Capacitor Allocation Optimization for Improved Distribution Network Performance

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***Abstract*— One of the most affordable methods for improving the performance of radial distribution networks is through the deployment of capacitors. However, the optimal allocation of capacitors is a serious issue that must be resolved. This paper proposed a novel dingo optimization algorithm (DOA) to tackle the problem of the allocation of capacitors. A single objective function, subjected to several equality and inequality constraints, was formulated and solved using the proposed DOA for capacitor allocation. The performance of the network was assessed using voltage profile, real power, and reactive power losses as the performance metrics. The results indicated a significant improvement in the performance of the network as real power as well as reactive power losses were greatly reduced by 34.44 and 35.20%, respectively, and the overall network voltage profile was enhanced. Thus, DOA proved effective in the allocation of capacitors in radial distribution networks.**

Keywords—capacitor allocation, dingo optimization algorithm, voltage profile, real power loss, reactive power loss

I. INTRODUCTION

Distribution networks face difficulties such as low voltage profile, among others, which impair network performance [1]. Power researchers have proposed a number of strategies to address some of these challenges and improve network performance. Reactive power compensation can significantly increase network performance by lowering the network's overall real power loss [2]. In a similar vein, enhancing the voltage profile of the network has a big impact on its functionality and dependability [3]. In the literature, there are several techniques for enhancing distribution networks' performance. These techniques include, among others, the penetration of distribution generation, the deployment of flexible alternating current, and the installation of capacitors. Capacitor placement is the most cost-effective of all these techniques, making it the most inexpensive when compared to other techniques already in use [4, 5]. Although the installation of capacitors may greatly enhance the performance of the network, the allocation of capacitors is a crucial matter that must be taken into consideration [6]. The allocation of capacitors is an optimization issue that may be solved using any optimization technique that has been put out in the literature.

In order to tackle the capacitor allocation problem, [7] employed a whale optimization approach with real power loss and loss reduction cost as the objective functions to be minimized. A mine blast algorithm (MBA) was put forth in [8] for the best placement and size of capacitors in numerous distribution networks. First, utilizing loss sensitivity factors, the buses that were the best candidates for inserting capacitors were recommended. The size and position of capacitors were then inferred from the selected buses using the suggested MBA. The objective function was to lower overall expenses and, as a result, raise annual net savings. The optimum capacitor placement problem in a radial distribution system was addressed by [9] using a flower pollination algorithm. By maximizing the placement and size of the capacitors, this challenge aimed to reduce the overall power loss and installation costs. Reference [10] proposed a technique for optimum capacitor location and size in a distribution network using a genetic algorithm with the objective of loss minimization and voltage profile enhancement. The suggested technique was tested using the IEEE 33-bus distribution test feeder. With the goal of improving voltage stability for optimal capacitor placement, [11] proposed a combination of a fuzzy expert system for capacitor placement and real-coded GA for capacitor sizing (FRCGA).

The various approaches discussed thus far have been tested and proven to be successful in capacitor allocation. However, some of these strategies do not produce the best results in terms of distribution network performance. Furthermore, some of the algorithms may lock in a local optimum, resulting in convergence failure. Proposing an approach that addresses the difficulties inherent in the other approaches is critical, which is why this study was conducted. The most significant contribution of the research is the proposal of a unique dingo optimization algorithm (DOA), which has never been applied to handle capacitor allocation problems in distribution networks. The

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proposed DOA approach was developed in MATLAB, and its effectiveness was tested on the IEEE 33 bus network.

II. Formulation of Problem

A. Objective Function

The objective function is the reduction of overall real power loss in the network, which is expressed as the sum of the losses in the branches given as in (1).

$$OF_{\min} = \sum_{i}^{N} |I_i|^2 R_i \tag{1}$$

where, N = total number of branches, $R_i = i^{th}$ branch resistance and $|I_i| = i^{th}$ branch current magnitude.

B. Constraints

The following constraints apply to the objective function formulated:

Power flow equations: These are power flow equations given as Equations (2) and (3). The equations were solved using Newton-Raphson power flow algorithm.

$$P_{gi} = P_{Di} + \sum_{j=1}^{n_b} |V_i||V_j|\left[G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right] \tag{2}$$

$$Q_{gi} = Q_{Di} + \sum_{j=1}^{n_b} |V_i||V_j|\left[G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right] \tag{3}$$

where V_i and V_j = bus voltage magnitudes; P_{gi} and P_{Di} = real power generated and demand; Q_{gi} and Q_{Di} = reactive power generated and demand; and θ_{ij} = voltage angle difference between buses '*i*' and '*j*'.

