Applied Soft Computing 32 (2015) 532–543

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

A PD-type Multi Input Single Output SSSC damping controller design employing hybrid improved differential evolution-pattern search approach

Sidhartha Panda[a,*], S. Harish Kiran[b], S.S. Dash[b], C. Subramani[b]

[a] Department of Electrical and Electronics Engineering, VSSUT, Burla, Odisha 768018, India
[b] Department of Electrical Engineering, SRM University, Chennai603203, India

ARTICLE INFO

Article history:
Received 19 May 2014
Received in revised form 6 April 2015
Accepted 6 April 2015
Available online 18 April 2015

Keywords:
Power system stability
Static Synchronous Series Compensator (SSSC)
Improved differential evolution algorithm
Pattern search
Multi Input Single Output controller

ABSTRACT

In this paper, a Proportional Derivative (PD)-type Multi Input Single Output (MISO) damping controller is designed for Static Synchronous Series Compensator (SSSC) controller. Both local and remote signals with associated time delays are chosen as the input signal to the proposed MISO controller. The design problem is formulated as an optimization problem and a hybrid Improved Differential Evolution and Pattern Search (hIDEPS) technique is employed to optimize the controller parameters. The improvement in Differential Evolution (DE) algorithm is introduced by changing two of its most important control parameters i.e. Scaling Factor *F* and Crossover Constant *CR* with an objective of achieving improved performance of the algorithm. The superiority of proposed Improved DE (IDE) over original DE and hIDEPS over IDE has also been demonstrated. To show the effectiveness and robustness of the proposed design approach, simulation results are presented and compared with DE and Particle Swarm Optimization (PSO) optimized Single Input Single Output (SISO) SSSC based damping controllers for both Single Machine Infinite Bus (SMIB) power system and multi-machine power system. It is noticed that the proposed approach provides superior damping performance compared to some approaches available in literature.

1. Introduction

Active power oscillations in power transmission systems may arise in corridors between interconnected areas as a result of poor damping of the interconnection [1]. Active power oscillation limits the power transmission capacity of interconnections between areas. Power System Stabilizers (PSS) are generally employed to damp these oscillations, but PSS are not effective in some cases, particularly when inter-area oscillations of typically 0.2–0.7 Hz are present. Alternatively, Flexible AC Transmission Systems (FACTS) controllers can be employed to damp the power system oscillations [2]. Static Synchronous Series Compensator (SSSC) is one of the important members of series FACTS controller [3]. If a SSSC is installed in a power system to enhance the power transfer controllability, a supplementary damping controller could be designed for SSSC to damp the power system oscillations [4].

Despite the availability of a variety of controller, the fixed gain, lead-lag compensation type of controller structure continues to be the most popular with the electrical utilities because of the ease of on-line tuning and also lack of assurance of the stability by some adaptive or variable structure techniques [5,6]. Most of the previous works on stability and damping improvement by SSSC are based on Single Input Single Output (SISO) based lead lag controllers using either local signal or remote signal [7–9]. To avoid additional costs associated with communication, input signal should preferably be locally measurable. However, local control signals, although easy to get, may not contain the desired oscillation modes. So, compared to wide-area signals, they are not as highly controllable and observable. Owing to the recent advances in optical fiber communication and global positioning systems, the wide-area measurement system can realize phasor measurement synchronously and deliver it to the control center even in real time. Hence both local and remote signals can be used reliably as control input signals. In this paper, a Multi Input Single Output (MISO) controller is proposed as SSSC based damping controller. While considerable work has been reported for the improvement of controller structure of a Proportional Integral Derivative (PID) controller, surprisingly, hardly any attempt has been made to improve the structure of a lead lag controller. The structure of a lead lag controller consists of a gain block which acts as a proportion gain and there is scope to add an additional gain term i.e. derivative term to improve the system response and the performance of the controller. In view of the above,

* Corresponding author. Tel.: +91 9438251162.
E-mail address: panda_sidhartha@rediffmail.com (S. Panda).

http://dx.doi.org/10.1016/j.asoc.2015.04.023
1568-4946/

a PD-type MISO controller for SSSC is proposed in the present work to damp power system oscillations.

