JOURNAL OF HARVESTING ENERGY
(Year) Volume / Issue: (2022) I / I
Page: 27-38

http://adyapublications.co.in/JHE.php

Optimal Placement of Capacitors in Radial Distribution Systems for Reducing Energy Loss

G V A S Suryavathi[1], K Subba Raju[2], K V S Ramachandra Murthy[3*]
[1,2,3] Aditya Engineering College, Surampalem, ADB Road, East Godavari District, 533437, India

***Email:** murthy.kvs@aec.edu.in

Abstract
In distribution systems, capacitor placement is optimized to reduce energy loss and improve voltage profile. In this article, two types of capacitor placement are implemented and compared. Fixed Location Variable Reactive Power (FLVQ) and Variable Location Fixed Reactive Power (VLFQ) approaches are carried out. Optimal locations are obtained from sensitivity analysis in FLVQ method. The FLVQ technique uses the Bat Algorithm (BA) to determine the best capacitor size. Direct Search Algorithm is used to obtain Optimal locations in the VLFQ method. The outcomes are compared and contrasted. In Engineering Optimization, the Bat Algorithm (BA), which is based on the echolocation behavior of bats, was proposed by Xin-She-Xang. This thesis explains the notion of Bat Algorithm as well as the mathematical formulation of the algorithm. Several simulations have been performed on various test systems in order to evaluate the efficiency of the VLFQ and FLVQ approaches. The aim function is intended to minimize the overall cost and, as a result, to raise the net savings each year throughout the course of the year. The suggested technique is being evaluated on radial distribution systems of 34 and 85 buses, respectively.

Keywords
Power, VLFQ, Energy, Bat Algorithm, Optimization, Capacitor

I. INTRODUCTION

It serves as a conduit for high voltage transmission to reach the end user's home or place of business. Distribution systems have a substantially higher power loss than high voltage transmission systems because of lower voltages and higher currents. I^2R losses on the distribution level account for up to 13% of the total power generated. As a result of these losses, reactive currents are to blame for some of the problem. The overall efficiency of electricity supply can be improved by reducing the total loss in distribution networks. It has become necessary for the power utilities to reduce distribution losses because of low power delivery efficiency [1].

Received- 03/01/2021 *Revised- 22/01/2022* *Published- 05/02/2022*

Please cite this article as: G. Suryavathi, K. Subba Raju, K. Ramachandra Murthy, "Optimal Placement of Capacitors in Radial Distribution Systems for Reducing Energy Loss" Journal of Harvesting Energy, Vol. 1, Issue 1, pp 27-38, 2022.

Planning a distribution system reduces power and energy losses, lowers capital expenses, and improves end-user supply quality. New modelling tools, optimization and programming methodologies have been developed to find the ideal position and connectivity between substations [2]. These systems use shunt capacitors to reduce losses and adjust for reactive power.

Methods to reduce distribution system losses have been published over the years. For calculating power loss, energy loss, and the decrease of energy loss by appropriate capacitor placement, generalized formulae have been provided in the literature Reactive power compensation can be used on a basic line feeder with evenly distributed load, according to previous studies and publications. It's possible that none of these is a viable method of dissemination [3]. The primary and secondary distribution systems account for 70% of the total system losses, whereas transmission and sub-transmission lines account for just 30% of the total losses. Losses must therefore be kept to a minimum in the primary and secondary distribution networks.

Goswami and Basu [4] proposed a straightforward technique for handling radial and mesh distribution networks. Kersting and Mendive used ladder network theory to solve radial distribution networks [5]. Johnson et al. advocated a longer empirical study. Combinatorial issues were studied using simulated annealing [6]. Their design issue is that each node has just two incoming branches. Jasmon and Lee developed a new radial distribution load flow mechanism. A single line can solve a distribution network load flow problem [7].

For distribution automation, Abul Wafa et al employed a graphical approach to create load flow equations in matrix form [8]. Kennedy J, Eberhart came up with a new method for solving nonlinear functions called a particle swarm. For poorly meshed distribution and transmission networks, Shi Mohammadi et al. have proposed a compensation-based power flow approach [9]. Tang et al. developed the genetic algorithm (GA) as an innovative signal processing optimization algorithm [10]. Applied to the travelling salesman problem by Dorigo et al [11] is a distributed method called as ant colony system (ACS). For radial and mesh distribution networks, Goswami has developed a direct method for solving them [12].

