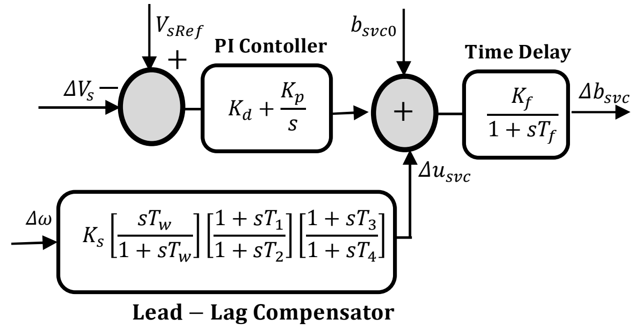

Fig.2: Lead Lag PSS.

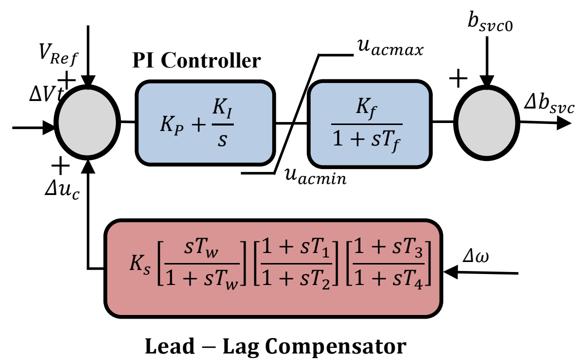

Fig.3: SVC damping controller.

2.4 Linearized Model:

The incremental linearized model around the operating point at normal conditions is usually employed for the analysis of the electromechanical mode of oscillations and to design the supplementary controller to provide adequate damping of system oscillation. Equation (5) shows the complete linearized system Model and K_1, K_2, K_3, K_4, K_5, K_6, K_{PZ}, K_{qz}, K_{VZ}, C_A, C_E and C_Z are linearization constants.

In short, the state equation is given by;

$$\dot{X} = AX + BU,$$

Where; the state vector X is

$[\Delta\delta \quad \Delta\omega \quad \Delta\acute{E}_q \quad \Delta E_{FD} \quad \Delta Z_{svc}]^T$ and U is $[\Delta u_{PSS} \quad \Delta u_{svc}]$.

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{\acute{E}}_q \\ \Delta\dot{E}_{FD} \\ \Delta\dot{Z}_{svc} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 \\ \frac{-\acute{K}_1}{M} & \frac{-D}{M} & \frac{-\acute{K}_2}{M} & 0 & \frac{-K_{Pz}}{M} \\ \frac{-\acute{K}_4}{\acute{T}_{d0}} & 0 & \frac{-\acute{K}_3}{\acute{T}_{d0}} & \frac{1}{\acute{T}_{do}} & \frac{-K_{qz}}{\acute{T}_{do}} \\ -\frac{\acute{K}_5 K_A}{T_A} & 0 & -\frac{\acute{K}_6 K_A}{T_A} & -\frac{1}{T_A} & \frac{-K_A K_{Vz}}{T_A} \\ C_A & 0 & C_E & 0 & C_z \end{bmatrix}$$

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{\acute{E}}_q \\ \Delta\dot{E}_{FD} \\ \Delta\dot{Z}_{svc} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & \frac{-\acute{K}_P}{M} \\ 0 & \frac{-\acute{K}_q}{\acute{T}_{do}} \\ \frac{K_A}{T_A} & \frac{-K_A \acute{K}_V}{T_A} \\ 0 & C_U \end{bmatrix} \begin{bmatrix} \Delta u_{PSS} \\ \Delta u_{SVC} \end{bmatrix} \quad (5)$$

3. The Proposed Approach

Originally, the aim of tuning the PSS, SVC based stabilizer controllers or coordinating between them is to damp the electrometrical low frequency oscillations which lead to enhance the overall power system stability. A heuristic technique (PSO) is proposed to address the problem and compute the optimal parameters of controllers.

