ASHESI UNIVERSITY

MINIMIZING POWER LOSSES IN HIGH VOLTAGE DISTRIBUTION SYSTEM

CAPSTONE PROJECT

BSc. Electrical and Electronic Engineering

Barnabas Kwame Sabbogu

2021

ASHESI UNIVERSITY

MINIMIZING POWER LOSSES IN HIGH VOLTAGE DISTRIBUTION SYSTEM

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirement for the award of Bachelor of Science degree in Electrical and Electronic Engineering

Barnabas Kwame Sabbogu

2021

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

………………………………………………………………………………………………

Candidate's Name:

………Barnabas Kwame Sabbogu………………..……………………………………

Date: ………………………………………………………………………………..

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

………………………………………………………………………………………………

Supervisor's Name:

………………………………………………………………………………………………

Date: ……………………………………………

Acknowledgement

To my supervisor, Mr Richard Awingot Akparibo whose encouragement and academic advice helped me undertake this project.

Abstract

The demand for electricity in Ghana keeps increasing as the population grows, which has led to concerns about power losses as well as rising energy cost. The popular convention is to increase the power production to take care the loss [1]. The project is based on the reduction in High Voltage Distribution System (HVDS) in the Upper West Region of Ghana. A distribution system takes carries electricity from the transmission system to the end user. The voltage in the buses reduces when moved away from the substation and this is because of insufficient reactive power which can be provided by capacitor shun and series compensation [2]. This project is aimed at identifying the optimal sizes and locations of a shunt capacitors to be replaced in a radial distribution system considering the overall economic savings due to power minimization and capacitor cost. The is achieved in two stages, the first step is carrying out a load flow of a pre-compensated distribution system. Loss Sensitivity Factor (LSF) is carried out based on the load flow solution to identify the potential locations for compensation. The LSF is used to identify the candidate buses. The second stage is using the Genetic Algorithm (GA) to identify the sizes of the capacitors for reducing the energy loss cost and the capacitor cost.

Table of Contents

List of Tables

List of figures

Chapter 1: Introduction

1.1 Background

The final part in the delivery of electricity to end-users is the distribution stage [3]. A distribution system carries electricity from the transmission system and delivers it to the consumer [4]. The distribution system consists of two parts: the primary distribution which extends either from the generating station or substation to distribution transformers, and the secondary distribution, which extends from the distribution transformers to the point of utilization. As the demand for electricity keeps increasing, power losses have greatly affected distribution companies both economically and technically [5]. The application of various techniques such as increasing cables sizes, adding parallel feeder and increasing the power generation seems to solve the problem [6]. However, these are very expensive approaches. This research seeks to explore a cost-effective yet efficient approach of minimizing power losses using Genetic Algorithm (GA) on capacitor placement.

1.2 Problem Definition

The general population of Ghana is growing at a rate of 2.2% which calls for an increase in demand for electricity. The electricity demand is increasing at an annual rate of 10% to 15% [7]. These statistics imply that electricity will continue to be on high demand and distribution companies must find ways of distributing power efficiently to reduce cost. Increasing the amount of power generated is not the way to go when considering the economic situation of Ghana. However, the implementation of intelligent system such as GA to the power system distribution network has been economical and efficient from the literature. Therefore, this research is focused on reducing power losses using GA.

1.3 Objectives of the Project Work

In this project, reducing losses in 11.5kV lines will be considered. The objectives of the project include:

1. To develop an Algorithm to optimized capacitor placement in a radial distribution system.
2. To identify the location and size of the capacitors in the system.
3. To analyse the efficiency, responsiveness, and overall performance of the GA system.
4. To account for the difference made by the GA implementation in the system.
5. To effectively conserve power through GA implementation.

1.4 Expected Out Comes of the Project Work

The following are the expected outcomes to be achieved at the end of the project.

1. A working Algorithm to determine the location and size of capacitors in a radial distribution system.
2. A model of the electrical distribution network that can accept data of a load for simulation.
3. An effective and responsive system that maximizes power output without overheating and damage to the transformer.
4. A cost and efficiency analysis of the whole system since less power is lost in the distribution process.

1.5 Motivation for Project Topic

The are several factors that propelled me to go into this research area. Apart from the interest in knowledge acquisition in power systems. The power sector is one of the important sectors moving the world. With the increasing population, the demand for energy for both domestic and industrial use has become more important than ever. Also, power companies will have to increase generation while managing losses. Hence, one motivation for this project is the need for effective power management by distribution companies with other motivations being the current technological advancement and the rising need for power stability.

1.6 Research Methodology to be Used

The following are the research method used in this project:

1. Systematic literature review.
2. Computer modelling and simulations.
3. Analyses and deductions from simulation results.

1.7 Facilities to be used for the Research

The key facilities needed for this project are:

1. Library and internet facilities
2. Load and line data from VRA
3. MATLAB software

1.8 Scope of Work

This project is to limit finding optimal sizes and location of capacitors to be installed on the distribution system to reduce power and improve voltage profile. The project will take into consideration the observation of simulations before and after capacitors placement using GA in a distribution system. The results of the simulation will be analysed to see the effectiveness.

Chapter 2: Literature Review

2.1 Introduction

The distribution system of electricity can either be overhead or underground construction. In Ghana, the overhead line is used because it is less expensive and easy to locate the faulty part for repairs and maintenance. The transmission systems run on a voltage of 161 kV, which is stepped down to 34.5 kV and 11.5 kV at the distribution substations. The 11 kV feeder branches further into subsidiary 11 kV feeders to carry power to the load points. A transformer further reduces the voltage from 11 kV to 415 V at these load points [8]. This provides the last-kilometer connection through 425 V feeders (Low Tension (LT) feeders) to customers either at 240 V (single-phase) or at 415 V (three-phase). For Township Distribution Network (TDN) lines, the span lengths for electricity projects nationwide are 45/50 meters [9]. In Ghana, the average span length for 11 kV and 415 V distribution lines is meters between two pools. [10]

2.2 Power Losses in High Voltage Distribution System

The power generated at various generation stations (plants) across the country is transmitted through transmission lines to many distribution circuits. The purpose of the distribution system is to take power from the transmission system to the customers, a significant part of the power that the utility generates is lost in the distribution system, such as transformers and distribution lines. Each of these components may have relatively small losses, but the large number of components involved makes it necessary to account for the distribution system's losses. The distribution system has some features that reduce voltage when it is moved from substations. The two types of power losses in distribution systems are cores losses, mostly in transformers at low power levels. The copper losses or I^2R losses become more significant as the load increases until they are approximately equal to the peak load's core losses [11].

2.3 Methods of Reducing Power Losses in High Voltage Distribution System

Much research and work have been carried out to reduce losses in the High Voltage Distribution System (HVDS). About 30% to 40% of the investment goes into the distribution system, but they have not received the same impact as generation and transmission [12]. In managing a loss reduction program in a distribution system, it is essential to apply effective and efficient computational tools to quantify the loss in the various network elements for loss reduction. There are various ways to reduce these losses like feeder reconstruction, Distributed Generation (DG) implementation and capacitor placement. Each of these methods are discussed below.

