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Voltage Control Using STATCOM Tuned Based on Particle Swarm Optimization in a Multi-Machine Power System

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Abstract: This paper presents the application of static synchronous compensator (STATCOM) to voltage support in a multi-machine electric power system. Particle Swarm Optimization (PSO) method as a meta-heuristic optimization method is considered for tuning the parameters of STATCOM. To show effectiveness of STATCOM in voltage support, a multi-machine electric power system installed with STATCOM is considered as case study. The results are compared with the system without STATCOM. Several nonlinear time-domain simulation tests visibly show the ability of STATCOM in voltage support.

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

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 conditions [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 [1].

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 [2-6]. Also it can be used for transient stability improvement by damping low frequency power system oscillations [7-10].

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 a STATCOM is considered as case study. The preferences of the proposed method are its feasibility and simplicity. Different load conditions are considered to study the performance of STATCOM. Simulation results show the validity of STATCOM in voltage support at large electric power systems.

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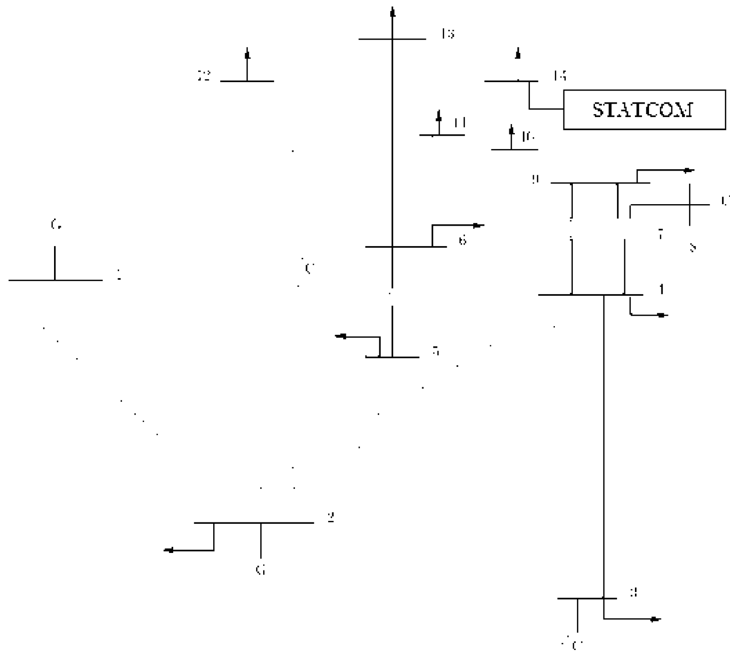

Fig. 1: Multi-machine electric power system installed with STATCOM

The Rest of paper is structured as follows: In section 2, STATCOM model and also dynamic model of multi-machine system containing STATCOM is presented. In section 3, a brief description about PSO technique is given. In section 4, adjustment of STATCOM based on PSO is discussed. In section 5, simulation results are presented. And finally, the paper is concluded in section 6.

System under Study: In this paper IEEE 14 bus test system is considered to evaluate the proposed method. The system data are completely given in IEEE standards. Figure 1 shows the system with a STATCOM installed in bus 14. Detail of the system data are given in [11]. To evaluate 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. Where, in the heavy condition, the active and reactive powers of loads are considered by 100% increasing from the nominal vales. Also, in this paper, turbine-governor system is also modeled to eliminate steady state error of responses.

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 [12].

$$\begin{cases} \dot{\omega} = (P_m - P_e - D?)/M \\ \dot{\delta} = \omega_0(\omega - 1) \\ \dot{E}_q = (-E_q + E_{fd})/T_{do} \\ \dot{E}_{fd} = (-E_{fd} + K_a(V_{ref} - V_t))/T_a \\ \dot{b}_{SVC} = (K_r(V_{ref} - V) - b_{SVC})/T_r \end{cases} \quad (1)$$

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.

