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Impact of Optimal Placement and Sizing of Capacitors on Radial Distribution Network using Cuckoo Search Algorithm

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Abstract:
Background*:Introduction of capacitor into a radial distribution network can bring about power loss reduction, minimization of total cost due to power loss and compensation, improvement of network voltage profile and stability index. This depends on the deliberate placement and sizing of shunt capacitor as improper allocation may yield negative results. Hence this paper aim to minimize the compensation cost, reduce total power loss, improve the voltage profile and stability index by the way of optimal placement and sizing of one to three shunt capacitors using Cuckoo Search Algorithm as optimization technique.*

Methodology*: In this paper, the objective function is the minimization of the total annual cost due to the radial distribution system power losses and reactive power compensation subject to the operating constraints. The cost of reactive power compensation includes purchase, installation and operating cost of capacitors. The applicability of the proposed method was tested on the standard IEEE 33-bus and Ayepe 34-bus Nigerian radial distribution network of the Ibadan Electricity Distribution Company. Four test cases were considered for the two test systems which are the base case, one, two, three installation of shunt capacitors.*

Results*: The simulation results of the four test cases obtained were compared. The results demonstrate that the proposed method is capable of saving significant amount total annual cost, reducing total power loss and attain improvement in voltage profile and stability index. The rate of improvement of the results tends to be insignificant as the number of capacitors optimally were increased beyond two.*

Conclusion:*Optimal allocation of capacitors in the radial distribution system is capable of improving the efficiency of the system.*

Key Word*:Radial distribution network; Shunt Capacitors; Cuckoo Search Algorithm; Reactive power compensation.*

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I. Introduction

In radial distribution networks, a significant amount of total power generated power is squandered as losses due to the active and reactive current components. Several researchers have shown that the optimal placement and sizing of shunt capacitors can reduce the losses because it provides reactive compensation [1]. Beside the advantage of loss reduction, proper placement of capacitor can also release additional reactive power capacity within the distribution network, improve the network voltage profile and voltage stability index, power factor correction, power quality improvement and reduction of the total of the total voltage harmonic distortion (THD) of the distribution network [2]. In radial distribution networks, the predominantly natures of loads, transformers and lines cause significant power losses due to lagging currents. The introduction of strategically placed capacitors within the distribution network help to reduce the losses created by an inductive system, thus increasing the system capacity, reducing the system losses and improving the voltage profile [3]. Due to the fact that there are many constraints and variables present, the process for calculating the placement and sizing of capacitors involves the evaluation of optimization function. Often this function will not only address technical aspect of a problem, but will evaluate its cost as well. Therefore, it becomes imperative to model a solution method that will optimize the objective function at minimal cost.

Numerous optimization techniques and models have been proposed for the solution of the optimal sizing and placement of capacitors in a radial distribution network by several researchers. The early proposed approaches are the analytical numeric programming optimization techniques like local variation method [4] and mixed integer programming techniques [5,6] have been used for solving the problem. In recent years, various meta-heuristic population based approaches have been introduced by researchers for capacitor placement problems.

Abdul-Wafa et al [7] proposed a combination of loss sensitivity factor and fuzzy real coded Genetic Algorithm for optimum capacitor sizing for achieving the maximum net money savings on power/energy loss and capacitor cost. In [8], Devabalaji et al presented a combination of LSF and VSI for capacitor placement and a Bacterial Foraging Algorithm for the capacitor sizing in a load varying environment. Sultana et al [9] used a hybrid combination of Bat Algorithm and Cuckoo Search for optimal allocation of capacitor banks for minimization of power and maximization of net savings. Askarzadeh et al [10] proposed a newly developed crow search algorithm for solving the problem of optimal capacitor allocation problem in the distribution network. El-Ela et al [11] proposed a water cycle algorithm for simultaneous optimal allocation of Capacitors and Distributed Generation units with the objective of minimizing the power losses, total energy cost and total emission.

The present study adopted the Cuckoo Search Algorithm for the optimal placement and sizing of shunt capacitors with the intention of investigating the impact of the number of shunt capacitors optimally installed on the total annual net saving, total real power losses, voltage profile and stability index of the radial distribution network.

II. Problem Formulation

Load flow for radial distribution networks

Due to the topology and radial structure of the distribution network, high resistance to reactance, large number of nodes, ill-conditioned and unbalanced nature of loads, conventional load flow methods (such as Gauss-Seidel, Newton Raphson, Fast decoupled methods) may provide inaccurate results and may not converge. Hence, the forward/backward sweep load flow method as given by [12] was used to obtain the losses in the system due to its high computational performance, implementation simplicity, robust convergence, low memory requirement [13]. It also takes advantage of the radial structure of the distribution system in order to achieve fast convergence.

Objective Function

The objective of the capacitor placement and sizing problem in the radial distribution network is to minimize the total annual cost due to the network power losses and reactive power compensation subject to the operating constraints. The cost of reactive power compensation includes purchase, installation and operation cost of capacitors. As the location and size of capacitors are to be treated discrete, the mathematical model can be expressed as constraint nonlinear integer optimization problem:

F_{min} = Cost of power loss + Cost of reactive power compensation

$$F_{min} = K_p \text{ x } P_{loss} + \alpha[(C_{inst} \text{ x N}) + C_{cap} \textstyle\sum_{i=1}^{N} Q_{ci}] + (C_{ope} \text{ x N}) \qquad (1)$$

Where P_{loss} is the total power losses, where K_p is the annual cost per unit of power losses ($/kW), C_{inst} is installation cost, N is the total number of candidate buses for capacitor placement, C_{cap} is the purchase cost of capacitor, Q_{cn} is the shunt capacitor size placed at bus n and C_{ope} is the operating cost of the capacitor.