Das et al. proposed a radial distribution network power flow method. It works well for radial distribution networks. Passino created foraging theory-based models of E. coli and M. Xanthus bacterium behavior. Genetic Algorithm (GA) results were published by Karaboga D for optimizing multivariable functions using the ABC algorithm [13]. The shuffled frog-leaping algorithm (SFLA) created by [14] is used to address combinatorial optimization issues.

II. IMPLEMENTATION OF FLVQ &VLFQ APPROACHES FOR OPTIMAL CAPACITOR PLACEMENT

In this section, two types of capacitor placement are implemented and compared. Fixed Location Variable Reactive Power (FLVQ) and Variable Location Fixed Reactive Power (VLFQ) approaches are carried out. Optimal locations are obtained from sensitivity analysis in FLVQ method. Bat Algorithm (BA) is implemented for optimal sizing of capacitors in FLVQ approach. Direct Search Algorithm is used to obtain Optimal locations in the VLFQ method.

The results are compared. Optimal Location for placement of capacitor in the second method, is obtained by power loss index method. For 15 Bus, 33 Bus, and 69 Bus Systems, the Bat Algorithm is used to determine the optimal size of capacitors. Appendix 5 has a sample programmed. Flow data for 15 Bus, 33 Bus, and 69 Bus Systems may be found in Appendices 1 through 4.

Objective Function

All real power losses in a given Radial Distribution System are to be minimized by determining the optimal location of capacitors. We can derive the Objective function as follows:

$$Min\ P_{loss} = R[k]\left[\frac{P[k]^2+Q[k]^2}{V[n]^2}\right] \tag{1}$$

Where,
P[k], Q[k] =Real and reactive power in the Branch k
V[n] =Voltage at node n
R[k] =Resistance of the branch k

Power loss index is obtained by the following formula for obtaining the optimal locations.

$$PLI_{(n)} = \frac{\text{Loss reduction}_{(n)} - \text{Loss reduction}_{\min}}{\text{Loss reduction}_{\max} - \text{Loss reduction}_{\min}} \tag{2}$$

BAT Algorithm (BA)

Heuristic and meta-heuristic algorithms developed from nature's biological and/or physical processes are the most common type of algorithm. The Bat Algorithm (BA) was devised by Xin-She-Xang for engineering optimization based on the echo locating behavior of bats. Different Bat Algorithms can be devised by idealizing the echolocation features of micro bats.

Implementation of Bat Algorithm

How to use the Bat Algorithm the Bat Algorithm is used to address the optimal capacitor placement problem in radial distribution networks.

Step 1: Problem definition and algorithm parameters Initialize parameters like population size (POP), issue dimension (Dimension), and maximum iterations (Intermix). A number of factors must be put up in order to gain a good image of the issue.

Step 2: Locations and capacitor sizes are generated at random using a computer programmed.

Step 3: The assessment of a person's physical condition. The annual network savings for any initial solution can be calculated by running through the load flow. Take note of the most effective strategy.

Step 4: Start the Bat Algorithm's evolution procedure by pressing the Start button. Randomly assign a frequency to each of the Bats.

Each bat should be assigned a frequency at random.

$$f_i = f_{min} + \beta * (f_{max} - f_{min})$$

Step 5: Positions of the Bats are generated at random (locations and sizes of capacitors)

for t=1:50

X(t,1)= X(t,1)+rand()(pbest(1)-X(t,1)) +rand()*(X(p,1)-X(t,1));*

X(t,2)= X(t,2)+rand()(pbest(2)-X(t,2)) +rand()*(X(p,2)-X(t,2));*

X(t,3)= X(t,3)+rand()(pbest(3)-X(t,3)) +rand()*(X(p,3)-X(t,3));*

end

Step 6: The assessment of a person's physical condition (Objective function) Calculate the system's genuine power loss and the annual network savings for each new solution.

Step 7: If you can't discover a better answer for a bat than the one you already have, you can try a new one.