2.3.1 Feeder Reconstruction

Feeder reconstruction method for loss minimization was proposed by Merlin et al [13] using discrete branch and bound analysis. To apply feeder reconstruction, all the switches are closed to form a meshed network to apply feeder reconstruction, and the switches are successively opened to restore to radial configuration. However, this method involves approximation which can be overcome by an algorithm where the switches are opened based on the algorithm flow. The concept of restricting the distribution system topology to minimize power losses can be cost-effective and efficient in electric utilities. Distribution system networks are configured as radial for protection of the coordination Reconstruction of distribution feeders by opening and closing switches simultaneously meet all the load requirements and maintains the radial network [14]. This requirement results in proper planning of the system to reduce loss and improve the system's efficiency.

2.3.2 Distributed Generation (DG) Implementation

Distributed Generation (DG) is any small-scale electrical generation technology that provides electric power near the load site. It is either directly connected to the distribution network, the customer's facility, or both. The distributed system generates power locally to fulfill customer needs. The placement and sizes of DG appropriately can reduce power losses in the system. The addition of DG can improve supply quality reliability. DG has the potential to change power flows and system performances. To get the best optimization from DG, proper planning is needed to determine the appropriate sizes and locations. One of the advantages of DG is that both active and reactive power can be injected to improve the voltage profile and satisfy customer needs. Voltage variation occurs in distribution systems and, line impedance causes drop in voltages. The long radial feeders, usually in rural areas, makes transmission of reactive power not possible by increasing voltage drop at the customer end. This accounts for the voltage at the load busses usually lower than those at the utility substation [15]. The smaller the deviation of the bus voltage form the nominal voltage, the better for the system. A voltage deviation index (TVD) is the sum of all the squared values of the absolute voltage difference between the nominal voltage and the actual voltage for all the busses in the system.

$$TVD = \sum_{i=1}^{N} |V_{n-}V_i|^2 \qquad (1.1)$$

Where N is the total number of busses, V_n is the nominal voltage and, V_i is the actual voltage at bus i. The inclusion of DG to the system can improve voltage profile and reduce voltage deviation. $TDV^{'}$ is the deviation with the inclusion of DG.

$$TDV^{'}=\sum_{i=1}^{N} |V_{n-}V_i'|^2 \qquad (1.2)$$

Replace V_i' with ($V_{i-}\triangle V_i$) we have,

$$TDV^{'}=\sum_{i=1}^{N} |V_{n-}V_{i-}\triangle V_i|^2 \qquad (1.3)$$

By substituting the values $\triangle V_i$ from the equation $\triangle V_X = \boldsymbol{a}\triangle V_{DG}$ from supposition of DG voltages.

$$TDV^{'}=\sum_{i=1}^{N} |V_{n-}(V_i + a_i\triangle V_{DG})|^2 \qquad (1.4)$$

The change in the voltage deviation index of the system due to DG injection can be obtained by subtracting Eqn 1.4 from Eqn 1.1

$$\triangle\text{TDV} = \sum_{i=1}^{N}[|V_{n-}V_i|^2 - |V_{n-}(V_i + a_i\triangle V_{DG}|^2] \qquad (1.5)$$

As shown in Eqn (1.5) the voltage profile can be improved by injecting current from the DG. The maximum voltage improvement can be obtained by determining optimal values for the DG current injection.

2.3.3 Capacitor Placement

Capacitor placement is a methods of minimizing distribution losses in high voltage systems, which will be applied in this project. This is done by replacing individual capacitor place (reactive power compensation) in the distribution system. The problem with this method is that the capacitors must be optimally placed with the appropriate size to achieve loss minimization. Some researchers place capacitors of various sizes randomly at any location within the network, but this did not help reduce the losses. Some overcompensated them ended up increasing the losses rather than reducing [16]. Artificial Intelligent (AI) techniques can be applied, and some have proven more efficient than others depending on the approaches used. One of the AI technique which will be applied in this project is the Genetic Algorithm approach to solve this problem of loss minimization.

2.4 Application of Artificial Intelligence in Minimizing Power Losses in High Voltage Distribution System

There have been many optimization methods to reduce losses in distribution systems using efficient and effective computational tools like MATLAB, Artificial Neural Network, which allow quantification of the losses analysis in each network for effective loss reduction [17]. Various optimization technologies applied to minimize power losses are classified based on the principles they are initiated to create the program. Table.2.4.1[18] shows the various application of (AI) in the optimization of distribution systems. Genetic algorithm has a considerable, good percentage loss reduction and general application method. The constrained management and the model precision are fair which is the best one among the other methods. Hence the use of the Genetic algorithm approach for this project is expected to give a good outcome.

Table 2.4.1: Optimization methods in minimizing distribution losses

Evolution method	Mixed method	Knowledge method
Simulated annealing	Linear programing +heuristic	Heuristic
Genetic algorithm	Genetic algorithm + fuzzy logic	Linear programming
Neural network	Fuzzy logic +heuristic	Expert system
Ant colony	Simulated annealing +heuristic	Fuzzy logic
Particle swamp optimization		Tabular search method

2.5 Review of Related Work in Minimizing High Voltage Distribution Power System Losses

Goyal and Singh, in 2014 [19], designed an optimal placement of capacitors in a radial distribution system to minimize variable load levels. The authors reported on an efficient approach for optimal capacitor placement in a radial distribution system. The objective was to improve the voltage profile and reduce power losses. It was done by determining the optimal location and sizes of capacitors using a genetic algorithm. The efficiency of the algorithm was tested on an IEEE 33-bus radial distribution network. It was observed that after the application of their algorithm, the voltage profile improves about 12% of the variable loads. The disadvantage was that even though GA solves the problem, the process was tedious and require fast computers and computing skill which is not readily available. And the data used was standard data and not actual or live data.

Hadi, Z.et al. [20] reported on Particle Swarm Optimization Algorithm for Optimal Capacitor Placement on Electric Power Distribution Networks. In the paper, the authors used Particle Swarm Optimization Algorithm for Optimal Capacitor Placement. The paper aimed to find the optimal sizes and location of capacitors installed on the distribution system to reduce losses. The report started with problem identification: operational constraints, objective function, capacitor function size, and cost. The problem with this optimization algorithm is that since the objective function is non-differentiable, all nonlinear optimization techniques will not yield, and standard data was required.

Anwar S. Siddiqui and MD. Farrukh Rahman, in 2012 [21], reported on the optimal capacitor placement to reduce losses in distribution system. In their report, the writers presented an approach for optical placement using shunt capacitors in a 10-bus radial distribution system as the model. To determine the capacitors' sizes and location, a load flow program was executed on MATLAB using the Fuzzy logic toolbox. This method of the Fuzzy technique is simple, less computational, and fast results. The algorithm used was relatively simple because few parameters needed to be manipulated. This method's problem is that it cannot be used directly on complex systems having sub feeders, and standard data was used.

