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Design Of Power System Stabilizers And Static Var Compensator Using Evolutionary Algorithm

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Abstract

In power system, most of the problem associated with low frequency oscillation in inter-connected power system, especially in the degradation paradigm. Small magnitude and low frequency oscillation often remains for long time which affects the dynamic performance. To improve dynamic performance, fast damping of oscillation is required in the system. Power system stability enhancement by designing of Power System Stabilizer (PSS) and a Static Var Compensator (SVC)-based controller is thoroughly investigated in this paper. The coordination among the proposed damping stabilizers and the SVC internal voltage regulators has also been taken into consideration. The design problem is formulated as an optimization problem with a minimization of integral of time weighted speed deviation as objective function. The proposed approach employs an Evolutionary Algorithm (EA) such as particle swarm optimization (PSO) technique to search for optimal settings of PSS and SVC parameters. The performance of the proposed PSO based PSS (PSOPSS) and SVC (PSOSVC) under loading conditions, and system configurations had been analyzed for different multi-machine power systems and to damp out the local and inter-area oscillations. MATLAB/SIMULINK is used to carry out simulations of the system under study and detailed results are shown to access the performance of PSS and SVC on the low frequency oscillation and voltage stability of the power system.

Keywords: *Static Var Compensator, Power System Stabilizers, Particle Swarm Optimization, Hydraulic Turbine and Governor, Excitation System.*

1. Introduction

Power systems are complex non-linear systems and often exhibit low-frequency electromechanical oscillations due to insufficient damping caused by adverse operating conditions. Low frequency oscillations can severely restrict system operation and can reduce power system security level. As power demand grows rapidly and expansion in transmission and generation is restricted with the limited availability of resources and the strict environmental constraints. This causes the power systems to be operated near their stability limits. In addition, interconnection between remotely located power systems gives rise to low frequency oscillations in the range of 0.1–3.0 Hz. If not well damped, these oscillations may keep growing in magnitude until loss of synchronism results [1]. Power system stabilizers (PSSs) are used as supplementary control devices to provide extra damping and improve the dynamic performance of the power system. Several PSS design techniques have been reported [1-3]. In some cases, if the utilization of PSS cannot provide enough damping for inter-area power swing, flexible AC transmission systems based (FACTS) damping controllers are alternative efficient resolutions. The most popular type of FACTS devices in terms of application is the Static Var Compensator (SVC). This device is well known to improve power system properties such as steady state stability limits, voltage regulation and var compensation, dynamic over voltage and under voltage control, and damp power system oscillations.

The evolutionary methods constitute an approach to search for the optimum solutions via some form of directed random search process. Recently, Particle Swarm Optimization (PSO) technique appeared as a promising algorithm for handling the optimization problems [6-10].

In this paper, the design problem of PSS and SVC based controller to improve power system stability is transformed into an optimization problem [4]. The design objective is to improve the stability of a multi-machine power system, subjected to a disturbance. PSO technique is employed to search for the optimal PSS and SVC controller parameters. PSO based PSS and SVC controller (PSOPSS) and (PSOSVC) are presented and their performances are compared with the coordinated design of PSOPSS and PSOSVC. Simulation results are presented to demonstrate the effectiveness of the proposed controller to improve the power system dynamic stability.

2. Study system model

To demonstrate the application and robustness of PSO in tuning PSS, a two machine power system [3] is simulated by using power system toolbox (PST) [3]. The single line diagram of the system with specification is shown in Fig. 1. In order to maintain system stability after faults, the transmission line is shunt compensated at its center by a 200Mvar Static Var Compensator (SVC). The SVC model is a phasor model valid only for transient stability solution. The SVC does not have a Power Oscillation Damping (POD) unit. The two machines are equipped with a Hydraulic Turbine and Governor (HTG), Excitation system (ES), these blocks is located in the two Turbine and Regulator subsystems. Despite its small size, it mimics very closely the behavior of typical systems in actual operation [1-8] and the parameters of the generators are shown in Fig. 1.

