# Optimal Capacitor Placement for Loss Reduction and Voltage Profile Improvement in Distribution System Using Genetic Algorithm

G.Saritha
Head, Dept. of EEE
Christu Jyoti Institute of Technology & Science
Colombonagar, Yeshwanthapur, Jangaon-T.S.-506167
Sarithareddy2210@gmail.com

*Abstract* - **Load flow study is the solution for the normal balanced steady-state operating conditions of an electric power system. It became an essential prerequisite for power system studies as it is used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. This paper presents a load flow solutions for radial distribution system based on the calculation of voltage at the buses, real and reactive power flowing through lines, real power losses and voltage deviation, using distribution load flow (DLF) program. In the process of load flow calculation, two developed matrices bus injection to bus current (BIBC) and branch current to bus voltage (BCBV), and a simple matrix multiplication are used to obtain load flow solutions. The solution converges very early, therefore execution time is very small. In this paper, the distribution load flow is run initially without capacitor placement and then the size and location of capacitor in distribution systems based on GA is determined for power loss minimization and voltage improvement. The effectiveness of the proposed method is examined on the IEEE 33 bus test system and comparative studies are conducted before and after capacitor installation on the test systems. Results illustrate significant reduction in losses and voltage profile improvement with the presence of capacitor.**

***Keywords—Distribution System, Genetic Algorithm, Power Loss, Voltage Profile***

## I. INTRODUCTION

Capacitors have been widely employed in distribution systems in order to achieve different objectives. For instance, in [1] reducing active power losses is the only purpose of capacitor allocation problem. Athores in [2] determined the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss in radial distribution systems. Sallam and his coauthors in [3] used shunt capacitors in distribution systems to improve the reliability indices. In [4], the authors proposed a comprehensive objective function to loss reduction and reliability enhancement in distribution network using optimal capacitor placement. For the capacitor placement problem in distribution system repeated load flow solution is required. There are a number of load flow solution techniques which are available in the text books such as Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow method, but most of the methods have been grown up around transmission systems [5-6]. The distribution system has high R/X ratio and the conventional load flow method may not be suitable.

A number of methods have been proposed in the literature [7-13] for the distribution networks. Shirmohammadi et al. [7] has proposed a load flow method for distribution networks using a multi-port compensation technique and basic formulations of Kirchhoff's Laws. Rajicic and Tamura [9] has modified the fast decoupled load flow method to suit high R/X ratio nature of distribution system. Various methods [10-13] have been reported for the load flow of radial distribution system. Ghosh and Das [10] have proposed a method for the load flow of radial distribution network using the evaluation based on algebraic expression of receiving end voltage. Teng [12,13] has proposed the load flow of radial distribution system employing bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) matrices.

## II. DISTRIBUTION LOAD FLOW ALGORITHM

### *A. Computation of Voltages at the Buses*

In order to obtain load flow solutions, first objective is to obtain voltages at the buses. If $V_k$ is the voltages of the buses after $k^{th}$ iteration, then voltages at the buses after $(k+1)^{th}$ iteration is given by

$$V^{k+1} = V^k - \Delta V^k \quad (1)$$

Here $\Delta V^k$ is change in bus voltages after two successive iterations.

*B. Real Power Flow*

The real power flow $P_{ij}$ through the line connecting $i^{th}$ and $j^{th}$ buses is given by

$$P_{ij} = Re\left[V_i\{(V_i - V_j)y_{ij}\}^*\right] \quad (2)$$

Here, $V_i$ and $V_j$ are the voltages of $i^{th}$ and $j^{th}$ bus respectively and $y_{ij}$ is the admittance of the line between $i^{th}$ and $j^{th}$ buses.

*C. Reactive Power Flow*

Similarly, the reactive power $Q_{ij}$ flowing through the line connecting $i^{th}$ and $j^{th}$ buses is given by,

$$Q_{ij} = Im\left[V_i\{(V_i - V_j)y_{ij}\}^*\right] \quad (3)$$

*.D. Real Power Loss*

The real power loss is given by

$$P_{Loss} = Re\left\{V_{ss}\sum_{j\in ss}[(V_{ss} - V_j)y_{ss,j}]^* - \sum_{j=1}^{N} PD_j\right\} \quad (4)$$

Where $V_{ss}$ and $V_j$ in Eq. 4 refers to the voltages at main substation and bus j, respectively, $y_{ss,j}$ refers to the line admittance between the main substation bus and bus j, $PD_j$ refers to the real power load at bus j and N the number of buses in the radial distribution system.

