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Ant Lion Optimizer Algorithm Based Profit Maximization of Electric Power Distribution Companies Considering Network Reconfigurations

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Abstract

A simple and powerful methodology for determining the optimal placement as well as size of the combined DGs and Capacitor units with network reconfiguration in deregulated power system is presented in this paper. The prime objective of the work is to maximize the profit of DG owner, minimize the operational cost of DISCOs, improve the voltage profile and minimize network losses by proper location of DGs and capacitors with proper network reconfigurations. A recently developed; the best and successful meta-heuristic optimization algorithm of Ant Lion Optimizer (ALO) is projected to solve this problem. The AFO is applied to 69-node test systems to justify the ability of ALO. The simulations are carried out using MATLAB platform and results show the applicability of the ALO in the DISCOs. The simulation results are compared with similar approaches in literature in order to validate the efficiency of proposed approach.

Keywords: Distribution Company, Optimal location and size of DG unit and capacitor, Power loss minimization, Profit maximization, Ant Lion Optimizer algorithm.

1. Introduction

The power system has become more competitive moving away from centrally planned system to one in which the system operates in a decentralized fashion. The new environment differs markedly from the one in which the system has been operated previously. Among different challenges faced by market and system operators, maintaining system security is one of the main concerns in the wake of privatization and deregulation around the world. The new structure of the power industry has pushed the power systems to be operated even closer to their limits, due to market pressures or physical limitations in the transmission network. This leads to the requirement of some new techniques and analysis methods for system operation and long term planning. This challenge has motivated researches to come up with optimal power flow models that better represent power system security in electricity markets. This work addresses the voltage stability problem [1-3] in deregulated power system.

The Distribution Generations (DGs) and Capacitors placements and network reconfiguration become major factors to improvise the efficiency and performance of DISCOs and DG owners. The proper placement and optimal sizing of DGs and capacitors effectively step-up the voltage stability, power quality and reduce the network losses, regulate the voltage profile, reliability and maximize operational benefits of DISCOs and DG owners [4-5].

The researchers have developed various mathematical and metta-heuristic approaches for DG placement, size of DG, Power Loss limitation and Voltage Level improvement of DN in the DISCOs. Lagrangian relaxation by Gautam and Mithulananthan, [6] method is being applied for optimal placement of DGs in the wholesale electricity market. This problem is for mulated to achieve two different objectives such as social welfare maximization and profit maximization.

The same problem has been solved using linear programming technique Wu *et al.,* [7] to improve the Voltage Stability Margin (VSM). Also a hybrid GA-Based Tabu Search method Mohammadi and Nafar, [8] has been investigated and analyzed in order to install at optimal location of DG units which are subjected to economical, technical and market constrains. When we consider the cost minimization the costs include capital cost, replacement cost, operation and maintenance cost, fuel cost, production cost, and reliability improvement cost. GA with straight forward sub-algorithm has been proposed Alemohammad *et al.,* [9] to solve the distribution reconfiguration problem under deregulated environment. This work minimize the cost of electricity purchased form wholesale market depending hourly vocational marginal prices (LMPS), in all power distribution layers from distribution to power transmission systems and in bilateral agreements with DGs.

Ameli *et al.,* and Ameli *et al.,* [10,11] using multi objective practical Swam Optimization method, the voltage profile maximization and power minimization have been achieved with the help of sizing as well as placement of DG. Also reliability improvement has been included as additional constrains in this work. Moreover, economic status of distribution companies and DG owners has been analysed. The performance of this method was analysed using IEEE33 bus radial test system. PSO algorithm Karimi and Dashti, and Saboori and Hemmati, [12, 13] can be used to enhance the voltage stability of distribution networks in the restructured power system by placement of appropriate size capacitors. In this work, to maximize the benefit of DISCOs through the distribution network management's view point is analysed. In addition, active power loss cost and cost of capacitor placement are considered for maximizing the benefit of distributors.

The deregulated power system faces a power loss in the distribution practices. In order to minimize the actual power loss in the total distribution system multi objective Differential Evolution algorithm Mounica and Devi, [14] has been applied to decide the optimal size and appropriate location of DG units. The algorithm is verified in IEEE 123 bus system; simultaneously the impacts and instances of distinct factors are studied.

