

## Effect of Using STATCOM Tuned Based on Genetic Algorithms on Voltage Support Improvement

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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. Genetic Algorithms (GA) 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:** Flexible AC Transmission Systems • Static Synchronous Compensator • Voltage Support • Multimachine Electric Power System • Genetic Algorithms

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### 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. Genetic Algorithms (GA) 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.

**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 GA technique is given. In section 4, adjustment of STATCOM based on GA 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 values. 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].

$$\begin{cases} \dot{\omega} = (P_m - P_e - D\omega) / M \\ \dot{\delta} = \omega(\omega - 1) \\ \dot{E}_q' = (-E_q' + E_{fd}) / T_{do}' \\ \dot{E}_{fd} = (-E_{fd} + K_a(V_{ref} - N_t)) / T_a \\ \dot{b}_{svc} = (K_r(V_{ref} - V) - b_{svc}) / T_r \end{cases} \quad (10)$$

Where,  $\delta$ : Rotor angle;  $\omega$ : 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  $\delta_E$ , exchanging active power between the STATCOM and the power system is controlled.

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

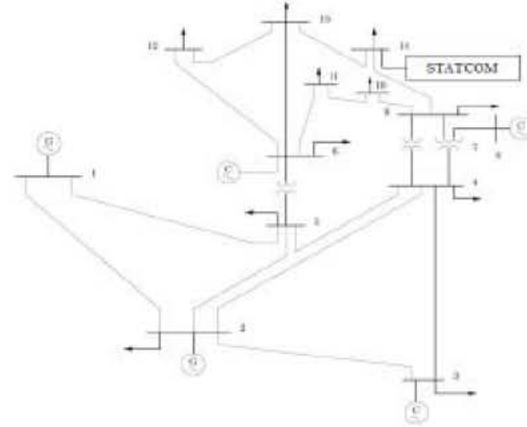


Fig. 1: Multi-machine electric power system installed with STATCOM

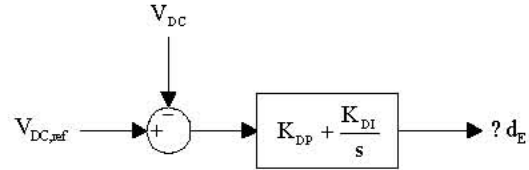


Fig. 2: DC-voltage regulator

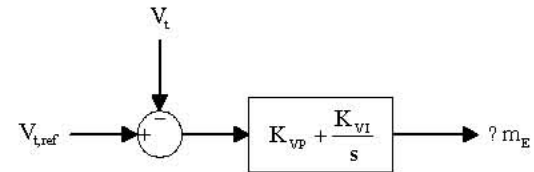


Fig. 3: Bus voltage controller

- DC-voltage regulator
- Bus-voltage regulator

STATCOM has two internal controllers which are Bus voltage controller and DC voltage regulator. 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  $K_{vl}$ . 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 GA is considered for tuning STATCOM parameters. In the next section an introduction about GA is presented.

**Genetic Algorithms:** Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics. They operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g. the binary alphabet  $\{0,1\}$ , so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation [13].

**STATCOM Tuning Based on GA:** In this section the parameters of the STATCOM controllers are tuned using GA. The optimum values of  $K_{DP}$ ,  $K_{DI}$ ,  $K_{VP}$  and  $K_{VI}$  which minimize different performance indices are accurately computed using GA. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (2). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

Table 1: Obtained values of STATCOM controller by using GA

Parameter	Optimal value
$K_{DP}$	30.77
$K_{DI}$	4.208
$K_{VP}$	50.044
$K_{VI}$	0.3591

$$ITAE = \int_0^t t |\Delta\omega_1| dt + \int_0^t t |\Delta\omega_2| dt + \int_0^t t |\Delta\omega_3| dt + \int_0^t t |\Delta\omega_4| dt + \int_0^t t |\Delta\omega_5| dt + \quad (2)$$

Where,  $\Delta\omega$  shows the frequency deviations and “ $t$ ” is the simulation time. The simulation time is considered from zero to 100 seconds. 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 GA. In order to acquire better performance, population size, number of chromosomes, number of iteration, mutation rate and crossover rate are chosen as 24, 4, 70, 0.05 and 0.5, respectively. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 1. In the proposed search, the limits of the parameters ( $K_{DP}$ ,  $K_{DI}$ ,  $K_{VP}$  and  $K_{VI}$ ) are chosen from 0.1 to 100.