In order to measure the value of the voltage stability in the radial distribution network, the Voltage Stability Index (VSI) is determined. Inspecting the VSI performance exposes the buses which undergoing huge voltage drops are weak and within the condition of corrective actions. VSI of a line can be calculated using Eq. (2) as given by [14]

$$\text{VSI}_{(i,i+1)} = |V_i|^4 - 4[P_{i+1}R_{i+1} + Q_{i+1}X_i]|V_{i+1}|^2 - 4[P_{i+1}R_{i+1} + Q_{i+1}X_{i+1}]^2 \qquad (2)$$

Where V_i, is the sending node voltage; while P_{ni}, Q_{ni}, R_{ni}, and X_{ni} are real power, reactive power, resistance, and impedance for the receiving node.

The reactive power support provided by the capacitors also helps to enhance the voltage stability of the distribution network.

Constraints

Each capacitor size minimizing the objective function, must satisfy the following constraints.

(i) Shunt capacitor limits

$$Q_{min} \leq Q_c \leq Q_{max} \qquad (3)$$

Where Q_{min} is the minimum compensation limit and Q_{max} is the maximum compensation limit

(ii) Bus bar voltage limits

$$V_{min} \leq V_i \leq V_{max} \qquad (4)$$

In radial distribution networks $V_{min} = 0.95$ and $V_{max} = 1.05$

(iii) Total reactive power injected

$$\textstyle\sum_{n=1}^{N} Q_{cn} < Q_{total} \qquad (5)$$

Where Q_{total} is the total reactive load

Cuckoo Search Algorithm

Cuckoo Search Algorithm (CSA) is a meta-heuristic optimization technique whose birth was claimed from inspiration surrounding the brood parasitism of cuckoo species, which lay their eggs in the nests of other host birds. CS Algorithm was developed by Yang and Deb in 2009 [15], and it has been applied to various engineering optimization problems. The fundamental ideas in modelling this algorithm was borrowed from the fact that if a host bird discovers foreign egg in its nest, it will either abandon the nest and build a new elsewhere or throw the foreign egg away.

Three rules are taken into account in cuckoo search algorithm as follows:

(i) At one time, each cuckoo only lays one egg, and leaves it in a randomly chosen nest;

(ii) The algorithm will carry over the best nest with high quality eggs (solutions) to the next generations;

(iii) A host bird can discover a foreign egg with a probability, p_a= [0, 1] while the number of available host nests is fixed. In this case, the host bird can either abandon its nest and build a completely new nest elsewhere or simply throw the eggs away [15].

A Lévy flight is performed in other to produce new solutions, $x^{i(t+1)}$for a cuckoo $i$as given in the equation.

$$x^{i(t+1)}=x^{i(t)}+ \alpha \oplus \text{Levy}(\boldsymbol{\lambda}) \tag{17}$$

where α is the step size which should be associated to the problem of interests scales; α can be set to value 1 in most situations. Equation (12) is basically the stochastic equation for random walk, which is a Markov chain whose next status or location only depends on the current status or location, and the transition probability, which are the first and second term respectively. The product $\oplus$ represents the entry wise multiplication, which is similar to those used in Particle Swarm Optimization (PSO). In terms of exploring the search space, random walk via Lévy flight is more efficient as its step length is much longer in the long run [16].

The random step length of Lévy flight, which fundamentally provides a random walk, is derived from a Lévy distribution with an infinite variance and infinite mean [15].

$$\text{Levy}\sim u =t^{-\lambda} \tag{18}$$

Here, the sequential jumps of a cuckoo fundamentally form a random walk process with a power law step length distribution with a heavy tail [16]. Numerous new solutions should be generated by Lévy walk near the best solution obtained, since this procedure will speed up the local exploration. However, to confirm the algorithm will not be trapped in a local optimum, a substantial part of the new solutions must be generated through far field randomization, so that the locations would be sufficiently far from the current best solution [15].

Application of Cuckoo Search Algorithm to Capacitor Placement

This paper reports the successful application of CS algorithm for capacitor placement problem to minimize the cost due to the system total power loss and reactive power compensation. The details of the solution procedure are provided below:

(1) Input data: the data to be fed as input are listed below.

(a) Number of buses.
(b) Load demand active (kW) and reactive (kVAr) power at each bus.
(c) Bus voltage limit (V_{min} and V_{max}).
(d) Distribution lines' impedances (resistance and reactance).
(e) Distribution lines' capacity (maximum allowable power flow).
(f) The number of capacitor banks to be installed (N=1,2 and 3)
(g) CS parameters (number of nests, n=25, step size, α=1, maximum number of iterations, K_{max} =100, probability to discover foreign eggs, $P_a = 0.6$).

(2) Perform the initial load flow analysis using the Backward/Forward Sweep load flow for radial distribution networks without capacitor compensation for the base case.

