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Coordinated design of power system stabilizers and TCSC employing improved harmony search algorithm

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ABSTRACT

Power System Stabilizers (PSS) are generally employed to damp electromechanical oscillations by providing auxiliary stabilizing signals to the excitation system of the generators. But it has been found that these Conventional PSS (CPSS) do not provide sufficient damping for inter-area oscillations in multi-machine power systems. Thyristor Controlled Series Capacitor (TCSC) has immense potential in damping of inter-area power swings and in mitigating the sub-synchronous resonance. In this paper Improved Harmony Search Algorithm (IHSA) has been proposed for coordinated design of multiple PSS and TCSC in order to effectively damp the oscillations. The results obtained by using IHSA on WSCC 3-machine, 9-bus system are found to be superior compared to the results obtained using Bacterial Swarm Optimization (BSO) algorithm. The damping performance of conventional PSS and TCSC controllers is also compared with coordinated design of IHSA based PSS and TCSC on New England 10-machine, 39-bus system over wide range of operating conditions and contingencies. To demonstrate the effectiveness of the proposed technique the results obtained on this test system are also compared with the results obtained with Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Harmony Search Algorithm (HSA) and Bacterial Swarm Optimization (BSO).

1. Introduction

Power systems are complex nonlinear systems and often exhibit low frequency power oscillations due to insufficient damping. These oscillations may sustain and increase, thus causing the separation of system if no adequate damping is available [1]. Conventional Power System Stabilizers (CPSS) are widely used to suppress the generator electromechanical oscillations and enhance the overall stability of power systems. CPSS based on linear control theory can very well be tuned to an operating condition and will provide excellent damping over a certain range around the design point. However, CPSS parameters may not be optimal for whole set of possible system parameters, operating conditions and configurations.

A comprehensive analysis of the effects of the different CPSS parameters on the overall dynamic performance of the power system has been presented in [2]. It is shown that the appropriate selection of CPSS parameters results in satisfactory performance during system upsets. Robust design of CPSS in multi-machine power systems using global optimization technique like genetic algorithm (GA) [3,4], and other heuristic techniques like tabu search (TS) [5], simulated annealing (SA) [6], particle swarm optimization (PSO) [7–9], bacterial foraging (BF) [10] and harmony search (HS) [11] have attracted the attention in the field of PSS parameter optimization. However, these techniques might fail by getting trapped in one of the local optimal.

Although PSSs provide supplementary feedback stabilizing signals, these controllers may not produce adequate damping during some operating conditions, and other effective controllers which can work in coordination with PSS are needed. Advancements in power electronic technologies have made the application of Flexible AC Transmission Systems (FACTS) devices to alleviate such conditions by controlling the power flow along the transmission lines which improves power oscillations damping [12]. Among these FACTS devices, the Thyristor Controlled Series Capacitor (TCSC) is a multi-functional FACTS controller, which allows quick and continuous changes of the transmission line impedance. TCSC has immense potential and application in precisely regulating the power flow on a transmission line, mitigating the sub-synchronous resonance, improving the transient stability and damping inter-area power swings [13].

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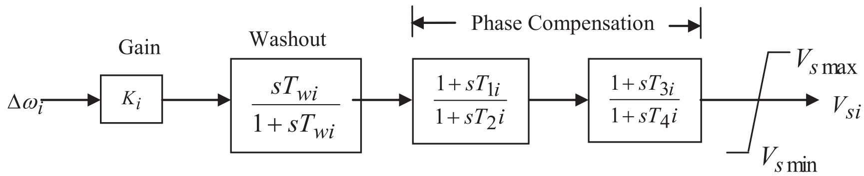

Fig. 1. Structure of PSS.

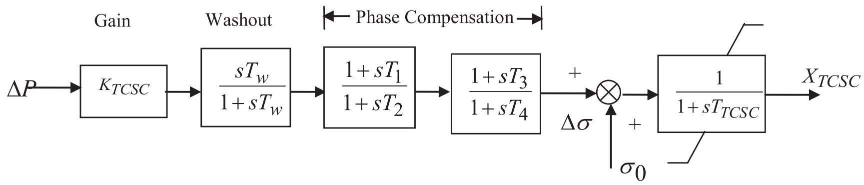

Fig. 2. Structure of TCSC controller.

