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Full Length Article

Ant lion optimizer for solving optimal reactive power dispatch problem in power systems

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ABSTRACT

This paper presents the use of a recent developed algorithm inspired by the hunting mechanism of antlions in nature, called ant lion optimizer (ALO) algorithm for solving optimal reactive power dispatch (ORPD) problem considering a large-scale power system. The ORPD is formulated as a complex combinatorial optimization problem with nonlinear characteristic. The ALO algorithm is inspired from the hunting mechanism of antlions. One of the most interesting things in antlions is that they have a unique hunting behaviour and exhibit high capability of escaping the local optima stagnation. The ALO is used to find the set of optimal control variables of ORPD problem, such as generators terminal voltage, position of tap changers of transformers, and number of switchable capacitor banks. The performance and feasibility of the proposed algorithm are demonstrated through several simulation cases on IEEE 30-bus, IEEE 118-bus power systems and large-scale power system IEEE 300-bus power system. Comparison of obtained results with those reported in the literature shows clearly the superiority of ALO algorithm over other recently published algorithms in regards to real power losses and computational time, and hence confirmation of the efficiency of ALO algorithm in providing near-optimal solution.

1. Introduction

At the present time, meticulous researchers on the Optimal Reactive Power Dispatch (ORPD) have been recorded due to the vital role of ORPD in the power system planning and operation. ORPD is considered as a complex combinatorial optimization problem with nonlinear characteristics. In the power system operation, every variations of load demand tend to change the applied reactive power generations, and hence load voltages variations. The adjustment of voltages can be accomplished locally by proper reactive power management. General objectives of ORPD are to minimize total real power losses and to improve the voltage stability index or voltage deviation. This is can be achieved through identification of optimal solution to the vector of control variables which consists of generator voltages as continuous variables, tap position of tap-changing transformers, and required number of shunt capacitors as discrete variables. This issue has undergone a growing interest over the last decade, to ensure safe and secure operation of an electric power system [1–5].

Over the past quarter of the previous century, a variety of classical optimization algorithms have been successfully applied for solving ORPD problem, among them the Newton Raphson methods' (NR) [3], quadratic programming (QP) [4], nonlinear programming (NLP) [5], and interior point methods (IP) [6]. However, from the use literature survey on the conventional optimization approaches (COA), appear that they are suffer from lack of flexibility with the practical systems and high computation time when dealing with complex objective functions (nonlinear handling characteristics). An additional problem is associated with these algorithms when dealing with discrete control variables since it sharply increases the complexity of the ORPD issue. This complexity grows exponentially as the number of discrete variables increases.

In recent years, numerous algorithms have been successfully introduced to deal the ORPD problem in an effort to alleviate the aforementioned drawbacks such as, genetic algorithms (GAs) [7], differential algorithm (DE) [2,8,9], simulated annealing (SA) [10], particle swarm optimization (PSO) [10,11], harmony search algorithm (HSA) [13], artificial bee colony algorithm (ABC) [14], gravitational search algorithm (GSA) [1] and Grey wolf optimizer (GWO)

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Nomenclature

ALO	ant lion optimizer
GWO	grey wolf optimizer
ABC	artificial bee colony algorithm
BA	bat algorithm
PSO	particle swarm optimization
P_{loss}	total power losses
g_k	conductance of kth branch connected between bus i and j
V_i, V_j	voltage magnitude of ith and jth bus
δ_{ij}	voltage angle difference between ith and bus jth
T_K	ratio of tap changing transformers
$T_k^{\max}$	maximum tap ratio of kth tap changing transformer
$T_k^{\min}$	minimum tap ratio of kth tap changing transformer
N_{PV}, N_{PQ}	number of PV and PQ buses respectively
P_g/Q_g	generator active/reactive power production
$P_{L,N_{PQ}}, Q_{L,N_{PQ}}$	active and reactive power at each PQ bus
NB	number of bus in the test system
NTL	number of transmission lines
NLB	number of load bus
NT	number of regulating transformer
NC	number of shunt capacitor banks
$X^{\max}$	maximum limit of state variables
$X^{\min}$	minimum limit of state variables
V_G	voltage magnitude for generator i
$V_{L,N_{PQ}}$	voltage magnitude for load bus i
$V_i^{\max}, V_i^{\min}$	maximum and minimum bus voltage magnitude at bus i
S_l	apparent power flow of branch
$S_l^{\max}$	maximum apparent power flow limit of branch i
$\lvert Y_{ij}\rvert, \theta_{ij}$	elements of the bus admittance matrix
$P_{d,i}/Q_{d,i}$	active/reactive load consumption at bus i
$Q_{Ci}^{\min}, Q_{Ci}^{\max}$	minimum and maximum VAR injection limits of shunt capacitor banks