(3) Generate initial population of the hoist nest (solution vector) X^N

The solution can be split into two parts, the first part carries the locations for capacitor banks and the second part carries the integer representing size of the capacitor bank to be placed. To extract the size of the capacitor bank, a multiplication factor is employed. KVAr = a*50 + 100, where, 'a' is an integer representing the size of the capacitor bank.

For installation of a single capacitor, N=1

$$X^1 = \begin{bmatrix} 5 & \vdots & 5 \\ 9 & \vdots & 3 \\ 15 & \vdots & 4 \\ 26 & \vdots & 8 \end{bmatrix} \tag{19}$$

For the installation of two capacitors, N=2

$$X^2 = \begin{bmatrix} 21 & 15 & \vdots & 4 & 5 \\ 13 & 16 & \vdots & 6 & 7 \\ 17 & 6 & \vdots & 3 & 5 \\ 9 & 18 & \vdots & 1 & 2 \end{bmatrix} \tag{20}$$

For the installation of three capacitors, N=3

$$X^3 = \begin{bmatrix} 32 & 24 & 12 & \vdots & 3 & 4 & 5 \\ 12 & 17 & 10 & \vdots & 2 & 8 & 9 \\ 13 & 14 & 18 & \vdots & 3 & 1 & 4 \\ 15 & 30 & 6 & \vdots & 4 & 6 & 2 \end{bmatrix} \tag{21}$$

Each row of the solution vector is one complete solution having information on locations and sizes of capacitor banks. For example in X^3 , consider the first solution vector $N_1^3 = [32\ 24\ 12\ \vdots\ 3\ 4\ 5]$. The first part gives the location and the second part gives the capacitor banks to be placed at corresponding locations. (32:3), (24:4), (12:5) are the location-bank pairs, (32:3) imply that at the 32nd bus a capacitor of size 250kVAr (3*50 + 100) will be placed and so for other pairs.

(4) Evaluate the solutions X^N using load flow and to get the following for each solution.

(a) the total active power losses, P_{loss}

(b) The voltage at each bus, V_{bus}

(c) Distribution line flows to determine the overloaded lines.

(5) Calculate the annual cost function for each nest (solution) using the objective function in Eq. (10).

(6) Calculate the fitness function for each nest.

$$FF = \{F_{min} + \sum_{i=1}^{n_b}(penalty\ factor) \times (V_i - V_{max})^2 + \sum_{i=1}^{n_b}(penalty\ factor) \times (V_i - V_{min})^2 +$$

i=1nbpenalty factor×Flowi−Flowimax2 (22)

Where the penalty factor is assigned as follows for radial distribution systems.

$$penalty\ factor = \begin{Bmatrix} 0 & if\ constraints\ are\ not\ violated \\ 500 \times F_{min} \times iteration^2 & if\ constraints\ are\ violated \end{Bmatrix} \tag{23}$$

(7) Generation of Cuckoo: A cuckoo, $x^{i(t+1)}$ which is a new solution is generated by Levy flight as given in Eq. (17).

(8) Evaluate the cuckoo, new solution, using the load flow to obtain its P_{loss}, V_{bus} and line flows. Calculate the annual cost function for the cuckoo using Eq. (10) and its fitness function, FF using Eq. (22) to determine the quality of the cuckoo.

(9) Replacement: A nest is selected among n randomly, if the quality new solution in the selected nest is better than the old solution, it is replaced by the new solution (cuckoo).

(10) Generation of new nest: The worst nest are abandoned based on the probability (P_a) and new ones are built using Levy flight.

(11) The stopping criterion is set to a tolerance value of 1×10^{-6} and maximum generation of 100 iterations in case of a divergent result. If the maximum number of iterations is reached or specified accuracy level is achieved, the iterative process is terminated and the result of the CSA displayed. Otherwise, go to step 7 for continuation.

III. Resultsand Discussion

The algorithm was tested on standard IEEE 33-bus and Nigerian Ayepe 34-bus radial distribution systems. The minimum and maximum bus voltage limits are fixed at 0.95 p.u. and 1.05 p.u. respectively. The loads are treated as constant power and considered as balanced. Design period of one year is taken at full load condition for the purpose of analysis and comparison. Various constants assumed and applied in the calculations are [17]: annual cost per unit of power losses (K_p) = 525.6 \$/kW, purchase cost of capacitor C_{cap} = 25 \$/kVAr, Installation cost C_{inst} = 1600 \$/location and operating cost C_{ope} = 300 \$/year per location. The maximum number of capacitor bank to be installed, N=3. Depreciation factor (α) of 10% is applied to installation and purchase cost of capacitor banks.

In this paper, four different test cases were explored which are as follows:

Case 1: the base case without installation of capacitor.

Case 2: 1 capacitor bank was installed in the distribution system in which the optimal location and size was obtained through the CSA.

Case 3: 2 capacitor banks were installed in the distribution system in which the optimal location and size was obtained through the CSA.

Case 4: 3 capacitor banks were installed in the distribution system in which the optimal location and size was obtained through the CSA.

The Standard IEEE 33-Bus Radial Distribution System

The IEEE 33-bus system is a standardized test system with a base voltage and base MVA of 12.66kV and 100MVA respectively. The power of all network buses are assumed to be delivered by the substation placed at node 1. The line and load data are gotten from [18]. The total real power loads and reactive loads on the 33 radial distribution system are 3.715 MW and 2.3 Mvar respectively. The test system has a total thirty-three buses with thirty branches as shown in Figure 1. The number of stages (number of iterations), K_{max} =100, and the possible capacitor banks in discrete sizes are assumed to be from 150 kVar to 1500 kVar in multiples of 50.
The simulation results of the four test cases after running the algorithm are tabulated in Table I while the characteristics of the voltage profile and the voltage stability index are illustrated in Figures (3) and (4) respectively.

