



## Reduction of Power Distribution System Losses by Using Novel Heuristic Algorithm

Muhammad Shakeel<sup>1</sup> Dr. Qadeer Ul Hassan<sup>2</sup> Dr. Nasrullah Khan<sup>3</sup>

<sup>1,2,3</sup> Department of Electrical Engineering, COMSATS University Islamabad, Islamabad 45750, Pakistan

<sup>1</sup>[engr.rshakeel@gmail.com](mailto:engr.rshakeel@gmail.com), [qadeer.hasan@comsats.edu.pk](mailto:qadeer.hasan@comsats.edu.pk)<sup>2</sup> [nasrullah.khan@abasyn.edu.pk](mailto:nasrullah.khan@abasyn.edu.pk)<sup>3</sup>

Corresponding Author: Muhammad Shakeel, Email: [engr.rshakeel@gmail.com](mailto:engr.rshakeel@gmail.com),

### ABSTRACT

The Distribution Networks are the most widespread part of electrical power systems. Researcher has been trying to in the solutions to reduce high energy losses associated with them due to the low voltage level of the supply framework. Capacitors based techniques have been proposed to reduce these losses. These techniques minimize power losses, improve stability, and enhance the voltage profile of the distribution system under normal operating conditions. Finding optimal place and proper size of the capacitor is still a very hot area of research. In this research work, an innovative procedure based on the Archimedes optimization Algorithm (AOA) is presented to solve the optimal capacitor placement as well as sizing problem to improve the voltage profile and reduce the energy losses in the network. The suggested AOA based technique, is implemented on IEEE 33 bus network to find the optimal locations to place the capacitors in the distribution network. The performance of AOA is also compared with a standard model to verify the effectiveness of the scheme. By using AOA active power losses reduced upto 23.62% and reactive loss by 21.86% respectively. The simulation results reveal that AOA based technique offer better results regarding the capacitor placement for voltage profile improvement of buses and significant reduction in active power losses as compared to previous studies.

**Key Words:** Optimization, voltage, Archimedes, capacitor.

### 1. INTRODUCTON

A distribution system, with radial structures is used to distribute power to end users. Through connected transmission networks, the primary distribution substation gets powers from the generating station or onwards distribution. The radial distribution system (RDS) remains a passive



network while transferring powers to the customers from the substations. Normally, the power flows in RDS are unidirectional. In distribution networks R/X ratio is relatively higher than the transmission system, which implies that the power loss in distribution network is higher as compared to the transmission network. High R/X ratio and voltage drop results in power loss in distribution network. In a majority of nodes, RDS experiences sudden collapses within voltage during the time of crucial load condition owing to lower voltage stability indexes. This research work proposes an RDS loss sensitivity factor (LSF) for every node. LSF will help to identify the appropriate bus having high losses that will be probably optimal place for the capacitor placement.

Currently, various techniques are used whereby situating scattered resources and injecting reactive powers through capacitor bank to obtain improvements in voltage levels and to reduce the power loss. Though the capacitor situating method seems to be reliable, the improvement in voltage profiles was less than desired voltage levels i.e. 1.0 p.u. Because of the passivity of RDs, it is not reliable. This is because the distribution network is passive, which means that there is no active control of the voltage levels. In a passive network, the voltage level at any given point in the network depends on the load demand and the network impedance. As a result, the voltage drop across the network cannot be controlled and may not be sufficient to compensate for the losses. Various solutions are put forward in the recent years to incorporate electric resources on the basis of renewable energy sources for overcoming the passivity of RDS and to improving the feasibility of the systems along with voltage profiles.

## **2. LITERATURE REVIEW**

In distribution networks the R/X ratio is relatively higher than the transmission system, which implies that the power loss in distribution network is higher as compared to the transmission network. It has been stated that 13% of the total power produced is lost as  $I^2R$  losses in distribution network [1]. And it directly impacts the cost of energy as well as imbalance in voltage profile of the distribution feeder. Therefore, reducing distribution losses has been one of the primary concerns in ensuring the economic and efficient operation of these systems. One approach to reducing distribution losses is to improve the design and layout of the network to minimize the distance between the sources and loads, reduce the impedance of the network, and improve the power factor [1]. In the meantime, a rapid increase in load requirement generates more voltage instability in the network. While there are several methods to reduce or overcome the losses such as higher voltage levels, induction of capacitors, reconductoring and reconfiguration of networks. Network reconfiguration is one of the commonly used approaches as it does not entail additional installation of equipment and it is cost effective [2]. Distribution system reconfiguration (DSR)



refers to the process of altering the physical configuration of the distribution system, typically by adjusting the status of switches, to improve its operational performance. The main objective of DSR is to resolve the radial operating framework of the distribution system in order to reduce overall power loss while taking into account the operational constraints of the system. Radial distribution systems are designed with a single power source, such as a substation, feeding a number of branches that are not connected to each other, forming a tree-like structure. The main disadvantage of radial distribution systems is that the further a load is located from the substation, the more voltage drop it experiences, leading to higher energy losses and poor voltage regulation. DSR can be used to address this problem by changing the configuration of the distribution system so that the loads are supplied with a lower voltage drop, leading to reduced energy losses and improved voltage regulation. This is done by changing the status of switches that control the connection of the different sections of the distribution system, with the objective of minimizing the overall power loss and maximizing the voltage profile. [3]. Hence the optimal amalgamation among these two issues gets to be an important and complex problem. Within the power system optimization domain, the most commonly used approach is to reduce distribution network losses and improve voltage profile, by employing multi-objective optimization techniques. Then placing the distributed generation at optimal points in the system. DG may be active or reactive power source. To overcome reactive power losses of the distribution network, the most widely method is capacitor bank placement in distribution network, but the major issue arises optimum placement i.e location selection and the optimum size of the capacitor. This issue is being resolved by optimization techniques based on multi objective functions.