Gnanasekaran et al. in 2016 [22] reported on optimal placement of capacitors in radial distribution system using shark smell optimization algorithm. The paper presented a technique to locate optimal sizes and locations of shunt capacitors to reduce power losses and reactive power compensation of the distribution system. The Shark Smell Optimization algorithm approach was considered in solving the problem. To demonstrate the effectiveness of this method, it was tested on an IEEE 34-bus and 188-bus radial distribution system. This method is good in reducing losses and improving voltage profile. It is also easy to understand and can be applied to a large-scale distribution network. The problem is that it is difficult to get the initial population (candidate solution) and standard data was used.

Mahela et al. [23] designed an optimal capacitor placement for loss reduction in radial distribution feeder. The paper presents a method to search for optimal shunt capacitor placement in radial distribution feeders. The primary objective is to reduce the feeders' losses and bring the bus voltage within their specific values. The method is tested on an IEEE 9-bus system using MATLAB for optimum capacitor sizes and location. The active power losses are calculated for different arrangements and sizes of capacitors. The power flow is calculated without capacitor placement for the first instance and the same calculation is done with capacitor placement. This method is simple and requires no complex optimization techniques. This approach's problem is that it will not be efficient on the more extensive bus system and maintaining bus voltage for each bus is very difficult and standard data was used.

Yasim and Ismail in 2016 [24] reported on power quality improvement via optimal capacitor placement in electrical distribution systems using a symbiotic organism search algorithm. In their paper, the author presents an approach to locating and finding capacitors' sizes in a radial distribution system using the symbiotic search algorithm. The aim is to increase efficiency by reducing losses and improve the voltage profile. The forward and backward sweep algorithm is used to analyze the power flow. The method is tested on an IEEE 9-bus radial distribution system. The symbiotic algorithm is easy to implement because no specific parameters are required. The problem with this method is that the algorithm requires more time in data representation, and the results are not encouraging.

Reddy and Veera in 2008 [25] reported on capacitor placement using fuzzy and particle swarm optimization method for maximum annual savings. In their paper, the author presents an approach using the Fuzzy and Particle Swarm Optimization method for the capacitor placement on the primary feeders to reduce loss and improve voltage profile. The author uses the Fuzzy technique in the first stage to find capacitor location, and the Particle Swarm Optimization is used in the second stage to see the capacitor sizes. The approach was tested on a 15-bus, 34-bus, and 69-bus system. This method provides a better way of locating capacitor sizes and locations. The Fuzzy logic offers a solution that is easily accessible. The problem with this method is that it is tedious since two ways are used.

Sarfaraz Nawaz et al. in 2018 [26] reported on Power Loss Minimization in Radial Distribution System using Network Reconfiguration and Multiple DG Units. This paper presents an approach to solving real power loss reduction and voltage profile improvement in the distribution system by network reconfiguration and placing distributed generation and capacitor units. A heuristic method is applied to solve the distributed generation problem. Power Voltage Sensitivity Constant (PVSC) is incorporated with real power loss and the system's voltage. The method is tested on a standard IEEE 33-bus distribution network. The approach is less costly and give a better loss percentage because the distributed generation. The disadvantage is that the introduction of a new index makes this method complex.

Chapter 3: Background to the Design

3.1 Introduction

A power system has a load flow that provides a steady-state solution in which parameters like voltage, current, apparent power, reactive power, and losses are found. There are several techniques for performing load flow analysis, including the Gauss-Seidel technique, Newton-Raphson technique, which is the most common to carry out load flow analysis. A modern computer can be used to analyze both methods. Using these methods is mostly based on a typical transmission system's general meshed topology, whereas most distribution systems have a radial structure. Additionally, there is a low R/X ratio in the distribution system, making the system weak. The distribution systems in Ghana have the following features [27].

They contain large number of buses.

i) They are radially structured.

ii) They have multiple phase operations.

iii) They have a high range of reactance and resistance value.

iv) They have unbalanced operations and unbalanced distribution loads.

The effectiveness of an optimization analysis of a distribution system depends on the load flow algorithm because the load flow must run several times. Hence, the load flow algorithm of the distribution system should be robust and time efficient. The method that can find a radial distribution system's load flow solution by using topological characteristics of a distribution network is applied. The use of this method will help to avoid applying a time-consuming Jacobian matrix or admittance matrix.

3.2 Load Flow of Radial Distribution

The method to carry load flow for a distribution system under balanced load conditions using a constant power load model can be accurately analyzed by the proposed load flow algorithm [28]. The load flow algorithm requires the formation of bus-injection to the branch current (BIBC) matrix with 1's and 0's as elements and branch-current to the bus voltage (BCBV) matrix with primitive impedance as elements and distribution load flow (DLF) matrix. The DLF matrix is obtained as a product of BIBC and BCBV matrices [29].

i. Equivalent Current Injection

The distribution system is analyzed using this method which is based on equivalent current injection. The complex power (S_i) at the bus specified, and the corresponding equal current injection at the k-th iteration of the solution is calculated as

$$S_i = \left(P_i + (j \times Qi)\right) where, i = 1, 2, 3 \ldots . N \qquad (3.0)$$

$$I^{K_1} = I^{K_1}\{V^{K_1} + (j \times (I^{K_1} \times V^{K_1}))\} = \frac{\left(P_i + (j \times Qi)\right)}{V^{K_1}} = \frac{\left(P_i + (jQi)\right)}{V^K} \qquad (3.1)$$

Where S_i is the complex power at the i-th bus.

P_i, real power at the i-th bus.

Q_i, reactive power at the i-th bus.

$V_i(K)$, bus voltage at the k-th iteration for i-th bus.

$I_i(K)$, equivalent current injection at the k-th iteration for the i-th bus.

$I(r)$ *and* $I(i)$, real and imaginary parts of the equivalent current injection at the k iteration for the i-th bus.

ii. Formation of the BIBC Matrix

The formation of the bus-injection matrix is explained with the help of a simple six bus radial distribution system as shown below.