STATCOM Controllers: In this paper two control strategies are considered for STATCOM:

- DC-voltage regulator.
- Bus-voltage regulator

STATCOM has two internal controllers which are Bus voltage controller and DC voltage regulator.

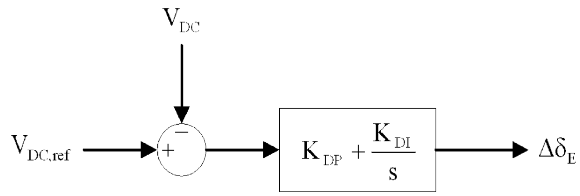

Fig. 2: DC-volage regulator

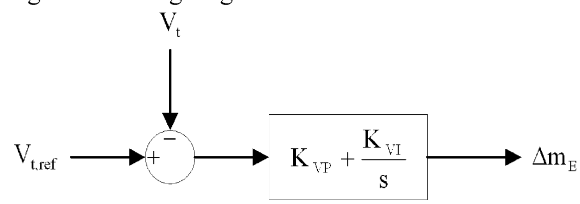

Fig. 3: Bus voltage controller

The real power output of the shunt converter must be equal to the real power input of the series converter or vice versa. In order to maintain the power balance between the two converters, a DC-voltage regulator is incorporated. DC-voltage is regulated by modulating the phase angle of the shunt converter voltage. Figure 2 shows the structure of the DC-voltage regulator. Also figure 3 shows the structure of the bus voltage controller. The bus voltage controller regulates the voltage of bus during post fault in system.

The most important subject is to tuning the STATCOM controller parameters K_{DP}, K_{DI}, K_{VP} and K_{DI}. 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 PSO is considered for tuning STATCOM 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 begins with a random population matrix. It has no evolution operators such as crossover and mutation. The rows in the matrix are called particles. 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 (2) and (3):

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

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

Where, $V_{m,n}$: Particle velocity; $P_{m,n}$: Particle variables; W: Inertia weight; r_1, r_2: Independent uniform random numbers; Γ_1, Γ_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 [13].

STATCOM Tuning Based on PSO: In this section the parameters of the STATCOM controllers are tuned using PSO. The optimum values of K_{DP}, K_{DI}, K_{VP} and K_{DI} 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 (4). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^t t\,|\Delta\omega_1|\,dt + \int_0^t t\,|\Delta\omega_2|\,dt + \int_0^t t\,|\Delta\omega_3|\,dt + \int_0^t t\,|\Delta\omega_4|\,dt + \int_0^t t\,|\Delta\omega_5|\,dt \quad (4)$$

Where, $\Delta\omega$ shows the frequency deviations. 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 1.

Table 1: Optimal parameters of STATCOM using PSO

Parameter	Optimal value
K_{DP}	33.411
K_{DI}	4.033
K_{VP}	49.615.061
K_{VI}	0.3717

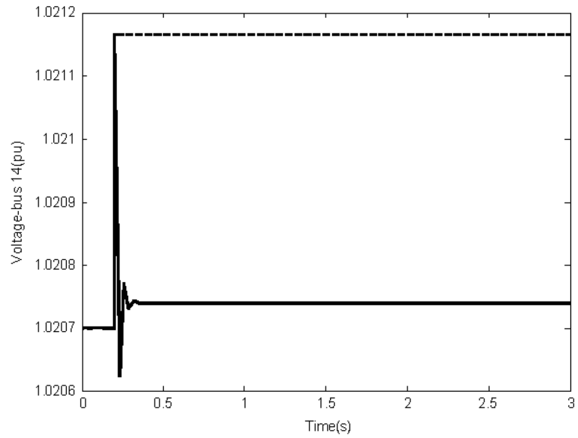

Fig. 4: Voltage of bus number 14 under scenario 1 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

