Investigation of STATCOM Ability in Voltage Support

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Abstract: This paper presents the application of static synchronous compensator (STATCOM) to control of voltage at a multi-machine power system installed with STATCOM as cast study. STATCOM is installed in one bus to control of voltage in the proposed bus. An optimization technique is used to tune the proposed STATCOM controllers. Several time-domain simulation tests visibly show the validity of proposed methods in voltage control and also damping of power system oscillations.

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1. Introduction

The rapid development of the high-power electronics industry has made Flexible AC Transmission System (FACTS) devices viable and attractive for utility applications. FACTS devices have been shown to be effective in controlling parameters of power system and also in damping power system oscillations. In recent years, new types of FACTS devices have been investigated that may be used to increase power system operation flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems.

It has long been recognized that the steady-state transmittable power can be increased and the voltage profile along the line also can be controlled by appropriate reactive shunt compensation. The purpose of this reactive compensation is to change the natural electrical characteristics of the transmission line to make it more compatible with the prevailing load demand. Thus, shunt connected, fixed or mechanically switched reactors are applied to minimize line overvoltage under light load conditions, and shunt connected, fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load condition [1].

The ultimate objective of applying reactive shunt compensation such as STATCOM in a transmission system is to increase the transmittable power. This may be required to improve the steady-state transmission characteristics as well as the stability of the system. Var compensation is thus used for voltage regulation at the midpoint (or some intermediate) to segment the transmission line and at the end of the (radial) line to prevent voltage instability, as well as for dynamic voltage control to increase transient stability and damp power oscillations.

The static synchronous compensator (STATCOM) is one of the most important FACTS devices and it is based on the principle that a voltage-source inverter generates a controllable AC voltage source behind a transformer-leakage reactance so that the voltage difference across the reactance produces active and reactive power exchange between the STATCOM and the transmission network. The STATCOM can be used for dynamic compensation of power systems to provide voltage support [2, 3]. Also it can be used for transient stability improvement by damping low frequency power system oscillations [4-7].

The objective of this paper is to investigate the ability of STATCOM for voltage support. Particle Swarm Optimization (PSO) method as a meta-heuristic optimization method is considered for tuning the parameters of STATCOM. A multi-machine power system installed with STATCOM is considered as case study. Simulation results show the validity of STATCOM in voltage support at bulk electric power systems.

2. Test system

A multi machine power system installed with STATCOM is considered as case study. The proposed test system is depicted in Figure 1. The system data can be found in [8]. In this paper, turbine-governor system is also modeled to eliminate steady state error of responses.

2.1. Dynamic model of the system with STATCOM

The nonlinear dynamic model of the system installed with STATCOM is given as (1). The dynamic model of the system installed with STATCOM is completely presented in [1].

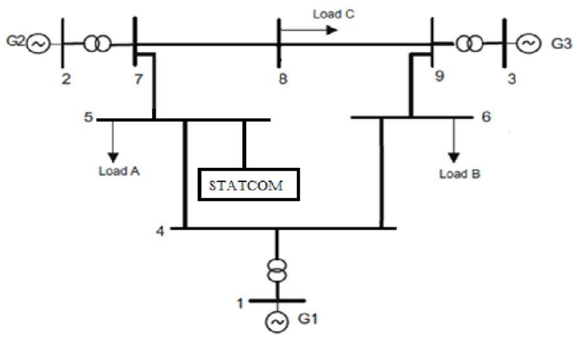

Figure 1. Multi-machine electric power system installed with STATCOM

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

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).

By controlling m_E, the output voltage of the shunt converter is controlled. By controlling δ_E, exchanging active power between the STATCOM and the power system is controlled.

2.2. STATCOM controllers

In this paper two control strategies are considered for STATCOM:

i. DC-voltage regulator

ii. Bus-voltage regulator

STATCOM has two internal controllers which are bus voltage controller and DC voltage regulator. A DC capacitor is installed behind the STATCOM; this capacitor is used to provide the reference voltage for PWM performance. In order to maintaining the voltage of this capacitor, a DC-voltage regulator is incorporated. DC-voltage is regulated by modulating the phase angle of the shunt converter voltage. This controller is commonly a PI type controller. A bus voltage controller is also incorporated based on STATCOM. The bus voltage controller regulates the voltage of bus where the STATCOM is installed.