Static Var compensator (SVC) is one of major device of Flexible AC Transmission (FACTS), improves power factor and reduces reactive power losses of the RDS with Optimum Power Flow using Artificial Bee Colony algorithm [4]. Like other devices of FACTS, STATCOM is used for voltage profile improvement in distribution network, optimal location for placement of STATCOM was located by using ABC Algorithm [5]. Moth-Flame Optimization was developed for optimal placement and sizing of the capacitor in radial distribution network, gave improved results with respect to base model [6]. Loss sensitivity method used for optimal placement selection for capacitor placement to overcome reactive power losses, the branch with maximum reactive losses is identified and capacitor is placed using accelerated particle swarm optimization [7]. Instead of Newton Raphson method for power flow analysis, Forward-backward Sweep Method (FBSM) is used for power flow analysis of IEEE-33 radial bus bar network. Plant growth simulation algorithm (PGSA) achieved 25.36% loss reduction [8]. Sine cosine algorithm considering power loss index for identification of optimal placement of capacitor was used on



IEEE-69 bus network, cost of generation is also considered while developing optimization objective function [9]. Evolutionary algorithm is tested on IEEE-34 node Algerian-Djanet distribution system for capacitor placement and achieved 5% loss reduction comparable to base network [10]. Loss sensitivity factor was considered for bus selection by using Flower Pollination Algorithm (FPA) on IEEE-12 and IEEE-28 Bus network and resulted in 24.46% cost reduction (M. & Manjappa, 2018). Genetic algorithm resulted promising results on IEEE-15 bus bar by placing capacitor under fault conditions [11]. Particle Swarm Optimization is implemented, The objective function was modeled to reduce the system power loss and consequently to increase the net saving as well as voltage profile improvement. Quantum- Behave PSO (QPSO) technique is tested on an IEEE 33- nodes test system level of a smart grid [12]. Mirjalili proposed Grey Wolf Optimization algorithm in 2014, the algorithm was tested on IEEE-69 bus bar network with 50% and 70% loading to optimize the size and placement of capacitor in distribution network [13]. Genetic algorithm resulted in 13.67% loss reduction and minimum voltage of network improved from 0.8687pu to 0.9269pu [14]. Bellman-Zadeh method was used for optimal capacitor placement and loss reduction on distribution network of Bosnia and Herzegovina , resulted in loss reduction of 7.5% [15]. By using DigSILENT Power Factory for multi objective including cost of capacitor, losses and voltage profile is implemented on local distribution network providing considerable improvement [16]. Sperm Whale Algorithm integrating High voltage and low voltage distribution network was tested with variable power supply to achieved loss reduction of 6.281% after capacitor bank placement with reference to basic network. [17]. Backward Forward Sweep (BFS) integrated with PSO was implanted on IEEE-30 and IEEE048 Bus bar for optimal placement of capacitor to reduce network losses [18]. Honey Bee Mating Optimization Algorithm was implemented on 34 bus network and reduced losses upto 30% (Jahromi, Dehghanian, Khademi, & Jahromi, 2021). Based on loss index method, Harmony Search Algorithm implemented on 15 bus network reduced 40% losses considering THD [19]. Genetic Algorithm resulted in 12.3% loss reduction for 15 node test network [20].

### 3. Mathematical Model of Problem

Let's consider there are two buses  $m$  and  $n$  with a distribution line having resistance  $R_{mn}$  and reactance  $X_{mn}$ . The voltage at bus  $m$  and  $n$  is given by  $V_m$  and  $V_n$  respectively, current flowing through the branch is  $I_{mn}$ . Load at Bus  $n$  is connected having active load  $P_L$  and reactive load  $Q_L$ . the power flowing through the branch will be  $P_{mn}$  and  $Q_{mn}$  respectively as shown in Fig.1

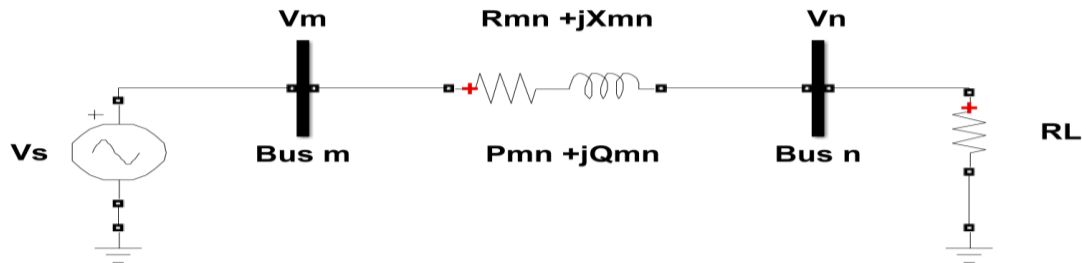


Fig. 1 Two Bus Model Power flow[21]

