

Harmony search algorithm for STATCOM controllers tuning in a multi machine environment

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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. Harmony Search (HS) Algorithm as a meta-heuristic optimization method is considered for tuning the parameters of STATCOM. In order to evaluate the performance of STATCOM in voltage support, a multi-machine electric power system installed with STATCOM is considered as case study. The system under study is IEEE 14 bus standard system testing. 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, Multi-Machine Power System; Harmony Search, Algorithm

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 (Hingorani & Gyugyi, 2000).

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 (Hingorani & Gyugyi, 2000).

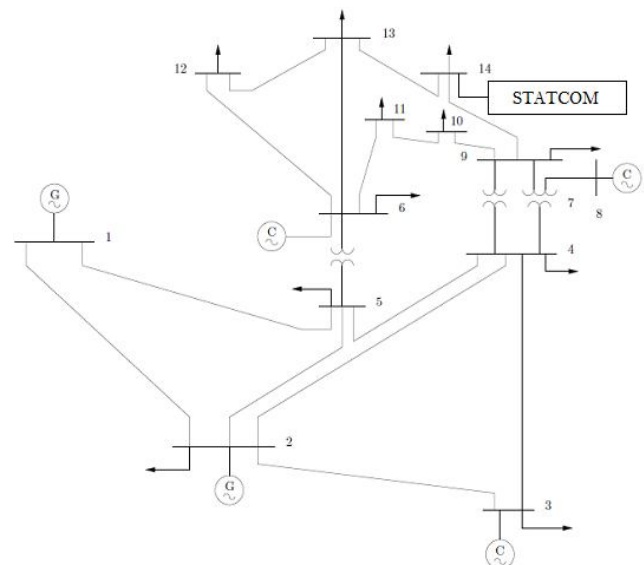
The static synchronous compensator (STATCOM) is one of the most important FACTS devices and it is based on the principle that a voltage-source inverter generates a controllable AC voltage source behind a transformer-leakage reactance so that the voltage difference across the reactance produces active 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 (Singh *et al.*, 2004; Li *et al.*, 2007; Lahaçani *et al.*, 2010; Valderrábano & Ramirez, 2010; Slepchenkov

et al., 2011). Also it can be used for transient stability improvement by damping low frequency power system

oscillations (Padiyar & Prabhu, 2006; Chatterjee & Ghosh, 2011; Furini *et al.*, 2011; Hemmati *et al.*, 2011).

The objective of this paper is to investigate the ability of STATCOM for voltage support. Harmony Search (HS) Algorithm 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

Fig.1. Multi-machine electric power system installed with STATCOM at bus 14



show the validity of STATCOM in voltage support at large electric power systems.

System under study

In this paper IEEE 14 bus system testing is considered to evaluate the proposed method. The system data are completely given in IEEE standards. Fig.1 shows the system with a STATCOM installed in bus 14. Detail of the system data are given in (University of Washington, electrical engineering department, power system test case archive, power flow test cases, IEEE 14 bus system testing). 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 (Wang, 1999).

$$\begin{cases} \dot{\omega} = (P_m - P_e - D\omega)/M \\ \dot{\delta} = \omega_0(\omega - 1) \\ \dot{E}'_q = (-E_q + E_{fd})/T'_{do} \\ \dot{E}'_{fd} = (-E_{fd} + K_a(V_{ref} - V_t))/T_a \\ \dot{V}_{dc} = \frac{3m_E}{4C_{dc}}(\sin(\delta_E)I_{Ed} + \cos(\delta_E)I_{Eq}) \end{cases} \quad (1)$$

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 considered for STATCOM are: i. DC-voltage regulator and 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. Fig.2 shows the structure of the DC-voltage regulator. Also Fig.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_{VI} . The system stability and suitable performance is

Fig. 2. DC-voltage regulator

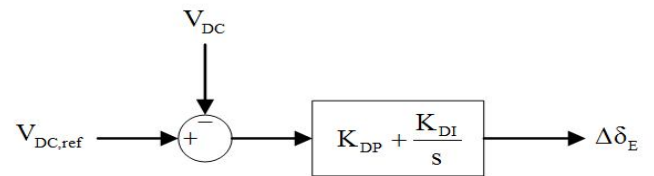
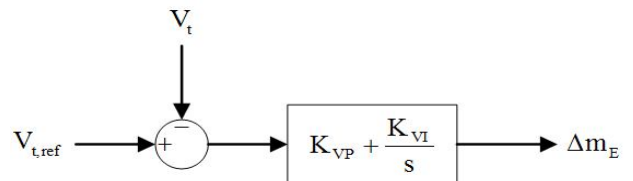


Fig. 3. Bus voltage controller



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 HS is considered for tuning STATCOM parameters. In the next section an introduction about HS is presented.