The most important subject is to tuning the STATCOM controller parameters. The system stability and suitable performance is guaranteed by appropriate adjustment of these parameters. Many different methods have been reported for tuning STATCOM parameters so far. In this paper, an optimization method named is considered for tuning STATCOM parameters. In the next section an introduction about the proposed optimization method is presented.

3. 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 below.

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (2)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma\, V_{m,n}^{new} \quad (3)$$

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 [9].

4. STATCOM tuning based on PSO

In this section the parameters of the STATCOM controllers are tuned by using PSO. The optimum values of controllers which minimize different performance indices are accurately computed using PSO. The performance index is considered as (4). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^t t\sum_{i=1}^{3}|\Delta\omega_i|dt + \int_0^t t\sum_{i=1}^{9}|\Delta v_i|dt \qquad (4)$$

Where, $\Delta\omega$ shows the frequency deviations and Δv shows the voltage of buses. To compute the optimum parameter values, different faults are assumed in all buses and then the minimum solution is chosen as final solution. The results are listed in Table 1.

Table 1. Optimal parameters of STATCOM

	gain	value
PI controller of voltage	Proportional gain	1.42
	Integrator gain	0.57
PI controller of DC link	Proportional gain	25.1
	Integrator gain	0.38

5. Simulation results

The proposed STATCOM is evaluated on the test system given in section 2. The disturbance is provided by a 10 cycles three phase short circuit in bus 1. This disturbance shows a large signal disturbance in power systems. The simulation results are presented in Figures 2-6. Where, solid line indicates the system installed with STATCOM and dashed line shows the system without STATCOM.

The STATCOM is installed in bus 5 and it is expected that voltage of bus 5 be controlled. In this regard, the voltage of all buses are depicted in Figures 2-10. It is clearly seen that the STATCOM can successfully control the voltage of bus 5. It is also seen that STATCOM has a positive effect on the voltage of rest buses. Where, the voltage profile in all buses is better than the system without STATCOM. The STATCOM is installed to control of voltage, bus is has an effect on the system dynamic performance. It is seen that the system with STATCOM is more stable than system without STATCOM. STATCOM affects the system damping and the oscillations are rapidly damped out with being of STATCOM.