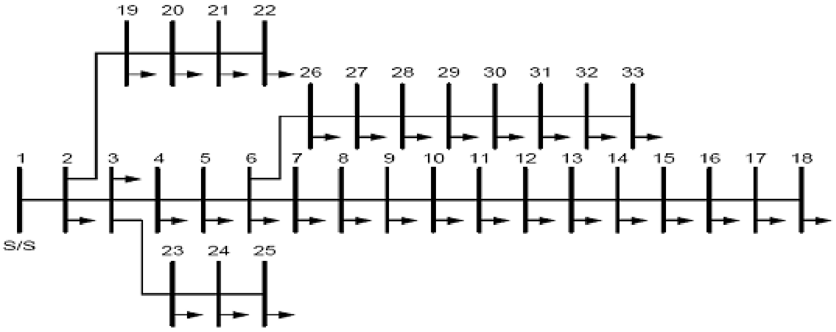


Figure 1: Standard IEEE 33-Bus Test System

Table no 1: Comparison of Results Between the Four Test Cases for Standard IEEE 33-Bus

	Base Case	1 Capacitor	2 Capacitors	3 Capacitors
Optimal Bus	-------	30	30, 13	30, 24, 11
Capacitor size (kVar)	------	1200	1000, 400	950, 400, 450
Power loss (kW)	210.99	151.52	142.07	138.65
Qloss (kVar)	143.13	103.38	96.62	94.41
Annual Cost ($)	110, 896.34	83,078.50	79, 148.97	78, 839.03
Net Savings ($)	--------	27,817.84	31,747.37	32,057.31
Min Voltage	0.9038 (18)	0.9159 (18)	0.9308 (18)	0.9321 (18)
Min VSI	0.6689	0.7041	0.7510	0.7554
Ploss Reduction	--------	59.47	68.92	72.34
% Ploss Reduction	--------	28.18	32.66	34.28
% Net Savings	--------	25.08	28.63	28.91

In Table I, it can be seen that the real power loss, reactive power loss and the annual cost for the base case are 210.99 kW, 143.13 kVar and $110, 896.34, respectively. After running the algorithm for optimal installation of one capacitor, the returned optimal size is 1200 kVar at bus 30 with total real power loss of 151.52 kW, total reactive power loss of 103.38 kVar and total annual cost of $ 83,078.50. For optimal installation of two capacitor banks, the optimum solutions obtained are 1000 kVar at bus 30 and 400 kVar at bus 13 with total power loss of 142.07 kW, total reactive power loss of 96.62 kVar and total annual cost of $79, 148.97. For optimal placement of three capacitor banks, the optimum sizes obtained by the algorithm are 950 kVar at bus 30, 400 kVar at bus 24 and 450 kVar at bus 11 with total real power loss of 138.65 kW, total reactive power loss of 94.41 kVar and total annual cost of $78,839.03.

It can be seen from Table I that the real power loss reduction in case of one, two, three capacitor banks optimal installation are 59.47 kW (28.18%), 68.92 kW (32.66%) and 72.34 kW (34.28%), respectively compared to the base case. The annual net savings for case two, three and four are $27, 817.84 (25.08%), $31, 747.84 (28.63%) and $32,057.31 (28.91%) compared to the base case. The results show that there are real power loss reduction and net savings with optimal installation of one capacitor bank and there is further loss reduction and more net savings with increase in the number of capacitors even though the rate of increment is declining as the capacitor banks are increased. From Figures 3 and 4, the voltage profile and VSI values of the distribution network were poor for the base case and improved after the installation of capacitor. There is further improvement in both the voltage profile and VSI values as the number of capacitors are increased even though it is very slim between cases three and four. The difference in the increment in both the voltage profile and the VSI values tends to decline as the number of shunt capacitors optimally installed are increased from two to three.

The results obtained for case four from the proposed algorithm is compared with other existing techniques as shown in Table 2. The results show the efficiency of the proposed method in finding optimal capacitor allocation. The convergence characteristics for cases two, three and four are illustrated in Figure 4. The performance of the proposed algorithm over 20 independent runs of simulation for compensation cost minimization for the different cases with best, average and worst values of power loss and its standard deviation is presented in Table 3. The results show that the algorithm is very precise which indicates its output consistency.