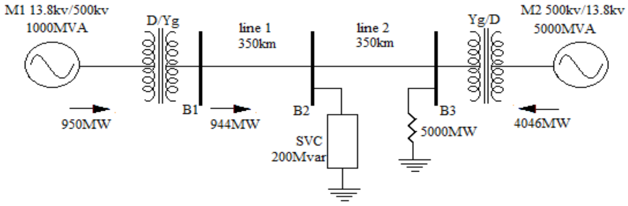


Fig. 1: Single line diagram for test power system

3. PROBLEM STATEMENT

3.1. Power System Model

In the system model, each generator is modeled by a set of nonlinear differential equation as:

$$\dot{x} = f(x, u) \quad (1)$$

Where x is the vector of the state variables, and u is the vector of the input variable and the PSS output signal, respectively.
In the design of PSSs, the linearized incremental models around an equilibrium point are usually employed. Therefore, the state equation of a power system with n-machine and n-PSS stabilizers can be written as:

$$\begin{aligned}\dot{x} &= Ax + Bu\\ y &= Cx + Du \quad (2)\end{aligned}$$

Where A is the power system matrix, B is the input matrix, C is the output matrix, and D is the feed-forward matrix. Therefore minimization of integral of time weighted speed deviation as objective function are formulated using only the unstable or lightly damped electromechanical oscillation, keeping the constraints of all the system modes stable under any condition.

3.2. Structure of Power System Stabilizer

The structure of PSS is to modulate the excitation voltage is shown in Fig. 2. The structure consists of a sensor, a gain block with gain K_{PSS}, a signal washout block and two-stage lead-leg blocks as shown in Fig. 2. The input signal of the proposed controller is the speed deviation (Δω), and the output is the stabilizing signal V_S which is added to the reference excitation system voltage. The basic equation of PSS is shown in equation 3. Hence, the transfer function of the i_{th} PSS is given by:

$$U_i = K_i\left(\frac{sTw}{1+sTw}\right)\left[\frac{(1+sT_{1i})}{(1+sT_{2i})}\frac{(1+sT_{3i})}{(1+sT_{4i})}\right]\Delta\omega_i \quad (3)$$

Where $\Delta\omega_i$ is the derivative of the synchronous speed and U_i is the output voltage signal which is added to the excitation system. The washout filter, which essentially act as a high pass filter, with the time constant T_W that allows the signal associated with oscillations in rotor speed to pass unchanged, and it does not allow the steady-state changes to modify the terminal voltage. From the view of point, the washout function value of T_W is usually not critical and it can be vary from 0.5 to 20 s.The five PSS parameters consisting of the four time constants $T1_{PSS}$ to $T4_{PSS}$ and one gain K_{PSS} need to be optimally chosen for each generator to guarantee optimal system performance under various system configurations and disturbances. The basic structure of PSS is shown in Fig.2.

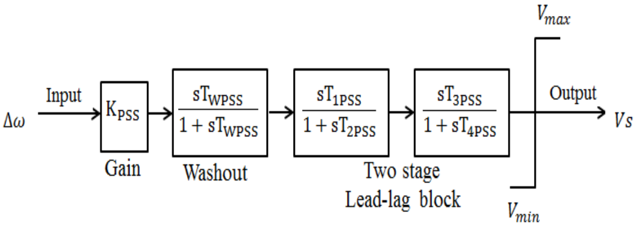


Fig.2. Basic Structure of PSS

3.3. Overview of Static Var Compensator

The SVC is basically a shunt connected static var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables. Typically, the controlled variable is the SVC bus voltage. One of the major reasons for installing a SVC is to improve Dynamic voltage control and thus increase system load ability. In this paper, the SVC is basically represented by a variable reactance with maximum inductive and capacitive limits to control the SVC bus voltage, with an additional control block and signals to damp oscillations, as shown in Fig.3.

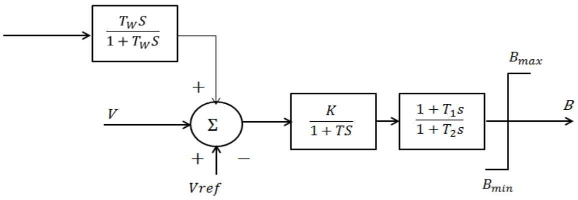


Fig.3. Structure of SVC controller with oscillation damping

The input signal of the proposed controller is the bus voltage (V), and the output is the incremental susceptance (B) which is added to the reference voltage. The fundamental frequency equivalent neglecting harmonics of the current results.

