OPTIMAL CAPACITOR PLACEMENT IN DISTRIBUTION SYSTEMS FOR LOSS REDUCTION USING ANT LION OPTIMIZATION ALGORITHM

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ABSTRACT

The utilization of fixed capacitors (FCs) in shunt connection is one of the common methods to improve the power quality of distribution systems. In this paper, a novel optimization technique called Ant lion optimizer (ALO) is used to determine the optimal generated VARs capacity and locations of FCs. The objective functions are adopted to minimize the total distribution power loss and to improve the voltage profile. The ALO is performed its ability to cover medium and large scales radial distribution systems (RDS) such as; IEEE 33-bus and 69-bus test systems. The Numerical results illustrate that the Ant lion optimizer (ALO) offer optimal solutions properly better than many other reporter heuristic algorithms.

Keywords: *Fixed capacitor, power flow, Ant lion optimizer, Radial distribution systems*

INTRODUCTION

Many distribution grids suffer from a lot of problems while feeding consumers with inductive loads. Some of these problems related with low voltage regulation, and high power losses. Increasing reactive power consumption leads to higher lines currents with un-allowed voltage drop. As a result, about 13% of total generated power is lost as power line losses. Consequently, about 40% of total cost is consumed to compensate what is lost. These losses should be reduced to increase capability of the system, decrease its overloaded components, and improve its stability.

Connecting Capacitor banks is one of intrinsic methods of DS in distribution grids which used to perform the last destinations. The merits of shunt capacitor usage are: its availability with low cost, simplicity of installation, and performance in operation. The main disadvantage of shunt capacitor is that the reduction in its output VARs is proportional to the power squared of bus voltage. As capacitors are available at specified sizes in market, so the capacitor size and placement in RDG are discrete variables. Recently several optimization techniques have been employed for solving the optimal allocation of capacitors such as particle swarm algorithm (PSO), genetic algorithm (GA), gravitational search algorithm (GSA) , analytical-IP, Seyedali Mirjalili et. Al proposed a novel meta-heuristic technique called Ant lion optimizer (ALO) which is inspired from the intelligence behavior of antlions in hunting ants.

In this thesis, ALO is utilized for two intrinsic principles: the reduction of the grid power losses and total annual cost to improve the stability and keeping voltage profile steady at all distribution systems. It is experienced on two test cases of standard distribution grids 33-bus and 69-bus systems. Net nresults from ALO are entered in competitive with those of other techniques and proved its efficiency in solving problems to confirm its performance.

2.PROBLEM FORMULATION:

2.1 Load Flows

The backward/forward sweep is a modern technique which widely utilized in recent years. Because of its accuracy, and simplicity, it is used in this paper to calculate power flow analysis of any sophisticated system using the following algebraic formulas supported with simple diagram as Fig. 1

Power flow solution is used in the planning and design stages as well as during the operating stages. Two matrices are developed to obtain load flow solution.

$$P_{Loss(i,i+1)} = R_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|Vi|^2}\right)$$

$$Q_{Loss(i,i+1)} = X_{i,i+1}\left(\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|Vi|^2}\right)$$

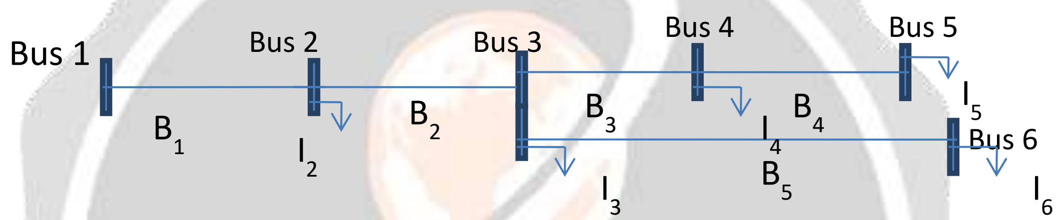

Fig1. Simple radial distribution system

- The bus-injection to branch-current matrix

[B] = [B I B C] [I] (2.1)

- The branch-current to bus-voltage matrix

[ΔV] = [B C B V] [B] (2.2)

Two matrices are developed, viz. the bus injection to branch current (BIBC) matrix and branch current to bus voltage (BCBV) matrix. By using simple multiplication of these two matrices, the load flow solution is obtained.