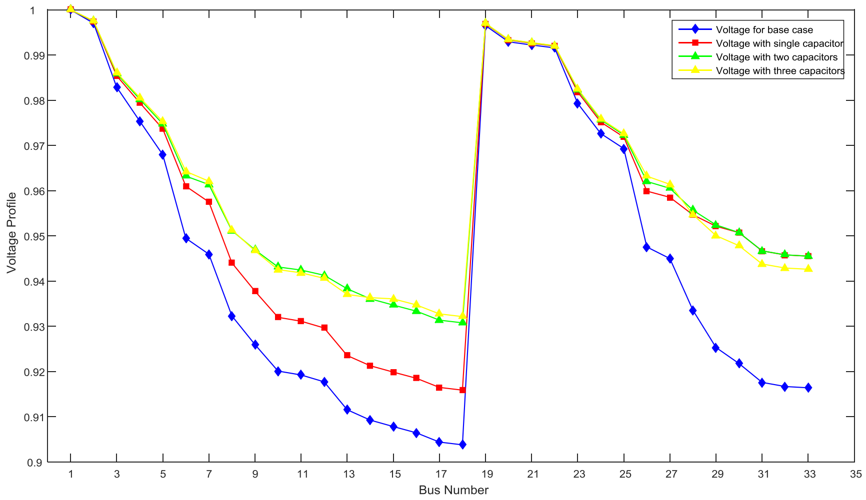


Figure 2: Voltage Profile of each bus in the 33 Bus for the Different Cases

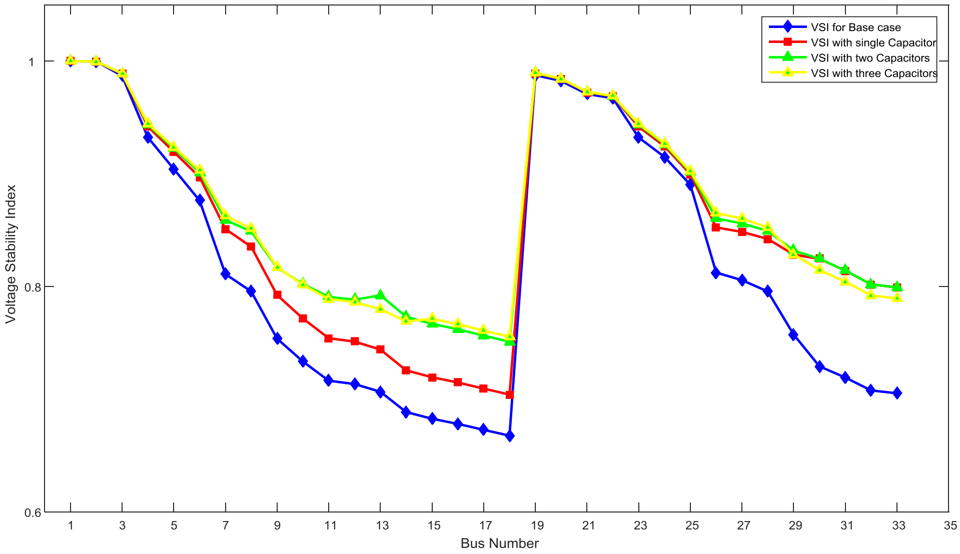
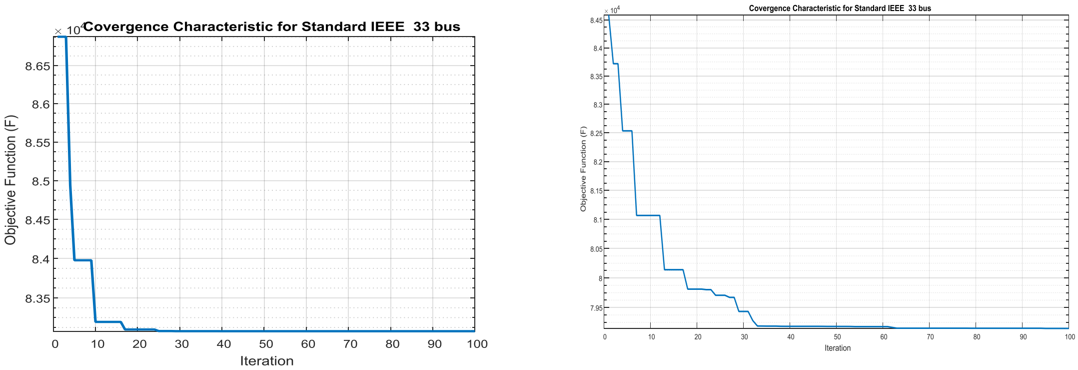


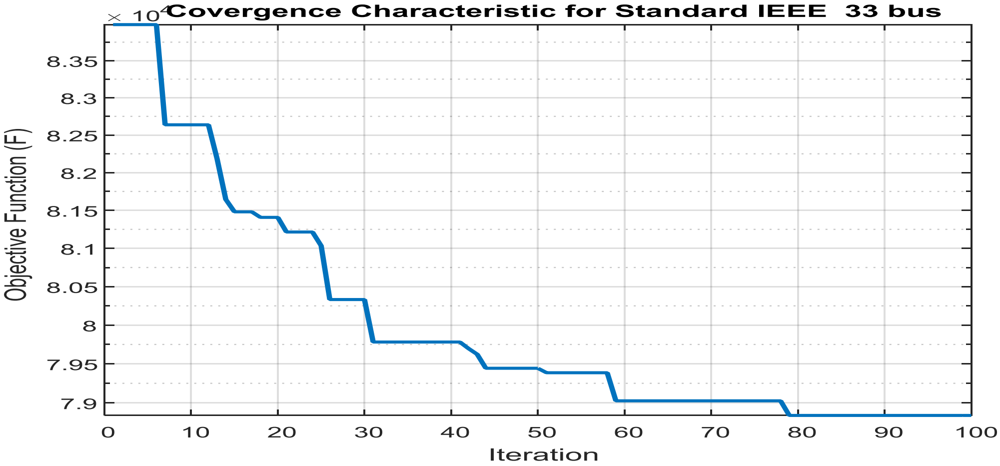
Figure 3: VSI values of the Standard IEEE 33 Bus for the Different Cases

