Ant Lion Optimization Optimal for Placement and Sizing of Distributed Generation in Radial distribution Networks

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Abstract

High power loss and voltage instability are the main concerns in electrical power distribution due to load influence and single power source. Distributed generation (DG) is an emerging technology in the modernized power system, and it plays an important role in electrical power distribution system for loss reduction and voltage profile enhancement. This evolutionary has changed the radial distribution system from the single power source to multiple power sources. This paper presents the optimal placement and size of DG unit in radial distribution network using ant lion optimization (ALO). The objective function of this paper is to minimize the costs of annual power loss and operating of DG unit. The proposed algorithm is tested with 15 and 33 buses of radial distribution systems and ALO based optimal DG location and sizing resulted in the minimum total cost of power loss and operation cost of DG unit.

Keywords: ant lion optimization, distributed generation, radial distribution networks.

1. Introduction

Distribution systems delivery the electrical power to the customers; hence, it has been considered as the most important among the three divisions of generation, transmission, and distribution. The power reliability mainly depends on an efficient distribution system. Distribution systems contribute about 70% of power loss while only about 30% of loss occurred in transmission and generation (Dinakara Prasad Reddy, Veera Reddy, & Gowri Manohar, 2017). Therefore, distribution is the main concerns to consider nowadays for power quality improvement and cost saving. With the continuous increasing of demands and system expansion, it has been caused the challenging for the utilities to maintain the system reliability and quality (Pandy & Bhadoriya, 2014), and when the heavy loads are connected to the system, the voltage magnitude is dropped and the power loss is also increased. Hence, the utilities have been looking for a smarter way to meet the customer requirements. One smart solution to solve these problems is to change the topology of the distribution system by installing the external power sources rather than reconfiguring the whole system (Vidyasagar, Vijayakumar, Sattianadan, & George Fernandez, 2016).

DG has been considered as the backbone in distribution network in power loss reduction and power quality improvement because the integration of DG in the system can reduce system loss and improve voltage profile economically and effectively (Georgilakis & Hatziargyriou, 2013). Integration of DG has great impacts on the system. Installation of DG in the system requires the high technical knowledge because there are several important factors to consider including DG technology, number, size, type, and connection. DG must be optimally placed and sized to get high benefits and avoid any negative impacts. However, non-optimal location and size of DG cause to increase system losses, voltage fluctuation, protection failure, system instability, and ineffective cost (Mishra & Bhandakkar, 2014).

In this paper, ALO which is the most recently nature-inspired algorithm was used to determine the optimal location and size of DG in radial distribution networks. The algorithm was tested on 15 and 33 bus system. This work was organized into 5 sections. The problem formulation of the objective function involving active power loss minimization and the system constraints of the controlled variables are presented in Section 2. The overview of ALO is described in Section 3, while the simulation results and discussions are placed in Section 4. Also, the algorithm procedure is presented. Finally, the conclusion of this work is located in Section 5.

2. Problem Formulation

2.1 Objective Function

The loss can be obtained by computing the power flow between two buses as illustrated in Fig. 1 and it can be formulated in the following equations.

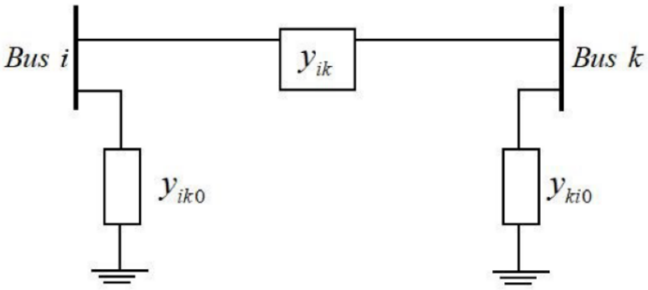

Fig. 1: Schematic of power flow between two bus models

Where V_i and V_k are the bus voltage at bus *i* and *k* respectively. The power flow between buses *i* and *k* at bus *i* is given as,

$$S_{ik} = P_{ik} + Q_{ik}, \tag{1}$$

$$S_{ik} = V_i I_{ik}^{*}, \tag{2}$$

$$S_{ik}^{'} = V_i \left(V_i^{*} - V_k^{*}\right)^{*} Y_{ik} + V_i V_i^{*} Y_{ik0}. \tag{3}$$

