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Full Length Article

A novel symbiotic organisms search algorithm for optimal power flow of power system with FACTS devices

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ABSTRACT

In this paper, symbiotic organisms search (SOS) algorithm is proposed for the solution of optimal power flow (OPF) problem of power system equipped with flexible ac transmission systems (FACTS) devices. Inspired by interaction between organisms in ecosystem, SOS algorithm is a recent population based algorithm which does not require any algorithm specific control parameters unlike other algorithms. The performance of the proposed SOS algorithm is tested on the modified IEEE-30 bus and IEEE-57 bus test systems incorporating two types of FACTS devices, namely, thyristor controlled series capacitor and thyristor controlled phase shifter at fixed locations. The OPF problem of the present work is formulated with four different objective functions viz. (a) fuel cost minimization, (b) transmission active power loss minimization, (c) emission reduction and (d) minimization of combined economic and environmental cost. The simulation results exhibit the potential of the proposed SOS algorithm and demonstrate its effectiveness for solving the OPF problem of power system incorporating FACTS devices over the other evolutionary optimization techniques that surfaced in the recent state-of-the-art literature.

1. Introduction

OPF has become one of the imperative tools for energy management in modern power systems [1]. The main purpose of OPF is the optimal adjustment of the power system control variables to optimize an objective function while satisfying a set of equality and inequality constraints [2–9]. Over the years, a wide range of conventional as well as evolutionary optimization techniques, such as quadratic programming [3], Newton method [4], interior point methods [4], genetic algorithm (GA) [5], particle swarm optimization (PSO) [6], biogeography-based optimization (BBO) [7,8], gravitational search algorithm (GSA) [9], etc., have been applied for solving OPF problem of power system.

In the recent past, energy, environment, right-of-way and increasing cost have delayed the construction of generation and transmission facilities. These problems have necessitated a much more intensive shared use of the existing transmission facilities [10,11]. By incorporating flexible ac transmission system (FACTS) devices such as thyristor controlled series capacitor (TCSC) and thyristor controlled phase shifter (TCPS) in the existing networks, it is possible to redistribute line power flow and regulate bus voltages and, hence, maximize the use of the existing transmission assets [12,13].

The conventional OPF algorithm needs to be modified in order to incorporate the FACTS devices in the power system structure [14]. In the recent past, various optimization algorithms such as hybrid GA [15], hybrid Tabu search and simulated annealing (TS/SA) [16], real coded GA (RCGA) [17], differential evolution (DE) [17,18], dynamic strategy based fast decomposed GA [19], craziness PSO [20] and turbulent crazy PSO [20], etc., have been proposed for solving the OPF problem of power system equipped with FACTS devices.

In the past, many researchers have implemented RCGA [17] and DE [17,18] most frequently to solve many complex engineering problems. Although those are found to be effective, they are also not free of limitations. DE [21] algorithm may not be able to solve optimal power flow (OPF) with non-smooth cost functions and exhibit unstable convergence in the last period and may be easily dropped into the regional optimum. Similarly, the conventional RCGA [22] causes loss of the genetic diversity, which means the number of base points in the searching space, because the lack of genetic diversity corresponds to loss of the base points. As a consequence, a drop in the genetic diversity leads to an ineffective search. The comparative analysis of the obtained results reflects superiority of the proposed SOS algorithm in finding global optimum values by eliminating the aforementioned limitations.

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Thus, literature survey reveals that a variety of evolutionary optimization techniques has been applied to solve the conventional OPF problem of power system. Literature survey also reveals that the solution of OPF problem of the power network along with FACTS devices require optimization techniques to solve these problems. Researchers over the globe are continuously searching for a better meta-heuristic for the solution of the optimization problems and the researchers, oriented toward the solution of engineering optimization task, are continuously searching for a better meta-heuristic to accomplish the same.

Cheng and Prayogo [23] introduced a novel optimization technique and named it as symbiotic organisms search (SOS) algorithm. It is based on the symbiotic interaction strategies that organisms use to survive in the ecosystem. A main advantage of the SOS algorithm over most other meta-heuristic algorithms is that the operation of this algorithm requires no algorithm specific parameters. SOS algorithm has been found to be very efficient in solving engineering field optimization problems with very fast convergence rate and less computational time [23,24].

In this work, SOS algorithm is applied for the solution of OPF problem of power system along with FACTS devices. IEEE standard power systems like modified IEEE-30 and IEEE-57 bus test systems are adopted and the OPF problem with FACTS devices of these test power systems are solved with different objectives such as (a) fuel cost minimization, (b) transmission active power loss (P_{Loss}) minimization, (c) emission reduction and (d) combined economic and environmental cost minimization, while maintaining power balance constraints, active and reactive power generation limits, voltage limits, transmission line limits and physical limits of FACTS devices, etc. In the current work, the strategic location of TCSC and TCPS are considered to be at fixed locations of the test power system and these locations are taken from the literature. Results obtained are compared to other computational intelligence-based meta-heuristic algorithms that surfaced in the recent state-of-the-art literature.

The rest of this paper is organized as follows. In Section 2, modeling of FACTS devices is presented. Mathematical problem of the OPF work with FACTS devices is discussed in Section 3. SOS algorithm is depicted in Section 4. In Section 5, application of SOS for the solution of OPF problem with FACTS is described. Simulation results are presented and discussed in Section 6. Finally, conclusions of the present paper are drawn in Section 7.