Development of these two matrices is explained with reference to figure.1

2.2.Equivalent current injection:

For distribution systems, the models which are based on the equivalent current injection are more convenient to use. At each bus 'I, the complex power S is specified by,

$$S_i = P_i + j\,Q_i \qquad (2.3)$$

Corresponding equivalent current injection at the k-th iteration of the solution is given by,

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \qquad (2.4)$$

V_i^k is the node voltage at the k^{th} iteration.

I_i^k is the equivalent current injection at the k-th iteration.

I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection at the k-th iteration respectively.

2.3.Bus injection to branch current matrix:(BIBC)
The power injections can be converted into equivalent current injections using the equation (2.4). The set of equations can be written by applying Kirchhoff's current law (KCL) to the distribution network. Then the branch currents can be formulated as a function of the equivalent current injections.

Consider the sample distribution system shown in the figure 2.1. Now applying Kirchhoff's current law (KCL) to the distribution network we get,

$$B_5 = I_6, \quad (2.5)$$

$$B_3 = I_4 + I_5, \quad (2.6)$$

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \quad (2.7)$$

Where B_1, B_3, $B_{5.....}$branch currents and I_2, I_3 and $I_{4....}$ are load currents respectively at buses 2, 3 and 4

$$[B] = [\ B\ I\ B\ C\ ]\ [\ I\ ] \quad (2.8)$$

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (2.9)$$

The constant BIBC matrix has non-zero entries of +1 only. For a distribution system with m-branch sections and n-buses, the dimension of the BIBC is m x (n-1).

3.PROPOSED APPROACH

The Ant Lion optimizer was produced in 2015 by Seyedali Mirjalili et.al . It is inspired from intelligence behavior of antlion's larvae in hunting ants.The ants perform the capacitors positions in free space, and the antlions perform the hidden positions. When an ant has a fittest solution than that of antlion, this means that antlion has caught the ant and consumed it. This antlion becomes the fittest and named as the elite.

3.1 Initialization of operation
The positions of ants and antlions are initially created with random numbers under dimensions and limits which modeled as:

$$X_{ij} = rand[0,1].\left(X_j^{max} - X_j^{min}\right) + X_j^{min}$$
$$\forall i \in \{1,2, \ldots..n\}, \text{j} \in \{1,2, \ldots..d\}$$

Where X_j^{max} and X_j^{min} are the upper and lower boundaries of the control variables.
The OF determines the antlions initial fitness and arranges them. The fittest antlions positions and optimal solutions are saved as the elite.

3.2 Five main steps of ALO algorithm
During searching for the optimal solution, there are five main steps are modeled mathematically in hunting the pray which proposed as:

3.2.1 Ants randomly walk

Ants improve their positions in searching for foods in free space every iteration which is given as:

$$X(t)= [\ 0, cumsum(2r(t_1)-1), cumsum(2r(t_2)-1), \ldots cumsum(2r(t_n)-1)$$

where cumsum is the cumulative sum of series numbers, n is the iterations number and r(t) is a random number which is modeled as:

$$r(t)=\begin{cases} 1 & if\ rand\ > 0.5 \\ 0 & if\ rand \leq 0.5 \end{cases}$$

This updating is tied to a range of upper and lower boundaries. To keep it between these ranges, the identified equation must be applied as:

$$X_i^t = \frac{(X_i^t - a_i) * (d_i^t - c_i^t)}{b_i - a_i} + c_i$$

where a_i is the lowest number of ants walks, b_i is the topmost number of ants walks in each iteration, c_i^t is the lowest variable of a changed function at t-*th* iteration, and d_i^t is the topmost variable of a changed function at t-*th* iteration.

3.2.2 Area of trap structure

The volume of the trap is direct proportional to the degree of antlion hunger by applying a roulette wheel which is given as:

$$\text{Accumulation} = \text{cumsum (Weights)}$$

$$\text{Weights} = \frac{1}{\text{sort}(M_{OAL})}$$

Where cumsum is the cumulative sum of series numbers, Weight is an array which determines the degree of antlions' fitness by arranging them according to preference and M_{OAL} is an array which saves the antlions' fitness.

3.2.3 Trapping in Antlion's pits

Fig. 2 illustrates the confused ants which are fallen in the trap of one chosen antlion only. *Decline the area around antlions' digs*

The random walk boundaries of ants are reduced during approaching from antlions' digs. This process can be modeled as:

$$C_i^t = \text{Antlion}_j^t + c^t$$

$$d_i^t = \text{Antlion}_j^t + d^t$$

Where c^t, d^t are the lowest and top most numbers of all variables in the current iteration, respectively. $c_i^t,\ d_i^t$ are the lowest and topmost numbers for the i-*th* respected to c^t, d^t variables, $Antlion_j^t$ is the position of antlion for j-*th* in free space for the current iteration.

