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Solution of optimal power flow using chaotic krill herd algorithm

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ABSTRACT

Recently, krill herd algorithm (KHA) is proposed for the solution of global optimization problem. Various chaotic maps are considered in the proposed chaotic KHA (CKHA) of the present work to improve the performance of basic KHA method. It is observed that Logistic map based CKHA offers better results as compared other chaotic maps. The performance of the proposed CKHA is tested on standard 26-bus and IEEE 57-bus test power systems for the solution of optimal power flow of power system with different objectives that reflect minimization of fuel cost or active power loss or sum of total voltage deviation. Results obtained by using CKHA are compared to other evolutionary optimization techniques surfaced in the recent state-of-the-art literature. The results presented in this paper show that the proposed CKHA algorithm outperforms the other techniques in terms of convergence rate and global search ability.

1. Introduction

Optimal power flow (OPF) is an important tool for power system operators both in planning as well as in operating stages. The main task of OPF is to adjust the settings of the control variables (e.g. active power generation, generators' terminal voltage, setting of on-load tap changing transformers and output of reactive power compensation device, etc.) of power system so that the optimal operating point may be achieved. With regard to the term *optimal*, it means this operating point may minimize (e.g. fuel cost, active power, etc.) or maximize (e.g. profit, voltage stability, etc.) certain objective function while satisfying certain constraints (e.g. bus voltage magnitude limits, generation limits of generator, etc.).

Many mathematical programming techniques such as linear programming, nonlinear programming [1], quadratic programming [2], Newton methods, etc. have been applied in the literature for solving OPF problem assuming convex, differentiable and linear cost function. However, the OPF problem, in general, is a large-scale highly constrained nonlinear, non-convex optimization problem [3]. Hence, it becomes essential to develop optimization technique that should be capable of overcoming these drawbacks and handling such difficulties.

In recent years, many heuristic algorithms such as genetic algorithm (GA), improved GA, enhanced GA, evolutionary programming (EP), differential evolution (DE), particle swarm optimization (PSO) [4], biogeography-based optimization (BBO) [5,6], gravitational search algorithm (GSA) [3,7], etc. have been proposed for solving the OPF problem. Some of these methods have been applied without any restrictions on the shape of the cost curves. The results reported were promising and encouraging for further research in this direction.

In 2012, Gandomi and Alavi introduced a novel meta-heuristic search approach, named as KHA [8]. KHA analogy is based on the simulation of the herding behavior of krill swarms in nature. The objective function used in KHA is supposed to be a combination of the least distances of the position of the food and the highest density of the herd. One major advantage of KHA is that it needs a very few control variables in comparison to other optimization methods but

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for solving multimodal functions, it may often fail to find the best solution for solving multi-modal functions which can be considered as a disadvantage of this method [9]. Recently, KHA has been used in some areas of research interest like multimodal numerical optimization problems [10], portfolio optimization problems, combined heat and power dispatch problem [11], structural optimization problems [12], optimum design of truss structures [13], etc.

Some parameters (like Lagrangian and evolutionary parameters) have been introduced in basic KHA algorithm to improve its performance [14]. A few variants of hybrid KHA have been also proposed in the literature like BBO based KHA (borrowing migration operator from BBO for benchmark test functions) [15], stud KHA (introducing stud selection and crossover operator for numerical optimization process) [16], simulated annealing based KHA [17], cuckoo search algorithm based KHA (for solution of global optimization problems) [18] and DE based KHA (for improvement of the global numerical optimization problems) [19]. Fuzzy based KHA (that uses fuzzy system as parameter tuner for benchmark test function optimization problems) [20] and DE assisted KHA (for economic load dispatch problem of power system) have been evolved to a new era of research in the modern power system engineering problems. So, it may be inferred from the literature review that KHA has secured a vital position not only in engineering optimization problems [21] but also for global numerical optimization problems [22]. Thus, the main motivation of the present work is to hybridize the basic KHA for power engineering optimization problem with an attempt to have better optimization capability.