2. Modeling of FACTS devices

2.1. Modeling of TCSC

The effect of TCSC on a power network may be represented by a controllable reactance inserted in series to the related transmission line. Active power flow through the compensated transmission line may be maintained at a specified level under a wide range of operating conditions [12,14]. The static model of the network with TCSC connected between i-th and j-th bus is shown in Fig. 1. The power flow equations of the branch having TCSC are given by (1) and (2) [16]

$$P_{ij} = V_i^2 G_{ij} - V_i V_j G_{ij}\cos(\delta_i - \delta_j) - V_i V_j B_{ij}\sin(\delta_i - \delta_j) \tag{1}$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i V_j G_{ij}\sin(\delta_i - \delta_j) + V_i V_j B_{ij}\cos(\delta_i - \delta_j) \tag{2}$$

Similarly, real and reactive power flows from j-th to i-th bus may be expressed by (3) and (4)

$$P_{ji} = V_j^2 G_{ij} - V_i V_j G_{ij}\cos(\delta_i - \delta_j) + V_i V_j B_{ij}\sin(\delta_i - \delta_j) \tag{3}$$

$$Q_{ji} = -V_j^2 B_{ij} + V_i V_j G_{ij}\sin(\delta_i - \delta_j) + V_{ij} V_j B_{ij}\cos(\delta_i - \delta_j) \tag{4}$$

where

Conductance of transmission line $(G_{ij}) = \dfrac{R_{ij}}{R_{ij}^2 + (X_{ij} - X_{C_{ij}})^2}$ and susceptance of transmission line $(B_{ij}) = \dfrac{X_{ij} - X_{C_{ij}}}{R_{ij}^2 + (X_{ij} - X_{C_{ij}})^2}$.

Also,

P_{ij}, Q_{ij}	: active and reactive power flows, respectively, between i-th and j-th bus;
V_i, V_j	: voltage magnitudes at i-th and j-th bus, respectively;
δ_i, δ_j	: angles at i-th and j-th bus, respectively;
R_{ij}, X_{ij}	: resistance and reactance, respectively, of transmission line connected between i-th and j-th bus; and
$X_{C_{ij}}$	: reactance of TCSC placed in the transmission line connected between i-th and j-th bus.

2.2. Modeling of TCPS

The static model of a TCPS connected between i-th and j-th bus, having a complex tapping ratio of $1:1\angle\phi$ and series admittance of $Y_{ij} = (G_{ij} - sqrt(-1)B_{ij})$ is shown in Fig. 2 [12,14]. Similar to TCSC, real and reactive power flows from i-th to j-th bus may be expressed by (5) and (6) [16]

$$P_{ij} = \frac{V_i^2 G_{ij}}{\cos^2\phi} - \frac{V_i V_j}{\cos\phi}[G_{ij}\cos(\delta_i - \delta_j + \phi) + B_{ij}\sin(\delta_i - \delta_j + \phi)] \tag{5}$$

$$Q_{ij} = -\frac{V_i^2 B_{ij}}{\cos^2\phi} - \frac{V_i V_j}{\cos\phi}[G_{ij}\sin(\delta_i - \delta_j + \phi) - B_{ij}\cos(\delta_i - \delta_j + \phi)] \tag{6}$$

Real and reactive power flows from j-th to i-th bus may be expressed by (7) and (8) [16]

$$P_{ji} = V_j^2 G_{ij} - \frac{V_i V_j}{\cos\phi}[G_{ij}\cos(\delta_i - \delta_j + \phi) - B_{ij}\sin(\delta_i - \delta_j + \phi)] \tag{7}$$

$$Q_{ji} = -V_j^2 B_{ij} + \frac{V_i V_j}{\cos\phi}[G_{ij}\sin(\delta_i - \delta_j + \phi) + B_{ij}\cos(\delta_i - \delta_j + \phi)] \tag{8}$$

The injected power model of TCPS is shown in Fig. 3 [12,14]. The injected real and reactive powers of TCPS at i-th and j-th bus may be represented by (9)–(12)

$$P_{is} = -G_{ij} V_i^2 \tan^2\phi - V_m V_j \tan\phi[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)] \tag{9}$$

$$Q_{is} = B_{ij} V_i^2 \tan^2\phi + V_i V_j \tan\phi[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)] \tag{10}$$

$$P_{js} = -V_i V_j \tan\phi[G_{ij}\sin(\delta_i - \delta_j) + B_{ij}\cos(\delta_i - \delta_j)] \tag{11}$$

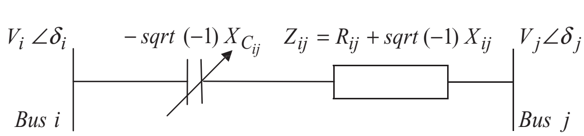

Fig. 1. Circuit model of TCSC connected between i-th bus and j-th bus.

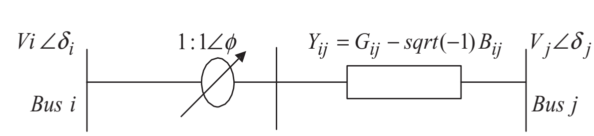

Fig. 2. Circuit model of TCPS connected between i-th bus and j-th bus.