Harmony search algorithm

Harmony search (HS) algorithm is optimization method based on natural musical performance processes that occur when a musician searches for a better state of harmony, such as during jazz improvisation. The engineers seek for a global solution as determined by an objective function, just like the musicians seek to find musically pleasing harmony as determined by an aesthetic (Hong-qi *et al.*, 2008). The HS algorithms is investigated in electric power systems (Shirvani Boroujeni *et al.*, 2011).

STATCOM tuning based on HS

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

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



Where, $\Delta\omega$ shows the frequency deviations and t is simulation time. Time period of simulation is considered from zero to 20s. 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 HS. To implement HS, number of decision variables (N), Harmony memory size (HMS), number of improvisations (NI) and HMCR are chosen as 4, 60, 100 and 0.9 respectively. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 1. Where, the limits for parameters are from 0.1 to 100.

Simulation results

In this section, the HS-based STATCOM is exerted to voltage support in the under study system. In order to study and analysis system performance under different

Table 1. Optimal parameters of SVC using HS

SVC parameters	Optimal value
K_r	111.09
T_r	12.89

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 Fig. 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 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 Fig. 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.

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

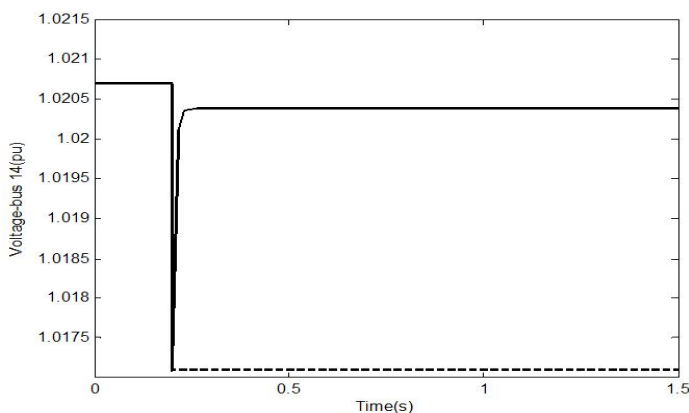


Fig. 5. Voltage of bus number 13 under scenario 1 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

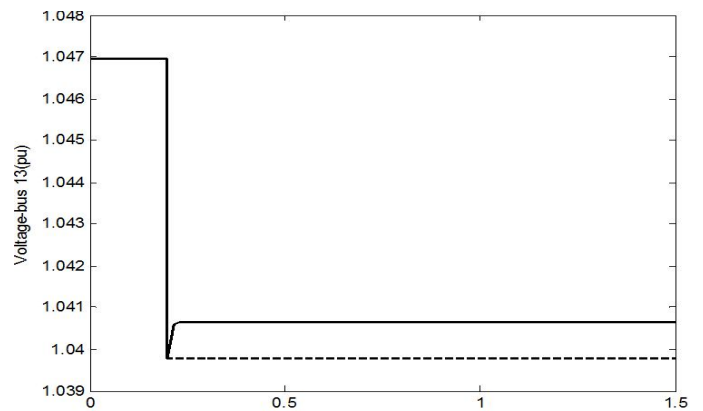




Fig. 6. Voltage of bus number 14 under scenario 1 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

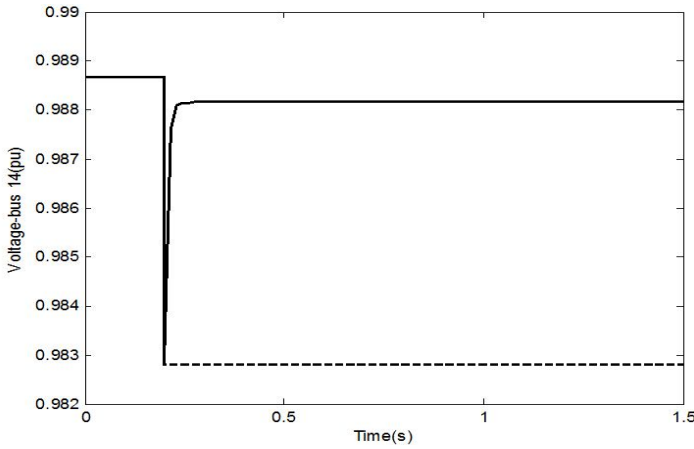


Fig. 7. Voltage of bus number 13 under scenario 1 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

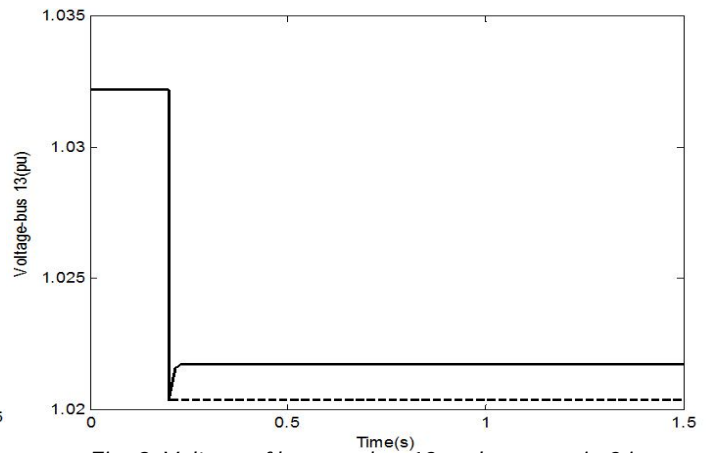


Fig. 8. Voltage of bus number 14 under scenario 2 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

