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Design and analysis of SSSC-based supplementary damping controller

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A B S T R A C T

Power-system stability improvement by a static synchronous series compensator (SSSC)-based damping controller is thoroughly investigated in this paper. The design problem of the proposed controller is formulated as an optimization problem, and real coded genetic algorithm (RCGA) is employed to search for the optimal controller parameters. Both local and remote signals with associated time delays are considered in the present study and a comparison has been made between the two signals. The performances of the proposed controllers are evaluated under different disturbances for both single-machine infinite-bus power system and multi-machine power system. Simulation results are presented and compared with a recently published modern heuristic optimization technique under various disturbances to show the effectiveness and robustness of the proposed approach.

1. Introduction

Series capacitive compensation was introduced decades ago to cancel a portion of the reactive line impedance and thereby increase the transmittable power. Recent development of power electronics introduces the use of flexible ac transmission systems (FACTS) controllers in power systems [1]. Subsequently, within the FACTS initiative, it has been demonstrated that variable series compensation is highly effective in both controlling power flow in the lines and in improving stability [2,3]. The voltage sourced converter based series compensator, called static synchronous series compensator (SSSC) provides the virtual compensation of transmission line impedance by injecting the controllable voltage in series with the transmission line. The ability of SSSC to operate in capacitive as well as inductive mode makes it very effective in controlling the power flow of the system [4,5].

An auxiliary stabilizing signal can also be superimposed on the power flow control function of the SSSC so as to improve power system oscillation stability [6]. Applications of SSSC for power oscillation damping, stability enhancement and frequency stabilization can be found in several references [7–10]. The influence of degree of compensation and mode of operation of SSSC on small disturbance and transient stability is also reported in the literature [11,12].

A number of conventional techniques have been reported in the literature pertaining to design problems of conventional power system stabilisers namely: the eigenvalue assignment, mathematical programming, gradient procedure for optimization and also the modern control theory. Unfortunately, the conventional techniques require heavy computation burden with slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal. The evolutionary methods constitute an approach to search for the optimum solutions via some form of

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directed random search process. A relevant characteristic of the evolutionary methods is that they search for solutions without previous problem knowledge. In recent years, new artificial intelligence-based approaches have been proposed to design a FACTS-based supplementary damping controller. These approaches include particle swarm optimization [13,14], genetic algorithm [15], differential evolution [16], multi-objective evolutionary algorithm [17]. In the design of an efficient and effective damping controller, selection of the appropriate input signal is a primary issue. Input signal must give correct control actions when a disturbance occurs in the power system. Most of the available literatures on damping controller design are based on either local signal or remote signal. Also the issues related to potential time delays due to sensor time constant and signal transmission delays are hardly addressed in the literature.

This paper investigates the design of a SSSC-based damping controller considering the potential time delays. Line active power as local signal and speed deviation as remote signal are considered as candidate input signals for the proposed SSSC-based damping controller. For controller design, real-coded genetic algorithm is employed to tune controller parameters. To show the robustness of the proposed design approach, simulation results are presented under various disturbance and faults for both single-machine infinite-bus and multi-machine power system. Also, a comparison has been made between remote and local signal and results are presented and analyzed. The effectiveness and superiority of the proposed design approach is illustrated by comparing the proposed approach with a recently published approach.

2. System model

2.1. Single-machine infinite-bus power system with SSSC

To design and optimize the SSSC-based damping controller, a single-machine infinite-bus system with SSSC, shown in Fig. 1, is considered at the first instance. The system comprises a synchronous generator connected to an infinite-bus through a step-up transformer and a SSSC followed by a double circuit transmission line. The generator is equipped with hydraulic turbine and governor (HTG) and excitation system. The HTG represents a nonlinear hydraulic turbine model, a PID governor system, and a servomotor. The excitation system consists of a voltage regulator and DC exciter, without the exciter's saturation function [18]. In Fig. 1, *T/F* represents the transformer; V_S and V_R are the generator terminal and infinite-bus voltages, respectively; V_1 and V_2 are the bus voltages; V_{DC} and V_{cnv} are the DC voltage source and output voltage of the SSSC converter, respectively; I is the line current and P_L and P_{L1} are the total real power flow in the transmission lines and that in one line, respectively. All the relevant parameters are given in Appendix A.

A SSSC is a solid-state voltage sourced converter (VSC), which generates a controllable AC voltage, and connected in series to power transmission lines in a power system. SSSC provides the virtual compensation of transmission line impedance by injecting the controllable voltage (V_q) in series with the transmission line. V_q is in quadrature with the line current, and emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The virtual reactance inserted by V_q influences electric power flow in the transmission lines independent of the magnitude of the line current [2]. The variation of V_q is performed by means of a VSC connected on the secondary side of a coupling transformer. The compensation level can be controlled dynamically by changing the magnitude and polarity of V_q and the device can be operated both in capacitive and inductive mode [1,4,5]. The VSC uses forced-commutated power electronic devices to produce an AC voltage from a DC voltage source. A capacitor connected on the DC side of the VSC acts as a DC voltage source. To keep the capacitor charged and to provide transformer and VSC losses, a small active power is drawn from the line. As presented in [14,17,18] VSC using IGBT-based PWM inverters is used in the present study. For further information about modeling of SSSC and its control system, please see Ref. [14].

The phasor solution method which is used in the present paper is mainly used to study electromechanical oscillations of power systems consisting of large generators and motors. In a transient stability study, the fast oscillation modes resulting from the interaction of linear R, L, C elements and distributed parameter lines are of no interest. These oscillation modes, which are usually located above the fundamental frequency of 50 Hz or 60 Hz, do not interfere with the slow machine modes and regulator time constants. In the phasor solution method, these fast modes are ignored by replacing the network's differential equations by a set of algebraic equations. The state-space model of the network is therefore replaced by a transfer

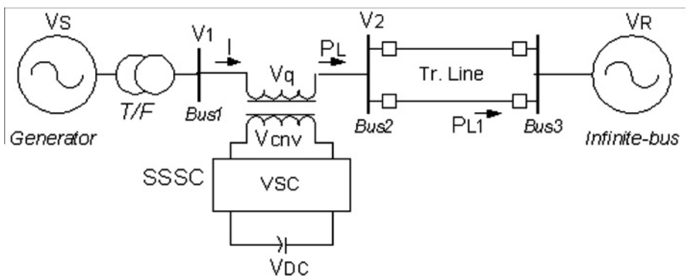

Fig. 1. Single-machine infinite-bus power system with SSSC.