*E. Voltage Deviation Index (VDI)*

In order to quantify the extent of violation of limits imposed on voltages at buses in a RDS, the following Voltage Deviation Index (VDI) has been defined.

$$VDI = \sqrt{\frac{\sum_{i=1}^{NVB}(V_{Li} - V_{LiLIM})^2}{N}} \quad (5)$$

Where NVB is the Number of Buses that Violates the prescribed voltage limits and $V_{LiLIM}$ is the upper limit of the $i^{th}$ load bus voltage if there is upper limit violation or lower limit if there is a lower limit violation.

The total power losses will be formulated as a function of the power injections based on the equivalent current injection. The formulation of total power losses will be used for determining the optimum size of DG and calculation of the system losses. At each bus i, the corresponding equivalent current injection is specified by:

$$I_i = \left(\frac{P_i + jQ_i}{V_i}\right)^* \qquad i = 1, 2, \ldots, n \quad (6)$$

Where $V_i$ is the node voltage, $P_i + jQ_i$ is the complex power at each bus i, n is the total bus number, *symbolizes the complex conjugate of operator. The equivalent current injection of bus i can be separated into real and imaginary parts by Eqs 7 and 8.

$$Re(I_i) = \frac{P_i.\cos(\theta_i) + Q_i.\sin(\theta_i)}{|V_i|} \quad (7)$$

$$Im(I_i) = \frac{P_i.\sin(\theta_i) - Q_i.\cos(\theta_i)}{|V_i|} \quad (8)$$

where $\theta_i$ is the angle of $i^{th}$ node voltage.

*F. Bus-Injection to Branch-Current Matrix (BIBC)*

The branch current B is calculated with the help of "Bus-Injection to Branch-Current matrix" (BIBC). The BIBC matrix is the result of the relationship between the bus current injections and branch currents. The elements of BIBC matrix consists of '0's or '1's.

$$[B]_{nb\times 1} = [BIBC]_{nb\times(n-1)}.[I]_{(n-1)\times 1} \quad (9)$$

Where nb is the number of branches, [I] is the vector of the equivalent current injection for each bus except the reference bus.

The total power losses can be expressed as a function of the bus current injections is given by

$$P_{loss} = \sum_{i=1}^{nb}|B_i|^2.R_i = [R]^T|[BIBC].[I]|^2 \quad (10)$$

Where $R_i$ is the $i^{th}$ branch resistance and the branch resistance vector is given in Eq. 11.

$$[R]_{nb\times 1} = [R_1 \ R_2 \ \ldots \ R_{nb}]^T \quad (11)$$

The total power losses can be written as a function of the real and imaginary parts of the bus current injection.

$$P_{loss} = [R]^T|[BIBC].[I]|^2$$
$$= [R]^T|[BIBC].[Re(I)] + j[BIBC].[Im(I)]|^2 \quad (12)$$

Where [Re(I)] and [Im(I)] are the vectors of real and imaginary parts of the bus current injection.

*G. Branch-Current to Bus-Voltage Matrix (BCBV)*

The voltage drop from each bus to the reference bus is obtained with Branch-Current to Bus-Voltage (BCBV) matrix. The BCBV matrix is responsible for the relations between the branch currents and the bus voltages. The elements of BCBV matrix consist of the line impedances.

$$[\Delta V] = [BCBV].[B] \quad (13)$$

$$[\Delta V]_{(n-1)\times 1} = [BCBV].[BIBC].[I] \quad (14)$$

$$[\Delta V] = [DLF][I] \quad (15)$$

### *H. Algorithm for creating BIBC and BCBV Matrix*

Step (1): For a distribution system with nb branch sections and n buses, the dimension of the BIBC matrix is nb × (n– 1)

Step (2): If a line section ($B_k$) is located between Bus i and Bus j, copy the column of the $i^{th}$ bus of the BIBC matrix to the column of the $j^{th}$ bus and fill +1 in the position of the $j^{th}$ bus column as shown below.

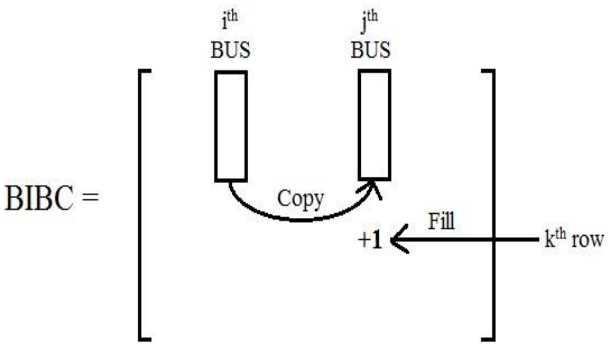


Fig. 1 Graphical view of creating BIBC

Step (3) : Repeat Step (2) until all the line sections are included in the BIBC matrix. The building Step (2) for the BIBC matrix is shown in Fig. 1.