Similarly, the power flow between buses *k* and *i* at bus *k* is given as,

$$S_{ki}^{'} = V_k \left(V_k^{*} - V_i^{*}\right)^{*} Y_{ki} + V_k V_k^{*} Y_{ki0}. \tag{4}$$

Hereby, the loss between these two buses is the sum of power flow in Equation (3) and (4).

$$S^{'}_{Total\,loss} = S^{'}_{ik} + S^{'}_{ki}. \tag{5}$$

The total power loss in a system is obtained by summing all the power flow of bus. The power loss in the slack bus can be obtained by summing the power flow at the terminated bus (Anumaka, 2012). In this paper, the reactive power loss is neglected, so the objective function of total real power loss reduction is obtained as,

$$F_{Loss} = real\left(\sum_{i=1}^{n} S_{i\,Total\ loss}\right). \tag{6}$$

The costs of power loss and DG can be defined as the following mathematical expressions (Gautam & Mithulananthan, 2007)**:**

$$C_{Loss} = F_{Loss} \times E_c \times T, \tag{7}$$

$$C_{DG} = \left[\sum_{i=1}^{N_{DG}} \left(aP_{DG,i}^{2} + P_{DG,i} + c\right)\right] \times T, \tag{8}$$

Where E_c is the price of energy rate in \$/kWh (0.06\$/kWh), T is time in hour per year (8760*h*), a, b, c are the cost coefficients (a=0.25, b=20, c=0), N_{DG} is the number of DG, P_{DG} is the size of DG unit, C_{Loss} is the cost of real power loss, and C_{DG} is the operating cost of DG. As a result, the main objective function of this paper is to minimize the total cost of loss and DG operation in a year. The formulation of the objective function can be formulated as the expression,

$$Minimize\ TC = C_{Loss} + C_{DG}. \tag{9}$$

Where *TC* is the total cost of real power loss and the operating cost of the DG unit.

3.2 System Limit Constraints

System limit constraints are considered as inequality constraints which comprise of voltage magnitude, current, and real power injection of DG. These variables are optimized and they are limited to be within the constraints during the optimization process.

$$|V_i|_{\min} \le |V_i| \le |V_i|_{\max}, \tag{10}$$

$$|I_{ik}| \le |I_{ik}|_{\max}, \tag{11}$$

$$|V_{DG}|_{\min} \le |V_{DG}| \le |V_{DG}|_{\max}, \tag{12}$$

$$P_{DG,\min} \le P_{DG} < P_{total\,demand}. \tag{13}$$

Where V_i is the voltage magnitude at bus *i*, V_{DG} is the voltage magnitude at the bus with DG, I_{ik} is the current of the branch, $I_{ik\max}$ is the maximum current of the branch, $P_{total\,demand}$ is the total real power demand in the system, and P_{DG} is the real power generation of DG.

3.3 Power Balance Constraints

The power balance is considered as the equality constraints which balance power generation, load demand, and power loss. Also, the relationship of active and reactive flow in the system can be expressed as the followings:

$$P_{Slack} = \sum_{i=1}^{N_L} P_{D,i} + \sum_{i=1}^{N_{br}} P_{Loss,i}, \tag{14}$$

$$Q_{Slack} = \sum_{i=1}^{N_L} Q_{D,i} + \sum_{i=1}^{N_{br}} Q_{Loss,i}, \tag{15}$$

The power flow equation considering with the presence of DG unit for practical distribution system and DG is the real power generation units operating in unity power factor in this paper. Then, the power flow equation can be written as,

$$P_{Slack} + \sum_{i=1}^{N_{DG}} P_{DG} = \sum_{i=1}^{N_L} P_{D,i} + \sum_{i=1}^{N_{br}} P_{Loss,i}, \tag{16}$$

$$Q_{Slack} = \sum_{i=1}^{N_L} Q_{D,i} + \sum_{i=1}^{N_{br}} Q_{Loss,i}. \tag{17}$$

Where P_{slack}, Q_{slack} are the active and reactive power at slack bus, respectively, $P_{D,i}, Q_{D,i}$ are the active and reactive power demands at bus i, respectively, $P_{loss,i}, Q_{loss,i}$ are the active and reactive power loss at bus i respectively and, $P_{DG,i}$ are the active power produced from DG unit at bus *i*.

