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Voltage Control in a Multi-Machine Power System by Using Static Var Compensator

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Abstract: Electrical loads both generate and absorb reactive power. Since the transmitted load varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage amplitude variations, a voltage depression, or even a voltage collapse. A rapidly operating Static Var Compensator (SVC) can continuously provide the reactive power required to control dynamic voltage swings under various system conditions and thereby improve the power system transmission and distribution performance. Installing an SVC at one or more suitable points in the network will increase transfer capability through enhanced voltage stability, while maintaining a smooth voltage profile under different network conditions. In addition, an SVC can mitigate active power oscillations through voltage amplitude modulation. Therefore, in this paper the application of SVC for voltage support at a multimachine electric power system is carried out. The proposed SVC is installed on the middle of the network and its parameters are adjusted by using Particle Swarm Optimization (PSO). The viability of SVC in voltage support is shown by nonlinear simulation results.

Key words: Static Var Compensator · Voltage Support · Multi-machine Electric Power System · Particle Swarm Optimization

INTRODUCTION

Today's changing electric power systems create a growing need for flexibility, reliability, fast response and accuracy in the fields of electric power generation, transmission, distribution and consumption. Flexible Alternating Current Transmission Systems (FACTS) are new devices emanating from recent innovative technologies that are capable of altering voltage, phase angle and/or impedance at particular points in power systems. Their fast response offers a high potential for power system stability enhancement apart from steady state flow control. Among the FACTS controllers, Static Var Compensator (SVC) provides fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time. SVC also dampens power swings and reduces system losses by optimized reactive power control. The simple structure of SVC makes it more viable and feasible.

Typically an SVC comprises a bank of individually switched capacitors in conjunction with a thyristor controlled air-or iron-cored reactor. By means of phase angle modulation switched by the thyristors, the reactor may be variably switched into the circuit and so provide a continuously variable MVAr injection (or absorption) to the electrical network. The SVC two control degrees of freedom can be mapped into freedom to exchange active and reactive power with the transmission system. The amount of exchanged reactive power is limited only by the current capacity of the converter switches, while the active power coupled to (from) the line has to be supplied from (delivered to) the DC terminals.

The SVC has been widely used for stability enhancement [1-4], voltage support [5-7] and also reliability improvement of power system [8].

In this paper the application of SVC for voltage control at a multi machine electric power system is presented. The proposed SVC controller is tuned using PSO. Simulation results clearly emphasis on the viability of SVC in voltage support.

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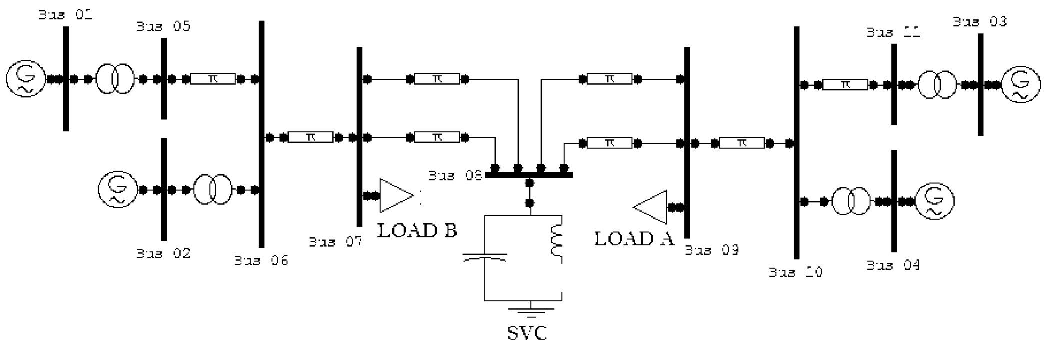

Fig. 1: Multi-machine electric power system installed with SVC

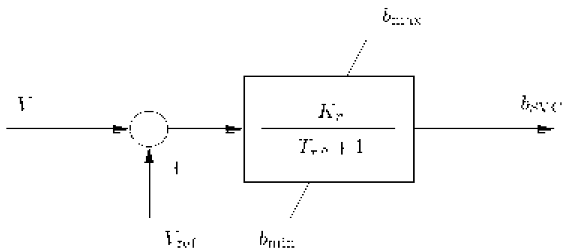

Fig. 2: The SVC model as a time constant regulator

Table 1: Considered system loading conditions

	Nominal		Heavy	
Load	P	Q	P	Q
A	18.5535	-2.625	20.4089	-2.82
B	10.1535	-1.050	11.1689	-1.15