4. Objective Function

In the present study system, a sensor time constant T_{SN}=15 ms and washout time constant T_W=0.7s are used in this PSS parameters. The controller gain K_{PSS} and the time constant $T1_{PSS}$, $T2_{PSS}$, $T3_{PSS}$ and $T4_{PSS}$ are to be determined.

It is worth mentioning that the proposed PSS controller is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. In the present study, an integral time absolute error of the speed deviations is taken as the objective function expressed as follows:

$$J=\int_{t=0}^{t=t_{sim}} |\Delta\omega| \,.\, t.\, dt \qquad (4)$$

Where Δω is the rotor speed deviation for a set of controller parameters and t_{sim} is the time range of the simulation, from the above objective function calculation, the time domain simulation of the power system model can be carried out by the simulation period.

$$\begin{aligned} &\text{Optimize } J \\ \text{subject to } \quad & K^{min} \le K \le K^{max} \\ & T_1^{min} \le T_1 \le T_1^{max} \\ & T_2^{min} \le T_2 \le T_2^{max} \\ & T_3^{min} \le T_3 \le T_3^{max} \\ & T_4^{min} \le T_4 \le T_4^{max} \end{aligned} \qquad (5)$$

The optimized parameter ranges are [1, 50] for K_{PSS}, and [0.01, 2] for $T1_{PSS}$, $T2_{PSS}$, $T3_{PSS}$ and $T4_{PSS}$. The proposed approach employs PSO to solve this optimization problem and since search for the optimal set of PSS and SVC parameters. Since there are two PSS and one SVC totally twelve parameters need to be optimized.

5. Overview of Particle Swarm Optimization

PSO technique conducts searches using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multidimensional search space until a relatively unchanged position has been encountered, or until computational limitations are exceeded. PSO system combines local search method (through self-experience) with global search method (through neighboring experience), attempting to balance exploration and exploitation [3-5]. A particle status on the search space is characterized by two factors, its position (X_i) and velocity (V_i), which are updated by following equations given in (6) and (7).

$$V_i^{k+1} = \omega \times V_i^k + c_1 \times r_1 \times (P_i^k - X_i^k) + c_2 \times r_2 \times (P_g^k - X_i^k) \qquad (6)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad (7)$$

where, $V_i = [v_{i,1}, v_{i,2}, \ldots, v_{i,n}]$ is called the velocity for particle i, which represents the distance to be traveled by this particle from its current position, $X_i = [x_{i,1}, x_{i,2}, \ldots, x_{i,n}]$ represents the position of particle i, Pi represents the best previous position of particle i that is called local-best position or its experience. Pg represents the best position among all particles in the population $X = [X_1, X_2, \ldots, X_n]$ that is called global-best position, r1 and r2 are two independent and uniformly distributed random variables with range [0.0, 2.0], c1 and c2 are positive constant parameters called acceleration coefficients which control the maximum step size, ω is called the inertia weight that controls the impact of previous velocity of particle on its current one. The inertia weighting function in (8) is usually evaluated utilizing the following equation:

$$\omega = \omega_{max} - (\omega_{max} - \omega_{min}) \times {}^{iter}/_{iter_{max}} \qquad (8)$$

Where ω_{max} and ω_{min} are maximum and minimum values of ω, $iter_{max}$ is the maximum number of iterations and $iter_{min}$ is the current iteration number. The detailed procedure for updating the position and velocity of individuals for PSO algorithm is presented in Fig.4. Tuning a controller parameter of optimization problem in multi-model space as many settings of the controller could be yielding better performance. In PSO based method, the tuning process is associated with an optimality concept through the defined objective function and the time domain simulation.