3. Ant Lion Optimization

ALO is a novel nature-inspired algorithm which is modelled based on the unique prey hunting behaviour of ant lion. ALO was proposed in 2015 by Mirjalili (Mirjalili, 2015), and it consists of two phases. Exploration phase is implemented by random walk and random selection, while exploitation phase is implemented by the trap.

3.1 Operator Search Agents of ALO

ALO algorithm mimics the hunting behavior of ant lion and ant in the trap. In this interaction, ants required to move on the search space, and ant lions are allowed to hunt them and become fitter using traps. Naturally, ants move stochastically to find the food sources. Hence, movement of ants is modeled by a random walk, and it can be formulated as the mathematical expressions as,

$$X(t) = \left[0,\ cumsum\left(2r\left(t_1\right)-1\right),\ cumsum\left(2r\left(t_2\right)-1\right),\ldots\ldots.,\ cumsum\left(2r\left(t_n\right)-1\right)\right] \quad (18)$$

$$r(t) = \begin{cases} 1 & if \quad rand > 0.5 \\ 0 & if \quad rand < 0.5 \end{cases}, \quad (19)$$

where, $Cumsum$ refers to a cumulative sum, n is the maximum number of iteration, t is the step of the random walk, and $rand$ is random number between [0,1].

The location of ants is recorded and form the matrix as shown in Eq. (20) during the optimization process. In addition, the position of ants refers to the variable of solutions and it is saved in the matrix M_{Ant} during the optimization implementation. Each ant is evaluated and its fitness values are stored in the matrix M_{OA} as expressed in Eq. (21), and F is the objective function.

$$M_{Ant} = \begin{bmatrix} A_{1,1} & A_{1,2} & \ldots.. & A_{1,d} \\ A_{2,1} & A_{2,2} & \ldots.. & A_{2,d} \\ : & : & & : \\ A_{n,1} & A_{n,2} & \ldots.. & A_{n,d} \end{bmatrix}, \quad (20)$$

$$M_{AO} = \begin{bmatrix} F_t\left(\left[A_{1,1} \quad A_{1,2} \quad \ldots.. \quad A_{1,d}\right]\right) \\ F_t\left(\left[A_{2,1} \quad A_{2,2} \quad \ldots.. \quad A_{2,d}\right]\right) \\ : \\ F_t\left(\left[A_{n,1} \quad A_{n,2} \quad \ldots.. \quad A_{n,d}\right]\right) \end{bmatrix}, \quad (21)$$

It is assumed that ant lions are hiding somewhere in search spaces; hence, the matrix $M_{Antlion}$ is used to store the position of ant lions, while their fitness values are saved in the matrix M_{OAL} as shown in Eq. (22) and (23) respectively.

$$M_{Ant\,lion} = \begin{bmatrix} A_{1,1} & A_{1,2} & \cdots\cdots & A_{1,d} \\ A_{2,1} & A_{2,2} & \cdots\cdots & A_{2,d} \\ : & : & : & \\ A_{n,1} & A_{n,2} & \cdots\cdots & A_{n,d} \end{bmatrix}, \tag{22}$$

$$M_{AOL} = \begin{bmatrix} F_t\left(\left[A_{1,1} \quad A_{1,2} \quad \cdots\cdots \quad A_{1,d}\right]\right) \\ F_t\left(\left[A_{1,1} \quad A_{1,2} \quad \cdots\cdots \quad A_{1,d}\right]\right) \\ : \\ F_t\left(\left[A_{1,1} \quad A_{1,2} \quad \cdots\cdots \quad A_{1,d}\right]\right) \end{bmatrix}, \tag{23}$$