Whereas  $P_{mn}$  is the total active while  $Q_{mn}$  is the total reactive power flow through the branch active and reactive power loss in the branch can be calculated as follow:

$$P_{LOSS_{mn}} = R_{mn} \frac{(P_{mn}^2 + Q_{mn}^2)}{V_m^2} \quad (1)$$

$$Q_{LOSS_{mn}} = X_{mn} \frac{(P_{mn}^2 + Q_{mn}^2)}{V_m^2} \quad (2)$$

So, total active and reactive power flow between two nodes will be sum of active load and reactive load and loss in the branch.

$$P_{mn} = P_{Load} + P_{LOSS_{mn}} \quad (3)$$

$$Q_{mn} = Q_{Load} + Q_{LOSS_{mn}} \quad (4)$$

After substituting values, we have

$$P_{mn} = P_L + R_{mn} \frac{(P_{mn}^2 + Q_{mn}^2)}{V_m^2} \quad (5)$$

$$Q_{mn} = Q_L + X_{mn} \frac{(P_{mn}^2 + Q_{mn}^2)}{V_m^2} \quad (6)$$

Whereas the voltage at node n will be calculated as under:

$$V_n^2 = V_m^2 - 2(P_{mn}R_{mn} + Q_{mn}X_{mn}) + (R_{mn}^2 + X_{mn}^2) \frac{(P_{mn}^2 + Q_{mn}^2)}{V_m^2} \quad (7)$$



If network has  $i$  number of buses, than the power loss of the network can be calculated as sum of losses between all nodes and all branches, total active and reactive power loss the system will be called as,

$$P_{Total\ loss} = \sum_{i=1}^{No\ of\ branches} P_{loss,i} \quad (8)$$

$$Q_{Total\ loss} = \sum_{i=1}^{No\ of\ branches} Q_{loss,i} \quad (9)$$

Here, the main requirement is to detect the optimal place for the capacitor placement, the capacitor is placed at the branch having maximum reactive power loss, this is termed as Loss Sensitivity Factor (LSF).

$$Candidate\ Bus_{For\ capacitor\ placment} = Branch\ with\ Max\ (Q_{loss}) \quad (10)$$

Whereas,

$$Capacitor_{size}\ (Kvar) \leq (Q_{loss}\ of\ Branch) \quad (11)$$

$$Capacitor_{size}\ (Farad) = \frac{Capacitor_{size}\ (Kvar)}{V_{node}} \quad as\ C = Q/V \quad (12)$$

**Fitness Function:** Objective is to find a location for capacitor's placement that minimize the network losses and improve voltage profile of the system. Here,  $N_{br}$  is total number of branches in network. This is multi objective function problem given as,

$$Objective\ Function\ F\ (P, Q, V) = \begin{cases} minimize\ P_{Totalloss} = \sum_{i=1}^{N_{br}} P_{loss,i} \\ minimize\ Q_{Totalloss} = \sum_{i=1}^{N_{br}} Q_{loss,i} \\ maximize\ V_{average} = (\sum_{i=1}^{Buses} V_i)/N_{br} \end{cases} \quad (13)$$

Where voltage of the nodes will remain within minimum and maximum values as given in the equation below.

$$V_{minimum} \leq V_{branch} \leq V_{maximum} \quad (14)$$

#### 4. Archimedes optimization Algorithm (AOA)

This algorithm is based on famous Archimedes Principle [22]. This principle states that “When an object is completely or partially immersed in float, the fluid exerts an upward force on the subject equal to weight of the fluid displaced by the object”. This upward force on the object is known as buoyancy force. This is illustrated by the given below:

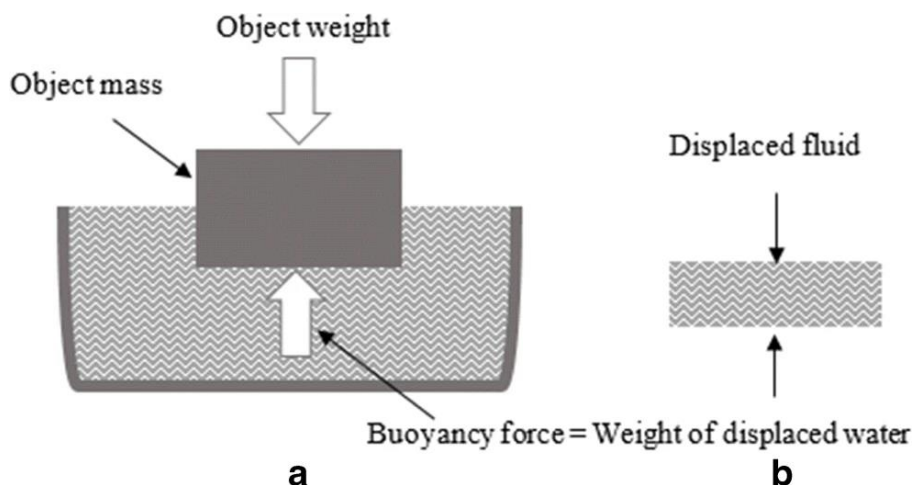


Figure 2 **a** An object is immersed in a fluid, and **b** The volume of fluid displaced [23]