System under Study: Fig. 1 shows a multi machine power system installed with SVC. The static excitation system, model type IEEE-ST1A, has been considered. Detail of the system data are given in [9]. To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, two different cases as nominal and heavy loading are considered and listed in Table 1. In this paper, turbine-governor system is also modeled to eliminate steady state error of responses.

SVC Model: The SVC is implemented as a time constant regulator to voltage support as depicted in Fig. 2. In this model, a total reactance is assumed equivalent to b_{SVC}. The differential equation of the model is as (1).

$$\dot{b}_{svc} = \left(K_r\left(V_{ref} - V\right) - b_{svc}\right)/T_r \tag{1}$$

The model is completed by the algebraic equation which expresses the reactive power injected at the SVC node as (2).

$$Q = -b_{svc}V^2 \tag{2}$$

The regulator has an anti-windup limiter, thus the reactance b_{SVC} is locked if one of its limits is reached and the first derivative is set to zero [10].

Dynamic Model of the System with SVC: The nonlinear dynamic model of the system installed with SVC is given as equations (3). The dynamic model of the system has been completely presented in [9] and also dynamic model of the system installed with SVC has been presented in [10].

$$\begin{cases} \dot{\omega} = \left(P_m - P_e - D\omega\right)/M \\ \dot{\delta} = \omega_0\left(\omega - 1\right) \\ \dot{E}'_q = \left(-E_q + E_{fd}\right)/T'_{do} \\ \dot{E}_{fd} = \left(-E_{fd} + K_a\left(V_{ref} - V_t\right)\right)/T_a \\ \dot{b}_{svc} = \left(K_r\left(V_{ref} - V\right) - b_{svc}\right)/T_r \end{cases} \tag{3}$$

Where, δ: Rotor angle; ω: Rotor speed (pu); P_m: Mechanical input power; P_e: Electrical output power (pu); M: System inertia (Mj/MVA); E'_q: Internal voltage behind x'_d (pu); E_{fd}: Equivalent excitation voltage (pu); T'_{do}: Time constant of excitation circuit (s); K_a: Regulator gain; T_a: Regulator time constant (s); V_{ref}: Reference voltage (pu); V_t: Terminal voltage (pu).

It is clear that by controlling b_{SVC}, the output reactive power of the shunt compensator would be controlled.

The most important subject is to tuning the SVC regulator parameters K_r and T_r. the system stability and suitable performance is guaranteed by appropriate adjustment of these parameters. Many different methods have been reported for tuning SVC parameters so far. In this paper, PSO is used for tuning SVC parameters. In the next section an introduction about PSO is presented.

Particle Swarm Optimization: PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous GA in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (4) and (5) [11].

$$V_{m,n}^{new}=w\times V_{m,n}^{old}+\Gamma_1\times r_1\times(P_{m,n}^{local\,best}-P_{m,n}^{old})+\Gamma_2\times r_2\times(P_{m,n}^{global\,best}-P_{m,n}^{old}) \quad (4)$$

$$P_{m,n}^{new}=P_{m,n}^{old}+\Gamma\, V_{m,n}^{new} \quad (5)$$

Where:
$V_{m,n}$ = particle velocity
$P_{m,n}$ = particle variables
W= inertia weight
r_1, r_2 = independent uniform random numbers
$\Gamma_1 = \Gamma_2$ = learning factors
$P_{m,n}^{local\ best}$ = best local solution
$P_{m,n}^{global\ best}$ = best global solution

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima [11].