3.1.1 Random Walk of Ants

Random walks of ants are modeled based on Eq. (18), and ants cannot move to a better due to limits of every search space. Therefore, they are normalized using the following equation.

$$X(t) = \frac{\left(X_i^{\,t} - A_i\right) \times \left(D_i - C_i^{\,t}\right)}{\left(D_i^{\,t} - A_i\right)} + C_i\,, \tag{24}$$

3.1.2 Trapping in Ant lion’s Pits

Ant lion’s trap has effects to the random walk of ants, and this assumption is modeled as the followings:

$$C_i^t = Ant\,lion_j^{\,t} + C^t\,, \tag{25}$$

$$D_i^t = Ant\,lion_j^{\,t} + D^t\,, \tag{26}$$

Where C_i^t, D_i^t are the minimum and maximum of all variables at *t*th iteration,C^t, D^t are the minimum and maximum of all variables for *t*th ants, and $Ant\,lion_j^{\,t}$ refers to the position chosen *j*th ant lion at *t*th iteration.

3.1.3 Building Trap

A roulette wheel is utilized to model the hunting ability of ant lions. During the optimization process, ALO is required to use roulette wheel operators to select ant lions based on their fitness values. Hence, the fitter ant lions have more chances to catch the ants.

3.1.4 Sliding Ants toward Ant lion

As mention above, ants are required to walk randomly, while ant lions build trap relatively to their fitness. When ant lions sense that there is an ant in the trap, they shoot the sand outward from the center of the pit. The action causes the ant that is trying to escape slide down, and it can be presented by the mathematical models as follows:

$$C^t = \frac{C^t}{I}, \tag{27}$$

$$D^t = \frac{D^t}{I}, \tag{28}$$

$$I = 10^w \frac{t}{T}, \tag{29}$$

Where t is the current iteration, T is the maximum number of iterations, and w is the constant defined based on the current iteration.

3.1.5 Catching Prey and Rebuilding the Pit

When the ants are pulled down to under the sand, and they are eaten by ant lion, it is the final stage of the hunting processes. In these regards, ant lions are required to move to the latest position of the hunted ants to enhance the hunting capability to catch the new ants. These processes are presented based on the following equations.

$$Ant\,lion = Ant\,lion_i^t \quad if \quad f\left(Ant_i^t\right) > f\left(Ant\,lion_i^t\right), \tag{30}$$

3.1.6 Elitism

It is an important point in the evolutionary algorithm that the best solution obtained is allowed to maintain at each step of the optimization processes. In ALO algorithm, the best ant lion obtained so far from each iteration is stored and it is considered as the elites. Elite is the fitness ant lion, so it should be capable to affect the motions of all ants during each iteration. As a result, it is assumed that every ant randomly walks around a selected ant lion by the roulette wheel and the elite simultaneously as follows:

$$Ant_i^t = \frac{r_a^{\,t} + r_e^{\,t}}{2}. \tag{31}$$

Where r_a^t is the random walk around the ant lion selected by the roulette wheel at *t*th iteration, r_e^t is the random walk around the elite at *t*th iteration, and Ant_i^t refers to the position of *i*th ant at *t*th iteration.

3.2 ALO for DG Application

The ALO algorithm for determining the optimal location and size of DG can be described as follows:

1. Read system data and compute load flow using the Newton-Raphson method.
2. Initialize setting parameters (maximum iteration, and population).
3. Compute power loss and store DG size.
4. Update the position of ant lions and calculate loss performing load flow.
5. If the obtained loss is less than the previous case, save the current results and discard the previous one or else go back to step 4.
6. Print the results if the stopping criteria is satisfied.
7. The algorithm is ended.

4. Simulation Result and Discussion

The proposed algorithm was implemented by MATLAB 2017a, and the 15 and 33 buses of radial distribution systems were the tested cases. The main aims of this paper were to determine the optimal location and size of DG in the radial distribution networks. The optimum location and size of DG could be obtained using the proposed algorithm. Moreover, single DG operating at unity power factor was considered in this research.