[15]. Extensive competitions between researchers have been done in last decade, in an effort to seek for a more suitable/reliable approach for handling different power system optimization problems [16–22]. In [16], the authors applied seeker optimization algorithm for solving optimal reactive power dispatch in larger power system with a detailed description of critical performance indices in which different objective functions are studied such as minimization of active power losses, improvement of voltage profile and minimization of voltage stability index. Also, in Xu et al. [17], an application of multi-agent based reinforcement learning for solving optimal reactive power dispatch problem is investigated. The objective is to minimize the active power loss. In another reported case, Ghasemi in [18], proposed an hybrid algorithm based on modified teaching learning algorithm and double differential evolution algorithm for solving ORPD problem, as a comparative study. In [19] Li *et al* proposed parallel PSO algorithm to deal the dynamic ORPD problem. In [20] the authors introduced the modified version of Gaussian bare-bones teaching-learning-based optimization (GBTLBO) algorithm to solve ORPD problem with both discrete and continuous optimisation variables in a medium-scale system. A firefly algorithm for real power loss minimization and voltage stability limit maximization as multi-objective optimization, has been offered by Balachennaiah in [21]. In [22] an novel hybrid particle swarm optimizer with multi verse optimizer (HPSO-MVO) is proposed for ORPD problem. However, these approaches already suffer from some disadvantages such as the susceptibility of falling into local optima, and difficulty tuning the main internal parameters such as mutation and crossover rate. In addition, there is no a global optimization algorithm for solving ORPD problem and on the basis of No-Free Lunch theorem, the seeking a more suitable approach for a such problem is remain necessary. The aforementioned reasons incite the present authors to highlight a simple, recently, and efficient optimization algorithm to solve the posed problem.

About one year ago, a new technique has been added to the meta-heuristic optimization approaches field, based on simulating of the hunting behaviour of antlions. This article proposes the use of ant lion optimization algorithm for solving the ORPD problem with an improved voltage stability index in power systems. The medium-scale, larger and large-scale test systems namely IEEE-30, IEEE-118 and IEEE 300-bus are selected to demonstrate the performance of the proposed approach. The obtained results by using ALO are compared with other results of recent published algorithms. Therefore, the results prove the consistency and robustness of ALO algorithm to find the optimal solution for each objective function.

The rest of the paper is structured as follows: the general formulations to the ORPD problem is introduced in Section 2 while Section 3 explains the proposed approach. Then, Section 4 is present the control variable treatment, and Section 5 of the paper is reserved to provide the experimental results along with a detailed comparison of ALO algorithm with some existing algorithms. Finally, Section 6 presents the conclusion of this paper.

2. Mathematical formulation

The mathematical formulation of ORPD problem is amply described in two parts as: objective functions and constraints, in which minimizes some objective functions while fulfilling equality and inequality constraints at the same time. Mathematically can be formulated as follows:

$$\text{Minimize } F(x,u) \tag{1}$$

$$\text{Subject to}: \begin{cases} g(x,u) = 0 \\ h(x,u) \leqslant 0 \end{cases} \tag{2}$$

where, F(x,u) is the objective function of transmission losses to be minimized, $g(x,u) = 0$ equality constraints, $h(x,u) = 0$ inequality constraints; x: is the vector of dependent variables or (control variables) consisting of load bus voltages, reactive power of generator, and transmission line loading.

Accordingly, vector x can be written mathematically as follow:

$$x^T = [V_L \ldots V_{L,N_{PQ}}, Q_{g,1} \ldots Q_{g,N_{PV}}, S_1 \ldots S_{NTL}] \tag{3}$$

u: is the vector of independent variables or (state variables) comprising: continuous and discrete control variables involving:

Voltages of PV bus as (continuous variables), transformer tap settings (discrete variables), and switching shunt capacitor banks (discrete variables). Hence, u can be illustrated mathematically as follow:

$$u^T = \left[\overbrace{V_{g,1} \ldots V_{g,N_{PV}}}^{\text{continuous}}, \overbrace{T_1 \ldots T_{NT}, Q_{C1} \ldots Q_{C,NC}}^{\text{Discrete}} \right] \tag{4}$$

In the present work, two different objective functions are separately studied:

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