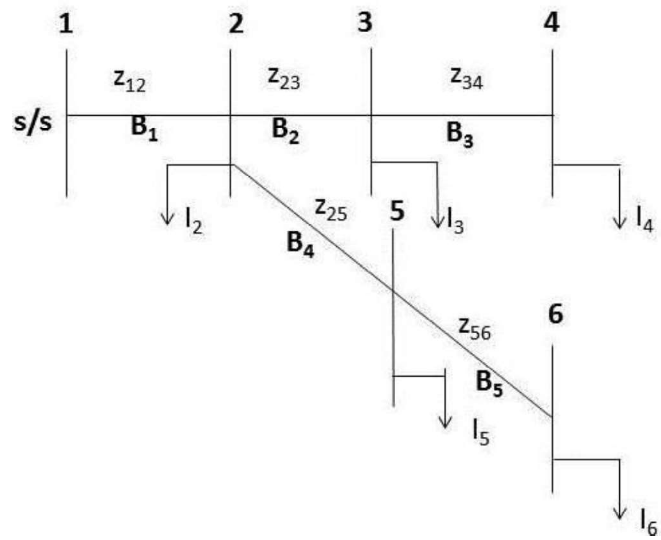

Figure 3.1 - A Typical Distribution System

The power injection at each bus can be converted into equivalent current injections by applying Kirchhoff's current law KCL at each bus. From Fig. 3.1, The branch currents can be formed as a function of the equivalent current injection as given from Eqn (3.2) and Eqn. (3.6)

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \qquad (3.2)$$

$$B_2 = I_3 + I_4 \qquad (3.3)$$

$$B_3 = I_4 \qquad (3.4)$$

$$B_4 = I_5 + I_6 \qquad (3.5)$$

$$B_5 = I_6 \qquad (3.6)$$

From the equations above it can be represented in matrix as

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (3.7)$$

Equation (3.7) in matrix form can be expressed in general form as

$$[B] = [BIBC][I] \quad (3.8)$$

The BIBC matrix has non-zero entries of +1 only.

The algorithm for the BIBC matrix can be developed as follows:

Step 1: For a distribution system with *m*- branch sections and an *n*-bus, the dimension of the *BIBC* matrix is $m \ x \ (n-1)$.

Step 2: If a line section (B_k) is located between Bus *Bus j and i*, copy the column of the *i*-th bus of the *BIBC* matrix to the column of the *j*-th bus and fill *a* + 1 in the position of the *k*-th row and the *j*-th bus column.

This is shown in the figure below:

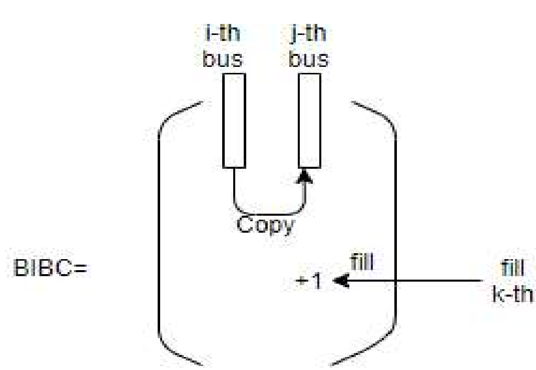

Figure 3.2 Formation of Step Two for BIBC Matrix

Step 3: Repeat Procedure/step (2) until all the line sections are included in the *BIBC* matrix.

NB: The algorithm can be easily expanded to a multi- Phase line section or bus. For example, if the line section between Bus *i* and Bus *j* is a three-phase line section, then the corresponding branch current B_i will be a 3 x1 vector, and the +1 in the *BIBC* matrix will become a 3 x3 identity matrix.

3.2.1 Formation of the BCBV Matrix

The Branch-Current to Bus Voltage simplifies the connection between current and bus voltages. The relationship between the branch current and bus voltages can be obtained from a distribution system by.

$$V_2 = V_1 - B_1 Z_{12} \quad (3.19)$$

$$V_3 = V_2 - B_2 Z_{23} \quad (3.10)$$

$$V_4 = V_3 - B_3 Z_{34} \quad (3.11)$$

$$V_5 = V_2 - B_4 Z_{25} \quad (3.12)$$

$$V_6 = V_5 - B_5 Z_{26} \quad (3.13)$$

Putting (3.10) and (3.11) into (3.13) gives

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (3.14)$$

Similarly, the other bus voltages can be written as

$$V_5 = V_1 - B_1 Z_{12} - C_4 Z_{25} \quad (3.15)$$

$$V_6 = V_1 - B_1 Z_{12} - B_4 Z_{25} - B_5 Z_{56} \quad (3.16)$$

The branch-current to bus voltage matrix can be derived as

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{35} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \text{..............} \quad (3.17)$$

The general form of the above matrix (3.17) can be formed as

$$[V] = [BCBV][B] \qquad (3.18)$$

The BCBV matrix can be formed through the following steps.

Step 1: For a distribution system with *m*- branch sections and an *n*-bus, the di- dimensional of the *BCBV* matrix is $(n-1)$ x m.

Step 2: 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. Its explained in the figure below.

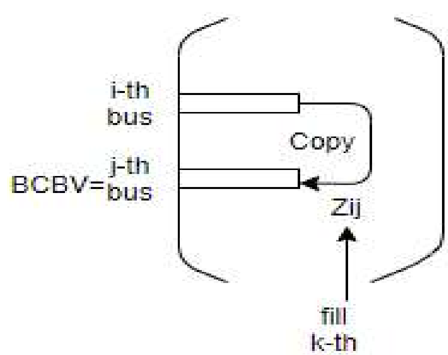

Figure 2.3 Formation of Step Two for BCBV Matrix

Step 3: Repeat Procedure/step (2) until all the line sections are included in the *BCBV* matrix. The algorithm can be expanded to a multi-phase line section or bus easily. For example, if the line section between Bus *i* and Bus *j* is a three-phase line section, then the corresponding branch current B_i will be a 3 x1 vector, and Z_{ij} in the $BCBV$ matrix will be a 3 x 3 impedance matrix.

From above, the building algorithms for the $BIBC$ and $BCBV$ matrices are similar. The only difference is the formation of BIBC matrix and BCBV matrix is that, in BIBC matrix the i-th bus column is copied to the column of the j-th bus and fill with +1 in the k-th column and the j-th bus column, while in BCBV matrix, row of the i-th bus is copied to the row of the j-th bus and fill the line impedance (Zij) in the position of the j-th bus row and the k-th column.

3.2.2 Solution Methodology

The BIBC and BCBV matrices are formed based on the topology of the distribution system. The BIBC matrix finds the relation between bus current injection and branch current. The corresponding variation at the branch current generated by the variation at the current injection buses can be found using the BIBC matrix. The BCBV matrix is also responsible for the relation between the branch current and the branch voltages. The corresponding variation of the of the bus voltages generated by the variation of the current can be found by using the BIBC matrix.