Step 8: A criterion for halting the process. The computation is halted if the maximum number of iterations is reached. Steps 4 to 7 are repeated if necessary. It is possible to summaries the Bat Algorithm (BA) pseudo code as follows:

Optimal Capacitor placement using VLFQ approach

Direct Search Algorithm is used for this purpose. The Objective of DSA is to compensate reactive power by capacitors.

Flow chart for the implementation of Direct Search Algorithm for capacitors is shown in Figure 2

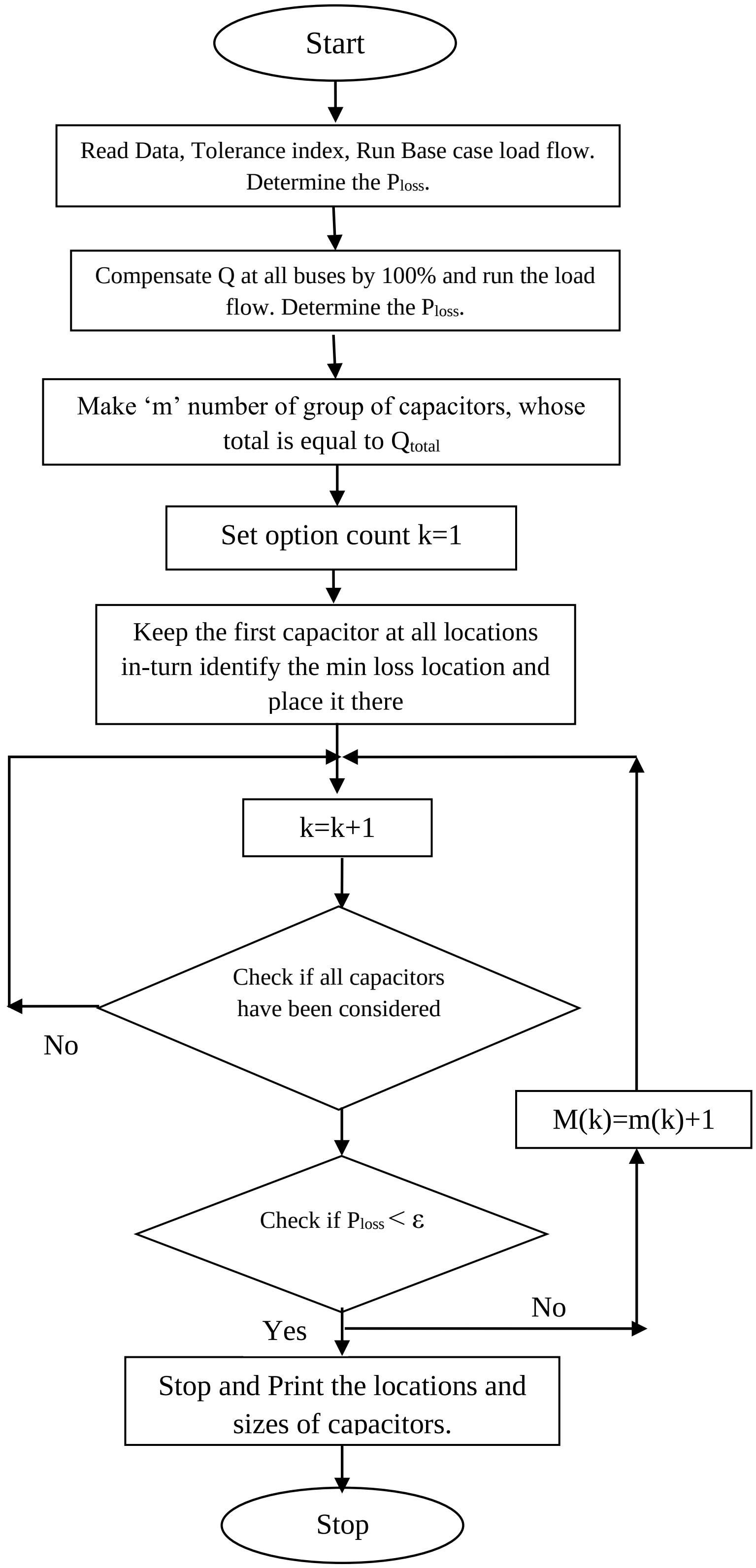

Figure 2. Flow chart for Direct Search Algorithm for placement of capacitors

Optimal Capacitor placement using VLFQ approach on 85 Bus System

Total Q in the system : 2622.2 KVAR.