3.1 The Optimized Technique

The Particle Swarm optimization (PSO) is a higher level heuristic algorithm for solving combinatorial optimization problem. An optimization technique starts with a population of random solutions 'Particles' in D-dimension space. The i-th particles is represents by $X_i = (x_{i1}, xi2 \ldots x_{iD})$. Each particle keeps track of its coordinates in hyperspace, which are associated with the best solution it has achieved so far. The local solution is called p_{best} and stored as $p_i = (p_{i1}, p_{i2} \ldots p_{id})$. The global version of the PSO keeps track of the global best solution g_{best} and its location, obtained thus far by any particle in the population. PSO at each step, changes the velocity (v_i) of each particle towards its p_{best} and g_{best} according to Equation (6) and the position of each particle updated according to Equation (7).

$$v_i^{new} = wv_i^{old} + c_1 r_1 * \left(P_i^{Local\ best} - P_i^{old}\right) + c_2 r_{2*}\left(P_i^{global\ best} - P_i^{old}\right) \quad (6)$$

$$x_{id} = x_{id} + v_{id} \quad (7)$$

Where $p^{local\ best}$: is the local best solution and $P^{global\ best}$ is the global best solution, c_1r_1 and c_2r_2 are PSO constants.

3.2 Objective Function

The goal of the application of damping controllers is to provide stabilizing signal to increase the damping ratio of electromechanical (EM) low frequency oscillations through shifting the real part of EM eigenvalues far of $j\omega$axis. For that, maximizing the damping ratio of the system has selected as objective function. The parameters to be coordinated and optimized (K_s, T_1, T_2, T_3, T_4,) for both PSS and SVC. The design problem can be formulated as:

$$J = Max\left({-\sigma}/{\sqrt{\sigma^2 + \omega^2}}\right) \quad (8)$$

Where; σ is real part of eigenvalues and ω is imaginary part of eigenvalues.

4. Results and Simulations

To evaluate the feasibility and effectiveness of PSO as proposed for addressing the problem of tuning and coordinating of multiple controllers in time for enhancing the dynamic and transient stability of power system. SMIB system equipped with PSS and SVC based damping controller was tested using MATLAB. The Eigenvalues of SMIB power system are given in Table (I) which were computed at normal operating load conditions (P_e=*0.5 p.u*), heavy loading condition (P_e=*0.7 p.u*), and light loading condition (P_e=*0.2 p.u*). Results are tabulated in Table (I) Note that the electromechanical mode of oscillations and their damping ratio and frequency respectively indicated by bold line. It is clear from Table (1) that the EM mode of original system under normal operating condition is poorly damped while the damping ratio improves with the addition of the SVC device. When the coordination between the PSS and SVC is enabled, the damping ratio is noted to have the highest value.

Table 1: System Eigenvalues and Damping Ratios With and without Control at Different Loading Conditions.

Loading	**No Control**	**SVC**	**PSS+SVC**
Nominal	-0.1515 ± j6.7330 (0.023, 1.07) -16.3317; -3.8626; -0.3551	-1.1136 ± j5.7414 (0.19, 0.93) -17.0023; -3.3035 ± j4.9466; -1.6692; -0.3559	-2.9739 ± j5.9871 (0.45, 1.06) -2.9500 ± j5.8837; -20.3232; -9.1216; -9.6564; -2.3930 ; -0.3547 ; -0.1000
Heavy	-0.1568 ± j7.0326 (0.022, 1.12) -16.5716; -3.6699; -0.5122	-3.6495 ± j8.9037 (0.38, 1.53) -0.7061 ±3.8997; -17.7060; -1.3824; -0.5209	-5.1703 ± j6.8260 (0.60, 1.36) -1.7413 ± j5.1206; -20.9945; -8.7306; -9.6941; -2.2904; -0.5111; -0.1000
Light	-0.0423 ± j6.2421 (0.007, 0.99) -15.9916; -4.3644; -0.1157	-0.0550±j6.1406 (0.009, 0.98) -4.3605 ± j1.7249; -2.4525; -16.0902; -0.1157	-0.7685 ± j6.2029 (0.12, 0.99) -5.3729 ± j3.9842; -18.6903; -9.3811; -9.5884; -2.6800; -0.1156; -0.1000

Table (2): The coordinated parameters setting of SVC damping controller and PSS, computed using the method described Section (3). Figure 4 shows the result of maximizing the damping ratio of system which has been selected as objective function.