SVC Tuning Based on PSO: PSO is used to find optimum values of SVC controller. The optimum values of K_r and T_r which minimize different performance indices are accurately computed using PSO. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (6). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

Table 2: Optimal values of parameters using PSO

SVC parameters	optimal value
K_r	18.455
T_r	0.05

Table 3: Optimal values of parameters using GA

SVC parameters	optimal value
K_r	10.922
T_r	0.18

$$ITAE = \int_0^t \sum_{i=1}^{n} t\left|?\,V_i\right| dt \quad (6)$$

Where, ΔV shows the voltage deviations and n is number of buses. It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 6 cycle three phase fault is assumed in bus 3 and the performance index is minimized using PSO. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 2. Also in order to show effectiveness of PSO method, the parameters of controller are tuned using the other optimization method, Genetic Algorithms (GA). In GA case, the performance index is considered as PSO case and the optimal parameters of controller are obtained as shown in Table 3.

Simulation Results: The proposed adjusted SVC is evaluated on the test system given in section 2. The adjustment of controller is performed in the nominal operating condition. In order to study and analysis system performance under different disturbances, two scenarios are considered as follows:

Scenario 1: disconnection of the line between bus 7 and bus 8.

Scenario 2: 10 cycle three phase short circuit in bus 3.

The simulation results are depicted in Figs. 3-10. Each figure contains three plots, solid line which indicates the PSO-SVC, dashed line for GA-SVC and dotted line for system without SVC. Results clearly show the effectiveness of SVC in voltage control as well as stability improvement. Fig. 3 shows the voltage of bus 8 where the SVC is installed, it is s een that the voltage is driven back to the nominal value after disturbances and the steady state error is zero. Although both the GA and PSO methods have successfully controlled the voltage, but from view of comparison, the PSO based SVC has a significant priority than the other method. Also the responses without SVC clearly show the voltage downfall in the proposed bus.

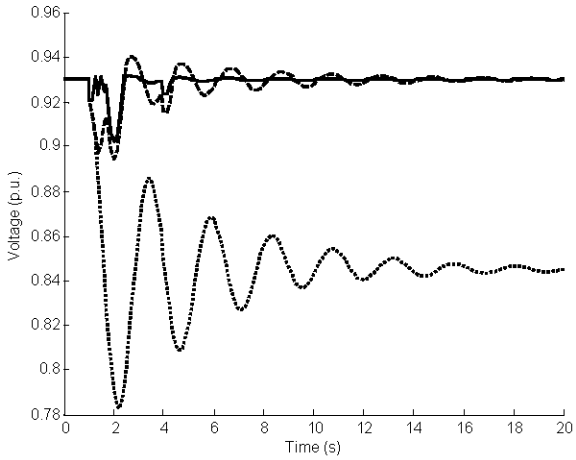

Fig. 3: Voltage of bus 8 under scenario 1 in nominal load condition Solid (PSO-SVC); Dashed (GA-SVC); Dotted (Without SVC)

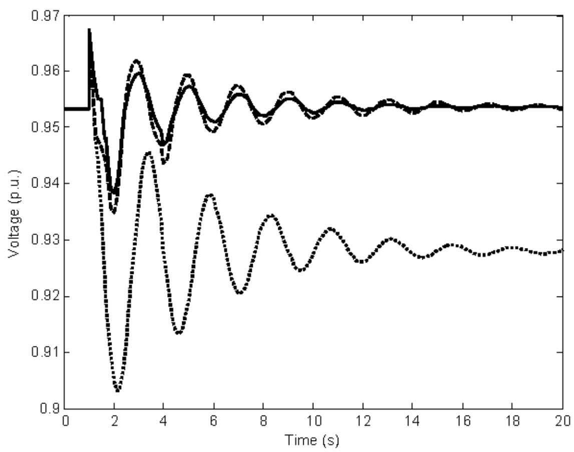

Fig. 4: Voltage of bus 7 under scenario 1 in nominal load condition Solid (PSO-SVC); Dashed (GA-SVC); Dotted (Without SVC)

