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A hybrid firefly algorithm and pattern search technique for SSSC based power oscillation damping controller design

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Abstract In this paper, a novel hybrid Firefly Algorithm and Pattern Search (h-FAPS) technique is proposed for a Static Synchronous Series Compensator (SSSC)-based power oscillation damping controller design. The proposed h-FAPS technique takes the advantage of global search capability of FA and local search facility of PS. In order to tackle the drawback of using the remote signal that may impact reliability of the controller, a modified signal equivalent to the remote speed deviation signal is constructed from the local measurements. The performances of the proposed controllers are evaluated in SMIB and multi-machine power system subjected to various transient disturbances. To show the effectiveness and robustness of the proposed design approach, simulation results are presented and compared with some recently published approaches such as Differential Evolution (DE) and Particle Swarm Optimization (PSO). It is observed that the proposed approach yield superior damping performance compared to some recently reported approaches.

1. Introduction

With growing power transfer, transient and dynamic stability is of increasing importance for secure operation of power systems. Recently developed Flexible AC Transmission System (FACTS) controllers have the potential to significantly improve the transient and dynamic stability margin [1]. FACTS controllers are capable of controlling the network condition in a very fast manner. FACTS controllers enable increased utilization of existing networks closer to their thermal loading capacity, thus avoiding the need to construct new transmission lines. Static Synchronous Series Compensator (SSSC) is one of the important members of series FACTS controller. SSSC is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive independently of the magnitude of the line current [2]. SSSC is also immune to classical network resonances. An auxiliary damping

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controller can be designed for SSSC to damp the power system oscillations [3].

A conventional lead-lag controller structure is preferred by the power system utilities because of the ease of on-line tuning and also lack of assurance of the stability by some adaptive or variable structure techniques. The problem of FACTS controller parameter tuning is a complex exercise. A number of conventional techniques have been reported in the literature pertaining to design problems of conventional power system stabilizers namely: the eigenvalue approach, pole placement technique and frequency domain optimization technique, etc. But, the conventional techniques 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 along with the increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems. In the recent years, new artificial intelligence-based approaches have been proposed to design a FACTS-based supplementary damping controller. These approaches include Particle Swarm Optimization (PSO) [4], Genetic Algorithm (GA) [5], Differential Evolution (DE) [6], multi-objective evolutionary algorithm [7], etc.

In [8], design of bacterial foraging optimization-based (BFO) SSSC controller for damping low frequency oscillations in a single – machine infinite – bus power system has been presented. The design of lead-lad controller is formulated as an optimization problem to minimize a time domain based objective function by employing BFO technique. Gravitational Search Algorithm (GSA) is employed in [9,10] to design a supplementary lead-lag structured damping controller for a SSSC for power system dynamic performance enhancement. The linear model of power system has been used for design and analysis purpose. A hybrid approach involving PSO and BFOA is presented for the design of SSSC based damping controller in [11] where the parameters of the lead-lag structured SSSC controller as well as the gains of AC and DC voltage regulator are optimized. Coordinated design of SSSC with Power System stabilizers by hybrid PSO and BFOA [12] and Improved Lozi map based Chaotic Optimization Algorithm (ILCOA) is proposed in [13]. A multi-objective GA approach is presented in [14] to design the SSSC based damping controller to improve the transient performance of a power system subjected to a severe disturbance by minimizing the power angle, terminal voltage and power flow time trajectory deviations with respect to a post-contingency equilibrium point for a power system installed with a SSSC. An Adaptive Neuro-Fuzzy Inference System (ANFIS) method based on the ANN was presented in [15] to design a SSSC based controller for the improvement of transient stability where the ANFIS structures were trained using the generated database by the fuzzy controller of the SSSC. It is clear from literature review [4–14] that, the lead-lag structured controller is preferred by the power system utilities due to its simplicity and the favorable ration between cost and benefits. It is also observed that remote speed deviation signal [4,7–14] and line active power [5–6] are used as the control input signal to the SSSC based damping controller.

It obvious from literature survey that, the performance of the power system depends on the artificial techniques employed, controller structure and control input signal as well as chosen objective function. Hence, proposing and implementing new high performance heuristic optimization algorithms with new control structure/signals to real world problems are always welcome. Recently, a new biologically-inspired meta-heuristic algorithm, known as the Firefly Algorithm (FA) has been developed by Yang [16,17]. FA is a population based search algorithm inspired by the flashing behavior of fireflies. FA is simple, flexible and versatile, which is very efficient in solving a wide range of diverse real-world problems. The characteristics of FA algorithm are as follows [18]:

- FA can automatically divide its population into subgroups, due to the fact that local attraction is stronger than long distance attraction. Hence, FA can deal with highly nonlinear, multi-modal optimization problems naturally and efficiently.
- FA does not use past individual best, and there is no explicit global best either. This avoids any potential draw-backs of premature convergence as those reported in PSO.
- FA has an ability to control its modality and adapt to problem landscape by controlling its scaling parameter.

FA has been successfully employed to solve the nonlinear and non-convex optimization problems [19–21]. Recent research shows that FA is a very efficient and could outperform other metaheuristic algorithms. The superiority of FA over Artificial Bee Colony (ABC) Algorithm, PSO and Bacteria Foraging (BF) Algorithm has also been reported in the literature [20,22–23]. In [20], FA has been applied to optimize the classical controller parameters. A binary real coded firefly algorithm has been applied to a static problem of power system in [22] and the results are compared with GA and PSO. In [23] FA is used for clustering on benchmark problems and the performance of the FA is compared with other two nature inspired techniques such as Artificial Bee Colony (ABC), PSO.

To achieve good performance by any meta-heuristic algorithm, a good balance between exploitation and exploration should be maintained during the search process. FA being a global optimizing method is designed to explore the search space and most likely will give an optimal/near-optimal solution if used alone. On the other hand, local optimizing methods such as Pattern Search (PS) are designed to exploit local areas, but they are usually not good at exploring wide area and hence not applied alone for global optimization [24,25]. Due to their respective strength and weakness, there is motivation for the hybridization of FA and PS.

In view of the above, a maiden attempt has been made in this paper for the application of a hybrid Firefly Algorithm and Pattern Search (h-FAPS) approach for the design of a SSSC based damping controller. In the design of a robust damping controller, selection of the appropriate input signal is a main 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 [4–14]. For local input signals, line active power, line reactive power, line current magnitude and bus voltage magnitudes are all candidates to be considered in the selection of input signals for the FACTS power oscillation damping controller. Among these possible local input signals, active power and current are the most