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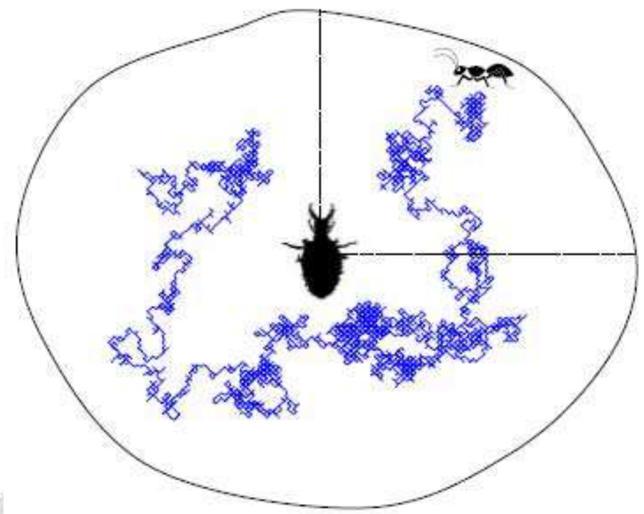

Fig.no.2 Random walk of trapped Ant

3.2.4 Sliding of ants inside the trap

After entering the circle receding of chosen antlion, it pushes the sand behind ants to slide down the ants towards the bottom of the cone where the antlion exists. The modeled equations are written as:

$$\mathrm{c}^{\mathrm{t}} = \frac{\mathrm{c}^{\mathrm{t}}}{\mathrm{I}}, \qquad \mathrm{d}^{\mathrm{t}} = \frac{\mathrm{d}^{\mathrm{t}}}{\mathrm{I}}$$

$$I = 10^{w} * \frac{t}{T}$$

where t is the current iteration, T is the maximum number of iterations, I is a ratio which is varied respected to the current iteration t and w is a constant which is varied respected to the current iteration t as follows:

$$w = \begin{cases} 2 & t > 0.1 \times Ni\_max \\ 4 & t > 0.75 \times Ni\_max \\ 6 & t > 0.95 \times Ni\_max \end{cases}$$

3.2.5 Consuming prey and re-modifying the trap

The final step of hunting, is while an ant reaches the bottom, the antlion catches it with its jaws then enter it inside the sand and consumed it (means that when the ant become fitter or has a better solution than the antlion, it takes its best solution to tie themselves up with ants). The mathematical model of this operation is offered as:

$$\mathrm{Antlion}_{\mathrm{j}}^{\mathrm{t}} = \mathrm{Ant}_{\mathrm{j}}^{\mathrm{t}}, \text{if } \mathrm{f}\left(\mathrm{Ant}_{\mathrm{j}}^{\mathrm{t}}\right) > f\left(\mathrm{Antlion}_{\mathrm{j}}^{\mathrm{t}}\right)$$

Where $Antlion_j^t$ is the position of antlion for j-th as a selected one at the t-th iteration.

3.2.6 Elitism

To obtain the best solution at each phase, this fittest one is saved and named as elite. The elite affects the steps of all ants random walks and therefore their destinations. This can be offered as:

$$\mathrm{Ant}_{\mathrm{j}}^{\mathrm{t}} = \frac{\mathrm{R}_{\mathrm{A}}^{\mathrm{t}} + \mathrm{R}_{\mathrm{E}}^{\mathrm{t}}}{2}$$

where R_A^t and R_E^t are random walks of an ant the first is around the trap of chosen antlion, and the second is around the trap of the elite respectively at t-*th B*iteration.

4. RESULTS AND DISCUSSION

To evaluate the performance of ALO technique, standard IEEE test systems are used (IEEE 33-bus and IEEE 69-bus test systems). However, the obtained results from the developed ALO algorithm are compared with other well-known optimization methods to proof its effectiveness and superiority. The selected parameters are adjusted as listed in Table I.

5.CONCLUSIONS

This paper has studied the ability of new optimization technique called ant lion optimizer (ALO) in order to find the optimal solution of capacitor allocation problem in radial distribution systems. The location and size of shunt capacitors have been determined based on the minimization of power loss and to improve the voltage profile.

The developed optimization algorithm has been applied on IEEE 33-bus and IEEE 69-bus radial distribution systems. However, the obtained results have been compared with other well-known methods. The numerical results verified that the ALO algorithm is capable of producing superior solutions with excellent performance of convergence.

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