Bus voltage limitation: The voltage magnitude must be within permissible limits for the distribution network as given in Equation (4).

$$V_{\min} \le V_i \le V_{\max} \tag{4}$$

where $V_{\min}$ and $V_{\max}$ = minimum voltage and maximum voltage.

Reactive power constraint on the capacitors: The size of each of the installed shunt capacitors is constrained within the limits given by Equation (5).

$$Q_{SC(\min)} \le Q_{SC} \le Q_{SC(\max)} \tag{5}$$

where $Q_{SC(\min)}$ = 100 kVar and $Q_{SC(\max)}$ is 75% of the overall network reactive power demand [12].

C. Test System

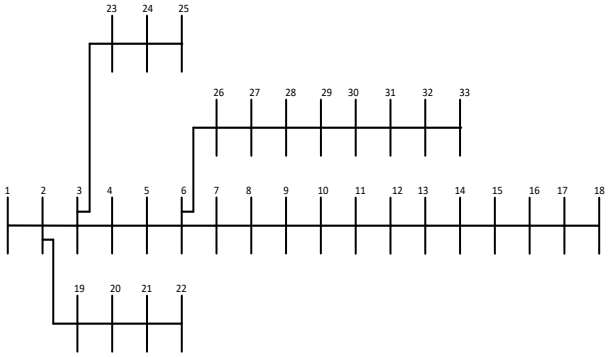


Fig. 1. The IEEE 33-bus network

Fig. 1 gives the single line diagram of the IEEE 33-bus system to test the effectiveness of the proposed DOA algorithm. The system has 33 buses and 31 branches. The line and load data of this test system were sourced from [13].

III. Dingo Optimization Algorithm

Dingo are clever, have good communication skills, and live in groups of 12 to 15. They live in an orderly social hierarchy. The algorithm was developed by Bairwa, who took his cues from the social structure and expert collective hunting behavior of dingoes while attacking their prey [14].

Dingoes have a structured social structure. As the group's leader, the alpha is in charge of making decisions that are enforced on all other group members. Beta dingoes serve as the group's second in command, enforce group rules, and serve as a liaison between the alpha and the other dingoes. The alphas and betas are assisted in their quest for prey and food for the pack by all the other dingoes [14].

A. Encircling

The gang of dingoes surrounds the prey after locating it, and this behavior is mathematically described by (6)–(10).

$$\overrightarrow{D_d} = \left|\vec{A}\cdot\overrightarrow{P_p}(x) - \vec{P}(i)\right| \tag{6}$$

$$\vec{P}(i+1) = \vec{P}_p(i) - \vec{B}\cdot\vec{D}(d) \tag{7}$$

$$\vec{A} = 2\cdot\vec{a}_1 \tag{8}$$

$$\vec{B} = 2\vec{b}\cdot\vec{a}_2 - \vec{b} \tag{9}$$

$$\vec{b} = 3 - \left(I * \left(\frac{3}{I_{\max}}\right)\right) \tag{10}$$

where $\vec{D}_a$ = the distance between the dingo and prey; $\vec{P}_p$ = position vector (prey); $\vec{P}$ = position vector (dingo); $\vec{A}$ and $\vec{B}$ = coefficient vectors; $\vec{a}_1$ and $\vec{a}_2$ = random vector in [0, 1], $\vec{b}$ linearly decreases from 3 to 0 at every iteration. Equations (6) and (7) help dingoes change their location inside the search space around the prey in any random location.

B. Hunting

Equations (11)–(16) update the dingoes' positions while the alpha dingo supervises the hunting process and occasionally participates with the beta dingo.

$$\overrightarrow{D_\alpha} = \left|\vec{A}_1\cdot\overrightarrow{P_\alpha} - \overrightarrow{P}\right| \tag{11}$$

$$\overrightarrow{D_\beta} = \left|\vec{A}_2\cdot\overrightarrow{P_\beta} - \overrightarrow{P}\right| \tag{12}$$

$$\overrightarrow{D_o} = \left|\vec{A}_3\cdot\overrightarrow{P_o} - \overrightarrow{P}\right| \tag{13}$$

$$\overrightarrow{P_1} = \left|\overrightarrow{P_\alpha} - \vec{B}\cdot\overrightarrow{D_\alpha}\right| \tag{14}$$

$$\overrightarrow{P_2} = \left|\overrightarrow{P_\beta} - \vec{B}\cdot\overrightarrow{D_\beta}\right| \tag{15}$$

$$\overrightarrow{P_3} = \left|\overrightarrow{P_o} - \vec{B}\cdot\overrightarrow{D_o}\right| \tag{16}$$