Ploss without compensation : 316.11 Kw.

If total Q =0, the loss obtained is = 141.02 Kw.

Using DSA, P_{min} loss = 141.01 kW.

Option 1 : Selection of capacitors – larger first and slowly decrease.

S. No.	Q kVAr compensated	Min Loss Location	Magnitude of Ploss after placing the capacitors. (kw)
1	450	36	247.24
2	300	69	212.31
3	150	30	188.52
4	150	80	178.05
5	150	66	168.91
6	150	61	161.80
7	150	14	155.96
8	150	26	151.68
9	150	57	148.68
10	150	8	146.83
11	150	20	145.30
12	150	6	144.62
13	150	18	144.17
14	150	17	144.01
Total Q	2550		

Option 2 : Q compensated starts from 900, 450, 300 150…

S. No.	Q kVAr compensated	Min Loss Location	Magnitude of Ploss after placing the capacitors.
1	900	33	210.70
2	450	72	174.96
3	300	80	161.11
4	150	69	156.16
5	150	57	153.12
6	150	8	151.23
7	150	20	149.69
8	150	18	149.00
Total Q	2400		.

Option 3 : Q compensated starts from 1200, 450, 150…

S. No.	Q kVAr compensated	Min Loss Location	Magnitude of Ploss after placing the capacitors.
1	1200	30	198.34
2	450	72	169.48
3	150	80	163.56
4	150	69	159.59
5	150	14	156.93
6	150	20	155.38
7	150	57	154.65
8	150	28	154.17
Total Q	2400		

Optimal Capacitor placement using VLFQ approach on 69 Bus System

Total Qload in the system : 2694 kVAr

Ploss with out compensation : 225 kW

If total Q is compensated, Ploss : 143.52 kW

Option 1 : Selection of capacitors –Starting from 900 kVAr, 450,450,450, 150. This option gives better result.

S. No.	Q KVAR compensated	Min Loss Location	Magnitude of Ploss after placing the capacitors. (kw)
1	900	62	159.42
2	450	16	151.92
3	450	61	**147.00**
Total Q	1800 KVAR.		Best ever result. If you add more Q, loss increases.

Option 2 : Selection of capacitors –Starting from 900 kvar, 900, 150,150, , 150.

S. No.	Q KVAR compensated	Min Loss Location	Magnitude of Ploss after placing the capacitors. (kw)
1	900	62	159.42
2	900	12	151.32
3	150	65	148.37
4	150	60	147.54
5	150	22	**147.01**
Total Q	1800 KVAR.		Best result. If you add more Q, loss increases.

III. RESULTS OBTAINED FROM FIXED LOCATION VARIABLE REACTIVE POWER (FLVQ) METHOD

Analysis on 15 Bus Organization

The power loss index approach was used to identify three best places on the 15 Bus system. Buses No. 6, 11, and 15 are among them. The Bat method was used to find the ideal dimensions. Table 1 shows the values of capacitors. Without compensation, the 15-bus system loses 61.80 kW, but the active power loss is only 31.26 kW. Figure 1 depicts the 15 Bus system's single-line diagram. Voltages before and after adjustment are depicted in Figure 2 (right).

Table 1: Capacitor placement and size are critical to the 15 Bus system's performance.