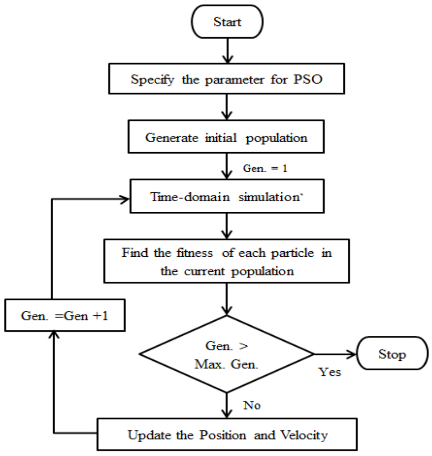


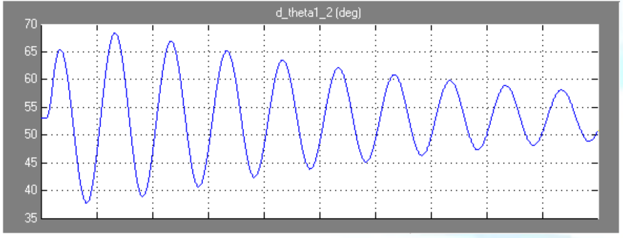
Fig.4. Flowchart of Particle Swarm Optimization

6. RESULTS AND DISCUSSIONS

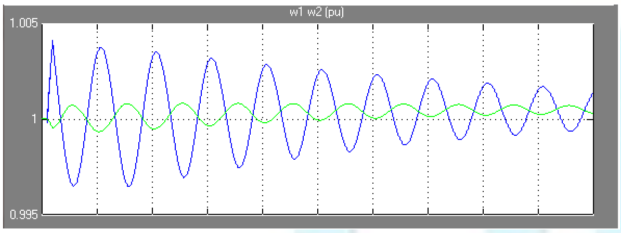
In order to start the simulation in steady-state you must first initialize the synchronous machines and regulators for the desired load flow. The machine 1 'Bus type' should be already initialized as 'PV generator', indicating that the load flow will be performed with the machine controlling its active power and its terminal voltage. Machine 2 will be used as a swing bus for balancing the power. The reference mechanical powers and reference voltages for the two machines are: Pref1=0.95pu (950MW), Pref2=0.8091pu (4046MW), Vref1=1pu; Vref2=1pu.

6.1. Effect of System responses without PSS and SVC

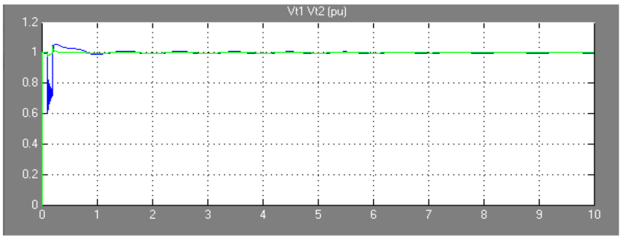
For an initial understanding of the network behavior, its open-loop responses (No-PSS) are simulated and applied for 50msec at the power reference of machine 1. All signals show undamped oscillations leading to instability without PSS and SVC application. Most of the significant variables such as the angle d-theta-12, the machine speed deviation dw, the terminal voltage Vt are instability slowly building up after a 10 seconds are given in Fig. 5.



(a)Rotor angle (d_theta1_2 v_s time in deg)



(b)Machine speed (dw1, dw2 v_s time in p.u)

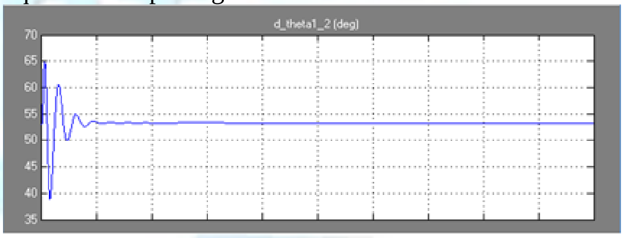


(c)Terminal voltage (vt1,vt2 v_s time in p.u)

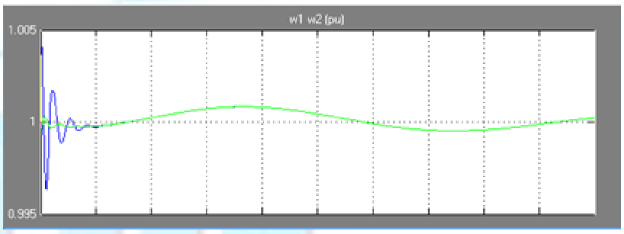
Fig. 5. System responses without PSS and No SVC after single phase fault disturbance.