A combined Evolutionary Algorithm and Game Theory approach Moradi *et al.,* [15] has been proposed to notice synchronously the optimal location and functioning of DGs. This technique is developed in two different phases. In the first phase, paying attention on active power loss reduction, voltage profile improvement, and voltage regulations as the objectives the appropriate location of DGs are determined using a multi-objective optimization problem. In the second phase, the optimal income of the DGs owners beside the most desirable total payment of the distribution corporation by adopting bi-level optimization technique with two agents are governed and Game theory is engaged to assist in noticing optimal contract prices.

The multi-objective voltage stability voltage stability optimization problem has been solved using e-constraint method, and with Fuzzy satisfying approach Abapour *et al.,* [16]. These methods not only solve the voltage stability problem but also attempt to maximize the DISCOs and DG owner's benefit. Safety is an important factor for the DISCOs. considering it an adaptive robust optimization method Mohiti *et al.,* [17] has been used for enabling the promoters of DISCOs and private micro grids (PMGs) to balance various conservation measures during working horizon. Here, minimization of total operating cost is considered as an important task in power distribution network. To achieve this goal, DN and PMGs are included with their synchronized operation.

An improved PSO with adaptive inertia weight (W) based an good result rate Ghatak *et al.,*[18] has been utilized to find the optimal allocation of DG and DSTATCM in a restructured power system. The problem mainly considered security limits but optimal sizing and installing of the device, economic and social objectives, logical and innovative indexes that are voltage profile improvement index, technological factors, benefit cost ratio and emission cost benefit index are also calculated with care.

All optimized algorithms based on evolutionary and swarm intelligence require common and specific control variables such as population size, number of generations, elite size etc. Specific parameters are very crucial factors for the proper tuning of these algorithms which affects the performance of the algorithms. Improper tuning of the algorithm with improper parameters would either increase the computational attempt or give a local optimal solution. Moreover, to enhance the effort of the algorithm, the common control parameters also have to be tuned in additional to the tuning of algorithm – specific parameters. The methodological revolution in the energy market imposes the need for renewed for mutation which doesn't require any algorithm- specific parameters. So, to avoid this complexity, optimization method, Ant Line optimizer (ALO) algorithm (Mirjalili 2015) and Kamboj *et al.,* [19-20] a parameter free algorithm has been introduced to solve complex optimization problem of voltage scalability. In this article, multi-objective optimization problem of optimal location and appropriate sizing of DGs in the distribution network are being (examined)(analyzed) under deregulated environment.

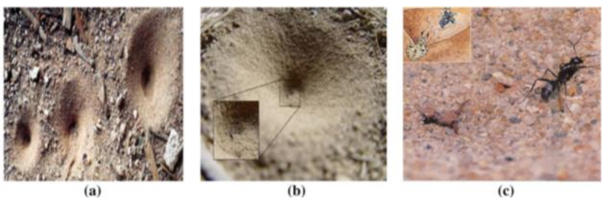
2. PROPOSED ANT LION OPTIMIZER AND ITS MATHEMATICAL FUNCTIONS

The ant line optimizer is a metta-heuristic population-based search optimization algorithm. This algorithm recently developed by Seyedali Mirjalili [20] in 2014 and used to solve the several Engineering constrained and non-constrained optimizations problems. The ALO is a trouble-free control parameters algorithm and has colony size, maximum cycle number and less parameter to tune and getting the global optimal solution. It is inspired by life cycle of Antlions (doodlebugs), which belong to the Myrmeleontidae family and Neuroptera order (net-winged insects).

The ALO algorithm mimics the hunting method of antlions (doodlebugs) and is based on the following steps of hunting the prey [17]

- Random walk of ants
- Building traps
- Entrapment of ants in traps
- Sliding ants toward antlion
- Catching preys and
- Re-building traps.

The steps for building traps and entrapment of ants in traps are shown in Fig. 1a–c.



The process of catching the prey and re-building traps are shown in Fig. 1 d–f.