Archimedes optimization Algorithm [23] was introduced in September 2020 based on Archimedes Principle. Let we consider many objects with different shapes are immersed in a fluid of same tank. Now the every object has its own buoyancy force. If some object is in a equilibrium state and floating on the fluid, its means

$$F_{buoyancy} = W_{object}$$

$$\rho_b v_b a_b = \rho_o v_o a_o \quad \text{which resulted in } a_o = \frac{\rho_b v_b a_b}{\rho_o v_o} \quad (15)$$

Here  $\rho$  is density,  $v$  is volume and  $a$  is acceleration associated with object and fluid.

The search space of an algorithm refers to the set of all possible solutions that can be generated and evaluated by the algorithm to solve a particular problem. The search space can be thought of as a multidimensional space, where each dimension represents a possible solution to the problem, and the goal of the algorithm is to search through this space in order to find the best solution that satisfies the problem constraints. The search space can be very large and complex, particularly for problems that involve a large number of variables or constraints. In such cases, it is often necessary to use heuristic search algorithms or optimization techniques to efficiently explore the search space and identify the best solutions. Here the lower limit of dispersed fluid is  $lb$  and upper limit is  $ub$ . Considering lower and upper bonds the search space is created for  $N$  number of objects  $O$ . Here Object  $O$  will be capacitor, whereas  $lb$  and  $ub$  are the minimum and maximum size of capacitor.



$$O_i = lb_i + rand * (ub_i - lb_i) \text{ whre } i = 1,2, \dots, N \quad (16)$$

Initial volume and density for each  $i_{th}$  object will be random, here acceleration of each object will be calculated as

$$den_i = rand \text{ and } vol_i = rand$$

$$acc_i = lb_i + rand * (ub_i - lb_i) \quad (17)$$

Density and volume of the object  $i_{th}$  will be updated in every iteration  $t+1$  by using equation

$$den_i^{t+1} = den_i^t + rand (den_{best} - den_i^t) \quad (18)$$

$$vol_i^{t+1} = vol_i^t + rand (vol_{best} - vol_i^t) \quad (19)$$

In the beginning, collision between objects occurs and, after a period of time, the objects try to reach at equilibrium state. This is implemented in AOA with the help of transfer operator TF which transforms search from exploration to exploitation, defined as under:

$$TF = \exp\left(\frac{t-t_{max}}{t_{max}}\right) \quad (20)$$

where transfer  $TF$  increases gradually with time until reaching 1. Here  $t$  and  $t_{max}$  are iteration number and maximum iterations, respectively

**Exploration Phase:** If the  $TF$  is less than 0.5, it shows collision between objects, this leads to change in acceleration of the object, mathematically given below:

$$acc_i^{t+1} = \frac{den_{mr} + vol_{mr} + acc_{mr}}{den_i^{t+1} + vol_i^{t+1}} \quad (21)$$

where  $den_{mr}$ ,  $vol_{mr}$ ,  $acc_{mr}$  represent the volume, density and acceleration of fluid.

**Exploitation Phase:** If the transfer operator is greater than 0.5, it shows no collision between the objects, this leads to change acceleration of object by equation given below,

$$acc_i^{t+1} = \frac{den_{best} + vol_{best} + acc_{best}}{den_i^{t+1} + vol_i^{t+1}} \quad (22)$$

where  $den_{best}$ ,  $vol_{best}$ ,  $acc_{best}$  represent the density, volume and acceleration of best object during  $t+1$  iteration.



This calculation can be utilized for non-straight issues, non-ceaseless and non-differentiable space work also. AOA can likewise work for time subordinate target capacities, multi-dimensional and requirement improvement with punishment utilities. Along these lines, by thinking about these in addition to focuses, we choose AOA as improvement system for the arrangement of issue which is underestimated right now.

The overall steps or stages of AOA can be described as follows:

- Step 1.** Read line data, load data and execute power flow and calculate all system parameters for without Capacitor case.
- Step 2.** Initialize AOA Parameters population size, number of iterations and limits.
- Step 3.** Generate population by execution of power flow and calculate system parameters.  
Equation 17
- Step 4.** Set Iteration=1
- Step 5.** Update density and volume of each object, here density will candidate bus and volume will be size of capacitor. Using equation 18 and 19
- Step 6.** If  $T.F < 0.5$ : In exploration phase, update capacitor location on different buses, Compute the fitness value. Replace the old value with new one if new value is better than old candidate bus. Using equation 21.
  - a. Compute the fitness function and the probability for solution.
- Step 7.** If  $T.F > 0.5$ : Exploitation stage, Using equation 22
  - a. For every candidate bus, select a capacitor size and depending on probability and produce a new size of capacitors.
  - b. Compute the fitness value. Replace the old capacitor value with new one if new position is better than old size.
- Step 8.** Evaluate each capacitor and location and select the one with best fitness value.
- Step 9.** Save the best solution in the memory.
- Step 10.** iteration = iteration + 1 until iteration = Maximum Iterations

