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Optimal SSSC design for damping power systems oscillations via Gravitational Search Algorithm

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ABSTRACT

In recent years, various heuristic optimization methods have been developed. Many of these methods are inspired by swarm behaviors in nature. In this paper, a new optimization algorithm namely Gravitational Search Algorithm (GSA) based on the law of gravity and mass interactions is illustrated for designing Static Synchronous Series Compensator (SSSC) for single and multimachine power systems. In the proposed algorithm, the searcher agents are a collection of masses which interact with each other based on the Newtonian gravity and the laws of motion. The proposed method has been compared with some well-known heuristic search methods. The obtained results confirm the high performance of the proposed method in tuning SSSC compared with Bacteria Foraging (BF) and Genetic Algorithm (GA). Moreover, the results are presented to demonstrate the effectiveness of the proposed controller to improve the power systems stability over a wide range of loading conditions.

Introduction

The Flexible AC Transmission System (FACTS) is designed to overcome the limitations of the present mechanically controlled AC power transmission systems. By using reliable and high-speed power electronic controllers, the technology offers a great control on power flows of the prescribed transmission routes, secure loading of transmission lines to levels nearer their thermal limits, major ability to transfer power between controlled areas, prevention of cascading outages, and damping of power system oscillations [1,2].

FACTS can be classified into two generations. The first generation of FACTS devices has a common characteristic that is the required necessary reactive power for the compensation is generated or absorbed by traditional capacitor or reactor banks, and thyristor switches are used to control the combined reactive impedance. Consequently, conventional thyristor controlled compensator presents a variable reactive admittance to the transmission network. Some of the first generation of FACTS devices are: Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC).

In last few years, many researchers have posed techniques for designing SVC to enhance the damping of electromechanical oscillations of power systems, regulate the transmission voltage, and improve power quality [3–8]. The main advantage of SVCs over simple mechanically-switched compensation schemes is their near-instantaneous response to changes in the system voltage [2]. Also, they are cheaper, higher-capacity, faster and more reliable than dynamic compensation schemes such as synchronous condensers. However, SVCs are more expensive than mechanically switched capacitors and produce harmonic currents.

TCSC is one of the important members of FACTS family that is increasingly applied by the utilities in modern power systems with long transmission lines. It has various roles in the operation and control of power systems, such as scheduling power flow, reducing net loss, providing voltage support, limiting short circuit currents, mitigating sub-synchronous resonance, damping power oscillations and enhancing transient stability. On the other hand, TCSC is significantly affecting the impedance of the transmission system and, therefore, there is major danger of having resonance problem. The applications of TCSC for power oscillations damping and stability enhancement can be found in [9–14].

The second generation of FACTS controllers is based on Voltage Source Converter (VSC), which uses turn off devices like GTOs. These controllers require lower ratings of passive elements and the voltage source characteristics present several advantages over conventional variable impedance controllers. Some of the FACTS controllers belonging to this category are: Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) [2].

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STATCOM is an advanced SVC using VSC with capacitors connected on DC side. STATCOM resembles in many respects a rotating synchronous condenser used for voltage control and reactive power compensation. As compared to conventional SVC, STATCOM does not require expensive large inductors. Moreover, it can also operate as reactive power sink or source which makes STATCOM more attractive. Because of its several advantages over conventional SVC, it is expected to play a major role in the optimum and secure operation of AC transmission system in future. In addition, the speed of response of a STATCOM is faster than that of a SVC and the harmonic emission is reduced. On the other hand, STATCOMs typically exhibit higher losses and may be more expensive than SVCs, so the (older) SVC technology is still widespread. The development, design and use of STATCOM controllers in power system transmission and control have been discussed in [15–17].

SSSC as a second generation of FACTS has several advantages over the conventional one due to its storage element. Also, the main control objective of the SSSC is to directly control the current and indirectly the power flowing through the line by controlling the reactive power exchange between the SSSC and the AC system. The main advantage of this controller over a TCSC is that it does not significantly affect the impedance of the transmission system and, therefore, there is no danger of having resonance problem. The theory, modeling, and applications of SSSC have been illustrated in [18–23].