The combination of the BIBC and the BCBV matrices give as the following.

$$[v] = [BCBV][BIBC][I_{node}] \qquad (3.19)$$

$$[DLF] = [BCBV][BIBC] \qquad (3.20)$$

$$[v] = [DLF][I_{node}] \qquad (3.21)$$

The solution for the load flow can be obtained by solving the following equations iteratively which are given below.

$$I^{K_1} = I^{K_1}\{V^{K_1} + (j \times (I^{K_1} \times V^{K_1}))\} = \left\{\frac{(P_i + (j \times Qi))}{V_i}\right\} * \qquad (3.22)$$

$$[v^{k+1}] = [DLF][I^{k}{}_{node}] \quad (3.23)$$

$$[v^{k+1}] = [V^0][v^{k+1}] \quad (3.24)$$

After the tolerance limit is achieved the real power and reactive power losses are calculated using the updated voltages from Eqn (3.25) and Eqn (3.26).

$$P_{real} = \frac{\left\{(P_{eff}^2[j] + Q_{eff}^2[j]) * R[k]\right\}}{V[j]^2} \quad (3.25)$$

$$Q_{reactive} = \frac{\left\{P_{eff}^2[j] + Q_{eff}^2[j]) \times X[k]\right\}}{V[j]^2} \quad (3.26)$$

As compared to Newton Rapson and Guess implicit Z matrix algorithm, which needs LU decomposition and forward/backward substitution of the Jacobian or Y admittance matrix, this formulation uses the DFL matrix to analyze the load flow problem. The LU decomposition and backward/forward substitution are time-consuming as compared to the DFL formulation. This reduces the computation and makes the proposed method suitable for on-line operation.

3.2.3 Algorithm for Distribution Load Flow

Step 1: Start by reading the distribution system data (that is the load and line data)

Step 2: Generate/form the BIBC matrix consisting of 0's and 1's by following the steps given above which the relationship can be expressed as $[B] = [BIBC][I_{node}]$

Step 3: Generate/form the BCBV matrix consisting of primitive impedances by following the steps outlined above and can be expressed as $[v] = [BCBV][B]$

Step 4**:** Create/form the distribution load flow matrix as explained above and the relationship can there for be expressed as

$[v] = [BCBV][BIBC][I_{node}]$ (3.28)

$[DLF] = [BCBV][BIBC]$ (3.29)

$[v] = [DLF][I_{node}]$ (3.30)

Step 5: Compute the nodal currents $[I_{node}]$

Step 6: Set iteration $k = 0$

Step 7: Iteration $k = k + 1$

Step 8: Then Update the voltages by using equations given above.

That is,

$$I^{K_1} = I^{K_1}\{V^{K_1} + (j \times (I^{K_1} \times V^{K_1}))\} = \left\{\frac{(P_i + (j \times Qi))}{V_i}\right\} \quad (3.31)$$

$$[v^{k+1}] = [DLF][I^k{}_{node}] \quad (3.32)$$

$$[v^{k+1}] = [V^0][v^{k+1}] \quad (3.33)$$

Step 9: Test for convergence, if ((|I(k+1)|-|(I(K)|) greater than tolerance) go to step 6 and increase the iteration count else stop

Step 10: Calculate the line flows and losses from the final bus bar voltages from the converged solution.

Step 11: Stop and read your results.

The above algorithm for the direct approach load flow is given in the flow chart below:

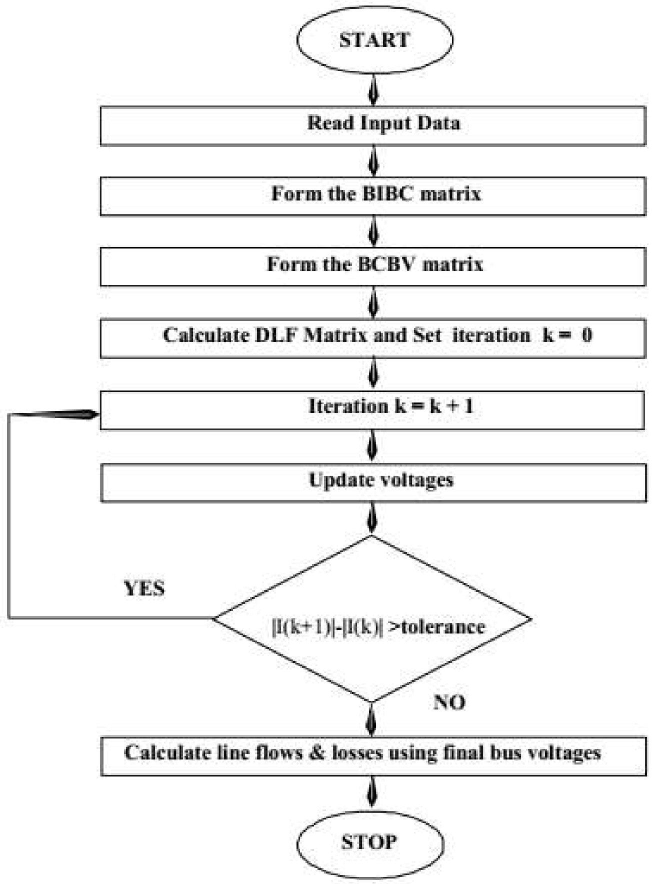

Figure 3.4-Flow Chart for The Load Flow Solution for Radial Distribution System

Using the direct approach method for the load flow for radial distribution system is formulated above. The BIBC matrix is responsible for the variation of the current bus injection and branches current. The BCBV is accountable for the difference between the branch current and the bus voltage. This load flow is based on the multiplication of the two matrices.

Chapter 4: Design Methodology

4.1. Introduction

Distribution losses in the power system have become a significant concern to power companies and consumers because a good amount of energy is lost. Studies have shown that about (65-70) % of power system losses occur in the distribution system while (30-35) % of losses occur in the transmission system [30]. Therefore, power companies have prioritized efficiency at the distribution level, where most of the losses occur [31]. As already mentioned in chapter 2 of this paper, there are many methods to improve the voltage profile in the distribution system.

1. Feeder reconstruction
2. Distributed generation implementation
3. Capacitor placement (i.e. reactive power compensation)

   Among others

Considering the above listed methods, capacitor placement will be used for this project. With capacitor placement, there are two methods. These are series and shunt capacitors for compensation of distribution systems. The series capacitor increases the steady state stability of the line. The shunt capacitor will be considered for this project due to the following reasons [32].

1. Minimize the real and active power of the system.
2. Improve power factor and stability of the system.
3. Improve voltage regulations.

Using the shunt capacitor's optimal location and sizes will helpfully derive the benefit of shunt capacitor installation. The objective function will influence the identification of the optimal location, and sizes for the compensation under consideration.

4.2 The Objective Function

The capacitor placement problem's main objective is to reduce the energy losses for a given period while minimizing the system's capacitors' cost. The objective function consists of two terms. The capacitor's cost is the first term associated with a fixed cost, purchase cost, and operational cost. The second term is the overall cost of the energy losses. The term is calculated by adding up the annual real power losses of the system. The cost function described is a step function, and not a differentiable function since capacitors are practically grouped in bank size. All non-linear optimizations are therefore not applicable since the objective function is non-differentiable.