Step (4) : For a distribution system with nb branch sections and n buses, the dimension of the BCBV matrix is (n – 1)× nb.

Step (5) : If a line section ($B_k$) is located between Bus i and Bus j, copy the row of the $i_{th}$ bus of the BCBV matrix to the row of the $j_{th}$ bus, and fill the line impedance ($Z_{ij}$) in the position of the $j_{th}$ bus row and the $k_{th}$ column. The building of Step (5) for the BCBV matrix is shown in Fig. 2.

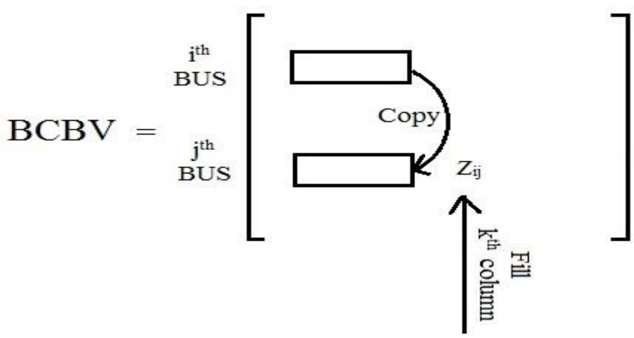


Fig. 2 Graphical view of creating BCBV

Step (6): Repeat Step (5) until all the line sections are included in the BCBV matrix.

### *I. Solution Technique Based on BIBC and BCBV*

(i) The BIBC and BCBV matrices are developed based on the topological structure of distribution systems.

(ii) The BIBC matrix is responsible for the relations between the bus current injections and branch currents.

(iii) The corresponding variation of the branch currents, which is generated by the variation at the current injection buses, can be found directly by using the BIBC matrix.

(iv) The BCBV matrix is responsible for the relations between the branch currents and bus voltages.

(v) The corresponding variation of the bus voltages, which is generated by the variation of the branch currents, can be found directly by using the BCBV matrix.

The solution for the distribution load flow can be obtained by solving Eq. 16 and Eq. 17 iteratively.

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \quad i = 1, 2, \dots, n \tag{16}$$

$$[\Delta V^{k+1}] = [DLF][I^k] \tag{17}$$

The flowchart for solving power flow problem is shown in Fig. 3 and named as DLF method.

## III. OPTIMAL PLACEMENT OF CAPACITOR USING GA

The developed algorithm for identifying the sizing and location is based on Genetic Algorithm (GA). A GA is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution in the set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators; the solution in this pool has better average fitness than that of initial population. The crossover and mutation operator are used to generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintaining fixed number of solutions in pool of selected population, as the iteration progresses, the solution improves and optimal solution is obtained.

The success of the GA structure will lie on the coding scheme. The coding scheme and the brief discussion of various operators with reference to the problem of interest is summarized as: Here the coding scheme for 33-bus radial distribution system has been discussed. First step is to obtain the base case load flow solution for distribution system using the DLF method shown in the figure. Then identify the potential buses for capacitor placement by using loss sensitivity factor.