In this article, the concept of chaos theory is incorporated with the basic KHA for achieving enhanced computational speed and improved convergence speed. This new variant of KHA may be applied to a power system optimization problem such as solution of OPF problems in power systems. Previously, chaotic sequences have been used in various metaheuristic optimization algorithms like GA, PSO, accelerated PSO [23], harmony search algorithm, ant colony optimization, firefly algorithm [24], bat algorithm [25], artificial bee colony optimization and simulated annealing. All of these newly introduced algorithms have shown improved response and increasing accuracy in different fields of engineering application as compared to their respective basic counterparts. Recently, chaos based KHA [26], imperialist competitive algorithm with chaos concept [27] and chaotic PSO-KHA [28] have also shown improved computational results and faster rate of convergence speed for global optimization problems.

In the present work, the effectiveness of the proposed CKHA algorithm is tested on standard 26-bus and IEEE 57-bus test power systems for the purpose of OPF study with three different objectives such as (a) fuel cost minimization, (b) transmission active power loss (P_{Loss}) minimization and (c) reduction of sum of total voltage deviation (TVD). The results obtained are compared to other computational intelligence-based techniques surfaced in the recent state-of-the-art literature.

The rest of this paper is organized as follows. In Section 2, mathematical problem formulation of the OPF work is discussed. Section 3 describes the basic KHA and its computational procedure. CKHA algorithm implementation in OPF problem is described in Section 4. Simulation results are presented and discussed in Section 5. Finally, conclusions of the present work are drawn in Section 6.

2. Problem formulation of OPF

The OPF problem is concerned with optimization of steady-state performance of power system with respect to specified objective function, subject to various equality and inequality constraints. Mathematically, OPF problem may be represented as [4,29]

$$\text{Minimize} \quad OF(\mathrm{x}, \mathrm{u}) \tag{1}$$

$$\text{subjectto}: \quad \left.\begin{matrix} eq(\mathrm{x}, \mathrm{u}) = 0 \\ ieq(\mathrm{x}, \mathrm{u}) \leq 0 \end{matrix}\right\} \tag{2}$$

where OF is the objective function to be minimized, x and u are the vectors of dependent and control variables, respectively.

The vector of dependent variables x may be represented by (3)

$$x^T = [P_{G_1}, V_{L_1} \ldots V_{L_{NL}}, Q_{G_1} \ldots Q_{G_{NG}}, S_{l_1} \ldots S_{l_{NTL}}] \tag{3}$$

where P_{G_1} is the slack bus power, V_L is the load bus voltages, Q_G indicates the reactive power outputs of the generators, S_l indicates the transmission line flows, NL is the number of load buses, NG is the number of generator buses and NTL is the number of transmission lines.

Similarly, the vector of control variables u may be written by (4)

$$u^T = [P_{G_2} \ldots P_{G_{NG}}, V_{G_1} \ldots V_{G_{NG}}, T_1 \ldots T_{NT}, Q_{C_1} \ldots Q_{C_{NC}}] \tag{4}$$

where NT is the number of tap changing transformers and NC is the number of shunt VAR compensators, V_G is the terminal voltage at the generator buses, P_G is the active power output of the generators, T is the tap setting of the tap changing transformers and Q_C is the output of shunt VAR compensators.

2.1. Constraints

2.1.1. Equality constraints

The set of equality constraints representing the load flow equations may be found in [6].

2.1.2. Inequality constraints

The set of system inequality constraints may be found in [6].

2.2. Objective function

In this paper, three different objective functions are considered to determine the effectiveness of the proposed algorithm. These three objective functions are as follows:

(i) *Minimization of fuel cost*: Mathematical representation of this type of objective function may be formulated for two cases i.e. minimization of (a) quadratic fuel cost and (b) quadratic fuel cost with valve-point loadings effect. This may be represented by (5)

$$\text{Minimize} \quad FC(P_G) \tag{5}$$

where $FC(P_G)$ indicates the total fuel cost in \$/h.