Table no 2: Optimal CBs Allocation in the 33-bus system (Case 3)

Optimization Technique	CBs size (kVAr) and location	Base Ploss (kW)	Ploss (kW)	Ploss Reduction
GSA [19]	450(13), 800(15), 350(26)	202.6	134.5	68.1
CSA [20]	600(11), 300(33), 450(24), 600(30)	202.6	131.5	71.1
PSO [20]	900(2),450(7), 450(11),300(15), 450(29)	202.6	132.48	69.52
BFOA [21]	349.6(18), 820.6(30), 277.3(33)	202.6	144.04	58.56
IMDE [22]	475(14), 1037(30)	202.6	139.7	62.9
WCA [11]	397.3(14), 451.1(24), 1000(30)	202.6	130.91	71.69
SSA [23]	450(10), 450(23), 1050(29)	202.6	132.35	70.25
Proposed method	450(11), 400(24), 950(30)	210.99	138.65	72.34



(a) Case Two (b) Case Three



(c) Case Four

Figure 4: Convergence Characteristics for the Different Cases

Table no 3: Simulation results of total annual cost achieved by the algorithm over 20 independent runs

	Best	Average	Worst	Standard deviation
Case 2 (kW)	83, 078.50	83, 295.04	84, 113.34	281.91
Case 3 (kW)	79, 148.97	81, 408.11	82, 674.34	1025.04
Case 4 (kW)	78, 839.03	80, 972.80	82, 203.25	1030.90

Ayepe 34-bus Nigerian radial distribution network

The second network used to test the algorithm is the Ayepe 34-bus radial distribution network of the Ibadan Electricity Distribution Company (IBEDC), Ibadan, Nigeria. The network consists of 34 buses with the first bus serving as the substation which delivers load to other buses in the network. The total real power loads and reactive loads on the 34 bus network are 4.12 MW and 2.05 Mvar respectively. The line and load data are obtained from [13]. The loads were modelled using steady state values of the real and reactive power they consumed. The single-line diagram of the Ayepe 34-Bus feeder is as depicted in Figure 5. The number of stages (number of iterations), K_{max} =100, and the possible capacitor banks in discrete sizes are assumed to be from 150 kVar to 1000 kVar in multiples of 50.

The simulation results of the four test cases after running the algorithm are tabulated in Table 4 while the characteristics of the voltage profile and the voltage stability index are illustrated in Figures (6) and (7) respectively.

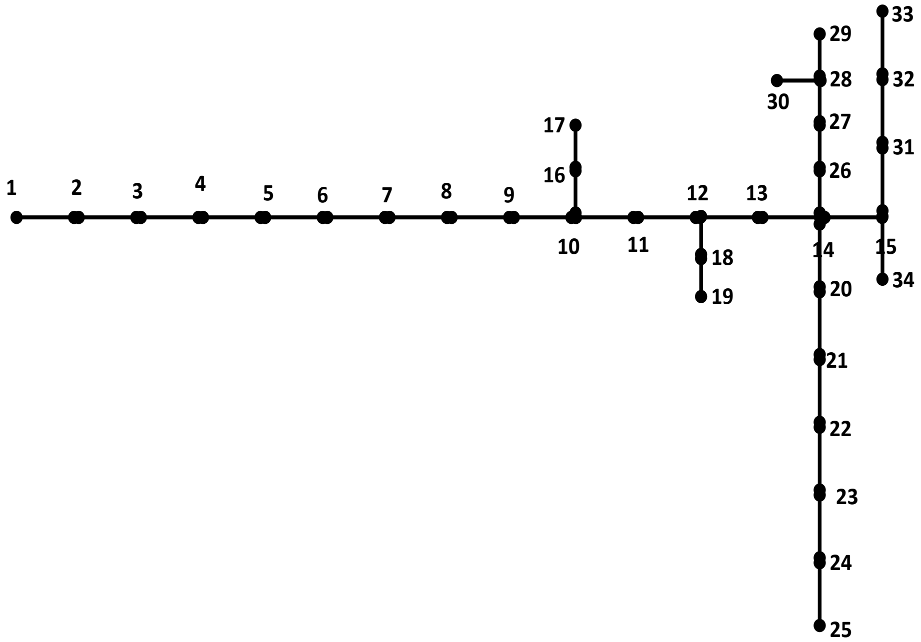


Figure 5: Ayepe 34-bus Nigerian Radial Distribution Network

Table no 4: Comparison of Results Between the Four Test Cases for Standard Ayepe 34-Bus

	Base Case	1 Capacitor	2 Capacitors	3 Capacitors
Optimal Bus	-------	14	13, 8	34, 21, 10
Capacitor size (kVar)	------	1500	1500, 300	500, 550, 800
Power loss (kW)	762.64	595.13	589.44	588.09
Qloss (kVar)	146.37	114.22	112.12	112.87
Annual Cost ($)	400,840.00	317, 012.59	315, 282.93	315 054.49
Net Savings ($)	---------	83,827.41	85,557.07	85,788.51
Min Voltage	0.8295(25)	0.8457(25)	0.8476(25)	0.8481(25)
Min VSI	0.4746	0.5123	0.5168	0.5181
Ploss Reduction	--------	167.51	173.20	174.55
% Ploss Reduction	--------	21.96	22.70	22.89
% Net Savings	--------	20.91	21.34	21.40