Table 2: Parameters of PSS & SVC damping controller

Parameters	PSS	SVC
Ks	1.0	82.2162
T1	1.5	1.1312
T2	0.1	0.1051
T3	1.4949	0.1
T4	0.3120	0.1053

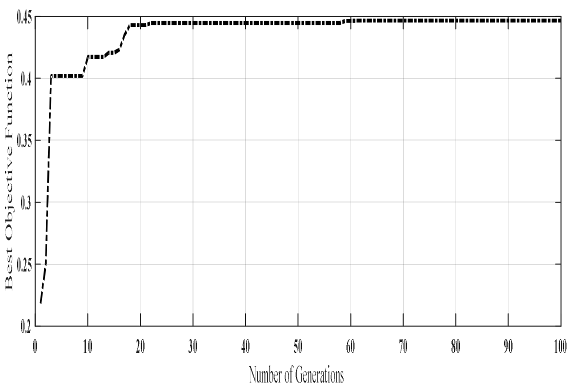

Figure (4): Optimal Objective Function.

To validate the robustness and effectiveness of damping controllers, Figures (5-9) shows the response of the system at nominal operating conditions when subjected to 3-phase S/C for few seconds. It is clear from the rotor angle response that, when the system is equipped with SVC it becomes more stable than the system without SVC controller. The system oscillates for 5 cycles and is then damped as compared with original system that was oscillatory. The coordinated PSS and SVC the system stability is also found to be superior to the system with the SVC only. The oscillations lasted only to 2 cycles and before been damped. Figures (10-11) represent the stabilizing signals of PSS and SVC damping controllers.

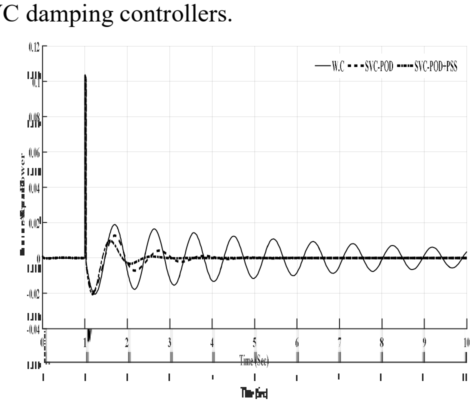

Fig. 5. Rotor angle for the three cases

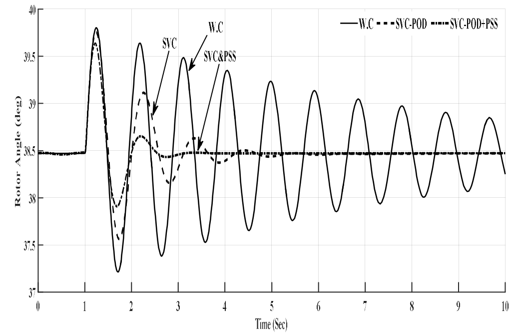

Fig.6. Rotor Speed for the three cases

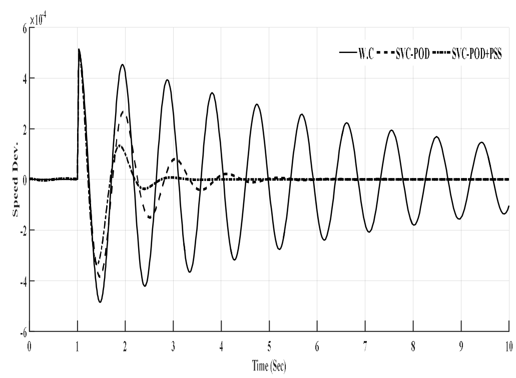

Fig.7. Speed Deviation for the three cases.

