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A new coordination strategy of SSSC and PSS controllers in power system using SOA algorithm based on Pareto method

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ABSTRACT

Along with the development of power grids and increasing the use of Flexible AC Transmission System (FACTS) devices, complex and unexpected interactions will be increased in power system. With considering to the non-linearity of power system, operating point changes and reaction between power system and FACTS devices, using of linear methods are not suitable for controller design. Therefore, the nonlinear model to design of Power System Stabilizer (PSS) and Static Synchronous Series Compensator (SSSC) coordinated controllers is considered here. In this paper, a new multi-objective function as an optimization problem is proposed for this coordination process. Also a beneficial strategy to solve this optimization problem using Seeker Optimization Algorithm (SOA) based on Pareto optimum method with high convergence speed is presented. In order to evaluate the performance of the proposed method, coordination strategy is applied on a four-machine system under different contingencies. The results of the proposed multi-objective function are obtained and compared with others in this system and finally, superior ability of the proposed method is observed.

Introduction

Problem statement and literature review

One of the most important issues in power system analysis is power system stability [1]. Long heavy loaded tie-lines in the wide spread interconnected power systems could be a source of different stability problems [2]. Thus, in recent decades, different methods have been used to design a suitable stabilizer. Due to the increasing the application of FACTS devices and their impact on improving the damping of power system oscillations, coordination of their controllers with Power System Stabilizer (PSS) is required. Since the power system is a nonlinear system, the design method for stabilizing and controlling parameters of FACTS devices must be performed for nonlinear models [1–3].

One of the most important FACTS devices that can be used to compensation process in the system is Static Synchronous Series Compensator (SSSC). When using this device and PSS at the same time in the power system, investigation of their coordination and introducing a suitable function to do this process is necessary. It usually can be an optimization procedure to obtain parameter of their controllers simultaneously.

In this regard, in recent years, definition of different functions to coordinate different types of FACTS devices and PSS controller together and with other parts of the system is considered. Also using of heuristic algorithms in order to solve optimization problems in this field is considered. Intelligent algorithms such as genetic algorithms (GA) [4], particle swarm optimization (PSO) [5], simulated annealing [6], modified particle swarm optimization (MPSO) [7]; are used to design and set-out the PSS parameters. Also, in [8] PSS design using bacterial foraging algorithm (BFA) and PSO are performed and the results are compared. A methodology for the synthesis of PSSs and speed governors in order to satisfy some objectives and constraints imposed by the evolution of large-scale interconnected power systems is presented in [9]. In [10] modeling of TCSC based damping controller in coordination with automatic generation control (AGC) is presented to damp the oscillations and thereby, improve the dynamic stability. The AGC and TCSC parameters are optimized simultaneously using an improved particle swarm optimization (IPSO) algorithm through minimizing integral of time multiplied squared error (ITSE) performance index.

Coordinated design of PSS and TCSC has been studied in [11–14]. To this end, neuro-fuzzy inference system in [11] and BFA in [12,13] are applied to tune the controller parameters of PSS and TCSC. The main objective in [12] is to maximize the margin of loading in the

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system before the occurrence of the Hopf Bifurcation. The coordination design in [14] is performed using the PSO algorithm.

In [15] the simultaneously design of PSS and SSSC using dynamic multi-objective scheduling are discussed. Coordinated design of PSS and SVC using probabilistic theory in [16] and using a bacterial-foraging oriented by particle swarm optimization (BFPSO) algorithm in [17] is proposed and in [18], the Seeker Optimization Algorithm (SOA) is used to coordinate the parameters of PSS and STATCOM. In [19], to compensation process, the dynamic power flow control of SSSC in coordination with superconducting magnetic energy storage (SMES) is proposed. Gains of the integral controllers and parameters of SSSC are optimized with an improved version of PSO. A coordination scheme to improve the stability of a power system by optimal design of multiple and multi-type damping controllers of PSS and SSSC is presented in [20]. The differential evolution (DE) algorithm is employed to search for the optimal controller parameters. In [21] a coordination scheme to improve the stability of a power system by optimal design of PSS and SSSC controller is presented. The coordinated design problem is formulated as an optimization problem and hybrid bacteria foraging optimization algorithm and particle swarm optimization (hBFOA–PSO) is employed to search for the optimal controller parameters.