6.2. Effect of System responses with and without PSS and with and without SVC after single phase fault disturbance

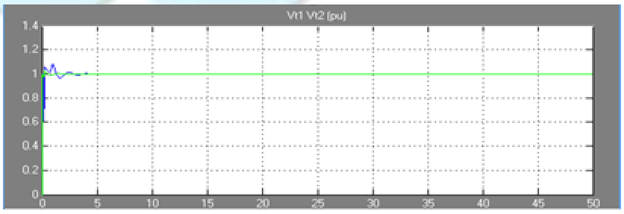
The SVC is set to operate in 'Var control (fixed susceptance)' mode with Bref=0, is equivalent to putting the SVC out of service. Verify also that the PSS (Pa-PSS) are in service. For Pa-PSS type of fault the system is stable without SVC. After fault clearing, the 0.8Hz oscillation is quickly damped. This oscillation mode is typical of interarea oscillations in a large power system. Figure 6.a shows the rotor angle difference d_theta between the two machines. Figure 6.b shows the machine speeds, that machine 1 speed increases during the fault because during that period its electrical power is lower than its mechanical power. Figure 6.c shows the voltage of SVC. Now SVC is set to operate in 'voltage regulation mode is equivalent to putting the SVC in service.



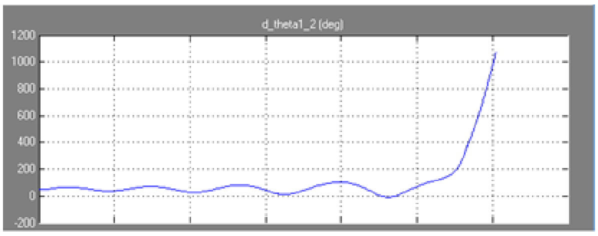
(a)Rotor angle (d_theta1_2 v_s time in deg)



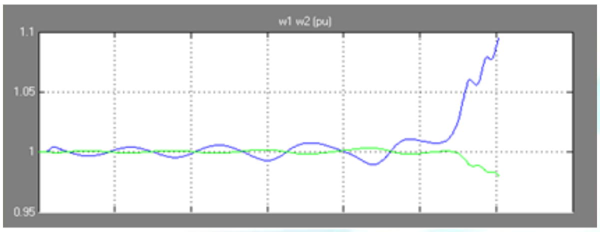
(b)Machine speed (dw1, dw2 v_s time in p.u)



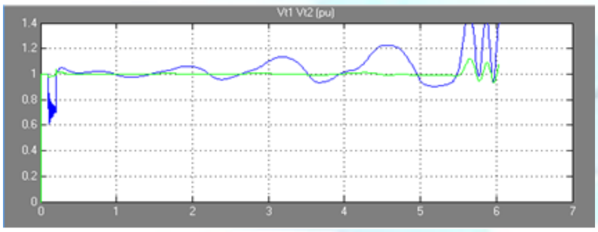
(c)Terminal voltage (vt1, vt2 v_s time in p.u)



(d)Rotor angle (d_theta1_2 v_s time in deg)



(e)Machine speed (dw1, dw2 v_s time in p.u)



(f)Terminal voltage (vt1, vt2 v_s time in p.u)

Fig. 6. System responses with and without PSS and SVC after single phase fault disturbance

6.3. Effect of system responses with PSO based PSS and SVC design algorithm

The proposed controller must be able to work well under all operating conditions, with the improvement for the damping of the critical modes. To acquire an optimal combination, this paper employs the PSO algorithm to improve the optimization synthesis and find the global optimum value. In order to acquire better performance, swarm size, itermax, c1, c2, wmin, wmax, are chosen as 20, 500, 2.0, 2.0, 0.45 and 0.95, respectively. It should be noted that the PSO algorithm is run several times and then optimal set of coordinated controller parameters is selected. To investigate the capability of PSS and SVC controller when applied individually and also through coordinated application, both are designed independently first and then in a coordinated manner. The final values of the optimized parameters for the proposed controllers are given in Table 1.and Table 2 and also shown in the Fig.8 & 9.