 Issn No : 1006-7930

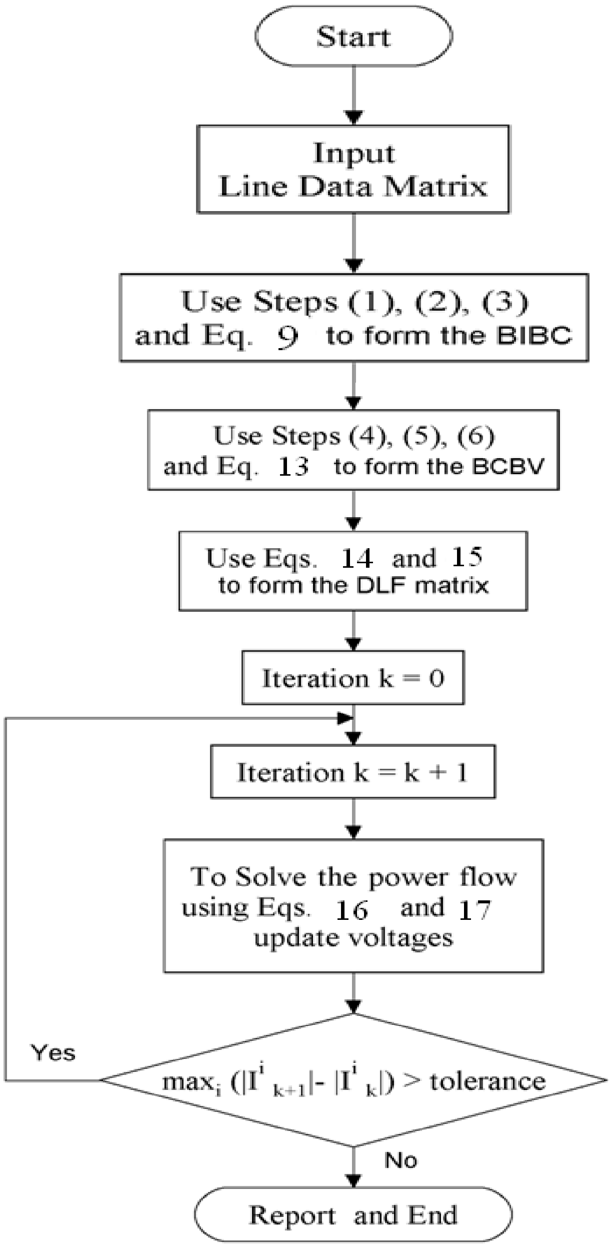


Fig. 3 Flowchart for solving power flow problem

Using the loss sensitivity factor, the potential buses for shunt capacitor placement are obtained and these potential buses should be preserved.

Let the numbers of Potential Buses = [29 7 30 28 12]

Having identified the potential buses, the sizing is attempted using GA. Let the capacitor allowable range is from 100 kVAR to 1100 kVAR in step size of 50 kVAR. The respective sizes of capacitor to be installed at those potential buses are given below:

Capacitor sizes = [300 150 750 250 350]

IV. RESULTS AND DISCUSSION

The proposed Genetic Algorithm (GA) is implemented using MATLAB 2011 and is tested for a IEEE 33-bus Radial Distribution System shown in Fig. 4. Substation voltage is 12.66 kV and base MVA is taken as 100 MVA

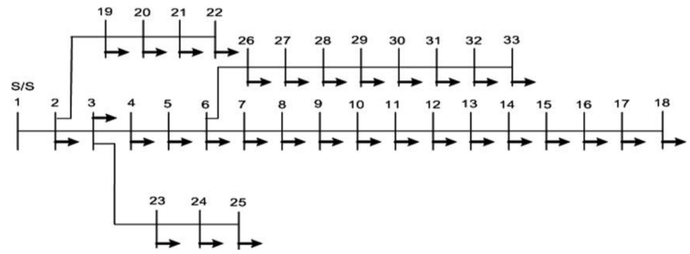


Fig. 4 IEEE 33 bus system

Capacitor placement optimization details for the same test system are presented in Table I and Table II for constant power load model and composite load model respectively.

Table I Capacitor optimization details for constant power load model

| Parameter | Without Capacitors | With Capacitors |
|---|---|---|
| Active Power loss in kW | 210.99 | 141.53 |
| Reactive Power loss in kVAR | 143 | 96 |
| Minimum Voltage in Per Unit | 0.9038 | 0.9257 |
| Maximum Voltage in Per Unit | 1.0000 | 1.0000 |
| Average Voltage in Per Unit | 0.9453 | 0.9603 |

Table II Capacitor optimization details for composite load model

| Parameter | Without Capacitors | With Capacitors |
|---|---|---|
| Active Power loss in kW | 189 | 107.6 |
| Reactive Power loss in kVAR | 127.9 | 75.8 |
| Minimum Voltage in Per Unit | 0.9095 | 0.9294 |
| Maximum Voltage in Per Unit | 1.0000 | 1.0000 |
| Average Voltage in Per Unit | 0.9498 | 0.9697 |

To reflect the voltage dependency nature of distribution systems, the loads are modeled as composite loads consisting of 45% constant power, 30% constant current and 25% constant impedance. Here in this composite load model, overall system power loss is less when compared to constant power load model. Table III shows the bus voltage values before and after installation of Capacitors at potential buses.

Table III Comparison of Voltage Profile of buses before and after Capacitor Installation