## 5. Testing and Results

The AOA algorithm was implemented and tested in MATLAB R2020a on a laptop with an Intel i7 8th Generation CPU 8550u 3.7 GHz processor, 8 GB RAM, 128 GB Solid State Drive M2 type, and 64-bit Windows operating system. The algorithm was configured with a maximum of 100 iterations and a population size of 30 particles. Power flow analysis was conducted using the Newton Raphson method and the MATPOWER Toolbox function.

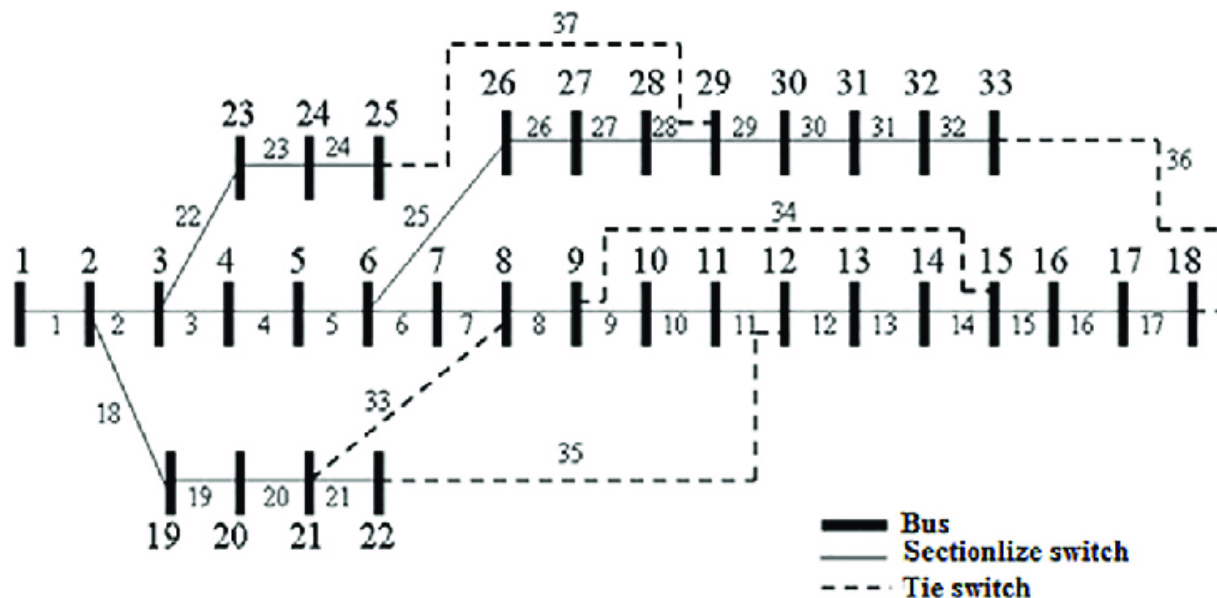


Figure 3 IEEE 33 bus bar Power Distribution Network

The Voltage Sensitivity index is used to select the appropriate bus for capacitor placement. The IEEE-33 bus bar standard network was utilized for testing and simulation purposes. This network consists of one slack bus and 32 PQ buses, with a total of 37 branch buses. The connectivity diagram of the distribution network is illustrated in Figure-4 above. To demonstrate the effectiveness of capacitor placement, simulations were conducted on the IEEE-33 network by placing capacitors at Bus 3 and 6. The comparative change in voltage profiles of the distribution network showed a significant increase in the average voltage from 0.9485pu to 0.9624 pu, indicating an improvement in the voltage profile of the network. Overall, the use of the Voltage Sensitivity index for bus selection and capacitor placement, coupled with simulations on the IEEE-33 network, provided valuable insights into the effectiveness of capacitor placement in improving the voltage profile of distribution networks.