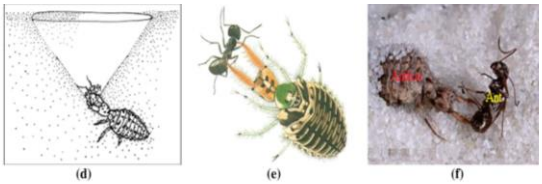


Fig. 1. a–c Building traps and entrapment of ants in traps; d–f catching the prey and Re-building traps

The mathematical functions of proposed ALO approach has been formulated as follows

2.1 Random walks of ants

The ants move stochastically searching for food in nature, The random/stochastic walks of ants can be mathematically model as

X(t)=[0,cumsum(2r(t_1),cumsum2r(t_2)-1),….,cumsum(2r(t_n)-1)]   (1)

Where cumsum calculates the cumulative sum, n is the maximum number of iteration, t shows the step of random walk (iteration in this study), and r(t) is a stochastic function represented as follows:

$$r(t) = \begin{cases} 1 \; if \; rand > 0.5 \\ 0 \; if \; rand \le 0.5 \end{cases} \qquad (2)$$

In order to keep the random walks of ants inside the search space, the positions of their walks are normalized using the min–max normalization equation:

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

(3)

2.2 Trapping in antlion's pits

The random walks of ants are affected by antlions' traps; the mathematical equation of trapping of ants in antlion's pits can be formulated as follows:

$$c_i^t = Antlion_j^t + c^t \qquad (4)$$

$$d_i^t = Antlion_j^t + d^t \qquad (5)$$

2.3 Building trap

In order to analysis hunting capability of antlion, the Roulette wheel is working. The ants are assumed to be trapped in only one selected antlion and shown in fig 2. During an optimization, the ALO is necessary to use a roulette wheel operator for selecting antlions based on their fitness. This process gives high probability to the fitter antlions for catching ants

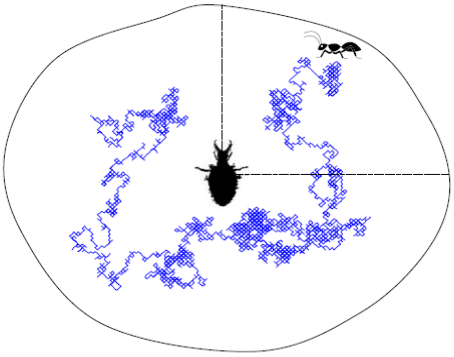


Fig. 2. Random walks of an ant inside an antlion's trap.

2.4 Sliding ants toward antlion

The sliding of ants toward antlions can be mathematically defines as

$$c^t = \frac{c^t}{I} \quad (6)$$

$$d^t = \frac{d^t}{I} \quad (7)$$

2.5 Catching prey, re-building the pit

Catching the ants by antlion and re-building the pit can be formulated as follows

Antlio $n_i^t = Ant_i^t$ if f(An t_i^t) >f(Antlio n_i^t) (8)

2.6 Elitism

Elitism is an significant function of evolutionary algorithms for stopping the program. It allows maintaining the finest solution(s) getting at any stage of optimization procedure. In this problem, the best antlion obtained in all iteration and is saved also it's considered as elite. The elitism operation can be performed by using the following equation.

3. PROBLEM FORMULATION

In this section, economical benefits and DG and Capacitor costs are submitted and modeled. In this modeling, distribution system companies are responsible for providing customer demand, DG operation and distribution system management. Therefore, costs and benefits of DGs and Capacitors allocation in a network can be expressed as follows

The cost of DG and Capacitor units, investigation fee, site preparation for DGs and Capacitors installations, construction, monitoring equipment, etc. are included in investment costs. These costs can be formulated as following eqn.

$$C_1 = \sum_{i=1}^{NDG} K_{DGi} \times IC_i + \sum_{i=1}^{NCap} K_{capj} \times IC_j \quad (9)$$

The operating costs of DG and Capacitor are based on the operation of DGs and Capacitors to produce electricity for consumers. The operating costs of Capacitors are nil. Therefore, operating costs are only of DGs in eqn.

$$C_2 = \sum_{i=1}^{NDG} \left[K_{DGi} \times OC_i \right] \times \Delta T \quad (10)$$

Where, OC_i is the operating cost of *i*th DG in `/MWh and ΔT is the total number of operating hours in a year.

If IR is the interest rate and IF the inflation rate, then the present worth factor can be represented as eqn..