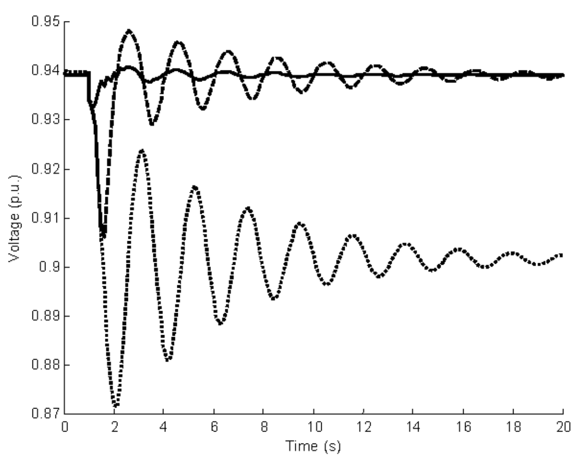

Fig. 5: Voltage of bus 8 under scenario 1 in heavy load condition Solid (PSO-SVC); Dashed (GA-SVC); Dotted (Without SVC)

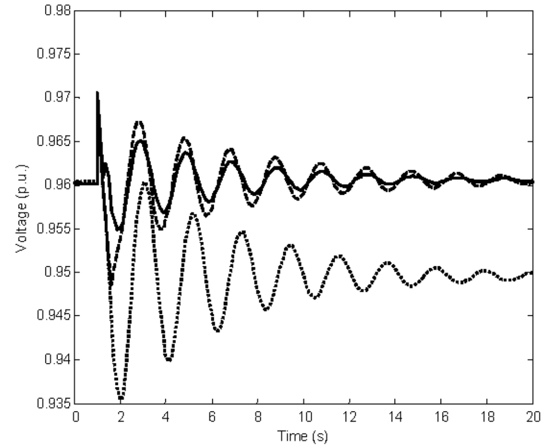

Fig. 6: Voltage of bus 7 under scenario 1 in heavy load condition Solid (PSO-SVC); Dashed (GA-SVC); Dotted (Without SVC)

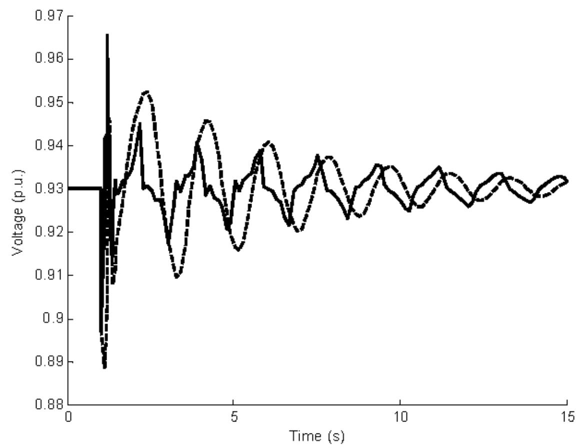

Fig. 7: Voltage of bus 8 under scenario 2 in nominal load condition Solid (PSO-SVC); Dashed (GA-SVC)

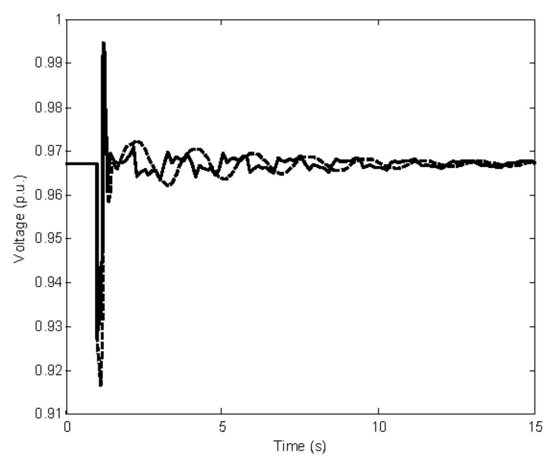

Fig. 8: Voltage of bus 9 under scenario 2 in nominal load condition Solid (PSO-SVC); Dashed (GA-SVC)