4.2. 1 Energy Loss Cost (Term One)

Given say I_i is the current of section-i in the time T, then the energy loss in section-i is given by:

$$EL_i = (I_i \times I_i \times R_i \times T) \quad (4.1)$$

Which can also be expressed as

$$P_{loss}(j, j+1) = T \times \left\{ \frac{\left\{ P_{eff}^2[j] + Q_{eff}^2[j]) * R[k] \right\}}{V[j]^2} \right\} \quad (4.2)$$

Hence, the energy loss (EL) in time T of a feeder with n sections can be calculated or found out as

$$E_L = \sum_{i=1}^{n} (EL_i) \quad (4.3)$$

The Energy loss cost (ELC) can be calculated by multiplying equation (4.3) with the energy rate K_e

$$ELC = K_e \times EL_i \quad (4.4)$$

EL_i is the energy loss in section-I in time duration T.

R_i is the resistance of section-i.

T is the time duration.

K_e is the energy rate.

ELC is the energy loss cost.

4.2.2 Capacitor Cost (term two)

The cost of installing capacitor includes purchase, installation, and operational cost of capacitors. Thus, the cost of capacitor is expressed as

$$CC = C_{ci} + \{C_{cv} \times O_{ck}\} \qquad (4.5)$$

Where,

C_{ci} is the constant installation cost of capacitor in $ per node.

O_{ck} is the rating of the capacitor on bus-k in KVAr.

C_{cv} is the rate of the capacitor per KVAr.

The cost function or objective function S is obtained by combining (4.4) and (4.5) which gives.

$$S = ELC + CC$$

$$S = K_e \times \sum_{i=1}^{n}(EL_i) + \sum_{k=1}^{n_{cap}}[C + (C_{cv} \times Q_{ck})] \qquad (4.6)$$

Where S is the cost function for minimization

By minimizing the cost function, the net saving due to reduction of energy losses for a given period include the cost of capacitors is given below.

$$Net\ Saving = \left[ELC_{without\ capacitor} - ELC_{with\ capacitor}\right] - CC \qquad (4.7)$$

$$AC = [ELC_{without\ capacitor} - ELC_{with\ capacitor}] \quad (4.8)$$

AC is the benefit due to energy loss reduction.

$ELC_{without\ capacitor}$ is the energy loss cost without capacitor.

$ELC_{with\ capacitor}$ is the energy loss cost with capacitor.

CC is the total capacitors cost expressed in

4.3 Loss Sensitivity Factor and Candidate Bus Selection

In identifying the optimal location for capacitors' placement, the loss sensitivity factor is applied [33]. We can predict which of the busses will significantly reduce when a capacitor is placed at those busses with the loss sensitivity factor. Hence, the sensitive busses will be where the capacitor will be placed. This will help us to reduce the search for space for the optimization problem. Few busses will be selected for candidate busses for the compensation, also decreasing the capacitor cost. For further analysis, consider a distribution line with impedance R +jX and a load of P_{eff} +jQ_{eff} connected between 'i' and 'j' buses as shown below.

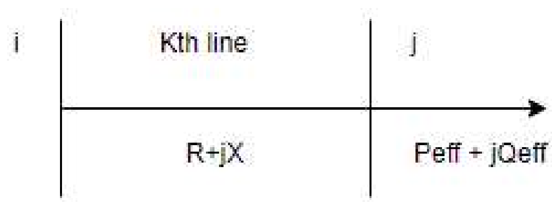

Figure 4.5 A Typical Distribution Line Consisting of Impedance and A Load.

The real power loss in the line in Fig. 4.5 is given by [I_k^2] * [R_k], which can also be expressed as in Eqn (3.25)

Similarly, the reactive power loss in the K-th line is given from Eqn (3.26).

Where,

$P_{eff}[j]$ = Total effective active power supplied beyond the bus 'j'

$Q_{eff}[j]$ = Total effective reactive power supplied beyond the bus 'j'

Now one can calculate the loss sensitivity factors as

$$\frac{\partial P_{loss}}{\partial Q_{eff}} = \frac{(2*Q_{eff}[j])*R[k]}{V[j]^2} \quad (4.11)$$

$$\frac{\partial Q_{loss}}{\partial Q_{eff}} = \frac{(2*Q_{eff}[j])*X[k]}{V[j]^2} \quad (4.12)$$

4.3.1 Using Loss sensitivity Factors for Candidate Bus Selection

The Loss Sensitivity Factor $\frac{\partial P_{loss}}{\partial Q_{eff}}$ is calculated from the base caseload flow. The values of the loss sensitivity factor are arranged in descending order and matched with the bus numbers are stored in bus position 'bpos [i]' vector. The descending order of the loss sensitivity factor elements of bpos[i] vector will determine way the busses will be considered for compensation. The base case voltage magnitude is determined for the bpos[i] is calculated by

$$Norm[i] = \frac{[V[i]]}{0.95} \quad (4.13)$$

Where V[i] is the base voltages of the corresponding bus.

Where Norm [i] decides whether the busses need reactive compensation or not.

The buses whose Norm [i] value is less than 1.01 are chosen as the candidate buses for the capacitor compensation. The "candidate bus" vector is is used to store the selected candidate buses. In determining the potential buses using the loss sensitivity factor, the following steps are performed to select potential busses for reactive power compensation.

Step 1: Calculate the Loss Sensitivity Factor at the buses of distribution system using.

Step 2: Arrange the value of Loss Sensitivity Factor in descending order. Also store the respective buses into bus position vector bpos[i].

Step 3: Calculate the normalized voltage magnitude Norm [i] of the buses of using.

Step 4: The buses whose Norm [i] is less than 1.01 are selected as candidate buses for capacitor placement.

4.3.2 Using Genetic Algorithm for Capacitor Allocation

The development of the proposed algorithm for identifying the sizes of capacitors to be positioned at various candidate buses for loss minimization in HVDS is based on the genetic algorithm. A genetic algorithm is an iterative process that starts with an initial population where a randomly set of solutions is generated. The objective function and the fitness value are computed for each of the population set. A pool of selected populations is formed based on the fitness function, making the new solution have a better fitness function than the initial. The addition of crossover and mutation operators helps generate new solutions with the aid of the new solution pool. While iterating the process, a fixed number of solutions is maintained in the pool of the selected population. The solution becomes better upon iteration for the optimal solution. In the iterative process, suitable candidates are more likely to be selected, while bad candidates might not be chosen.

Crossover happens next after reproduction. Crossover happened when proper encoding methods are applied. Crossover works with the selected genes/candidates form two-parent chromosomes which are used to create new offspring/ candidates. In performing crossover, the simplest method is to choose a crossover point between two parents. The parents are selected randomly from a pool of populations chosen using the selection procedure. Crossover produces two offspring, which some basic properties of the parent. The third operator is mutation where off springs are generated using a randomly solution from the pool. The newly formed solution is evaluated by finding the objective and the fitness function. The population and the newly created offspring are combined through a selection-by-selection operators. The following steps gives an algorithmic flow of the description above.

Step 1: Randomly generate initial population strings of n chromosomes.