Present Worth Factor,

$$\beta^t = \sum_{t=1}^{n} \left(\frac{1+IF}{1+IR} \right)^t \quad (11)$$

Where, n is the total number of year of planning period. The present worth value ofoperating cost in a given planning year can be calculated as eqn.

$$PWV(C_2) = \sum_{i=1}^{NDG} \left[K_{DGi} \times OC_i \right] \times \Delta T \times \beta^t \quad (12)$$

Another yearly cost of DGs and Capacitors are related to maintenance cost. Maintenance costs include the annual mechanical and electrical renovation cost. This cost is not related to placement of DG and Capacitor and is equal for all placements in eqn.

$$C_3 = \left[\sum_{i=1}^{NDG} \left(K_{DGi} \times IC_i \right) \times MC_{DGi} + \sum_{i=1}^{NCap} \left(K_{capj} \times IC_j \right) \times MC_{capj} \right] \quad (13)$$

The present worth value of this annual cost in the planning period is calculated aseqn.:

$$PWV(C_3) = \left[\sum_{i=1}^{NDG} \left(K_{DGi} \times IC_i \right) \times MC_{DGi} + \sum_{i=1}^{NCap} \left(K_{capj} \times IC_j \right) \times MC_{capj} \right] \times \beta^t \quad (14)$$

In restructured power system, Distribution Company purchases its power from transmission grid to meet the power demand of distribution system customers. Distribution Company can supply power demand with considering DGs in network and gets lower electric power from transmission grid. i.e., Distribution Company can sell the energy to electricity market (Grid) as per the contractual agreement and can be given as:

Energy sold to the electricity market (Grid) during ?T time segment in eqn.,

$$B_1 = \sum_{i=1}^{NDG} K_{DGi} \times EP_G \times \Delta T \quad (15)$$

Where, EP_G is the electricity price of grid power in `/kWh. The present worth value of electricity generated from DG by the distributed company can be calculated as eqn.:

$$PWV(B_1) = \sum_{i=1}^{NDG} K_{DGi} \overset{i}{\times} EP_G \times \Delta T \times \beta^t \quad (16)$$

The optimal placement of DGs and Capacitors in the distribution system minimizes the real power loss. The loss reduction is the primary goal for the Company for maximizing the profit. The loss reduction revenue in the presence of DGs and Capacitors can be evaluated as eqn.:

$$B_2 = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \quad (17)$$

$$PWV(B_2) = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \times \beta^t \quad (18)$$

Power flow equations and constraints

- Power flow equations corresponding to both active and reactive power balance for all the buses are expressed by following equations (8.19) must be satisfied.

$$P_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)\right]$$
$$\forall i = 1,2,3,\ldots\ldots N \quad (19)$$

$$Q_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)\right]$$
$$\forall i = 1,2,3,\ldots\ldots N \quad (20)$$

- Considering total real and reactive power loss in system, the total active andreactive power losses are expressed as follows in eqns. (8.15) and (8.16):

$$P_i = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij}\left(P_i P_j + Q_i Q_j\right) + \beta_{ij}\left(Q_i P_j - P_i Q_j\right)\right] \quad (21)$$

$$Q_i = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\gamma_{ij}\left(P_i P_j + Q_i Q_j\right) + \zeta_{ij}\left(Q_i P_j - P_i Q_j\right)\right] \quad (22)$$

Where, $\alpha_{ij}, \beta_{ij}, \gamma_{ij}, \zeta_{ij}$ are calculated by the following equations:

$$\alpha_{ij} = \frac{R_{ij}}{|V_i V_j|} \cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{X_{ij}}{|V_i V_j|} \sin(\delta_i - \delta_j)$$

$$\gamma_{ij} = \frac{R_{ij}}{|V_i V_j|} \cos(\delta_i - \delta_j)$$

$$\zeta_{ij} = \frac{X_{ij}}{|V_i V_j|} \sin(\delta_i - \delta_j)$$

The DGs & Capacitors under study are supplying real power & reactive power respectively.