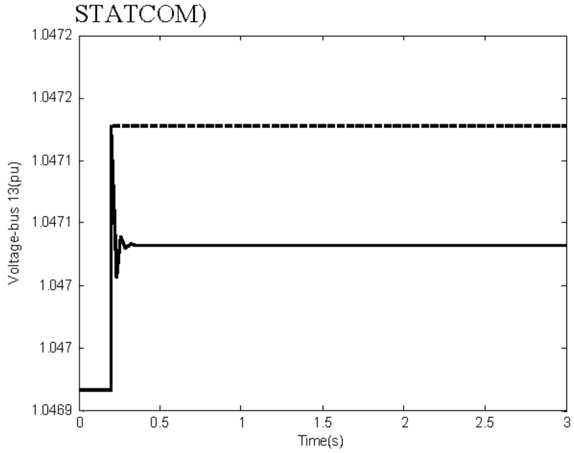

Fig. 5: Voltage of bus number 13 under scenario 1 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

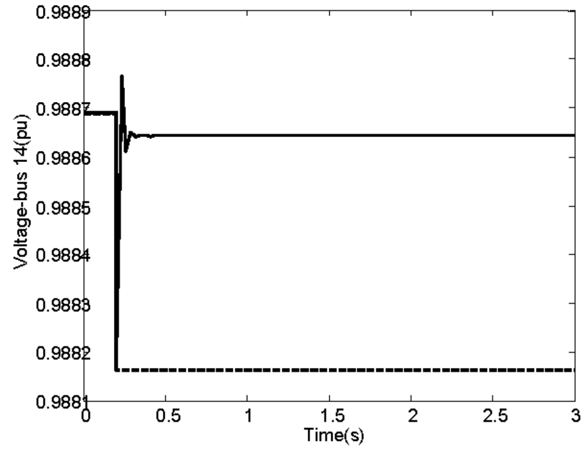

Fig. 6: Voltage of bus number 14 under scenario 1 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

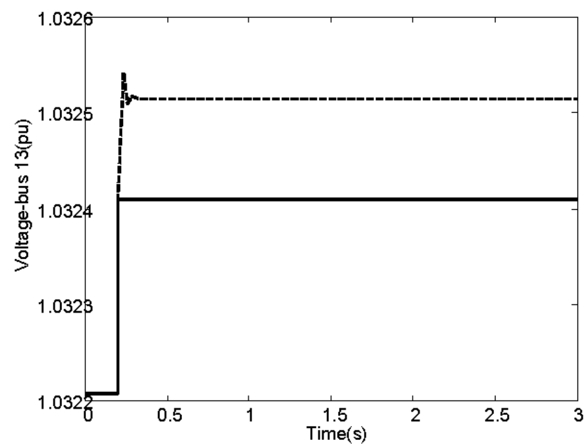

Fig. 7: Voltage of bus number 13 under scenario 1 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

Simulation Results: In this section, the PSO-based STATCOM is exerted to voltage support in the under study system. In order to study and analysis system performance under different scenarios, two scenarios are considered as follows:

Scenario 1: Disconnection of the line between bus 7 and bus 9 by breaker.

Scenario 2: 20 cycle three phase short circuit in bus 10.

It should be noted that this tuning have been done for the nominal operating condition. The simulation results are presented in figures 4-11.

Each figure contains two plots; solid line which indicates the system installed with STATCOM and dashed line for system without STATCOM. The STATCOM is placed in bus 14.

As it is clear from the figures, in case with STATCOM, the voltage of bus 14 which installed with STATCOM is controlled very well. Where, the bus voltage is driven back to the nominal value during post-fault. However, bus voltage without STATCOM is not driven back to nominal value and contains a steady state error. It should be noted that although STATCOM has been used for the purpose of controlling the voltage of bus number 14, it has also a good effect on the voltage of other buses. For example, the voltage of bus 13