The problem of FACTS controller parameter tuning is a complex task. The conventional techniques that are reported in literature pertaining to the tuning of FACTS controller suffer from heavy computation burden and the search process is likely to be trapped in local minima as the optimal solution may not be obtained. The growth in size and complexity of electric power systems have necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems. In recent years, a lot of interest has been drawn to the applications of intelligent techniques to power system problems. Differential Evolution (DE) is a population-based direct search algorithm for global optimization capable of handling non-differentiable, non-linear and multi-modal objective functions, with few, easily chosen, control parameters [10]. DE uses a greedy selection procedure with inherent elitist features and has fewer control parameters, which can be tuned effectively [11]. But, the success of DE in solving a particular problem significantly depends on suitable choice of control parameter values namely the Scaling Factor (F) and Crossover Constant (CR) [12]. It is advantageous to use appropriate F and CR values at different stages of evolution/search process instead of using fixed F and CR values for the entire search process [13,14]. The key to achieving high performance for any meta-heuristic algorithm is to maintain a good balance between exploitation and exploration in the search process. DE being a global optimizing method is designed to explore the search space and most likely will give an optimal/near-optimal solution. On the other hand, local optimizing methods like Pattern Search (PS) are designed to exploit the local area, but they are usually not good at exploring wide search space and hence generally not applied alone for global optimization problems [15,16]. Due to their respective strength and weakness, there is motivation for the hybridization of DE and PS. In view of the above, an attempt has been made in this paper for the application of a hybrid improved DE and PS (hIDEPS) for the design of a SSSC based damping controller.

In this paper, a Multi Input Single Output (MISO) controller is proposed for SSSC to damp power system oscillations following a disturbance. The MISO controller consists of two PD-type lead lag controllers with both remote signal (speed deviation signal) and local signal (tie-line power deviation signal). The design problem of proposed controller is formulated as an optimization problem and hIDEPS technique is employed to find the optimal controller parameters. The performance of the proposed controller is evaluated in two test systems subjected to different transient disturbances. To show the effectiveness and robustness of the proposed approach, simulation results are presented and compared with some SISO based damping controllers approaches reported in literature [7,8].

2. Mathematical modeling of system under study

2.1. Single machine infinite bus power system with SSSC

A Single Machine Infinite Bus (SMIB) power system shown in Fig. 1 is considered at the first instance to design the PD-type MISO damping controller for SSSC. The system consists of a synchronous generator connected to an infinite-bus through a step-up transformer and a SSSC through a double circuit transmission line. The generator is provided with Hydraulic Turbine and Governor (HTG) and excitation system. The HTG consists of a hydraulic turbine, a governor system, and a servomotor. The excitation system consists of a voltage regulator and DC exciter, as recommended in IEEE Recommended Practice for Excitation System Models for Power System Stability Studies [17]. 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 is the total real power flow in the transmission line respectively.

2.2. Modeling of machine

The dynamics of the stator, field and damper windings are included in the present analysis. Two-axis reference frame (d–q frame) is used to express the stator and rotor quantities. All rotor quantities are referred to stator (represented by primed variables) as given in (1)–(8):

$$V_d = R_S i_d + \frac{d}{dt}\varphi_q - \omega_R \varphi_q \tag{1}$$

$$V_q = R_S i_q + \frac{d}{dt}\varphi_q + \omega_R \varphi_d \tag{2}$$

$$V'_{fd} = R'_{fd} i'_{fd} + \frac{d}{dt}\varphi'_{fd} \tag{3}$$

$$V'_{kd} = R'_{kd} i'_{kd} + \frac{d}{dt}\varphi'_{kd} \tag{4}$$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\varphi'_{kq1} \tag{5}$$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\varphi'_{kq2} \tag{6}$$

where

$$\varphi_d = L_d i_d + L_{md}(i'_{fd} + i'_{kd})\varphi_q = L_q i_q + L_{mq} + i'_{kq}$$

$$\varphi'_{fd} = L'_{fd} i'_{fd} + L_{md}(i_d + i'_{kd})$$

$$\varphi'_{kd} = L'_{kd} i'_{kd} + L_{md}(i_d + i'_{fd})\varphi'_{kq1} = L'_{kq1} i'_{kq1} + L_{mq} i_q$$

$$\varphi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q$$

In the above equations, the subscripts: d and q stand for d-axis and q-axis quantities, R and s stand for rotor and stator quantities, f and k stand for field and damper winding, l and m stand for leakage and magnetizing inductance.

The mechanical equations are given by:

$$\frac{d}{dt}\omega_r = \frac{1}{J}(P_e - F_r\omega_r - P_m) \tag{7}$$

$$\frac{d}{dt}\theta = \omega_r \tag{8}$$

where ω_r and θ are angular velocity and angular position of the rotor respectively, P_e and P_m represent electrical and mechanical power respectively, J and F_r represent inertia and friction of rotor respectively.

3. The proposed approach

3.1. Structure of SSSC based controller

The proposed MISO controller structure consists of two PD-type lead lag controllers as shown in Fig. 2. Each lead lag structure consists of a proportional gain and a derivative gain block, a signal washout block and two-stage phase compensation block. Derivative mode improves stability of the system. However, when the input signal has sharp corners, the derivative term will produce unreasonable size control inputs to the plant. Also, any noise in the control input signal will result in large control output signals. These reasons often limit the practical applications of derivative term in the controller. The practical solution to the these problems is to put a first filter on the derivative term and tune its pole so that