- Voltage constraint at each bus must be satisfied using equation.

$$|V_i|^{\min} \le |V_i| \le |V_i|^{\max} \qquad \forall i \in N \quad (23)$$

- The current in distribution lines should not exceed from their ratings:

$$I_i \le I_i^{Rated} \qquad \forall i \in N_{Br} \quad (24)$$

4. Results And Discussion

In order to validate the ability of the ALO algorithm, a large scale test system of 69 bus test system is tested to obtain maximum profit of DISCOs. The 10 years of planning period is considered in the 69-bus test system. For proper tuning, we selected the following parameter values: number of search agents or no. of ant lions = 50, Maximum number of iterations = 500 and Number of variables = 12. The ALO algorithm computes the required configuration with best location and size of the DG and capacitor. The one line diagram of network reconfiguration with placement of DG and Capacitor in 69 bus test system is shown in fig.3.The switches 15 10 53, 21, 12 are opened and connecting the tie-line switches 69, 70, 71, 72, 73 for improving the voltage profile and profit of DISCOs. ALO algorithm efficiently identifies the location of DG and capacitor which is placed at bus 62 and 61 with optimal value of 1.5 MW and 1.05 MVAr respectively.

Voltage profile for base case and reconfiguration with placement of DG and capacitor in 69-bus test system are numerically and graphically reported in fig. 4 Similarly the VSI of base case and after reconfiguration with placement of DG and capacitor are numerically and graphically displayed in fig.5.. The optimized values of system variables including network loss, minimum voltage and minimum VSI are given Table 1.

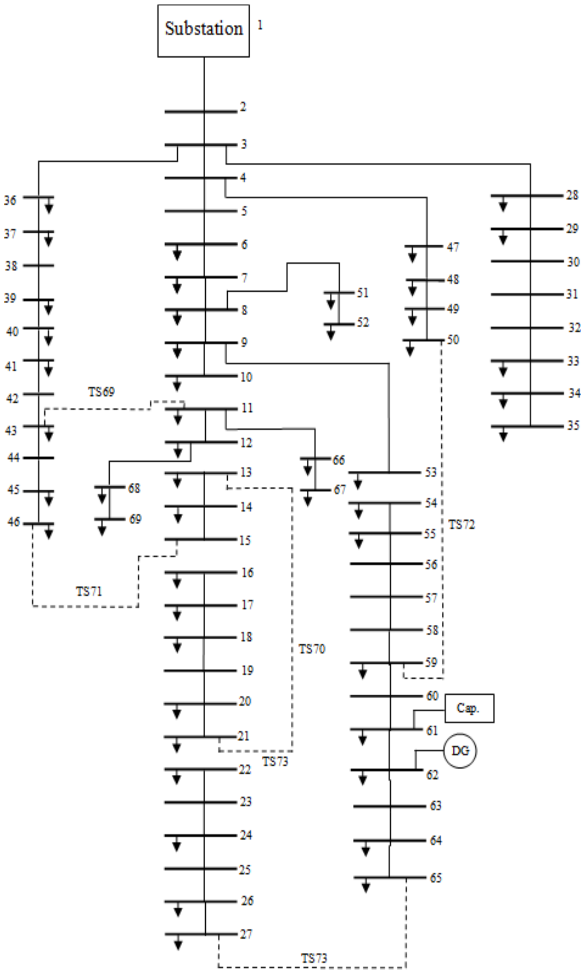


Fig. 3 Network Reconfiguration with placement of DG and Capacitor in 69bus test system

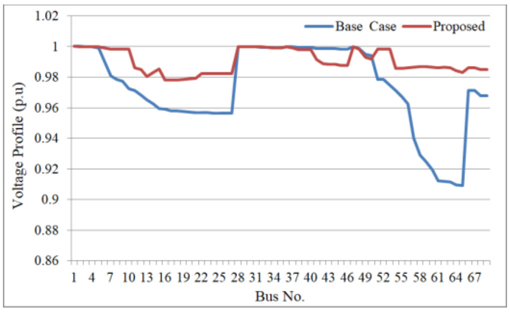


Fig. 4 Voltage profile for base case and Reconfiguration with placement of DGand capacitor in 69-bus test system

