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STATCOM Tuned based on Tabu Search for Voltage Support in Power Systems

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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. Tabu search (TS) 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.

Keywords: Static Synchronous Compensator; Voltage Support; Multi-machine Electric Power System; Tabu search

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. Tabu search (TS) 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 TS technique is given. In section 4, adjustment of STATCOM based on TS 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].

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

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 d_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:

i. DC-voltage regulator

ii. 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_{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 TS is considered for tuning STATCOM parameters. In the next section an introduction about TS is presented.

Tabu Search

Tabu search (TS) was first presented in its present form by Glover [13]; Many computational experiments have shown that TS has now become an established optimization technique which can compete with almost all known techniques and which - by its flexibility - can beat many classical procedures. Up to now, there is no formal explanation of this good behavior. Recently, theoretical aspects of TS have been investigated [14]. The success with TS implies often that a serious effort of modeling be done from the beginning. In TS, iterative procedure plays an important role: for most optimization problems no procedure is known in general to get directly an "optimal" solution.

The general step of an iterative procedure consists in constructing from a current solution x_i a next solution x_j *and* in checking whether one should stop there or perform another step.

In other hand, a neighborhood $N(x_i)$ is defined for each feasible solution x_i, and the next solution x_j is searched among the solutions in $N(x_j)$.

In this part we summarize the discrete TS algorithm in four steps. Assume that X is a total search space and x is a solution point sample and f (x) is cost function:

1- Choose x ∊ X to start the process.

2- Create a candidate list of non-Tabu moves in neighborhood. (x_i, i=1,2,...,N)

3-Find x_{winner} ∊ $N(x)$ such that $f(x_{winner}) < f(x_i)$, $i \neq winner$.

4- Check the stopping criterion. If satisfied, exit the algorithm. If not, winner $x = x_{winner}$, update Tabu List and then go to step 2.

In order to exit from algorithm, there are several criterions that are considered in our research.

1- by determining a predetermined threshold: If the value of cost function was less, algorithm would be terminated.

2- Determination of specific number of iterations.

3- If the value of the cost was remained invariable or negligible change for several iterations, algorithm would be terminated.

A didactic presentation of TS and a series of applications have been collected in [15].

STATCOM Tuning Based On TS

In this section the parameters of the STATCOM controllers are tuned using TS. The optimum values of K_{DP}, K_{DI}, K_{VP} and K_{DI} which minimize different performance indices are accurately computed using TS. 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).

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

Where, Dw 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 TS. 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.

Simulation Results

In this section, the TS-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 2 and bus 4 by breaker Scenario 2: 10% load change It should be noted that, in scenario 2, the load has two step changes. In first it is increased at 1 second and then driven back to the nominal load at 2th second; then the load is reduced at 3th second and driven back to the nominal load at 4th second. Also this tuning has been done for the nominal operating condition. The simulation results are presented in figures 4-11.