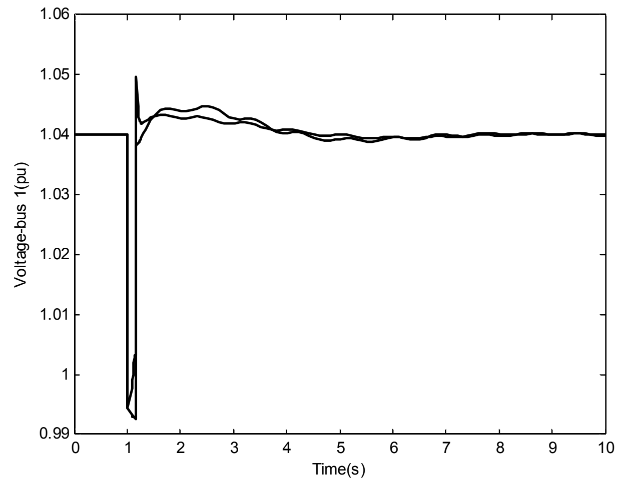

Figure 2. Voltage bus 1 following disturbance

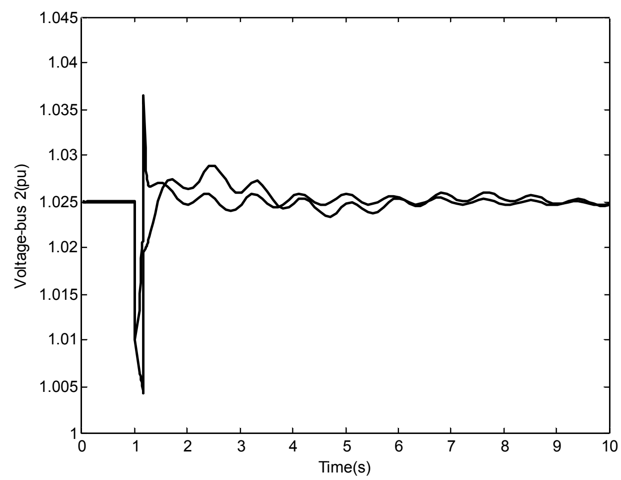

Figure 3. Voltage bus 2 following disturbance

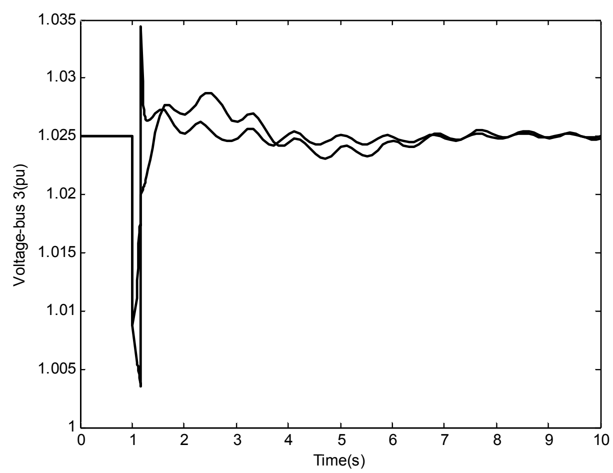

Figure 4. Voltage bus 3 following disturbance

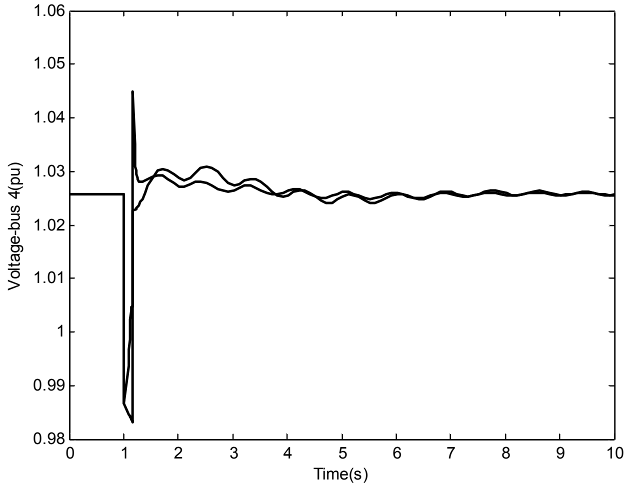

Figure 5. Voltage bus 4 following disturbance

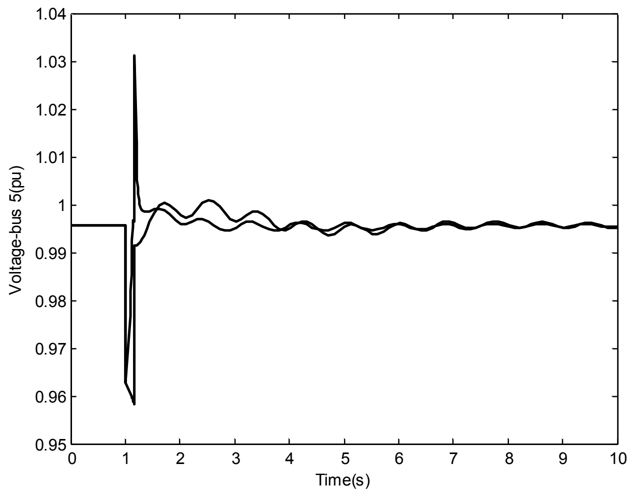

Figure 6. Voltage bus 5 following disturbance

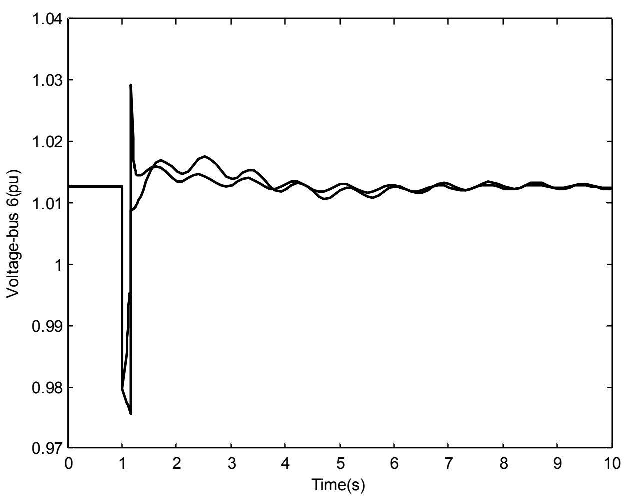

Figure 7. Voltage bus 6 following disturbance

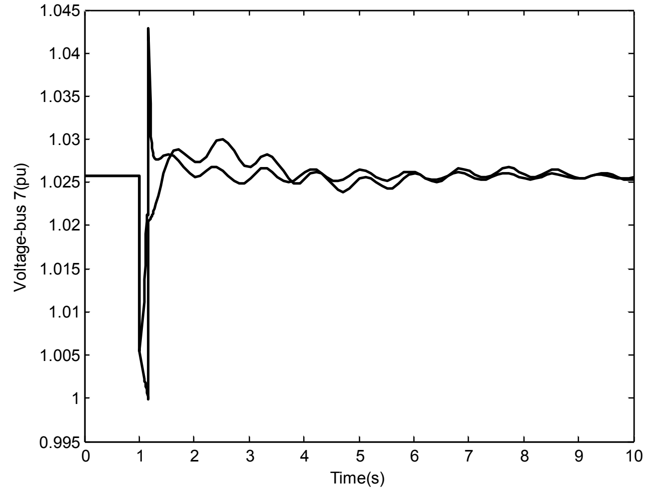

Figure 8. Voltage bus 7 following disturbance

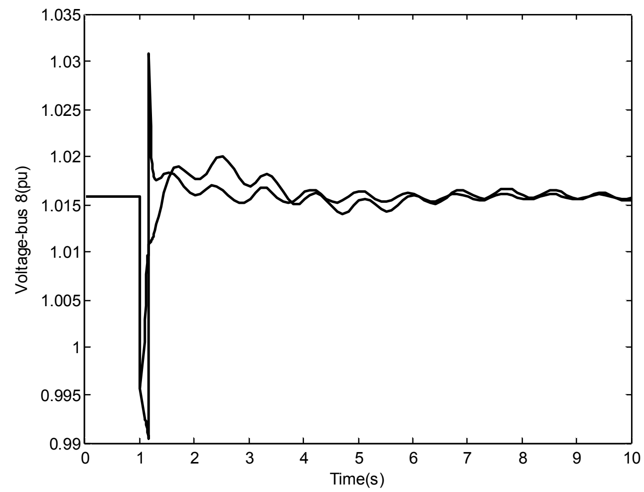

Figure 9. Voltage bus 8 following disturbance

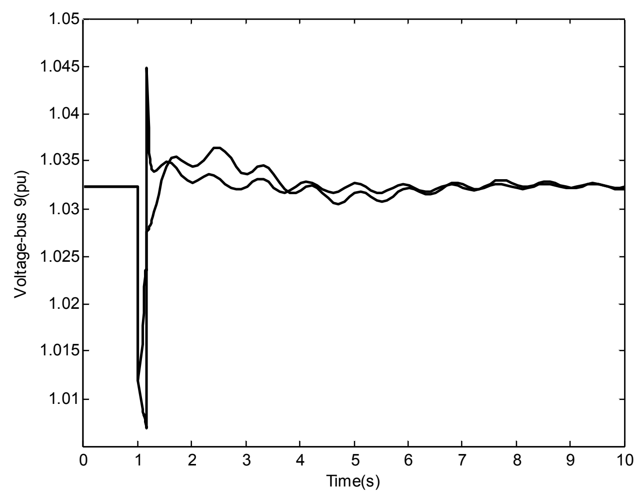

Figure 10. Voltage bus 9 following disturbance

6. Conclusions

The application of STATCOM in voltage support was investigated in this paper. A multi-machine electric power system installed with STATCOM was assumed to demonstrate the ability of STATCOM in voltage support. The parameters of the proposed STATCOM were tuned by using a Meta-heuristic optimization method. The proposed optimization procedure guaranteed the solution to reach a suitable and optimal response. Three phase short circuit was considered as disturbance, this is the worst case fault in power system which was assumed to evaluate the dynamic performance of system. Simulation results demonstrated that the designed STATCOM can guarantee the robust stability and robust performance under large signal disturbances.

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