Received: 16-01-2024

Revised: 12-02-2024

Accepted: 07-03-2024

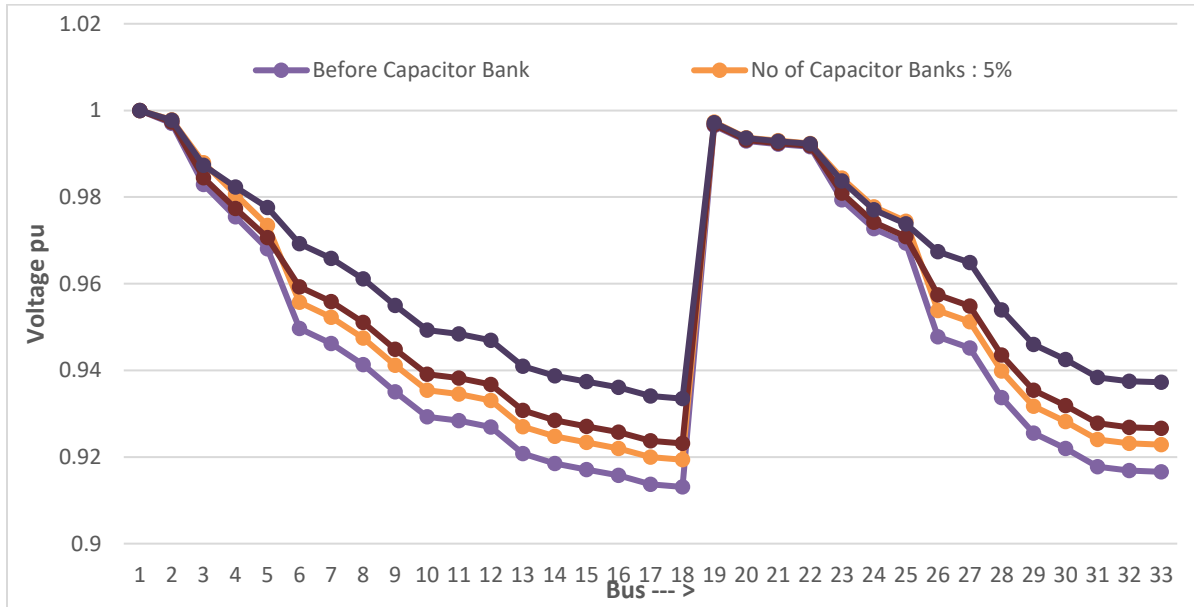


Figure 4 Voltage Comparison of IEEE 33 buses before and after capacitor placement

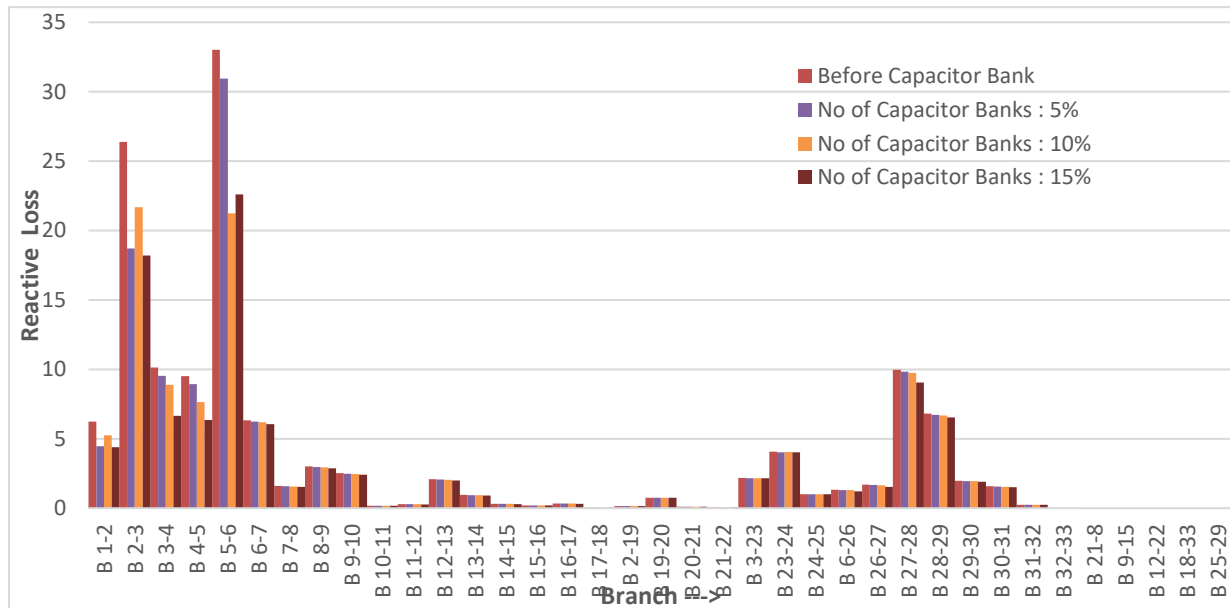


Figure 5 Reactive Power Losses comparison in IEEE 33 distribution network before and after capacitor placement