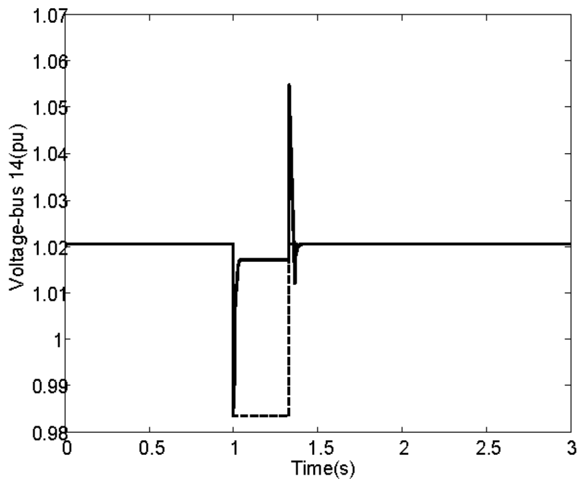

Fig. 8: Voltage of bus number 14 under scenario 2 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

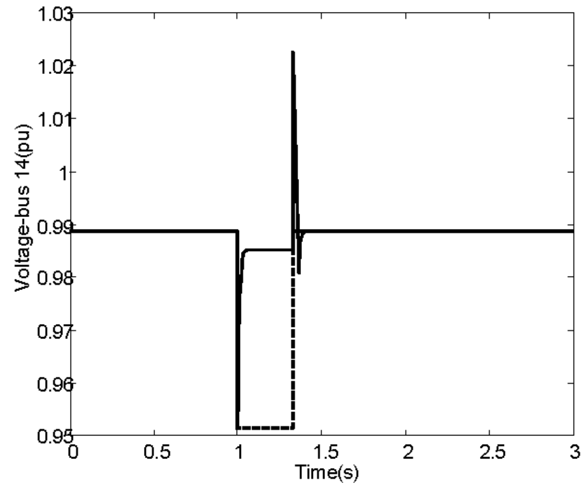

Fig. 10: Voltage of bus number 14 under scenario 2 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

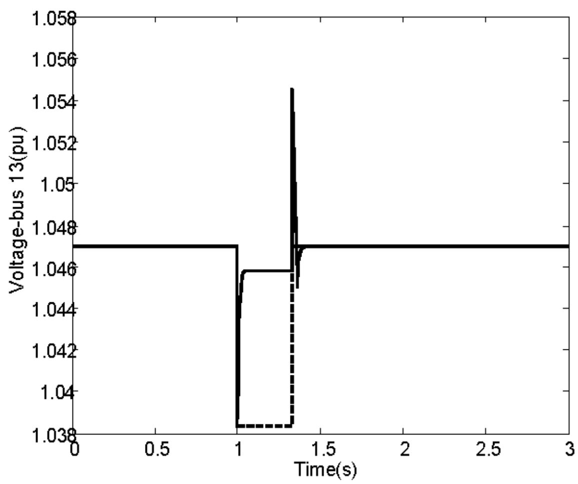

Fig. 9: Voltage of bus number 13 under scenario 2 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

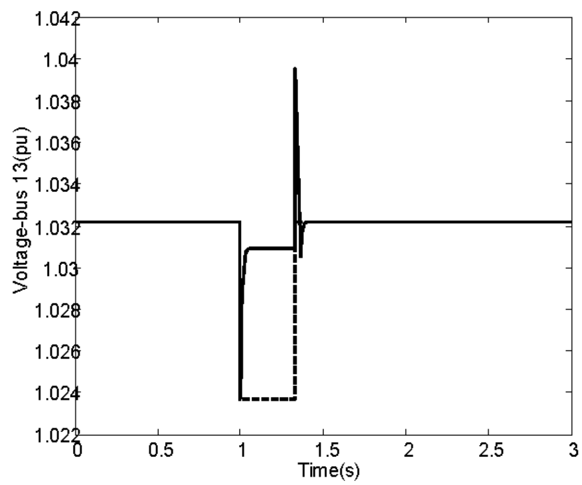

Fig. 11: Voltage of bus number 13 under scenario 2 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

in the case of having STATCOM has less error comparing with the case of lack of STATCOM.

In general, STATCOM not only controls the voltage of buses which installed on it, but also controls the voltage of the other buses and has direct good effect on the system stability.