**Simulation Results:** In this section, the GA-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 4 and bus 5 by breaker

**Scenario 2:** 10 cycle three phase short circuit in bus 12

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

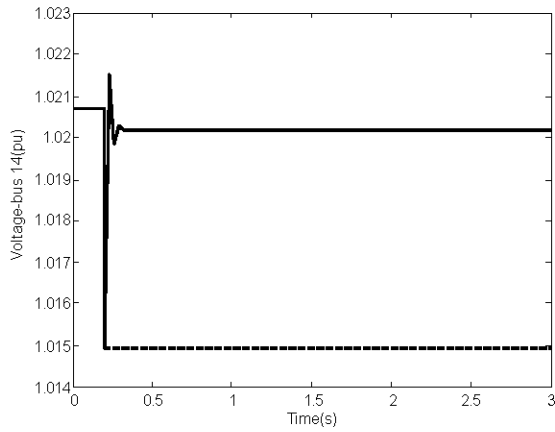


Fig. 4: Voltage of bus number 14 under scenario 1 in nominal load condition Solid (with STATCOM); Dashed (without STATCOM)

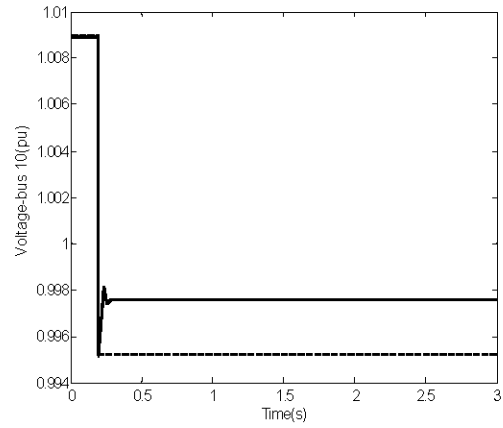


Fig. 7: Voltage of bus number 10 under scenario 1 in heavy load condition Solid (with STATCOM); Dashed (without STATCOM)

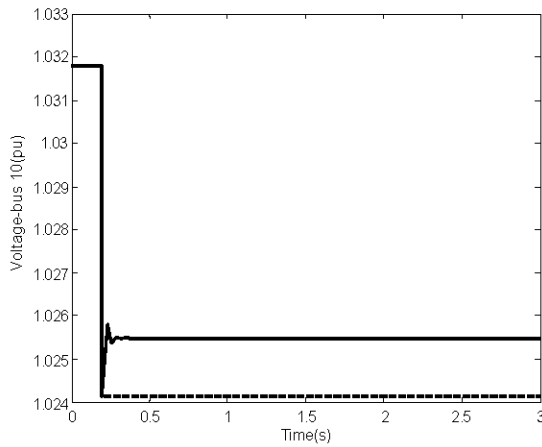


Fig. 5: Voltage of bus number 10 under scenario 1 in nominal load condition Solid (with STATCOM); Dashed (without STATCOM)

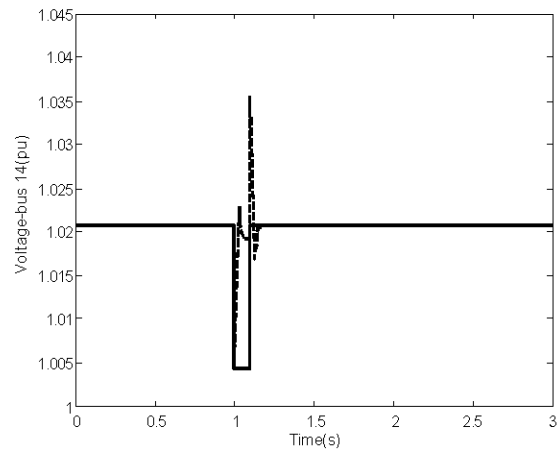


Fig. 8: Voltage of bus number 14 under scenario 2 in nominal load condition Solid (with STATCOM); Dashed (without STATCOM)