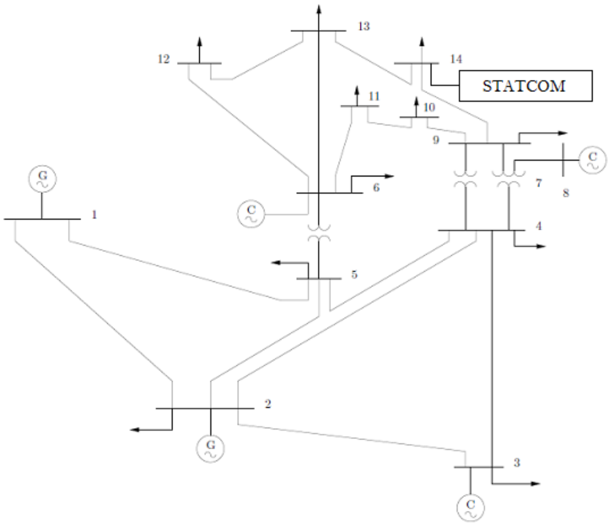

Fig.1. Multi-machine electric power system installed with STATCOM

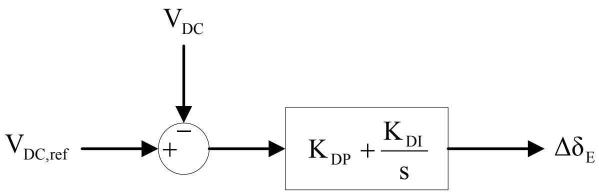

Fig.2. DC-voltage regulator

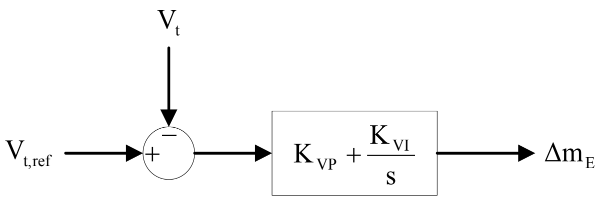

Fig.3.Bus voltage controller

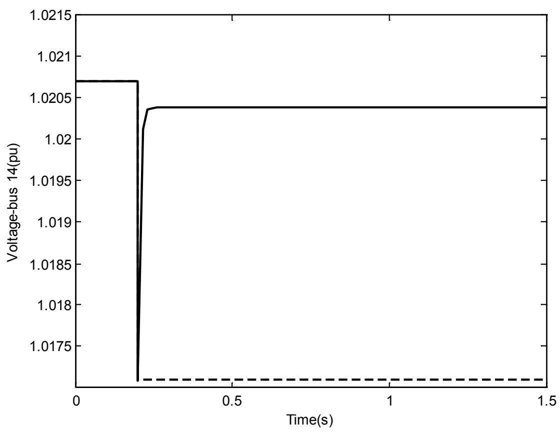

Fig.4. Voltage of bus number 14 under scenario 1 in nominal load condition

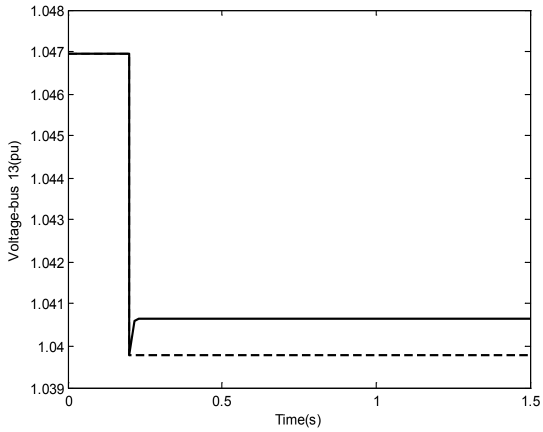

Fig.5. Voltage of bus number 13 under scenario 1 in nominal load condition

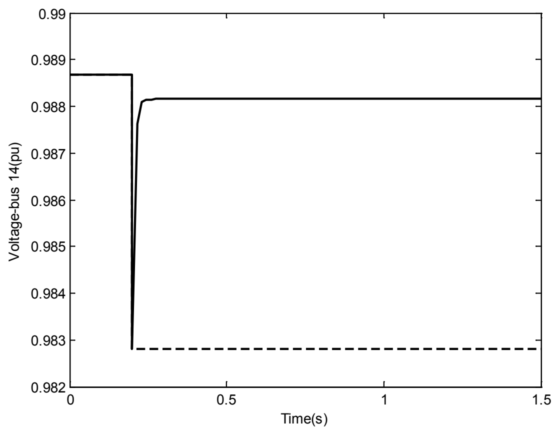

Fig6. Voltage of bus number 14 under scenario 1 in heavy load condition

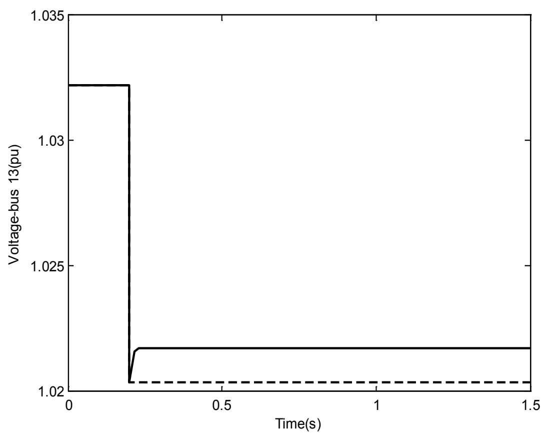

Fig.7. Voltage of bus number 13 under scenario 1 in heavy load condition

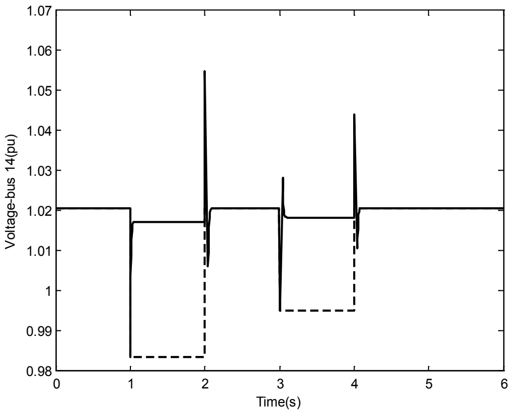

Fig.8. Voltage of bus number 14 under scenario 2 in nominal load condition

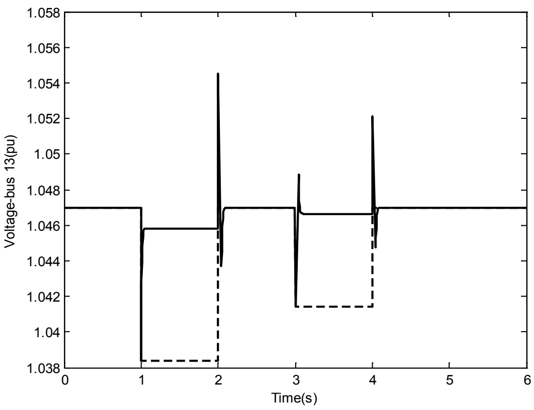