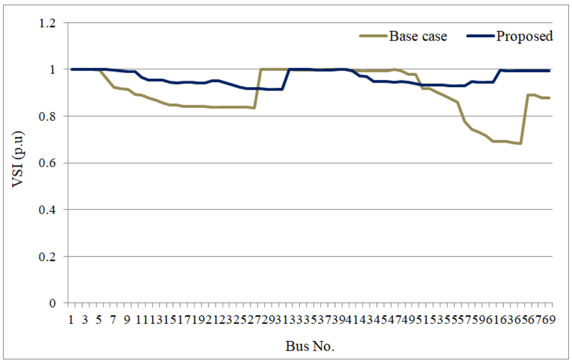


Fig. 5 VSI for base case and Reconfiguration with placement of DG andcapacitor in 69-bus test system

Table 1 Optimal location and sizing of DG and capacitor for 69- node DISCOsconsidering network reconfiguration

Parameters	Optimal Value
Open switches	15 10 53 21 12
Tie-line switches	69, 70, 71, 72, 73
Optimal location of DG and Capacitor	62 61
Optimal sizing of DG and Capacitor	1.5 MW 1.05 MVAr
Minimum Voltage (p.u)	0.97808
Voltage stability index (p.u)	0.914779
Power loss (KW)	20.3816

Table 2 Cost-Benefit analysis of DISCOs for 69-bus test system

Costs, Benefits and	Values (Rs)

Profits of DISCOs	
Installation cost of DG	375 x 10^5
Installation cost of Capacitor	10.5 x 10^4
Benefits of loss reduction	6.806 x 10^7
Benefits of reduction in purchased energy	6.806 x 10^7
Operational costs of DG	2.495 x 10^8
Maintenance cost of DG	6.342 x 10^7
Maintenance cost of Capacitor	2.215 x 10^5
Planning period	10 year
Total profit of DISCOs	**2163.15 x 10^5**

The cost-benefit analysis of proposed test system is given in Table 2.. In this table, Installation cost of DG and capacitor is 375 x 10^5 and 10.5 x $10^{4.}$ Benefits obtained from loss reduction and purchased energy is 6.806 x 10^7 and 6.806 x $10^{7.}$ Operational costs of DG are 2.495x$10^{8..}$ Maintenance cost of DG and Capacitor is 6.342 x 10^7 and 2.215 x 10^5 respectively. The maximized profit computational time of DISCOs by proposed ALO algorithm is Rs 2163.15 x 10^5 and 48.5 sec. In this table, the proposed method has minimum installation and maintenance cost of capacitor compared with PSO method. Similarly, benefit and profit of DISCOs are effectively improved by best configuration with optimal placement of DG and capacitor in a proper manner. Convergence curve of Reconfiguration with placement of DG and capacitor in 69-bus test system is shows in fig. 6.

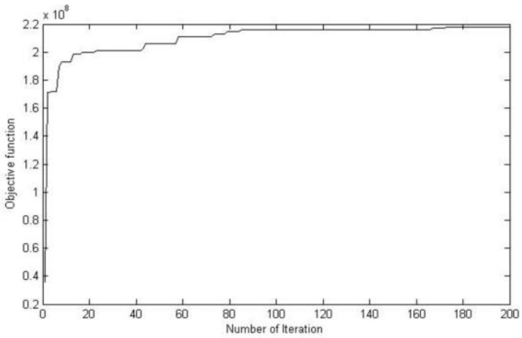


Fig. 6 Convergence curve of Reconfiguration with placement of DG andcapacitor in 69-bus test system

5. CONCLUSION

In this paper, the voltage stability problem is modeled as a single objective optimization problem under deregulated environment. The combined DGs and capacitors with network configurations are provided for the optimal solution of the problem. The powerful nature inspired optimization algorithm of ant lion optimizer is used to solve the voltage stability problem to maximize the profit of DG owners and maximize the total operating cost of DISCOs. The devised algorithm professionally identified the optimal sitting and size of DG and capacitor units. Case study with 69-node test systems is considered to illustrate the essential features of the proposed method. The applied ALO determined the optimal sitting and size of the DG and capacitors, improve voltage profile, minimized power loss, profit of DG owners and total operating cost DISCOs. Comparative studies with PSO algorithm have also been made to analyze the capability of the projected algorithm..The test results indicate that the proposed method improves the profit, converge much faster and more reliable than the other available methods.

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