Application of static synchronous compensator in multi machine power systems

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Abstract: Multi machine electric power systems are complicate and interconnected. Studying the performance of electric components in large electric power systems is very suitable and practical. In this regard, static synchronous compensator (STATCOM) is investigated in this paper. STATCOM is used to control of voltage and improvement of voltage profile in multi machine power systems. An optimization technique is used to tune the proposed STATCOM controllers. The results are compared with the system without STATCOM. Simulation results visibly show the ability of STATCOM in voltage support.
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1. Introduction

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. Simulated Annealing (SA) 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.

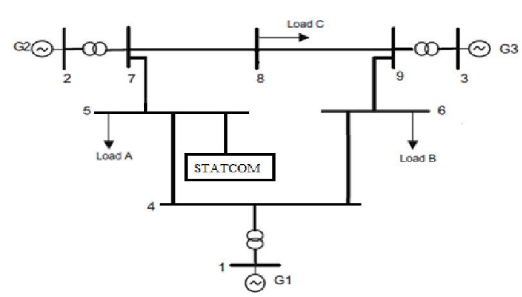

Figure 1. Multi-machine electric power system installed with STATCOM

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].

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

Where, δ: Rotor angle; ω: Rotor speed (pu); Pm: Mechanical input power; Pe: Electrical output power (pu); M: System inertia (Mj/MVA); E´q: Internal voltage behind x´d (pu); Efd: Equivalent excitation voltage (pu); T´do: Time constant of excitation circuit (s); Ka: Regulator gain; Ta: Regulator time constant (s); Vref: Reference voltage (pu); Vt: 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. Simulated Annealing

In the early 1980s the method of simulated annealing (SA) was introduced in 1983 based on ideas formulated in the early 1950s. This method simulates the annealing process in which a substance is heated above its melting temperature and then gradually cooled to produce the crystalline lattice, which minimizes its energy probability distribution. This crystalline lattice, composed of millions of atoms perfectly aligned, is a beautiful example of nature finding an optimal structure. However, quickly cooling or quenching the liquid retards the crystal formation, and the substance becomes an amorphous mass with a higher than optimum energy state. The key to crystal formation is carefully controlling the rate of change of temperature.

The algorithmic analog to this process begins with a random guess of the cost function variable values. Heating means randomly modifying the variable values. Higher heat implies greater random fluctuations. The cost function returns the output, *f*, associated with a set of variables. If the output decreases, then the new variable set replaces the old variable set. If the output increases, then the output is accepted provided that:

$$r \le e^{[f(P_{old})-f(P_{new})]/T} \quad (2)$$

Where, *r* is a uniform random number and *T* is a variable analogous to temperature. Otherwise, the new variable set is rejected. Thus, even if a variable set leads to a worse cost, it can be accepted with a certain probability. The new variable set is found by taking a random step from the old variable Set as (3).

$$P^{new}=dP^{old} \quad (3)$$

The variable *d* is either uniformly or normally distributed about p^{old}. This control variable sets the step size so that, at the beginning of the process, the algorithm is forced to make large changes in variable values. At times the changes move the algorithm away from the optimum, which forces the algorithm to explore new regions of variable space. After a certain number of iterations, the new variable sets no longer lead to lower costs. At this point the value of T and d decrease by a certain percent and the algorithm repeats. The algorithm stops when $T\simeq 0$.The decrease in *T* is known as the cooling schedule. Many different cooling schedules are possible. If the initial temperature is T_0 and the ending temperature is T_N, then the temperature at step *n* is given by (4).

$$T_n = f(T_0, T_N, N, n) \quad (4)$$

Where, *f* decreases with time. Some potential cooling schedules are as follows:

Linearly decreasing: $T_n=T_0-n(T_0-T_n)/N$

Geometrically decreasing: $T_n=0.99\ T_{n-1}$

Hayjek optimal: $T_n = c/\log(1+n)$, where c is the smallest variation required to get out of any local minimum.

Many other variations are possible. The temperature is usually lowered slowly so that the algorithm has a chance to find the correct valley before trying to get to the lowest point in the valley. This algorithm has been applied successfully to a wide variety of problems [9].

4. STATCOM tuning based on SA

In this section the parameters of the STATCOM controllers are tuned by using SA. The optimum values of controllers which minimize different performance indices are accurately computed using SA. The performance index is considered as (5). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$\mathrm{ITAE} = \int_0^t t \sum_{i=1}^{3} |\Delta\omega_i|\, dt + \int_0^t t \sum_{i=1}^{9} |\Delta v_i|\, dt + \qquad (5)$$

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	1.2
	Integrator gain	0.4
PI controller of DC link	Proportional gain	23.6
	Integrator gain	0.35

5. Simulation results

The proposed STATCOM is evaluated on the test system given in section 2. The disturbance is provided by disconnection of line between bus 8 and bus 9. 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 bus 5 and bus 1 are depicted in Figures 2-3. 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 bus 1 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. Figures 4-6 show the speed of generators following disturbance. 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.