Table 1. The optimal parameter setting of the proposed controller of pss

	K_g	T_1	T_2	T_3	T_4
PSS1	43.7868	1.8426	2.5093	2.5760	3.6019
PSS2	64.3746	1.5091	0.8779	0.9642	2.2753

Table 2. The optimal parameter setting of the proposed controller of svc

	K_P	K_i
SVC	22.9318	11.7688

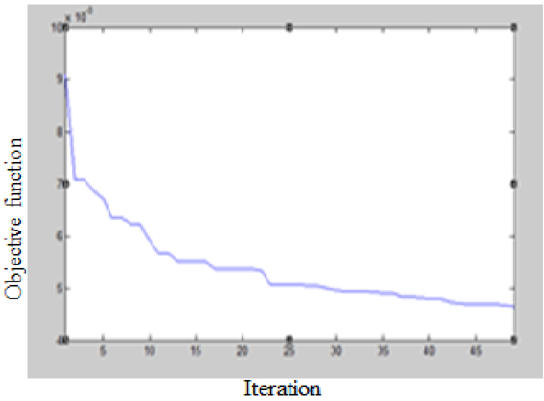
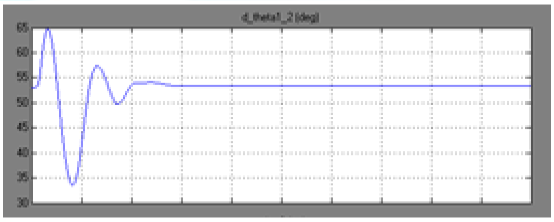
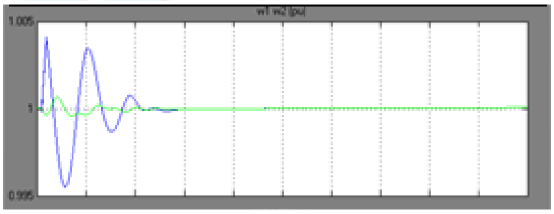


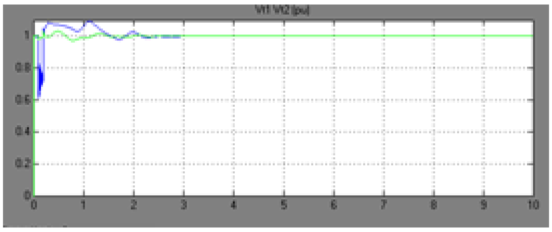
Fig. 8. Convergence of fitness value



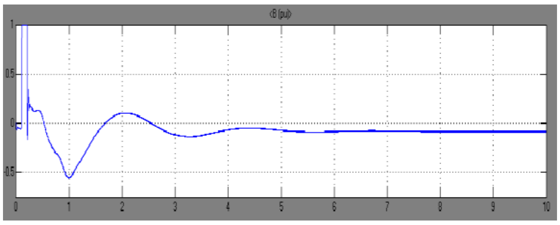
(a)Rotor angle (d_theta1_2 v_s time in deg)



(b)Machine speed (dw1, dw2 v_s time in p.u)



(c)Terminal voltage (vt1, vt2 v_S time in p.u)



(d)SVC voltage (B_{SVC} v_S time in p.u)

Fig.9. System responses of PSO based PSS and SVC

7. CONCLUSION

This paper has shown an application of a PSO algorithm to determine the optimal tuning of power system stabilizers and static var compensator parameters. The coordination among the proposed damping stabilizers and the SVC internal voltage regulator has also been taken into consideration. For the design problem, minimization of integral of time weighted speed deviation as objective function, to increase the power system stability is used and PSO optimization technique is employed to optimally tune the parameters of the proposed controllers. Moreover, time domain simulations also showed that the oscillations of synchronous machines can be rapidly damped for power systems with the proposed PSSs and SVC over a wide range of conditions. The optimal parameter setting for the PSS and SVC is evaluated using PSO algorithm. It is observed that the proposed design provide efficient damping to power system oscillations for any disturbance.

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