The applications of TCSC for power oscillation damping and stability enhancement can be found in [14–16]. However, these works are limited for single machine connected to infinite bus (SMIB) system. A reduced rule base self-tuning fuzzy PI controller (STFPIC) for TCSC is proposed in [17]. A supplementary damping control system design for TCSC based on natural inspired Virtual Bees Algorithm (VBA) is presented in [18]. An attempt is made to suppress oscillations in a multi-machine power system using bacterial foraging algorithm based TCSC is illustrated in [19].

In recent years, little work has been reported in the literature on the coordination problem investigation of multiple damping controllers for multi-machine power systems [20–22]. However, uncoordinated local control of TCSC controller and PSS may cause unwanted interactions that may further result in system destabilization. To improve overall system performance, many studies were made on the coordination among PSS and FACTS controllers [23–25]. Unfortunately, the problem of coordinated design of conventional power oscillation damping controllers is a multi-modal optimization problem and conventional tuning methods may not provide sufficient damping for stabilizing inter-area oscillations. Hence the meta-heuristic methods, which are widely used for global optimization problems, have been used to solve this coordinated design problem. Abido et al. [26] have presented coordinated design of a PSS and an SVC-based controller using real coded Genetic Algorithm (GA). Particle Swarm Optimization (PSO) for simultaneous coordination designing of PSS and TCSC damping controller in multi-machine power system is developed in [27]. But GA exhibits degraded efficiency when the system has a highly *epistatic* objective function (i.e., where the parameters being optimized are highly correlated) and number of parameters to be optimized are large [28]. PSO suffers from the partial optimism, which causes the less exact at the regulation of its speed and the direction. Further, PSO algorithm cannot solve the problems of scattering and non-coordinate system optimization [29].

Several optimization techniques using the swarming principle have been adopted to solve a variety of engineering problems in the recent past. An improved multi-objective particle swarm optimization algorithm is applied for improving power system stability and to economic load dispatch problem in [30,31]. Ali et al. [32] have proposed a novel bacterial swarm optimization algorithm for simultaneous design of PSS and TCSC. A novel approach for determining the optimal solution of economic dispatch (ED) problem employing Firefly Algorithm (FA) and hybrid of bacterial foraging and simplified swarm optimization algorithm are presented in [33,34]. Ghasemi et al. [35,36] have adopted modified teaching learning algorithm, double differential evolution algorithm and hybrid modified imperialist competitive algorithm–invasive weed optimization (IWO) for optimal reactive power dispatch problem. In [37,38] modified imperialist competitive algorithm and hybrid of imperialist competitive algorithm and teaching learning algorithm have been applied for optimal power flow problem.

In this paper, Improved Harmony Search Algorithm (IHSA) is employed for coordinated design of the parameters of PSS and TCSC controllers simultaneously. By minimizing the objective function in which the influences of both PSS and TCSC controllers are considered simultaneously, interactions among these controllers are improved. These controllers have been applied and tested on New England 10-machine, 39-bus system under wide range of loading conditions and severe disturbances. The eigenvalue analysis and non-linear simulation results are presented to demonstrate the effectiveness and robustness of the proposed controllers in damping low frequency inter-area oscillations.

2. Statement of the problem

2.1. Power system model

A power system can be modeled by a set of nonlinear differential equations as $\dot{X} = f(X, U)$, where X is the vector of the state variables, and U is the vector of input variables. In this study, all the generators in the power system are represented by their fifth order models and equipped with single time constant fast exciters.

For a given operating condition, the multi-machine power system is linearized around the operating point. The closed loop eigenvalues of the system are computed and the desired objective function is formulated using only the unstable or lightly damped electromechanical eigenvalues, keeping the constraints of all the system modes stable under any condition.

2.2. PSS structure

The structure of the speed based conventional PSS considered in this study is shown in Fig.1.

Here $\Delta\omega_i$ is the deviation of the speed of the rotor of ith generator from synchronous speed. The $\frac{sT_{wi}}{1+sT_{wi}}$ term in the above diagram is the washout term with a time constant T_{wi} which is generally 1–20 s. The washout block serves as a high-pass filter to allow signals in the range of 0.2–2.0 Hz associated with rotor oscillations. T_{wi} is chosen such that undesirable generator voltage excursions during system-islanding are eliminated. The phase compensation block provides compensation for the phase lag/lead that is introduced in the circuit between the exciter input (i.e. PSS