Rebecca Ng Shin Mei [1,*], Mohd Herwan Sulaiman[1], Zuriani Mustaffa[2]

J. Electrical Systems x-x (xxxx): xxx-xxx

Regular paper

Ant lion optimizer for optimal reactive power dispatch solution

This paper proposes the application of the recent meta-heuristic method namely Ant Lion Optimizer (ALO) in solving Optimal Reactive Power Dispatch (ORPD) problem. The objective is to minimize the transmission losses by finding the best combination of control variables including generator voltages, transformer tap ratios and reactive compensation devices. In order to show the effectiveness of ALO in solving ORPD, IEEE 30-bus system is utilized. The comparison with other methods also reported in this paper.

Keywords: Optimal reactive power dispatch; Ant lion optimizer; meta-heuristic method.

1. Introduction

Optimal reactive power dispatch (ORPD) is a nonlinear optimization problem in power system which involving discrete and continuous control variables meanwhile satisfying both equality as well as inequality constraints. ORPD is a sub problem of Optimal Power Flow (OPF) calculations which identifies the controllable variables besides minimizes transmission losses and other objective functions. Since transformer tap ratios and outputs of shunt capacitors have discrete nature, whereas, on the other hand, reactive power output of generators and static VAR compensators, bus voltage magnitude and angles are continuous variables. The ORPD therefore can be formulated as a large scale mixed integer nonlinear programming (MINLP) model [1-4]. Undeniably, ORPD plays an important role in securing both electricity and economic operation of power system.

Various techniques on ORPD have been reported in literature. According to [1, 5-8], classical methods including linear and nonlinear programming (LP & NLP), quadratic programming (QP), gradient method, interior point method as well as Newton method havse been carried out to solve ORPD problem. Nevertheless, latter development in meta-heuristic methods can yield a better outcome in overcoming ORPD problem compared with classical conventional method. Furthermore, a numerous noticeable search techniques have been implemented for solving ORPD problem such as Genetic Algorithm (GA), Evolutionary Programming (EP), Evolutionary Strategy (ES), Particle Swarm Optimization (PSO) and Tabu Search (TS). However, they are not efficient in solving optimization problems with discrete nature although they are excellent in producing global optimum as well as in overcoming non-convex and discontinuous objective functions [2]. Hence, meta-heuristic methods have been developed to solve ORPD such as Artificial Bee Colony (ABC) [2], Particle Swarm Optimization (PSO) [3], Differential Evolution (DE)[4], Harmony Search Algorithm (HSA) [9], and many more.

In this paper, application of Ant Lion Optimizer (ALO) [10] has implemented in solving ORPD problem. The rest of this paper is organized as follows: Section 2 presents the notation used throughout the paper. Section 3 discusses the problem formulation of ORPD

* Corresponding author: Rebecca Ng Shin Mei, Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang Malaysia, E-mail: rebeccamei527@gmail.com

[1] Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang Malaysia

[2] Faculty of Computer System & Software Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang Malaysia

followed by a brief description of ALO. Section 4 introduces on the case study as well as the simulation results and discussion. Last but not least, the conclusion is stated in Section 5.

2. Notation

The notation used throughout the paper is stated below.

Constants:

x	vector of dependent variables
u	vector of control variables
Nl	number of transmission lines
Nd	number of load buses
V_i	voltage at load bus-*i*
V_i^{sp}	specified value, usually set as 1.0 p.u.
P_i	active load demand
Q_i	reactive load demand
G_{ij}	conductance between bus-*i* and bus-*j*
B_{ij}	susceptance between bus-*i* and bus-*j*
P_{Gi}	real power generation
Q_{Gi}	reactive power generation
V_{Gi}	generation of bus voltage
N_G	number of generators
N_T	number of transformers
N_C	number of shunt compensators
a_i	minimum of random walk of *i*-th variable
b_i	maximum of random walk of *i*-th variable
c_i^t	minimum of i-th variable at *t*-th iteration
d_i^t	maximum of i-th variable at *t*-th iteration
c_j^t	minimum of all variables for *i*-th ant
d_j^t	maximum of all variables for *i*-th ant
c^t	minimum of all variables at *t*-th iteration
d^t	maximum of all variables at *t*-th iteration
$Antlion_i^t$	position of the selected *j*-th antlion at *t*-th iteration
R_A^t	random walk around the antlion selected by the roulette wheel at *t*-th iteration
R_E^t	random walk around the elite at *t*-th iteration

3. Problem formulation

3.1. Objective function

The objective function of ORPD is to determine the minimum system transmission losses and the smallest voltage deviation on load busses concurrently satisfying both the equality as well as inequality constraints. The ORPD problem can be formulated as follows:

Minimize $f(x,u)$

Subjected to

$g(x,u)=0$

$$h(x,u)\le 0 \qquad (1)$$

where function $f(x,u)$ is the objective function, $g(x,u)=0$ is the equality constraint which is the power flow equalities and $h(x,u)\le 0$ is the inequality constraint. Undeniably, transmission losses must be taken into account as it is an economic loss which does not provide any profit. Another objective function is to satisfy consumers' needs at lowest cost with smallest voltage deviation. The total transmission loss, *F*, is expressed as follows:

$$F = P_{Loss}(x,u) = \sum_{L=1}^{Nl} P_{Loss} \tag{2}$$

3.2. Constraints

For equality constraint, the total power generation must be equal to the total loads demands and the total real power losses of the system, which can be illustrated as follows:

$$P_{Gi} - P_{Di} = V_i \sum_{j \in N_i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \tag{3}$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j \in N_i} V_j (B_{ij} \cos\theta_{ij} - G_{ij} \sin\theta_{ij}) \tag{4}$$

There are basically three inequality constraints: generator constraints, transformer tap setting and as well reactive compensators (or shunt VARs). For generator constraints, the real and reactive power generation and generation bus voltage must be within their upper and lower bounds:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1,..., N_G \tag{5}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1,..., N_G \tag{6}$$

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max}, i = 1,..., N_G \tag{7}$$

The transformer tap setting is limited by their upper and lower bounds as below:

$$T_i^{\min} \le T_i \le T_i^{\max}, i = 1,..., N_T \tag{8}$$

The reactive compensators are restricted within their maximum and minimum limits as below:

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}, i = 1,..., N_c \tag{9}$$

3.3. Ant Lion Optimizer (ALO)

Ant Lion Optimizer (ALO) is the latter nature-inspired meta-heuristic method introduced by [10] which mimics the hunting behavior of antlions. ALO is exploited based upon five main stages: random walks of ants, building pits, entrapment of ants, catching preys and lastly rebuilding pits. The steps of ALO can be explained as below. In nature, ants move randomly when searching for food which the random movement of ants can be modeled as follows:

$$X(t) = [0, cumsum(2r(t_1) - 1), cumsum(2r(t_2) - 1), ..., cumsum(2r(t_n) - 1)] \tag{10}$$

Stochastic function, $r(t)$ is expressed as below where *rand* is a random number produced within [0,1] uniformly.

$$r(t) = \begin{cases} 1 if rand > 0.5 \\ 0 if rand << 0.5 \end{cases} \tag{11}$$

Random walks of ants: For each optimization, ants will update their locations with random walk. In order to update the positions of ants within the boundary of the search space, equation (10) are normalized using the following equation:

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i \tag{12}$$

Trapping in antlions' traps: The following equations are applied to express the effect of antlions' traps on random walks of ants.

$$c_i^t = Antlion_j^t + c_t \tag{13}$$

$$d_i^t = Antlion_j^t + d_t \tag{14}$$

Building traps: During optimization, ALO employed roulette wheel operator for choosing antlions based on their fitness as this mechanism gives high chance to the fitter antlions for trapping ants.

Sliding ants against towards antlions: Once antlions realize an ant is in trap, they will shoot the sand outward the middle of the trap. This mechanism slides the trapped ant down to the center of the pit which can be illustrated mathematically as below, where *I* is the ratio.

$$c^t = \frac{c^t}{I} \tag{15}$$

$$d^t = \frac{d^t}{I} \tag{16}$$

Catching preys and rebuilding the traps: Catching preys occurred when ants becomes fitter than it predator. Then, antlion will update its latest location of the hunted ant to improve its opportunity of catching new prey, which this mechanism can be modeled as below:

$$Antlion_j^t = Ant_i^t \, iff(Ant_j^t) > f(Antlion_j^t) \tag{17}$$

Elitism: The movements of all ants are be able to be affected by the fittest antlion which we called it elite during each iteration. Thence, it is assumed that each ant randomly walks around a selected antlion by the roulette wheel and the elite concurrently are modeled as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{18}$$

4. Results and discussion

To illustrate the effectiveness of the proposed algorithm in solving ORPD problem, the IEEE 30-bus system is used. This system consists of 6 generators, 41 lines, 4 transformers and 3 capacitor banks as reactive compensation located at buses 3, 10 and 24. The maximum and minimum boundaries for control variables are exhibited in Table 1. The load demand for this study is set to $S = P + jQ = 2.832 + j1.262$ p.u.

The best result of ALO is presented in Table 2. For fair comparison, the results presented in [9] are also mapped into the MATPOWER program for load flow assessment. It can be noted that the optimal results obtained by ALO gives the lowest power loss among all the techniques. Comparison ALO with the HSA is about 9.6% loss reduction. It can be seen also that all the optimize variables are within the specified boundaries as shown in Table 1.