Received: 16-01-2024

Revised: 12-02-2024

Accepted: 07-03-2024

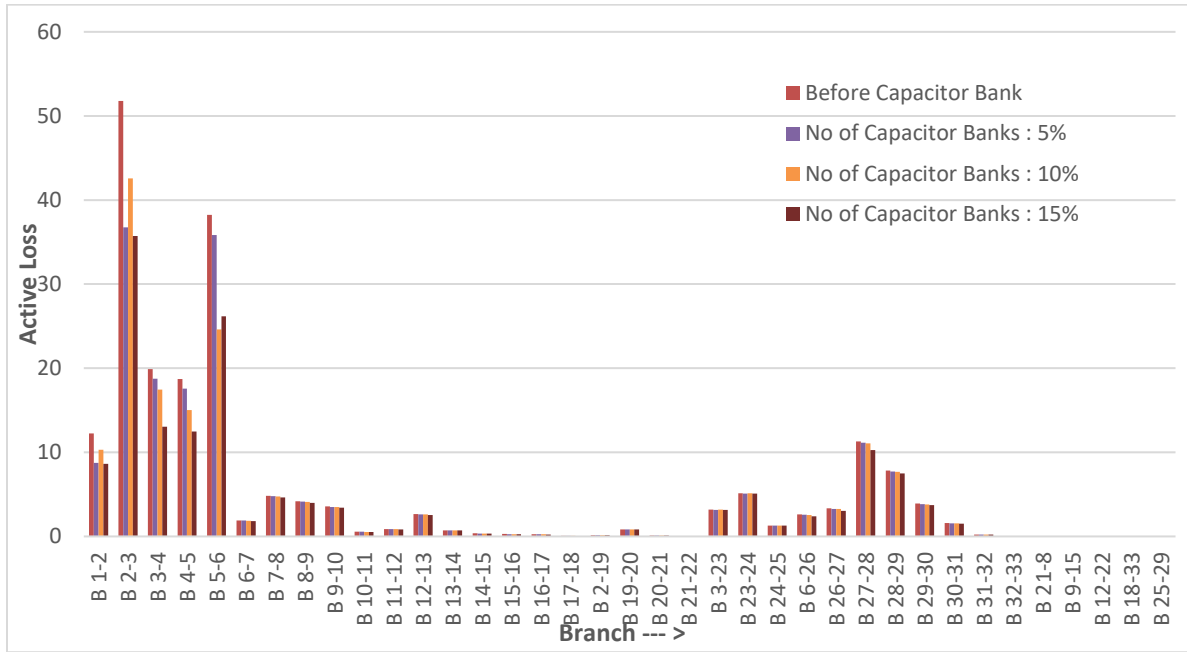


Figure 6 Active Power Losses comparison in IEEE 33 distribution network before and after capacitor placement

Table 1 Comparative result after capacitor placement

Parameter	Base Model	Candidate Buses with 5%	Candidate Buses with 10%	Candidate Buses with 15%
Candidate Buses	-	6, 3	6,3,4,5	6,3,4,5,28
Capacitor Bank size [MVAR]	-	0.1259, 2.5559	1.6240 ,0.4700, -0.2266, -1.0605	2.2370, 0.2073 -0.0377, -0.0991, 0.0457
Minimum Voltage	0.9131	0.9194	0.9231	0.9335
Maximum Voltage	1	1	1	1
Average Voltage	0.9485	0.9534	0.9551	0.9624
Active Loss	202.6771	178.6507	170.6793	154.8050
Percentage Active Loss Reduction	-	-11.85%	-15.79%	-23.62%
Reactive Loss	135.141	121.8241	113.6783	105.5996
Percentage Reactive Loss Reduction	-	-9.85%	-15.88%	-21.86%



The impact of capacitors on distribution network losses can be seen in Figures 5 and 6. The total active power losses were reduced from 202.6771 kW to 154.8050 kW, representing a 23.62% reduction. The reactive power losses decreased from 135.141 kVAR to 105.5996 kVAR, indicating a 21.86% reduction, thanks to the capacitor placements at buses 6, 3, 4, 5, and 28. The capacitor sizes, expressed in MVAR, were calculated as 2.2370, 0.2073, -0.0377, -0.0991, and 0.0457. Capacitors placed at buses 4 and 5 absorbed reactive power, while those at buses 6, 3, and 28 delivered reactive power. If we increase the number of candidate buses for capacitor placements, the voltage can be further improved. However, excess capacitors can result in a massive loss of power flow in the network, violating voltage upper limits and standards. The processing time of the system was 44.56 seconds.

## 6. Conclusions

The increasing population in cities and overloading of power systems have led to several problems, including low voltage profiles and rising reactive power supply during faulty conditions. To address these issues, this paper proposes the use of the Archimedes optimization algorithm (AOA) to reduce distribution network losses and improve the voltage profile by placing capacitors at optimal locations with optimum size. The proposed model was tested on the IEEE 33 Bus Network with varying and constant loads, and the results were compared to those of the base model. The simulation results demonstrate the significant impact of capacitor placement in reducing losses and improving the voltage profile of the network. The AOA algorithm was successful in finding optimal capacitor placement locations, which resulted in a reduction in active and reactive power losses. Moreover, the voltage profile was significantly improved, resulting in more stable and efficient power distribution. Overall, the proposed model and AOA algorithm provide a promising solution to the challenges faced by power systems due to increasing overloading in cities. By optimizing capacitor placements, power losses can be reduced, and the voltage profile of the distribution network can be improved, leading to a more reliable and efficient power supply.