Fig.9. Voltage of bus number 13 under scenario 2 in nominal load condition Solid (with STATCOM); Dashed (without STATCOM)

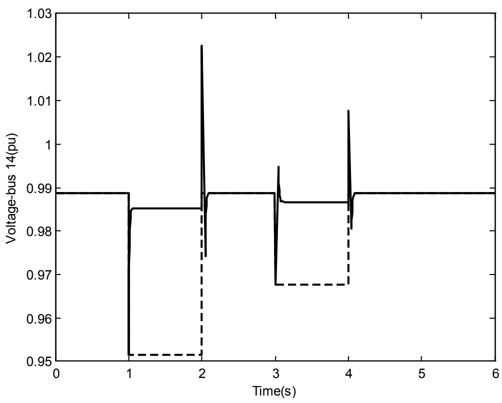

Fig.10. Voltage of bus number 14 under scenario 2 in heavy load condition Solid (with STATCOM); Dashed (without STATCOM)

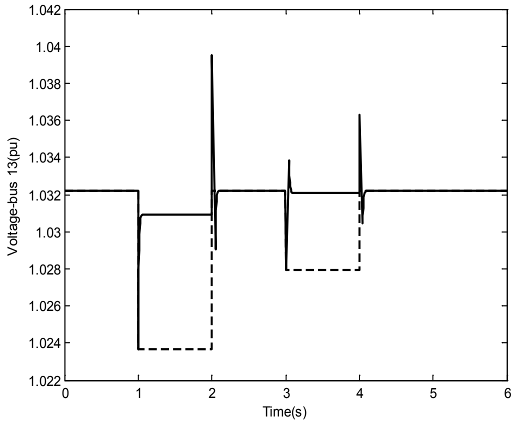

Fig.11. Voltage of bus number 13 under scenario 2 in heavy load condition

Table1. Optimal parameters of STATCOM using TS

Parameter	Optimal value
K_{DP}	30.19
K_{DI}	4.41
K_{VP}	51.91
K_{VI}	0.4091

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 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.

CONCLUSION

In this paper Tabu search (TS) 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 TS 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.

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