4.1 15 Bus System

15 buses of the radial distribution system which was tested with the proposed algorithm are shown in Fig. 2. The bus data and line data can be obtained (Das , Kothari & Kalam, 1995). Bus 1 is considered as the reference bus and bus 2 to 15 are the load buses.

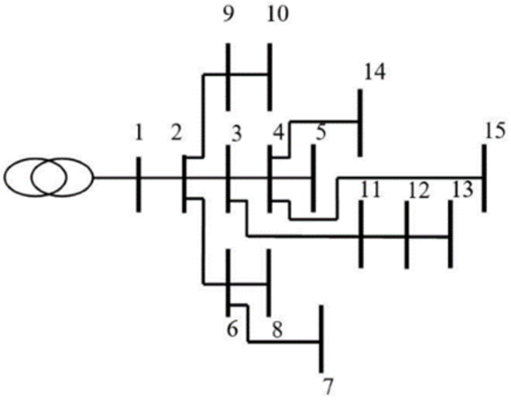

Fig. 2: 15 buses of radial distribution system

Table 1 shows the summaries of the obtained results of 15 bus system. It was proved that the power loss was reduced from 43.2kW to 26.97kW after placing a DG unit at the 3rd bus with the capacity of 932.40kW. The cost of DG operation unit was 165213.60$ and the cost of power loss could be reduced from 22705.92$ to 14175.432$. It was saved up to 8530.48$. Moreover, the minimum voltage at the 14th bus was improved from 0.9578 p.u. to 0.9836 p.u. with the installation of DG unit.

Table 1: Results of 15 bus system

	Before DG	After DG
Loss (kW)	43.2	26.97
Cost of loss ($)	22705.92	14175.43
Location (bus)	-	3
DG Size (kW)	-	932.40
Operation cost of DG ($/h)	-	165213.60
Loss saving (kW)	-	16.23
Cost of loss saving ($)	-	8530.48
Loss reduction (%)	-	37.56
Minimum voltage (p.u.)@bus	0.9578@14	0.98750@14

Figure 3 shows the voltage profile of after placing DG unit in the system. It was noticed that the voltage profile has been dropped with the growth of loads over years, and it conveyed the great impact of DG presence in improving the voltage profile and reliability of the system. Moreover, the voltage of some nodes located at the end of the system are closed to the lower boundary, and they were improved effectively after placing DG at the optimal point.

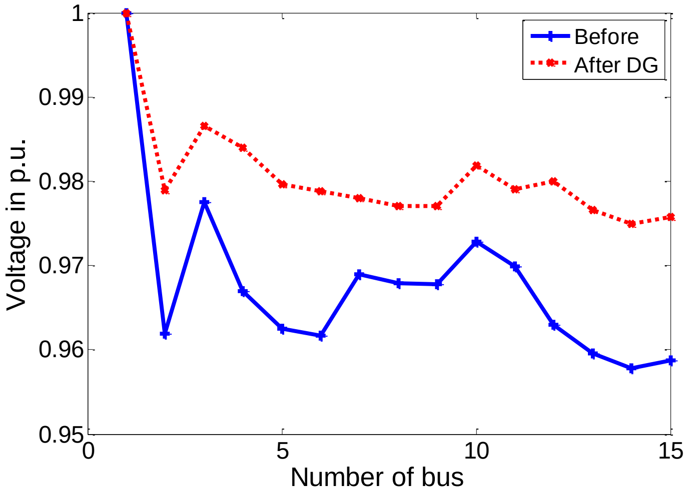

Fig. 3: Voltage profile comparison of 15 bus system

4.2 33 Bus System

The 33 buses of the radial distribution system are shown in Fig. 4. It consists of totally 33 buses and 32 lines or branches. The whole system is connected to a power transformer at 12.66kV of the secondary side while it is loaded totally of 3.715MW and 2.3MVar. Bus 1 is considered as the reference bus and others are load buses. The system data can be obtained (Baran & Wu, 1989).