## BIBLIOGRAPHY

- [1] A. Merlin and H. Back, "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system," *Fifth Power Systems Computation Conference*, 1975.
- [2] S. Jena and S. Chauhan, "Solving distribution feeder reconfiguration and concurrent dg installation problems for power loss minimization by multi swarm cooperative PSO



- algorithm,” in *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference*, 2016, vol. 2016-July. doi: 10.1109/TDC.2016.7520021.
- [3] F. M. F. Flaih, X. Lin, M. K. Abd, S. M. Dawoud, Z. Li, and O. S. Adio, “A new method for distribution network reconfiguration analysis under different load demands,” *Energies*, vol. 10, no. 4, 2017, doi: 10.3390/en10040455.
- [4] M. R. Shaik and A. S. Reddy, “Optimal placement of STATCOM with ABC algorithm to improve voltage stability in power systems,” 2017. doi: 10.1109/SCOPE.2016.7955520.
- [5] M. R. Shaik and A. S. Reddy, “Optimal placement and sizing of FACTS device to overcome contingencies in power systems,” 2017. doi: 10.1109/SCOPE.2016.7955559.
- [6] O. Ceylan and S. Paudyal, “Optimal capacitor placement and sizing considering load profile variations using moth-flame optimization algorithm,” 2017. doi: 10.1109/MPS.2017.7974468.
- [7] N. A. Basyarach, O. Penangsang, and A. Soeprijanto, “Optimal capacitor placement and sizing in radial distribution system using accelerated particle swarm optimization,” in *2017 International Seminar on Intelligent Technology and Its Application: Strengthening the Link Between University Research and Industry to Support ASEAN Energy Sector, ISITIA 2017 - Proceeding*, 2017, vol. 2017-January. doi: 10.1109/ISITIA.2017.8124061.
- [8] A. A. Mohamed, S. Kamel, and M. M. Aly, “A simple analytical technique for optimal capacitor placement in radial distribution systems,” in *2017 19th International Middle-East Power Systems Conference, MEPCON 2017 - Proceedings*, 2018, vol. 2018-February. doi: 10.1109/MEPCON.2017.8301291.
- [9] S. R. Biswal and G. Shankar, “Optimal Sizing and Allocation of Capacitors in Radial Distribution System using Sine Cosine Algorithm,” 2018. doi: 10.1109/PEDES.2018.8707739.
- [10] Y. Amrane, R. Gueddouche, A. Elmaouhab, and M. Boudour, “Optimal Capacitor Placement and Sizing in Radial Distribution Feeders using evolutionary Algorithm: A case study of the Algerian-Djanet distribution system,” 2019. doi: 10.1109/CISTEM.2018.8613322.
- [11] M. H. el Banna, N. H. Abbasy, and A. I. Megahed, “Optimal Capacitor Placement in Distribution Networks Considering Fault Periods,” 2019. doi: 10.1109/MEPCON.2018.8635276.
- [12] R. N. D. C. Filho, “Optimal capacitor placement in radial distribution system using QPSO,” 2018. doi: 10.1109/SBSE.2018.8395844.
- [13] V. P. S. Bhadouria and L. Srivastava, “Grey Wolf optimization algorithm for optimal siting and sizing of capacitors,” 2018. doi: 10.1109/ICPEICES.2018.8897330.



Received: 16-01-2024

Revised: 12-02-2024

Accepted: 07-03-2024

- [14] H. Hartono, M. Azis, and Y. Muharni, "Optimal Capacitor Placement for IEEE 118 Bus System by Using Genetic Algorithm," 2019. doi: 10.1109/ICHVEPS47643.2019.9011111.
- [15] M. Šarić and J. Hivziefendić, "Optimal Capacitor Placement in Distribution Network for Loss Reduction and Voltage Profile Improvement," 2019. doi: 10.1109/INFOTEH.2019.8717769.
- [16] Z. Muminovic, M. M. Dedovic, and S. Avdakovic, "Optimal capacitor placement in low voltage distribution grid," 2019. doi: 10.1109/icat47117.2019.8938988.
- [17] O. Ivanov, B. C. Neagu, G. Grigoras, and M. Gavrilas, "Capacitor Banks Placement Optimization Improvement Using the Sperm Whale Algorithm," 2019. doi: 10.1109/ECAI46879.2019.9042117.
- [18] T. Amara, S. Asefi, O. B. Adewuyi, M. Ahmadi, A. Yona, and T. Senjyu, "Technical and economic performance evaluation for efficient capacitors sizing and placement in a real distribution network," 2019. doi: 10.1109/SCORED.2019.8896285.
- [19] M. Asadi *et al.*, "Optimal Placement and Sizing of Capacitor Banks in Harmonic Polluted Distribution Network," 2021. doi: 10.1109/TPEC51183.2021.9384992.
- [20] G. G. Soma, "Optimal Sizing and Placement of Capacitor Banks in Distribution Networks Using a Genetic Algorithm," *Electricity*, vol. 2, no. 2, 2021, doi: 10.3390/electricity2020012.
- [21] Hadi Saadat, *Power System Analysis*. New York: McGraw-Hill, 1999.
- [22] M. E. Loverude, C. H. Kautz, and P. R. L. Heron, "Helping students develop an understanding of Archimedes' principle. I. Research on student understanding," *American Journal of Physics*, vol. 71, no. 11, 2003, doi: 10.1119/1.1607335.
- [23] F. A. Hashim, K. Hussain, E. H. Houssein, M. S. Mabrouk, and W. Al-Atabany, "Archimedes optimization algorithm: a new metaheuristic algorithm for solving optimization problems," *Applied Intelligence*, vol. 51, no. 3, 2021, doi: 10.1007/s10489-020-01893-z.