Several optimization techniques have been adopted to solve different engineering problems in the past decade. GA has attracted the attention in the field of controller parameter optimization. Although GA is very satisfactory in finding global or near global optimal result of the problem; it needs a very long run time that may be several minutes or even several hours depending on the size of the system under study. Moreover swarming strategies in bird flocking and fish schooling are used in the PSO and introduced in [24]. However, PSO suffers from the partial optimism, which causes the less exact at the regulation of its speed and the direction. Also, the algorithm cannot work out the problems of scattering and optimization [25]. In addition, the algorithm pains from slow convergence in refined search stage, weak local search ability and algorithm may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called BF scheme has been addressed by [26] and further established recently by [27]. The BF algorithm depends on random search directions which may lead to delay in reaching the global solution. GSA is a newly developed stochastic search algorithm based on the law of gravity and mass interactions [28–32]. This approach provides an iterative method that simulates mass interactions, and moves through a multi-dimensional search space under the influence of gravitation. In GSA, agents are considered as objects and their performances are measured by their masses; these objects attract each other by gravitational force which causes a global movement of all objects toward objects with heavier masses [28–32]. Also, it has been reported in the literature that GSA is more efficient in terms of CPU time and offers higher precision with more consistent results [33–35]. This new algorithm is adopted in this paper to design SSSC controller for various power systems.

This paper proposes a new optimization algorithm known as GSA for optimal designing of the SSSC to damp power systems oscillations. The performance of GSA has been compared with those of GA and BF in tuning the SSSC damping controller parameters for different power systems. The design problem of the proposed controller is formulated as an optimization problem and GSA is employed to search for optimal controller parameters. By minimizing the time domain objective function, in which the deviations in the speed are involved; stability performance of the system is improved. Simulation results assure the effectiveness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions. Also, these results validate the superiority of the proposed method in tuning controller compared with BF and GA.

Power system modeling

SSSC is installed in series with transmission line as shown in Fig. 1. The generator is represented by the third order model that comprising of the electromechanical swing equations and the generator internal voltage equation. The IEEE type ST1 excitation system is used [1]. Details of single machine infinite bus system (SMIB) data are given in Appendix.

$$\dot{\delta} = \omega_B(\omega - 1) \tag{1}$$

$$\dot{\omega} = \frac{1}{\tau_j}(P_m - P_e - D(\omega - 1)) \tag{2}$$

where P_m and P_e are the input and output powers of the generator, respectively; τ_j and D are the inertia constant and damping coefficient, respectively; δ and ω are the rotor angle and speed, respectively; ω_B is the synchronous speed.

The output power of the generator can be expressed in terms of the d axis and q axis components of the armature current and terminal voltage as following:

$$P_e = v_d i_d + v_q i_q \tag{3}$$

The internal voltage, E'_q, equation is shown below:

$$\dot{E}'_q = \frac{-1}{\tau'_{do}}E'_q + \frac{1}{\tau'_{do}}E_{fd} + \left(\frac{X_d - X'_d}{\tau'_{do}}\right)i_d \tag{4}$$

where E_{fd} is the field voltage; τ'_{do} is the open circuit field time constant; X_d and X'_d are the d axis reactance and d axis transient reactance of the generator, respectively.

Modeling of SMIB with SSSC

The SSSC is a VSC connected in series with the transmission line at its midpoint through an insertion transformer as shown in Fig. 1. The SSSC output voltage is defined by the following equation [36,37]:

$$\overline{V}_b = cV_{DC}(\cos\psi + j\sin\psi) \tag{5}$$

where c is the amplitude modulation ratio, ψ is the phase angle modulation ratio of the SSSC and V_{DC} is the SSSC DC voltage.

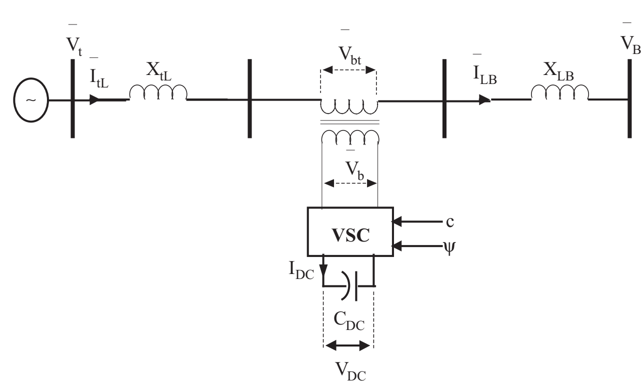

Fig. 1. SMIB with SSSC.