Optimal Location (Bus No.)	Optimal Size
6	422
11	374
15	338

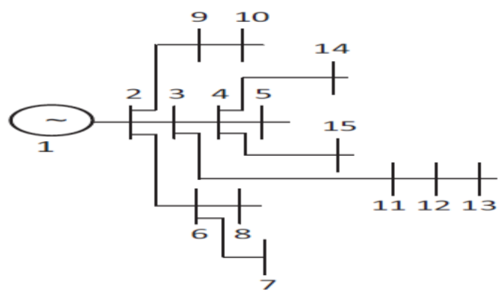

Figure 1: 15 Bus system

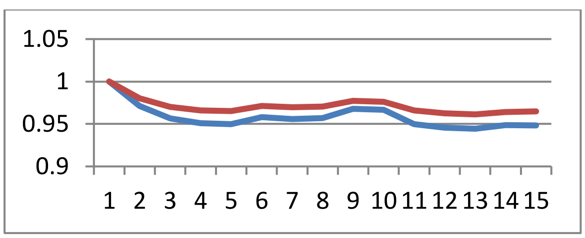

Figure 2: 15 Bus voltage profile before and after capacitor placement

Investigation on 33 Bus Scheme

Using the power loss index approach, three ideal locations were found on the 33 Bus system. Buses No. 32, 30, and 14 are among them. The Bat method was used to find the ideal dimensions. Table 2 shows the values of capacitors. Without compensation, the 33 Bus system loses 210.74 kW. And the active power loss is 157.7 kW, after adjustment. Table 3 shows the voltage before and after the procedure. Before and after adjustment are shown in Fig. 3.

Table 2: Capacitor placement and size optimization on the 33 Bus system

Optimal Location (Bus No.)	Optimal Size (kVAr)
32	110
30	189
14	1373

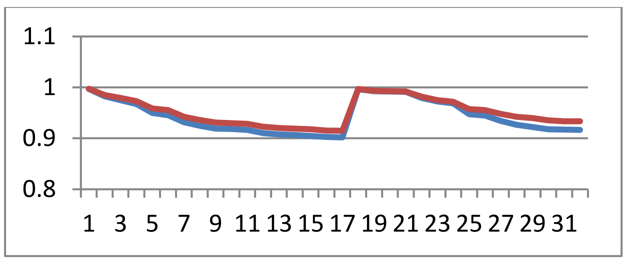

Figure 3: Before and after voltage profiles on the 33 Bus system

Investigation On 69 Bus Organization

The power loss index approach was used to identify three best sites on the 69 Bus system. Buses 61 and 21 are on the list. The Bat method was used to find the ideal dimensions. Table 3 shows the capacitance values of several devices. Active power loss is reduced from 225 kW to 151.65% after correction is applied to 69 Bus's system. Table 6 shows a comparison of the voltage before and after. Fig. 4 depicts the 69 Bus system's single-line diagram. Before and after adjustment are shown in Fig. 5.

Table 3: Capacitor placement and size are critical to the 69 Bus system's performance.

Optimal Location (Bus No.)	Optimal Size (kVAr)
60	972
61	334
21	362

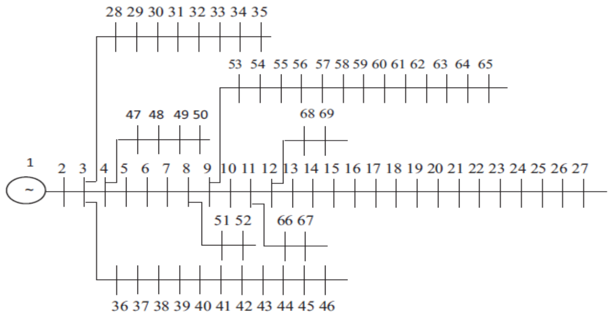

Figure 4: Single line diagram 69 Bus system

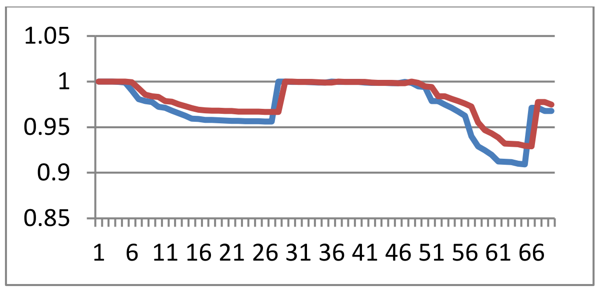

Figure 5: Before and after the installation of a capacitor on the 69 Bus system

IV. CONCLUSIONS

In this paper, two types of capacitor placement is implemented and compared. Fixed Location Variable Reactive Power (FLVQ) and Variable Location Fixed Reactive Power (VLFQ) approaches are carried out. The FLVQ technique uses the Bat Algorithm (BA) to determine the best capacitor size. The VLFQ method's optimal locations are found using the Direct Search Algorithm. There is a comparison of the data. Bat echolocation is the basis of the Bat Algorithm (BA). Simulations on the 15, 34, 69, and 85 Bus test systems have been used to evaluate the effectiveness of the VLFQ and FLVQ approaches. The goal is to minimize the overall loss of active power. Radial distribution systems are used to test the two methods. Two separate approaches are utilized to verify the efficiency of the two different approaches to minimize losses and total cost as well as to boost voltage profile and net savings for various distribution systems by using data from this study.