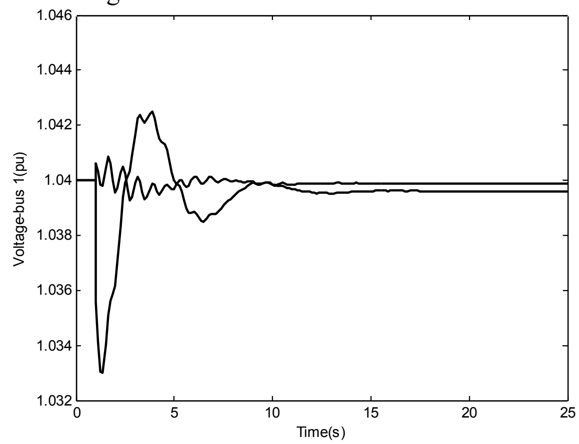

Figure 2. Voltage bus 1 following disturbance

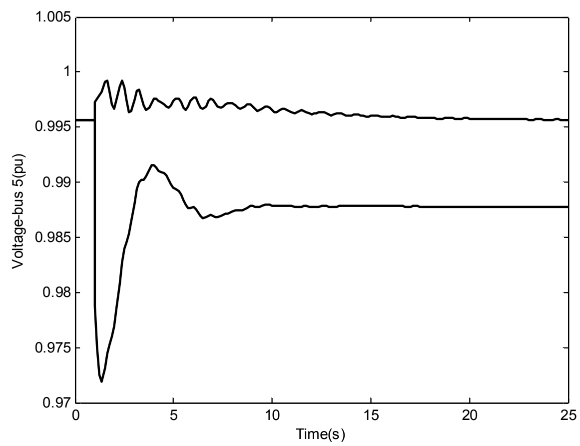

Figure 3. Voltage bus 5 following disturbance

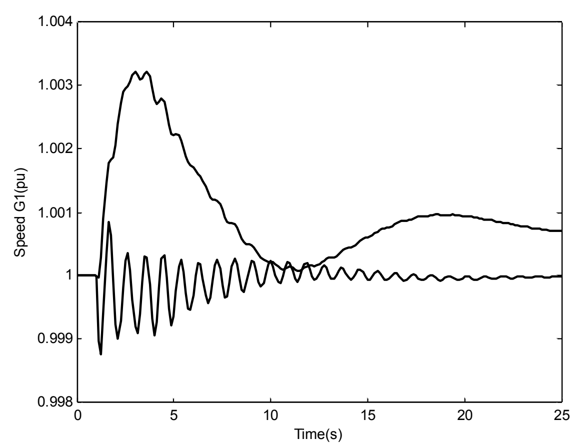

Figure 4. Speed G_1 following disturbance

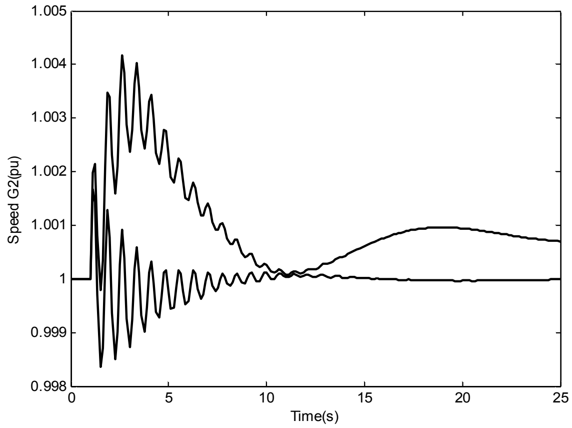

Figure 5. Speed G_2 following disturbance

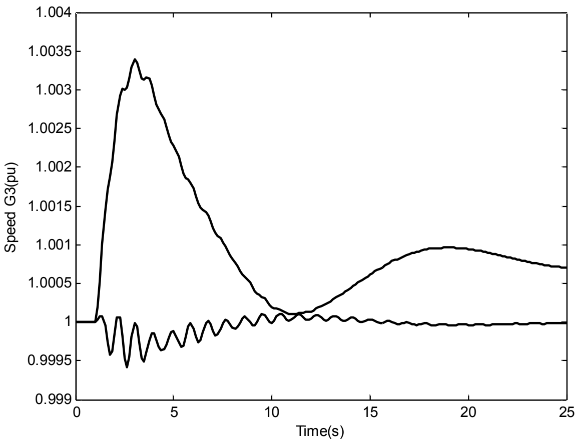

Figure 6. Speed G_3 following disturbance

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. Line disconnection 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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References

[1] N.G. Hingorani, L. Gyugyi, M. El-Hawary, Understanding FACTS: concepts and technology of flexible AC transmission systems: IEEE press New York; 2000.
[2] AHMA Rahim, M.F. Kandlawala, Robust STATCOM voltage controller design using loop-shaping technique, Electric Power Systems Research. 68 (2004) 61-74.
[3] C.A. Cañizares, C. Cavallo, M. Pozzi, S. Corsi, Comparing secondary voltage regulation and shunt compensation for improving voltage stability and transfer capability in the Italian power system. Electric Power Systems Research. 73 (2005) 67-76.
[4] M.A. Abido, Analysis and assessment of STATCOM-based damping stabilizers for power system stability enhancement. Electric Power Systems Research. 73 (2005)177-85.
[5] S.A. Al-Baiyat, Power system transient stability enhancement by STATCOM with nonlinear H∞ stabilizer. Electric Power Systems Research. 73 (2005) 45-52.
[6] W. Du, X. Wu, H.F. Wang, R. Dunn, Feasibility study to damp power system multi-mode oscillations by using a single FACTS device, International Journal of Electrical Power & Energy Systems. 32 (2010) 645-55.
[7] M.A. Furini, A.L.S. Pereira, P.B. Araujo, Pole placement by coordinated tuning of Power System Stabilizers and FACTS-POD stabilizers, International Journal of Electrical Power & Energy Systems. 33 (2011) 615-22.
[8] P.W. Sauer, M. Pai, Power system dynamics and stability: Prentice Hall New Jersey; 1998.
[9] R.L. Haupt, S.E. Haupt, Practical genetic algorithms: Wiley-Interscience; 2004.

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