Step 2: Compute/calculate the fitness value for each string/chromosones in the generated population.

Step 3: Create the new population, based on the fitness function.

Step 4: Generate/ create off springs using the cross over operator (Recombination)

Step 5: Generate/create off springs using the mutation operator (mutate chromosomes)

Step 6: Evaluate the off springs and calculate the fitness value for each solution.

Step 7: If the search goal is obtained, or an allowable generation is obtained, return the best chromosome as the solution else go to step three and start the process all over .

Step 8: If search goal is attained replace old with new population and new generation.

Below is a flow chart showing the procedure of genetic algorithm as explained above:

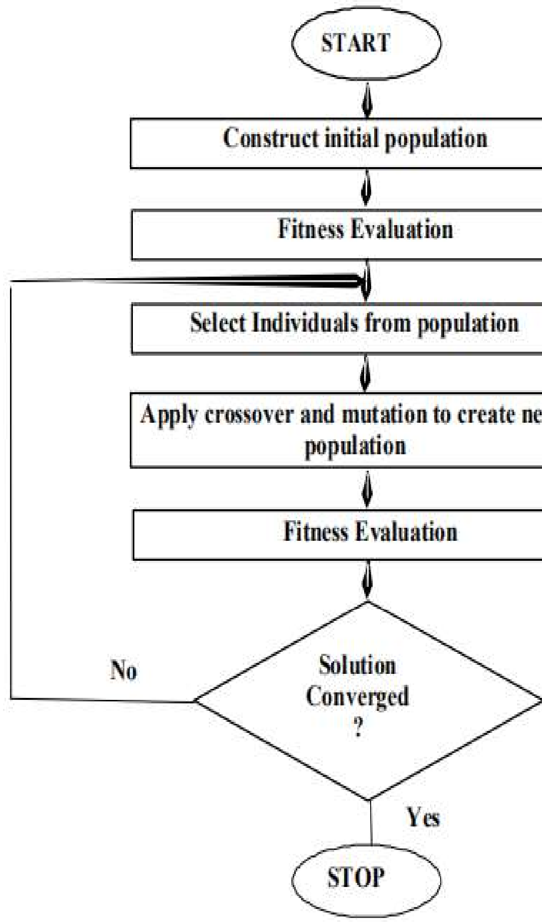

Figure 4.3 Flow Chart of Genetic Algorithm

4.3.3 Coding Scheme

In this part the coding scheme for the 33-bus radial system has been explained below. The base caseload flow was determined at the beginning using the direct approach load flow technique explained in the earlier chapters. This is followed by the identification of candidates buses for shunt compensation using loss sensitivity factor which are preserved. After the identification of these buses, the sizing is done using genetic algorithm. The allowable range is from 10 kVAr to 50 kVAr using the IEEE standards.

4.3.4 Initialization and Fitness Function

Initialization is like reproduction which is the generation of initial population (chromosomes). The initial population is generated randomly which is the capacitor sizes to be installed at the buses location for loss reduction. The population size determines the affects the efficiency of the algorithm. After initial population of the needed sizes, the selected load flow must run to evaluate the objective function S and the fitness function F(x) which is calculated as

$$S = K_e \times \sum_{i=1}^{n}(ELI) + \sum_{k=1}^{n_{cap}} C + (C_{cv} \times Q_{ck}) \quad (4.14)$$

$$F(x) = \frac{1}{s+1} \quad (4.15)$$

The load flow, objective function and fitness function is calculated again for all strings of the population. In the shunt capacitor placement problem, the objective function is the minimization of the cost function.

4.3.5 Reproduction

Reproduction is the first stage of the genetic algorithm operator. It determines which string in the present population will be used to generate new population. This is done using a biased random selection method. The parents are randomly selected initial population where the best strings in the population have more chances of being selected. The Boltman selection, rank selection and roulette wheel selection can be used to achieve this. The solution with higher fitness value has is the most probable to be selected into mating pool and contribution to one or more off-spring to the next generation. The procedure which is used is the roulette wheel selection process [34].

Step 1: Sum the fitness of all population (chromosomes), and call it as total fitness.

Step 2: Generate a random number between zero and the total fitness value.

Step 3: Choose a population number whose cumulative fitness obtained from adding its fitness to the fitness of the proceeding population members is greater than or equal to the random number generated previously.

4.3.6 Crossover

During crossover two selected parents are used to produce two off-spring who bear some useful characteristics of the parent and expected to be more fit than the parent. Crossover can be performed using techniques like single point crossover or the uniform cross over arrangements. The single point crossover is applied in this paper. In the single point crossover, assume parent1 and parent2 the are the parent selected randomly for crossover. The strings of parent1 and parent2 as shown below and the crossover site is selected as an integer.

$$Parent_1 = \{100 \quad 300 \quad 700 \quad 400 \quad 600\}$$

$$Parent_2 = \{400 \quad 600 \quad 900 \quad 100 \quad 300\}$$

The five strings taken is for illustration but depending on the number of candidate buses selected for compensation will determine the length of the string. So let the crossover point be the 2nd position where the offspring that is child1 and child2 are produced.

$$Child_1 = \{100 \quad 300 \quad 900 \quad 100 \quad 300\}$$

$$Child_2 = \{400 \quad 600 \quad 700 \quad 400 \quad 600\}$$

As illustrated above each crossover resulted in two children. In attempt to control crossover the parameters used is the cross over probability (P_c). The crossover probability is used to decide the variable before performing crossover. Crossover probability normally lies in the range of 0.7 - 1. The following step are followed for crossover to be achieved.

Step 1: Select two parents randomly from the initial population.

Step 2: Generate a random number between 0 and 1.

Step 3: Chose/set a cross over probability.

Step 4: If the randomly generated number is greater than the cross over probability, child1 and child2 are directly selected as parent one and two. This step is almost equivalent to the case of crossover where crossover site is equal to the string length.

Step 5: If the randomly generated number is less than cross over probability, then crossover takes place.

3.5.5 Mutation

The mutation is applied to create new genetic material in the population to maintain diversity with the people. It is used to randomly alternate the capacitor sizes. An illustration of mutation is shown below.

Make mutation site to be the 3rd position of the string.

$$Original\ offspring\ = \{100 \quad 200 \quad 400 \quad 700 \quad 900\}$$

$$Sting\ after\ mutation\ = \{100 \quad 200 \quad 430 \quad 700 \quad 900\}$$

After the mutation site, as shown above, a random value is generated from 100 to 1000 is placed at the mutation site. The mutation probability lies in the range of 0.0001 to 0.01. Below are the steps to perform mutation.

Step 1: Generate a random number between zero and one.

Step 2: Set a mutation probability.

Step 3**:** If the randomly generated number is less than the mutation probability Pm then mutation is performed on the off springs generated by crossover.

4.6 Algorithm for Capacitor Placement

The general procedure for loss sensitivity factor and the genetic algorithm used for capacitor placement problem as elaborated in the previous chapter. Below is a series of procedures outlined to solve the capacitor problem.