From Table 4 above, the real power loss, reactive power loss and the annual cost for the base case are 762.64 kW, 146.37 kVar and $400,840.00 respectively. After running the algorithm for optimal installation of one capacitor, the returned optimal size is 1500 kVar at bus 14 with total real power loss of 595.13 kW, total reactive power loss of 114.22 kVar and total annual cost of $ 317,012.59. For optimal installation of two capacitor banks, the optimum solutions obtained are 1500 kVar at bus 13 and 300 kVar at bus 8 with total power loss of 589.44 kW, total reactive power loss of 113.12 kVar and total annual cost of $315, 282.93. For optimal placement of three capacitor banks, the optimum sizes obtained by the algorithm are 500 kVar at bus 34, 550 kVar at bus 21 and 800 kVar at bus 10 with total real power loss of 588.09 kW, total reactive power loss of 112.87 kVar and total annual cost of $315, 054.49.

It is clearly shown in Table 4 that the real power loss reduction in case of one, two, three capacitor banks optimal installation are 167.51 kW (21.96%), 173.20 kW (22.70%) and 174.55 kW (22.89%), respectively compared to the base case. The annual net savings for case two, three and four are $83, 827.41 (20.91%), $85, 557.07 (21.34%) and $85, 788.51 (21.40%) compared to the base case. The results show that there are real power loss reduction and net savings with optimal installation of one capacitor bank and there is further loss reduction and more net savings with increase in the number of capacitors even though the rate of increment is declining as the capacitor banks are increased. From Figures 3 and 4, the voltage profile and VSI values of the distribution network were poor for the base case and improved after the installation of capacitor. There is further improvement in both the voltage profile and VSI values as the number of capacitors are increased even though it is very slim between cases three and four. The difference in the increment in both the voltage profile and the VSI values tends to decline as the number of shunt capacitors optimally installed are increased from two to three.

to decline as the number of shunt capacitors optimally installed are increased beyond two.

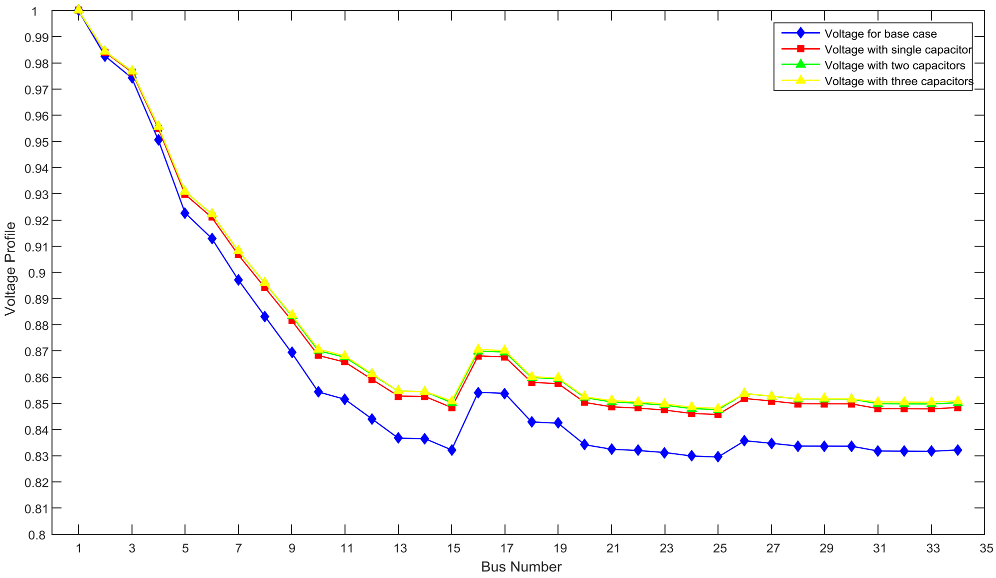


Figure 6: Voltage Profile of each bus in the Ayepe 34-Bus for the Different Cases