| Bus number | Per Unit Voltages at each bus | |
|---|---|---|
| | Before Capacitor | After Capacitor |
| 1 | 1.00000 | 1.00000 |
| 2 | 0.99703 | 0.99753 |
| 3 | 0.98290 | 0.98612 |
| 4 | 0.97539 | 0.98063 |
| 5 | 0.96796 | 0.97531 |
| 6 | 0.94948 | 0.96435 |
| 7 | 0.94596 | 0.96311 |
| 8 | 0.93230 | 0.95137 |
| 9 | 0.92597 | 0.94616 |
| 10 | 0.92009 | 0.94140 |
| 11 | 0.91922 | 0.94064 |
| 12 | 0.91771 | 0.93932 |
| 13 | 0.91153 | 0.93329 |
| 14 | 0.90924 | 0.93106 |
| 15 | 0.90782 | 0.92966 |
| 16 | 0.90644 | 0.92831 |
| 17 | 0.90439 | 0.92631 |
| 18 | 0.90377 | 0.92572 |
| 19 | 0.99650 | 0.99701 |
| 20 | 0.99292 | 0.99343 |
| 21 | 0.99222 | 0.99273 |
| 22 | 0.99158 | 0.99209 |
| 23 | 0.97931 | 0.98255 |
| 24 | 0.97264 | 0.97590 |
| 25 | 0.96931 | 0.97259 |
| 26 | 0.94755 | 0.96315 |
| 27 | 0.94499 | 0.96160 |
| 28 | 0.93355 | 0.95660 |
| 29 | 0.92533 | 0.95276 |
| 30 | 0.92177 | 0.95041 |
| 31 | 0.91761 | 0.94638 |
| 32 | 0.91669 | 0.94549 |
| 33 | 0.91641 | 0.94521 |

It is observed from Table III, that with optimal location of capacitor at potential buses in the system, the voltage profile of all buses remains stable within tolerable limits.

## V. CONCLUSION

In this paper, optimal location and size of capacitor are identified by using Genetic Algorithm for a IEEE 33 bus system. The comparison is made without and with capacitors in terms of total power loss and voltage profile of all the buses. The total power loss without capacitor was 211 kW and after connecting capacitors at potential buses in the system, the power loss is reduced to 141.53 kW. Thus the total loss was reduced to 67% of total power losses in the system and the voltage profile of all the buses remained stable within the tolerable limits. Hence, the power quality of the system is improved. The step size of 50 KVAR from 100 kVAR to 1100 kVAR is considered for the present study. Providing compensation at more than 5 buses yields lesser reduction of power loss and higher cost of overall installation.

## REFERENCES

[1] Y. G. Bae. Analytical method of capacitor allocation on distribution primary feeders. IEEE Transaction on Power Apparatus and Systems, v97, n4, July, 1978, pp.1232-1238.
[2] R. Srinivasas Rao, S. V. L. Narasimham, M. Ramalingaraju. Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm. Electrical Power and Energy Systems, v33, n5, June, 2011, pp.1133– 1139.
[3] A. A. Sallam, M. Desouky, H. Desouky. Shunt capacitor effect on electrical distribution system reliability. IEEE Transaction on Reliability, v43, n1, March, 1994, pp.170-176.
[4] A. H. Etemadi, M. Fotuhi-Firuzabad. Distribution system reliability enhancement using optimal capacitor placement. IET Generation. Transmission & Distribution, v2, n5, Sept, 2008, pp.621-631.
[5] J. J. Grainger and W. D. Stevenson, 'Power System Analysis', Tata McGraw-Hill, New Delhi, 2005.
[6] G. L. Kusic, 'Computer Aided Power Systems Analysis', Prentice-Hall of India, New Delhi, 1996.
[7] D. Shirmohammadi, H. W. Hong, A. Semlyen and G. X. Luo, "A Compensation- Based Power Flow Method for Weakly Meshed Distribution and Transmission Networks", IEEE Transactions on Power Systems, vol. 3, no. 2, pp. 753- 762, 1988.
[8] G. X. Luo and A. Semlyen, "Efficient Load Flow for Large Weakly Meshed Networks", IEEE Transactions on Power Systems, vo1. 5, no. 4, pp. 1309-1316, 1990.
[9] D. Rajicic and A. Bose, "A modification to the fast decoupled power flow for networks with high R/X ratios", IEEE Transactions on Power Systems, vol. 3, no. 2, pp. 743-746, 1988.
[10] S. Ghosh and D. Das, "Method for load-flow solution of radial distribution networks", IEE Proceedings on Generation, Transmission & Distribution, vol. 146 no. 6, pp. 641-648, 1999.
[11] R. Ranjan and D. Das, "Simple and Efficient Computer Algorithm to Solve Radial Distribution Networks", Electric Power Components and Systems, vol. 31, no. 1, pp. 95-107, 2003.
[12] J. H. Teng, "A Network-Topology-based Three-Phase Load Flow for Distribution Systems", Proceeding National Science Council, Republic of China, vol. 24, no. 4, pp. 259-264, 2000.
[13] J. H. Teng, "A Direct Approach for Distribution System Load Flow Solutions", IEEE Transactions on Power Delivery, vol. 18, no. 3, pp. 882-887, 2003.