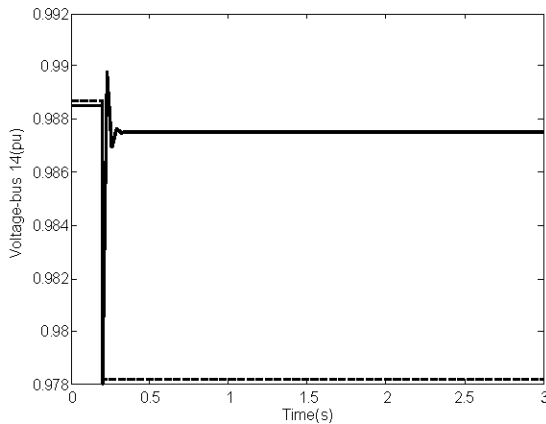


Fig. 6: Voltage of bus number 14 under scenario 1 in heavy load condition Solid (with STATCOM); Dashed (without STATCOM)

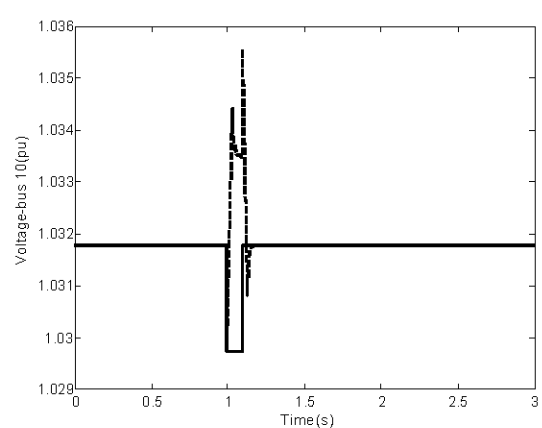


Fig. 9: Voltage of bus number 10 under scenario 2 in nominal load condition Solid (with STATCOM); Dashed (without STATCOM)

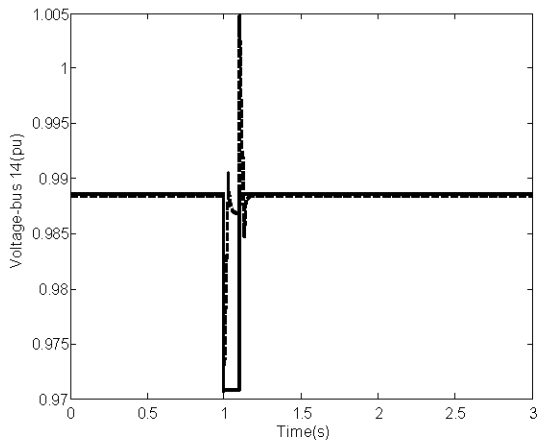


Fig. 10: Voltage of bus number 14 under scenario 2 in heavy load condition Solid (with STATCOM); Dashed (without STATCOM)

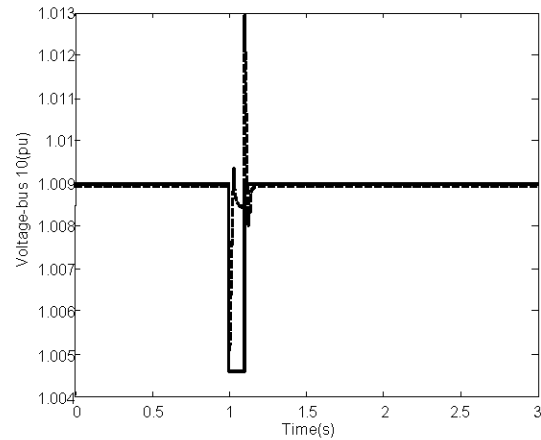


Fig. 11: Voltage of bus number 10 under scenario 2 in heavy load condition Solid (with STATCOM); Dashed (without STATCOM)

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 10 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 10 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 Genetic Algorithms (GA) 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 GA 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. and 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, 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. *International J. Electrical Power and Energy Sys.*, 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. *International J. Electrical Power and Energy Sys.*, 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. Science 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 Sys.*,
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 and Sons.