REFERENCES

[1] T. Inoue, K. Takano, T. Watanabe, J. Kawahara, R. Yoshinaka, A. Kishimoto, and Y. Hayashi, “Distribution loss minimization with guaranteed error bound”, IEEE Transactions on Smart Grid, vol. 5, No. 1, pp. 102-111, 2014.

[2] K. K. Mehmood, C.H. Kim, S.U. Khan, and Z.M. Haider¸ “Unified planning of wind generators and switched capacitor banks: A multiagent clustering-based distributed approach”, IEEE Transactions on Power Systems, vol. 33, No. 6, pp. 6978-6988, 2018.

[3] A. Shefaei, M.J. Vahid-Pakdel, and B. Mohammadi-Ivatloo, “Application of a hybrid evolutionary algorithm on reactive power compensation problem of distribution network”, Computers & Electrical Engineering, vol.72, pp. 125-136, 2018.

[4] W. H. Kersting and D. L. Mendive, “An application of ladder network theory to the solution of three phase radial load flow problem”, Proceedings of IEEE PES Winter meeting, New York, January 1976, pp. A76 0448.

[5] D. Shirmohammadi, H.W. Hong, A. Semlyen, and G.X. Luo, “A compensation-based power flow method for weakly meshed distribution and transmission netowkrs”, IEEE Transaction, On Power System, Vol 3, pp 753-762, 1988.

[6] D.S. Johnson, C.R. Aragon, L.A. McGeoch, and C. Schevon, “Optimization by simulated annealing: An experimental evaluation; part I, graph partitioning”, Operations research, vol. 37, No. 6, pp.865-892, 1989.

[7] S. K. Goswami and S. K. Basu, “Direct solution of distribution systems”, IEE Transactions on Generation, Transmission & Distribution, 1991, vol. 138, No. 1, pp. 78-88, 1991.

[8] S.K. Nagaraju, S. Sivanagaraju, T. Ramana, S. Satyanarayana, and P.V. Prasad, “A novel method for optimal distributed generator placement in radial distribution systems”, Cogeneration and Distributed Generation Journal, vol. 26, No. 1, pp. 7-19, 2011.

[9] D. Wang, D.Tan, and L. Liu, “Particle swarm optimization algorithm: an overview”, Soft Computing, vol. 22, No. 2, pp. 387-408, 2018.

[10] D. Das, D.P. Kothari and A Kalam, “Simple and effcient method for load flow Solution of radial distribution networks”, Electrical Power and Energy Systems, Butterworth, Heinmann Publications, vol. 17, No.5, pp. 335 – 346, 1995.

[11] A. Ghaheri, S. Shoar, M. Naderan, and S.S. Hoseini, “The applications of genetic algorithms in medicine”, Oman medical journal, vol. 30, No. 6, 2015.

[12] M. Dorigo, L.M. Gambardella “Ant colony system: a cooperative learning approach to the traveling salesman problem”, IEEE Trans Evol Comput, vol. 12, pp. 53–66, 1997.

[13] R. A. Conde-Gutiérrez, U. Cruz-Jacobo, A. Huicochea, S.R. Casolco and J.A. Hernández, “Optimal multivariable conditions in the operation of an absorption heat transformer with energy recycling solved by the genetic algorithm in artificial neural network inverse”, Applied Soft Computing, vol. 72, pp. 218-234, 2018.

[14] S. Panda, A. Sarangi, and S.P. Panigrahi, “A new training strategy for neural network using shuffled frog-leaping algorithm and application to channel equalization”, AEU-International Journal of Electronics and Communications, vol. 68, No. 11, pp. 1031-1036, 2014.