Table 1: Limit setting for the variables for IEEE 30-bus system

Variables	Lower limit	Upper limit
Generator Voltges	0.9 p.u	1.1 p.u
Tap setting of transformers	0.95 p.u	1.05 p.u
Capacitor banks	-12 MVar	36 MVar

Table 2: ORPD results of control variables by using HSA, PSO, SGA and ALO

Control device	HSA [9]	PSO [9]	SGA [9]	ALO
V_1	1.0726	1.0313	1.0512	1.1
V_2	1.0625	1.0114	1.0421	1.0948
V_5	1.0399	1.0221	1.0322	1.0759
V_8	1.0422	1.0031	0.9815	1.0774
V_{11}	1.0318	0.9744	0.9766	1.0761
V_{13}	1.0681	0.9987	1.1	1.1
T_1	1.01	0.97	0.95	1.03
T_2	1	1.02	0.98	1.00
T_3	0.99	1.01	1.04	1.01
T4	0.97	0.99	1.02	0.98
Q_1	34	17	12	-1
Q_2	12	13	-10	25
Q_3	10	23	30	11
Loss (MW)	5.109	5.8815	6.5318	4.616

The performance of ALO is further analysed by performing 30 free running simulations. The performance is exhibited in Figure 1. It can be seen that the results are varied between 4.61 and 4.68 MW which is just about 1.5% deviation for 30 runs. The convergence performance for the best and worst results is depicted in Figure 2.

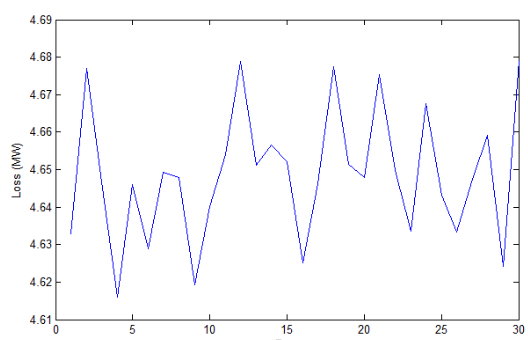

Figure 1: Performance of ALO for 30 free running of simulations

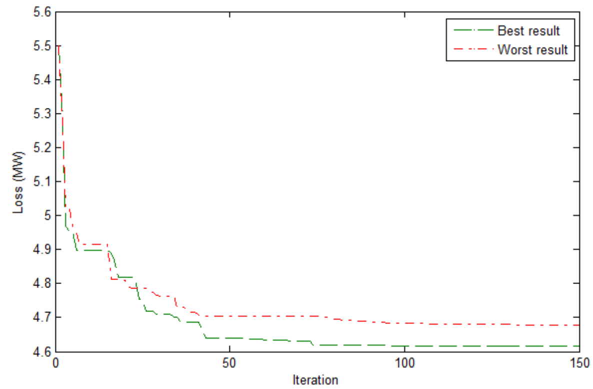

Figure 2: Performance of ALO for the best and worst results

5. Conclusion

A recent meta-heuristic technique namely ant lion optimizer for solving ORPD problem has been presented in this paper. The performance of ALO was evaluated using IEEE 30-bus system. The simulation results show that ALO able to obtain minimum loss compared to other techniques proposed in the literature.

References

[1] M. Varadarajan and K. S. Swarup, "Differential evolution approach for optimal reactive power dispatch," *Applied Soft Computing,* vol. 8, pp. 1549-1561, 9// 2008.

[2] K. Ayan and U. Kılıç, "Artificial bee colony algorithm solution for optimal reactive power flow," *Applied Soft Computing,* vol. 12, pp. 1477-1482, 5// 2012.

[3] B. Zhao, C. X. Guo, and Y. J. Cao, "A multiagent-based particle swarm optimization approach for optimal reactive power dispatch," *Power Systems, IEEE Transactions on,* vol. 20, pp. 1070-1078, 2005.

[4] M. Varadarajan and K. S. Swarup, "Differential evolutionary algorithm for optimal reactive power dispatch," *International Journal of Electrical Power & Energy Systems,* vol. 30, pp. 435-441, 10// 2008.

[5] E. Acha, H. Ambriz-Perez, and C. R. Fuerte-Esquivel, "Advanced transformer control modeling in an optimal power flow using Newton's method," *Power Systems, IEEE Transactions on,* vol. 15, pp. 290-298, 2000.

[6] D. S. Kirschen and H. P. Van Meeteren, "MW/voltage control in a linear programming based optimal power flow," *Power Systems, IEEE Transactions on,* vol. 3, pp. 481-489, 1988.

[7] I. Perez Abril and J. A. G. Quintero, "VAr compensation by sequential quadratic programming," *Power Systems, IEEE Transactions on,* vol. 18, pp. 36-41, 2003.

[8] E. M. Soler, E. N. Asada, and G. R. M. da Costa, "Penalty-Based Nonlinear Solver for Optimal Reactive Power Dispatch With Discrete Controls," *Power Systems, IEEE Transactions on,* vol. 28, pp. 2174-2182, 2013.

[9] A. H. Khazali and M. Kalantar, "Optimal reactive power dispatch based on harmony search algorithm," *International Journal of Electrical Power & Energy Systems,* vol. 33, pp. 684-692, 3// 2011.

[10] S. Mirjalili, "The Ant Lion Optimizer," *Advances in Engineering Software,* vol. 83, pp. 80-98, 5// 2015.