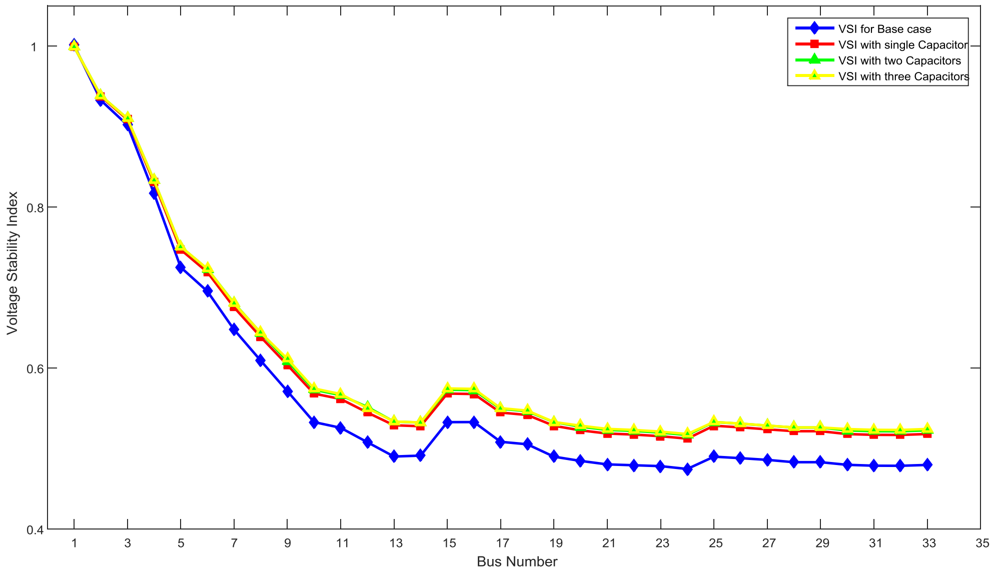
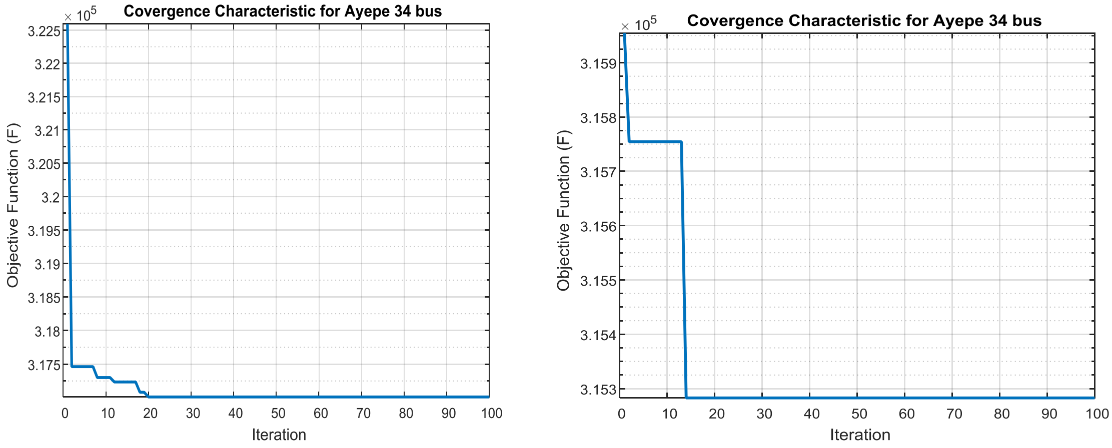
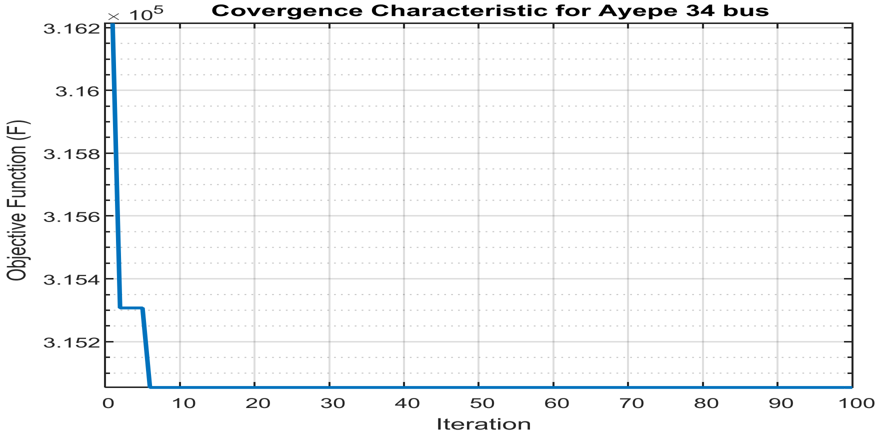


Figure 7: VSI values of the Ayepe 34-Bus for the Different Cases

The convergence characteristics for cases two, three and four are illustrated in Figure 4. The performance of the proposed algorithm over 20 independent runs of simulation for compensation cost minimization for the different cases with best, average and worst values of power loss and its standard deviation is presented in Table 5. The results show that the algorithm is very precise which indicates its output consistency.



(a) Case Two (b) Case Three



(c) Case Four

Figure no 8: Convergence Characteristics for the Different Cases for Ayepe 34-bus

Table no 5: Simulation results of total annual cost achieved by the algorithm over 20 independent runs for Ayepe 34-bus

	Best	Average	Worst	Standard deviation
Case 2 (kW)	317, 012.59	317, 019.58	317, 082.52	20.92
Case 3 (kW)	315,282.94	315, 768.50	316,086.17	267.55
Case 4 (kW)	315, 054.49	315, 772.92	316, 225.11	377.79

IV. Conclusion

In this paper, a cuckoo search algorithm has been applied to find the optimal placement and size of shunt capacitor banks in a standard and practical radial distribution systems with the objective of minimizing the cost due to the total power loss and reactive power compensation. The study also investigated the impact of the number of capacitors optimal placed on the total annual cost, total power loss, voltage profile, annual net savings and the voltage stability index of the radial distribution systems. It is demonstrated that the proposed method is capable of saving significant amount of total annual cost, reducing total power losses, attain improvement in voltage profile and stability by comparing the simulation results for different test cases in radial distribution systems. Better results were obtained as the number of shunt capacitor banks optimally installed were increased to two but the rate of improvement tends to diminishas the shunt capacitors were increased to three. Shunt capacitor banks have been taken as a discrete variable, which is an added advantage for the practical applicability of the solution.

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