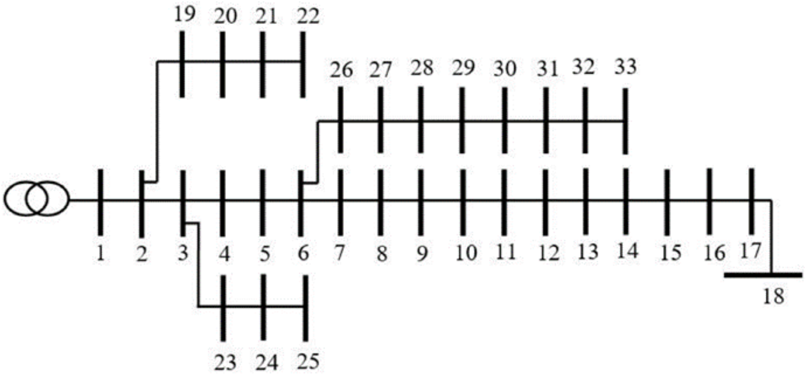

Fig 4. 33 buses of radial distribution system

The summaries of the obtained simulation results of 33 bus system were shown in Table 3. From the obtained results, it was observed that the power loss after simulation was reduced from 206.5kW to 103.6kW which corresponds to 49.84% of loss reduction. Also, the cost of power loss was reduced from 108536.40$ to 54452.16$, so the cost of loss could be saved to 54084.24$. The most suitable location for DG installation was the 6th bus with the suitable capacity of 2.62MW, and the cost of the DG operation unit was 474003.60$/h. The minimum voltage at the 19th bus was increased from 0.9032 p.u. to 0.9433 p.u.

Table 2: Results of 33 bus system

	Before DG	After DG
Loss (kW)	206.5	103.6
Cost of loss ($)	108536.40	54452.16
Location (bus)	-	6
DG Size (MW)	-	2.62
Cost of DG ($/h)	-	474003.60
Loss saving (kW)	-	102.9
Cost of loss saving ($)	-	54084.24
Loss reduction (%)	-	49.84
Minimum voltage (p.u.)@bus	0.9032@19	0.9424@19

The voltage of some nodes was so poor, but it was enhanced significantly with the DG unit installation at the optimal bus as illustrated in Fig. 5. It was shown the voltage profile comparison of before and after placing DG unit in the system of both scenarios. It proved the importance of DG unit presence in maintaining the voltage stability and security in the system.

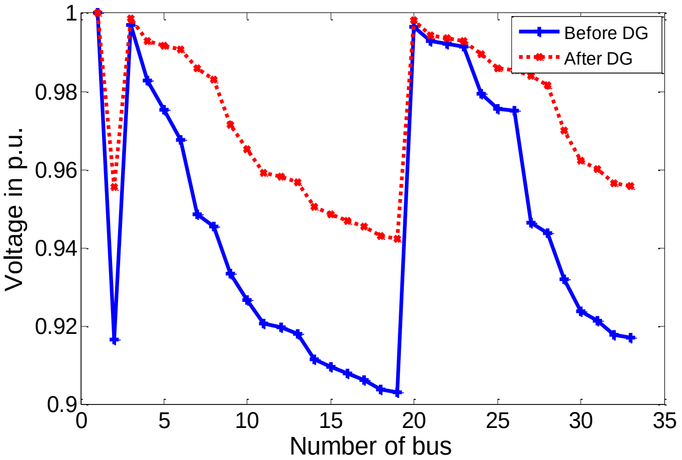

Fig. 5: Voltage profile comparison of 33 bus system

5. Conclusion

In this paper, ALO which is a recent nature-inspired algorithm was used to determine the optimal location and size of DG unit in radial distribution networks. Cost of power loss and DG operation were the main objectives functions taken in this research. Single DG unit operating at unity power factor was carried out and the method was tested on four systems of 15 and 33 bus system. From the results, it could be concluded that there was much reduction in power loss and increment of energy saving costs after placing DG unit at an optimal location with optimal size. Moreover, this study proved the positive impacts of DG presence in the distribution for power loss reduction and voltage profile improvement, and it conveyed the effectiveness and good performance of the proposed method in solving DG application optimization in distribution systems.

6. Reference

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