Paper contribution and layout

As it has been described in the field of multi-objective way for coordination, there are a few works specifically in the field of PSS and SSSC coordination in a power system. In recent years, as can be seen in previous subsection, Refs. [19–21] have taken into account coordination of SSSC controller with elements of system like PSS but all of them introduce a way for single-objective consideration with a specific method. In Ref. [15] a multi-objective function is introduced for the coordination of PSS and SSSC but it does not consider important items of overshoot, undershoot and settling time of rotor speed to have a suitable solution with lower oscillations to reach the steady state solution.

In this paper, a multi-objective method is proposed for coordinated design of the PSS and SSSC controllers to damp the oscillations and improve system stability. For this purpose, three different objective functions- two single-objective function and one multi-objective function- are proposed. The rotor speed, rotor angle and tie-line power deviations and the values of characteristics of the speed curve variations such as overshoot, undershoot and settling time are employed as input of the method. In the multi-objective function, mentioned parameters as two objective functions are taken into account with weighting factors. Then for optimal solving the single-objective and multi-objective functions, optimization strategies based on Seeker Optimization Algorithm (SOA) and also SOA algorithm based on Pareto optimum method are proposed for them respectively. To demonstrate the effectiveness of the proposed method coordinated design of PSS and SSSC regarding the actual and complete model of the power system, four-machine system is taken into consideration. Also to show the effectiveness of the proposed method in multi-objective condition against single-objective one, different contingency case studies are considered too. Simulation results show the capability of the multi-objective proposed algorithm comparing with single-objective one for coordination of SSSC and PSS to improve the stability of the system.

Power system modeling

To design the PSS and SSSC-based damping controllers coordinately, a single-machine infinite-bus power system depicted in Fig. 1 is considered at the first instance. The generator is equipped with hydraulic turbine and governor (HTG), excitation system and a Power System Stabilizer (PSS) [21,22].

In Fig. 1, V_T and V_B are the generator terminal and infinite-bus voltages respectively; V_1, V_2 and V_3 are the bus voltages; V_{DC} and $V_{conv.}$ are the DC voltage source and output voltage of the SSSC converter respectively; I is the line current and P_L is the total real power flow in the transmission line.

Power System Stabilizer (PSS)

Power System Stabilizers (PSSs) are complementary controllers in the excitation system in order to increase damping of generator rotor oscillations. This is necessary as high gain AVRs can contribute to oscillatory instability in the power systems, which are determined by low frequency oscillations (0.2–2.0 Hz). The washout circuit is considered to delete the steady state bias in the output of the PSS [23]. The dynamic compensator has the following transfer function:

$$T(s) = K_s \frac{1 + sT_1}{1 + sT_2} \tag{1}$$

where the constant gain K_s and time constants T_1 and T_2 are chosen depending on the required compensation for damping.

Static Synchronous Series Compensator (SSSC)

A Static Synchronous Series Compensator (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 variation of V_q is performed by means of a voltage sourced converter (VSC) connected on the secondary side of a coupling transformer. 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 [24–27]. The VSC using IGBT-based PWM inverters is used in this study. Therefore the equations applicable for the network power flow in presence of SSSC are given below [28]:

$$P_q = \frac{V^2}{X_{\text{eff}}} \sin\delta = \frac{V^2}{X_L(1 - X_q/X_L)} \sin\delta \tag{2}$$

$$Q_q = \frac{V^2}{X_{\text{eff}}}(1 - \cos\delta) = \frac{V^2}{X_L(1 - X_q/X_L)}(1 - \cos\delta) \tag{3}$$

where V, X_{eff}, and δ are bus voltage, effective reactance of the transmission line, and phase angle respectively. Also X_L and X_q are transmission line reactance and compensating reactance of SSSC respectively.

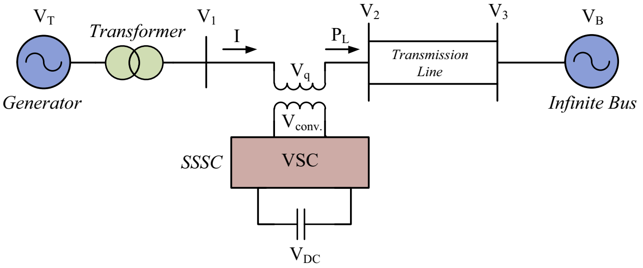

Fig. 1. Single-machine infinite-bus power system with SSSC.