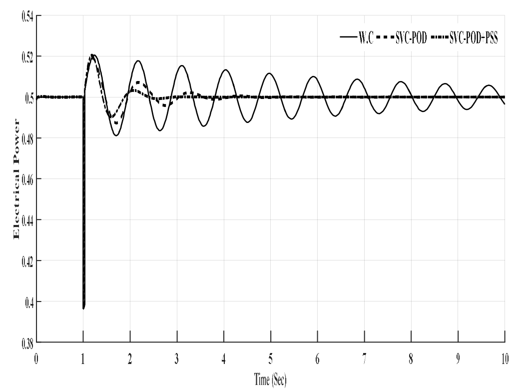

Fig.8. Electrical Power for the three cases

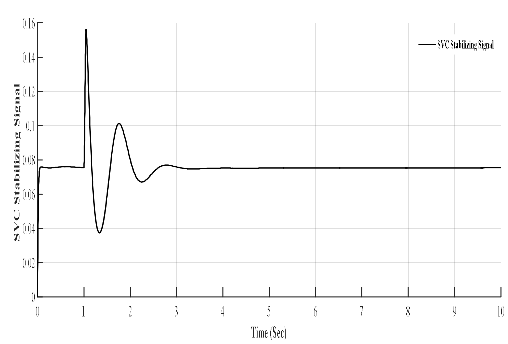

Fig.9. Acceleration Power for the three cases

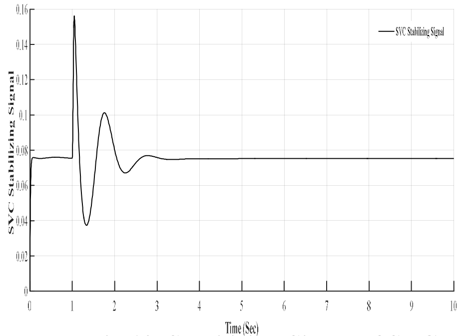

Fig.10. Stabilizing Signal of SVC

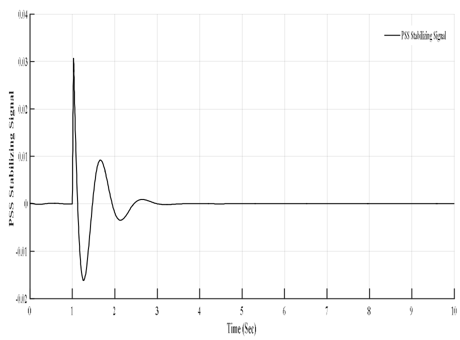

Fig.11. Stabilizing Signal of PSS

5. CONCLUSION

In this paper, PSS with SVC based stabilizer controllers tuning is proposed for damping power system oscillations. PSO method was proposed to compute the optimal parameters of the controllers and coordinate between them. To evaluate the usefulness of the proposed controllers, SMIB was used and investigated. Eigenvalue analysis results explained the capability of employing multiple controllers to enhance the system stability. Simulation results show that PSS with SVC controllers have a better control performance than SVC in terms of settling time and damping effect when the system is subjected to 3-phase S/C at nominal operating condition.

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10. Appendix

The system data are as follows:

$x_d = 1$	$x_q = 0.8$	$\acute{x}_d = 0.15$
$f = 50\ Hz$	$\acute{T}_{do} = 5.044\ s$	$V_b = 1$
$x_{svcc} = 1$	$k_{VP} = 1$	$k_{VP} = 1$
$x_{svcl} = 1$	$T_{svc} = 0.012\ s$	$V_s = 1.0$
$R_e = 0$	$x_{tr} = 0.3$	$x_{sb} = 0.3$
$M = 6\ s$	$K_A = 20$	$T_A = 0.05\ s$