Equations (17)–(19) estimates the intensity of each dingo

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$$\vec{I}_{\alpha} = \log\left(\frac{1}{F_{\alpha} - (1E-100)} + 1\right) \quad (17)$$

$$\vec{I}_{\beta} = \log\left(\frac{1}{F_{\beta} - (1E-100)} + 1\right) \quad (18)$$

$$\vec{I}_{o} = \log\left(\frac{1}{F_{o} - (1E-100)} + 1\right) \quad (19)$$

C. Attacking Prey

A dingo has attacked the prey if there is no update. In order to simulate this tactic, $\vec{b}$'s value is progressively lowered.

D. Searching

Dingoes constantly move forward to pursue and pounce on their prey. The dingo is moving away from the prey when $\vec{B}$ is less than 1, and toward the prey when B is more than 1. Anytime the conditions for termination are satisfied, DOX terminates itself.

Fig. 2 illustrates the application of the DOA technique to address the network capacitor allocation problems in the distribution network.

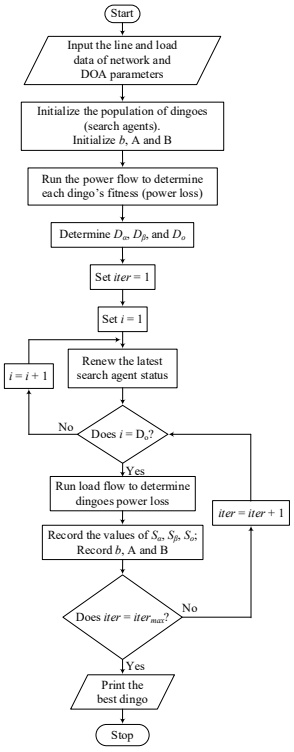


Fig. 2. Flow chart of the proposed method

IV. Results Discussion

The ideal capacitor placements and sizes found using the proposed DOA technique are shown in Table I for the simulation results. Table I indicates that buses 12, 24, and 30 were the best locations for the capacitors, with optimal capacitor sizes of 342, 711, and 1014 kVAr at these locations. The following subsections provide a systematic discussion of the simulation results that demonstrate the network's performance in terms of improved voltage profile and loss minimization.

TABLE I. Capacitors Allocation

Capacitor Size (kVAr)	Location
342	12
711	24
1014	30

A. Voltage Profile

Fig. 3 shows the voltage profile of the network both before and after capacitor allocations. The base case voltage profile showed that bus 18 of the network saw the lowest voltage, which was 0.913 p.u. However, following the deployment of capacitors, this lowest voltage was increased to 0.934 p.u. A close examination of Fig. 3 reveals that although other buses' voltage magnitudes significantly improved, buses 19 and 22's voltage magnitudes improved just somewhat. The network's performance was enhanced as a result of the general rise in voltage magnitude. As shown in Fig. 3, using the proposed DOA approach effectively increased the voltage profile of the network.

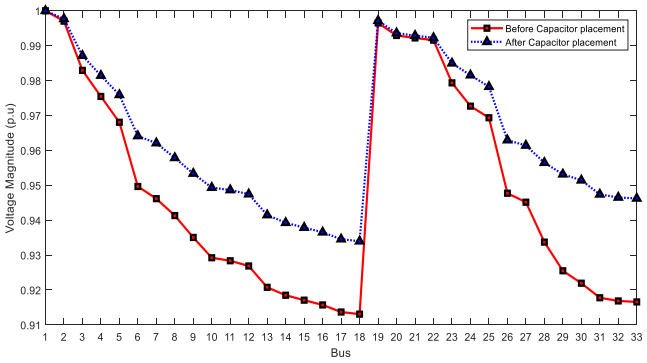


Fig. 3. Voltage profile before and after capacitors placement.