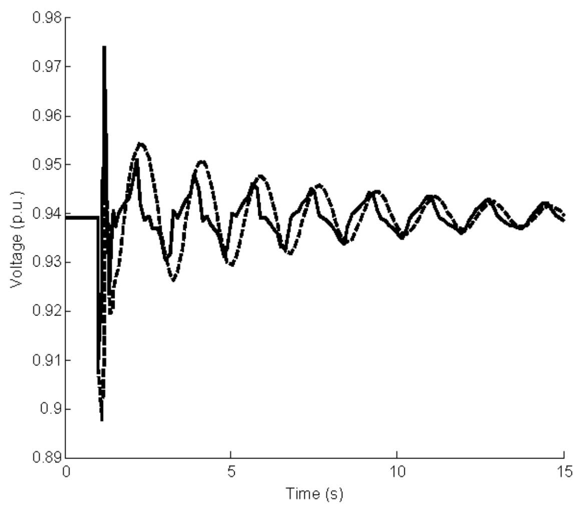

Fig. 9: Voltage of bus 8 under scenario 2 in heavy load condition Solid (PSO-SVC); Dashed (GA-SVC)

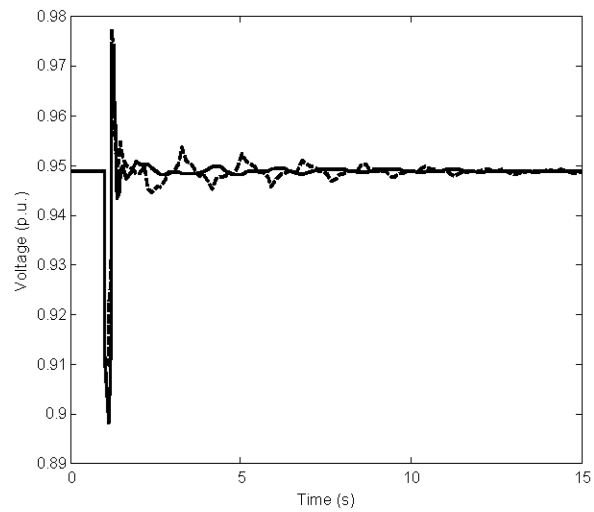

Fig. 10: Voltage of bus 9 under scenario 2 in heavy load condition Solid (PSO-SVC); Dashed (GA-SVC)

The study of the SVC effect on the other buses except bus 8 can be useful. In this view, the voltage of bus 7 is depicted in Fig. 4. The figure shows that SVC not only controls the voltage of its bus, but also has a positive effect on the voltage of the other buses. The effect of SVC on the nearby buses is more than the farther buses.

The power system responses with changing system operating condition from nominal to heavy are depicted in Figs. 5-6. As figures show the system responses with changing load goes to fluctuations. But SVC performance in voltage control is achieved in this condition.

Another disturbance scenario has been carried out in Figs. 7-10. As seen from the figures, the SVC performance under different scenarios is suitable. The SVC controls voltage of the installed bus and also has an effective performance at other buses. The PSO based SVC shows a great better performance than GA based SVC at all operating conditions and all scenarios.

CONCLUSIONS

This paper provides a detailed description of a modern, thyristor-controlled SVC installed on a multi machine electric power system. The compensator is typical of many such installations on high voltage transmission systems, but many of its design features are reproduced in load compensators also, particularly in supplies to electric arc furnaces. The thyristor controllers, reactor and capacitor are essentially the same in both cases. The main differences are in the control strategy and the system voltage. Although the SVC is a controller for voltage regulation, that is, for maintaining constant voltage at a bus, a finite slope is incorporated in the SVC's dynamic characteristic and provides the following advantages despite a slight deregulation of the bus voltage.

- Substantially reduces the reactive-power rating of the SVC for achieving nearly the same control objectives;
- Prevents the SVC from reaching its reactive-power limits too frequently;
- Facilitates the sharing of reactive power among multiple compensators operating in parallel.

Static var compensators (SVCs) are used primarily in power system for voltage control as either an end in itself or a means of achieving other objectives, such as system stabilization.

This paper presents a detailed overview of the voltage-control characteristics of SVC and the principles of design of the SVC voltage regulator. The performance of SVC voltage control is critically dependent on several factors, including the influence of network resonances, transformer saturation, geomagnetic effects and voltage distortion. When SVCs are applied in series-compensated networks, a different kind of resonance between series capacitors and shunt inductors becomes decisive in the selection of control parameters and filters used in measurement circuits.

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