Also, the system responses have fewer fluctuations when STATCOM is included. Therefore STATCOM is beneficial for the system stability.

System responses in heavy load condition have been demonstrated. As is clear these figures, by increasing system load and resultant heavier operation condition, STATCOM has good performance in voltage control and cause the voltage to return to its nominal value.

The voltages of bus number 14 and 13 under second scenario have been shown in figures 8 to 11. In this scenario, a three phase short circuit fault occurs and then it is removed. So the system operation point doesn't change and voltages return to nominal value with and without STATCOM. But it should be noted that STATCOM has tremendous effect on damping of oscillations and make the system response faster.

CONCLUSIONS

In this paper Particle Swarm Optimization (PSO) method has been successfully exerted to adjust STATCOM parameters. A multi-machine electric power system installed with a STATCOM with various load conditions and disturbances has been assumed to demonstrate the ability of STATCOM in voltage support. Considering real world type disturbances such as three phase short circuit and line disconnection guarantee the results in order to implementation of controller in industry. Simulation results demonstrated that the designed STATCOM capable to guarantee the robust stability and robust performance under a different load conditions and disturbances. Also, simulation results show that the PSO technique has an excellent capability in STATCOM parameters tuning. Application to a multi-machine electric power system which is near to practical systems can increase admission of the technique for real world applications.

REFERENCES

1. Hingorani, N.G., L. Gyugyi, 2000. Understanding FACTS. IEEE Press.
2. Slepchenkov, M.N., K.M. Smedley and J. Wen, 2011. Hexagram-Converter-Based STATCOM for Voltage Support in Fixed-Speed Wind Turbine Generation Systems. IEEE Transactions on Industrial Electronics, 58(4): 1120-1131.
3. Li, K., J. Liu, Z. Wang and B. Wei, 2007. Strategies and Operating Point Optimization of STATCOM Control for Voltage Unbalance Mitigation in Three-Phase Three-Wire Systems. IEEE Transactions on Power Delivery, 22(1): 413-422.
4. Singh, B., S.S. Murthy and S. Gupta, 2004. Analysis and design of STATCOM-based voltage regulator for self-excited induction generators. IEEE Transactions on Energy Conversion, 19(4): 783-790.
5. Lahaçani, N.A., D. Aouzellag and B. Mendil, 2010. Static compensator for maintaining voltage stability of wind farm integration to a distribution network. Renewable Energy, 35(11): 2476-2482.
6. Valderrábano, A. and J.M. Ramirez, 2010. StatCom regulation by a fuzzy segmented PI controller. Electric Power Systems Res., 80(6): 707-715.
7. Chatterjee, D. and A. Ghosh, 2011. Improvement of transient stability of power systems with STATCOM-controller using trajectory sensitivity. Int. J. Electrical Power & Energy Systems, 33(3): 531-539.
8. Padiyar, K.R. and N. Prabhu, 2006. Design and performance evaluation of subsynchronous damping controller with STATCOM. IEEE Transactions on Power Delivery, 21(3): 1398-1405.
9. Furini, M.A., A.L.S. Pereira and P.B. Araujo, 2011. Pole placement by coordinated tuning of Power System Stabilizers and FACTS-POD stabilizers. Int. J. Electrical Power & Energy Systems, 33(3): 615-622.
10. Hemmati, R., S.M. Shirvani Boroujeni, E. Behzadipour and H. Delafkar, 2011. Supplementary stabilizer design based on STATCOM. Indian J. Sci. and Technol., 4(5): 525-529.
11. University of Washington, electrical engineering department, power system test case archive, power flow test cases, IEEE 14 bus test system.
12. Wang, H.F., 1999. Phillips-Heffron model of power systems installed with STATCOM and applications. IEE Proc. Generation, Trans. and Distribution, 146(5): 521-527.
13. Randy, L.H. and E. H. Sue, 2004. Practical Genetic Algorithms, Second Edition, John Wiley & Sons.