B. Real Power Loss

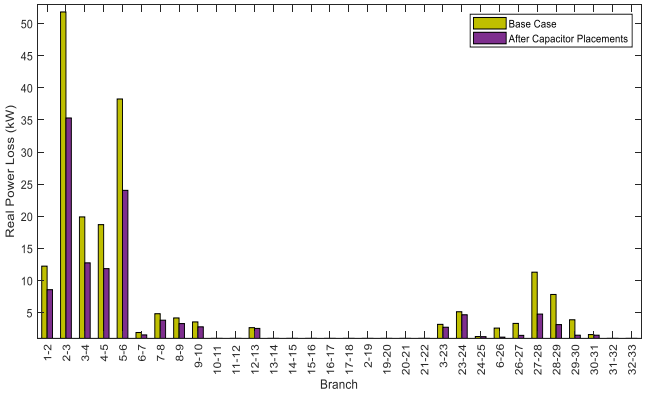


Fig. 4. Real power losses in the network branches

The base case findings demonstrated that the network was considerably experiencing real power loss, with a total real power loss of 202.71 kW. Fig. 4 depicts these losses in the network's branches to demonstrate how this total real power loss was distributed throughout the branches both before and after the deployment of capacitors. Branch 2-3 saw the biggest real power loss. Because the branch was so near to the substation and

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carried the most current while the network was in operation, this was to be expected. Additionally, a thorough examination of Figure 4 reveals that branch 32-33 demonstrated the least real power loss. However, these losses were reduced. Overall, all of the branches showed a decrease in real power losses, which led to an increase in network performance. Furthermore, the entire network power loss, which was 202.71 kW before the deployment of the capacitors, was significantly decreased to 132.89 kW, corresponding to a 34.44% reduction.

C. Reactive Power Loss

Before the installation of capacitors, there was a total reactive power loss of 135.16 kVAr. However, when capacitors were strategically positioned on the network, this total reactive power was greatly decreased to 88.94 kVAr, which corresponds to 35.20%. The distribution of this total loss throughout the network's branches is shown in Fig. 5. The most significant reactive power loss was seen in branch 5-6, according to a critical examination of Fig. 5. Branch 32-33 also exhibited the least reactive power loss. However, both these losses, in addition to the losses in the other branches, were reduced following capacitor placements. The network performance improved as a result of the reduction of these losses as well as losses in the other branches. These outcomes demonstrate the effectiveness of DOA in optimizing capacitors to boost distribution network performance.

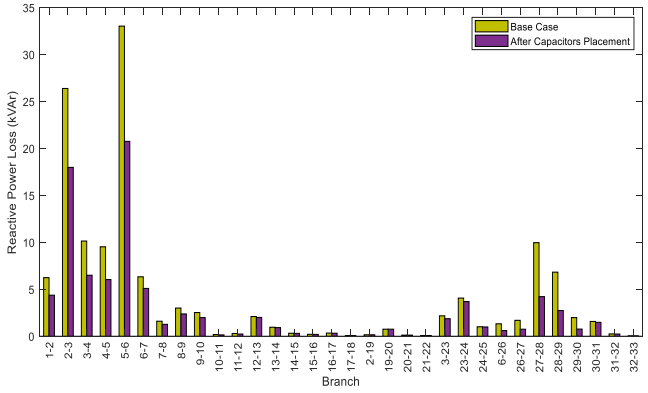


Fig. 5. Reactive power losses in the network branches

V. Comparison with the Other Methods

To demonstrate the superiority of the proposed DOA approach, a comparison with various optimization methods from the literature was done. The comparison of the proposed method's outcomes with those of the other approaches is shown in Table II. It is clear from Table II that the proposed DOA approach provided a higher loss reduction percentage. DOA therefore outperformed other optimization techniques.

TABLE II. Comparison Summary for IEEE 33-Bus Network

Methods	Size (kVAr) and location	% Loss Reduction	Minimum Voltage (p.u)
WOA	1223(30), 511(24), 435(11)	33.74	0.9315
FPA	900(30), 450 (13), 450 (24)	32.97	0.9327
FRCGA	25 (28), 475 (6), 300 (29), 175 (8), 400 (300), 350 (9)	31.66	0.9340
Proposed Method	342 (12), 711 (24), 1014 (30)	34.44	0.9340

VI. Conclusion

The IEEE 33-bus network was used as a test system in this study to apply a unique DOA strategy to tackling capacitor allocation challenges. The network's performance was improved as a consequence of the proposed approach's substantial allocation of capacitors, which improved the network voltage profile and decreased both real and reactive power losses. DOA also outperformed other optimization techniques in comparison. As a result, DOA is a successful optimization strategy for capacitor allocations in distribution networks.

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