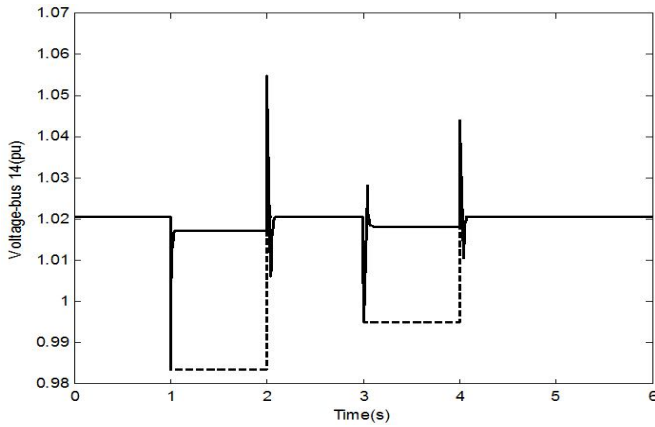


Fig. 9. Voltage of bus number 13 under scenario 2 in nominal load condition
Solid (with STATCOM); Dashed (without STATCOM)

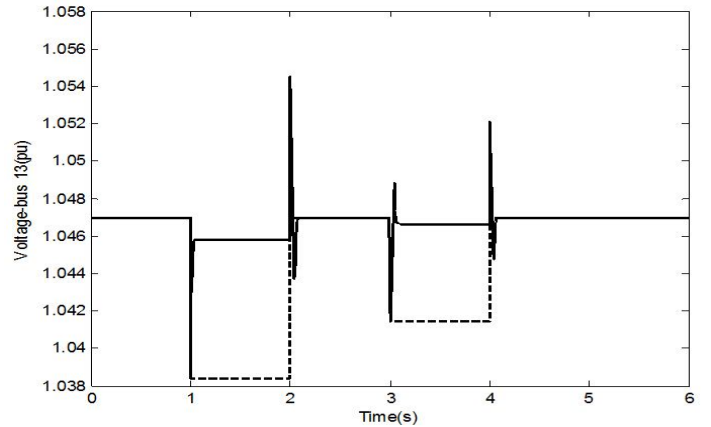


Fig. 10. Voltage of bus number 14 under scenario 2 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)

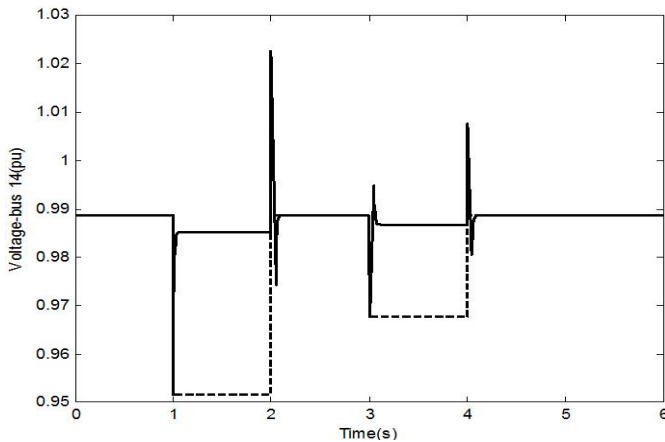
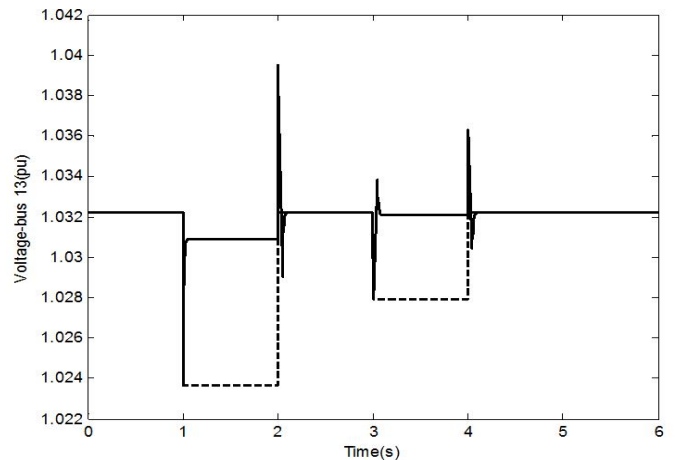


Fig. 11. Voltage of bus number 13 under scenario 2 in heavy load condition
Solid (with STATCOM); Dashed (without STATCOM)





Conclusions

In this paper Harmony Search Algorithm 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 HS 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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