Step 1: Read the distribution load and line data.

Step 2: Run the load flow as explained above to find out the voltage magnitudes at the various buses and the total power loss in the system.

Step 3: Select the candidate buses by using sensitivity analysis as explained in previous chapters.

Step 4: Set GEN = 0

Step 5: Form the initial population of real numbers which is randomly selected value of capacitors to installed at the candidate buses for shunt capacitor compensation.

Step 6: Update the reactive power at the respective candidate buses.

Step 7: Run the load flow of the distribution system again with the updated reactive power at the candidate buses for each population.

Step 8: Calculate the total energy loss cost and the capacitor cost for each population as explained in the previous chapter.

Step 9: For each of the populations calculate the objective function and the fitness value, the objective function for each population is the total energy loss cost and the capacitor cost is give and explained in previous chapters.

Step 10: GEN = GEN + 1

Step 11: Select the solutions in the pool from the previous population by using the roulette wheel selection procedure/technique.

Step 12: Perform crossover on the solutions, which are randomly selected from the pool as explained above and generate two offspring.

Step 13: Perform mutation on the off springs generated by crossover operation as explained in subsequent chapter and produce offspring.

Step 14: Calculate the energy loss cost and the capacitor cost and evaluate the objective and the fitness function of each of the off springs.

Step 15: Put the solutions of the pool and the offspring's together and refer to them as the new population.

Step 16: Replace initial population with new population for next generation.

Step 17: Go to step 10 and repeat the process until the solution converges.

Step 18: Stop.

The above steps for capacitor placement shown in a flow chart below:

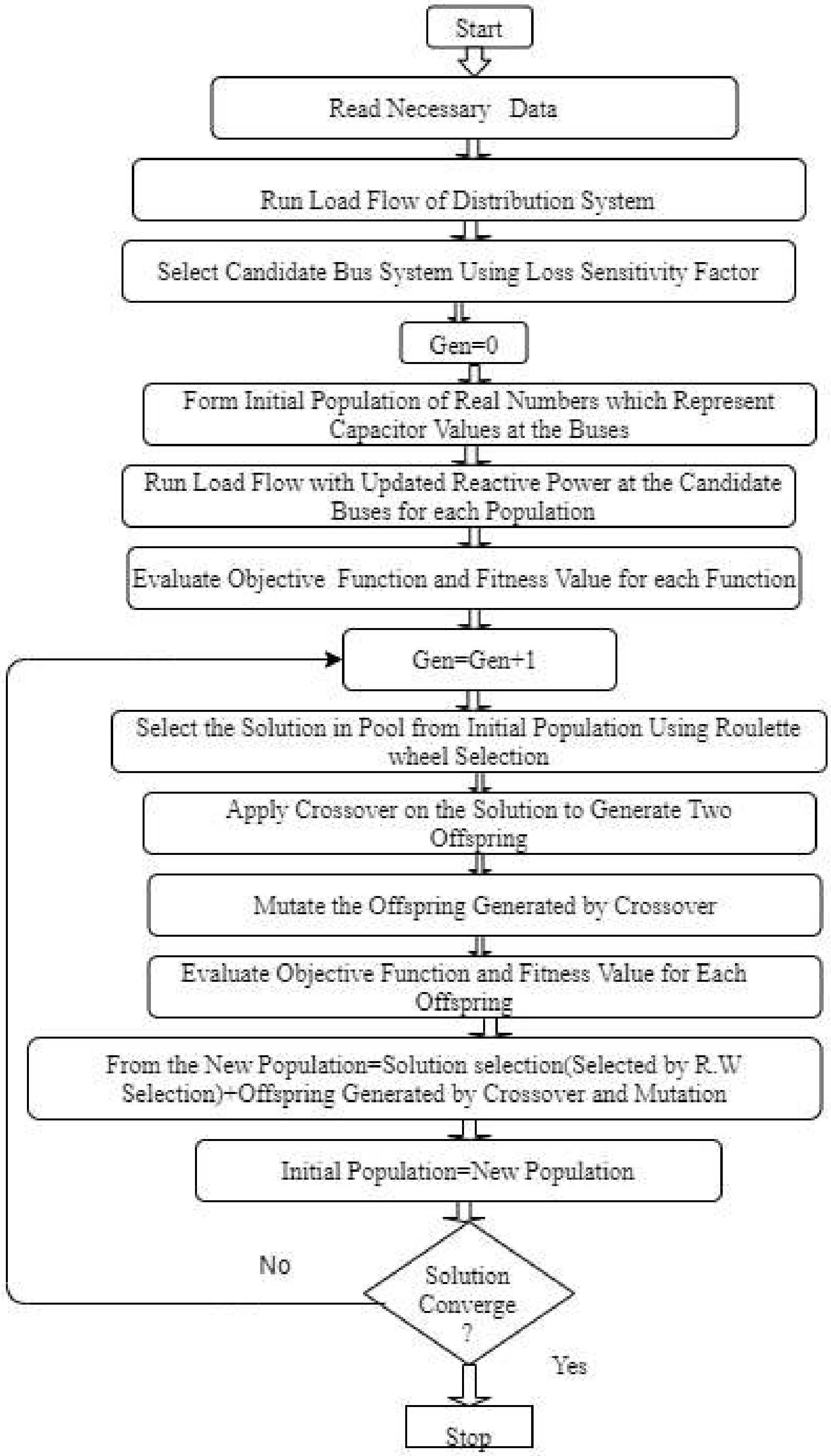

Figure 4.7 Flow Chart of Capacitor Placement Problem (Solution) In RDS

The loss sensitivity factor analysis and the genetic algorithm for such capacitor compensation in a radial distribution system have been duly discussed. The application of the loss sensitivity factor determines the candidate busses for capacitor placement, and the genetic algorithm is used to show the capacitor sizes to be installed at the candidate busses for loss minimization.

Chapter 5: Results and Discussion

5.1 Introduction

This chapter will analyze the results obtained after the implementation of the algorithms in chapter four. All algorithms are developed in the MATLAB environment. A 33-bus radial distribution system with lateral branches is considered using the described methods in chapter four. An 11 kV feeder is considered in the distribution system. The node numbers and the appropriate reactive and actual power loads are given in Appendix B. The loss sensitivity factor discussed in chapter four is used to selected potential buses. Different numbers of candidate buses are selected among the possible buses. The efficiency of the compensation is analyzed for annual savings.

The following are the control parameters used for the simulation.

Population size = 50

Crossover probability = Pc=0.7

Mutation Probability = Pm=0.003

Capacitor size boundary = $10<Qc<50$

gmax=1000 Maximum number of

Iterations

Energy rate for High Voltage= 0.834562 GH₵/kWh, according to Public Utilities Regulatory Commission for 2021 Electricity tariffs [35].

String length = 6

Number of strings generated = 20

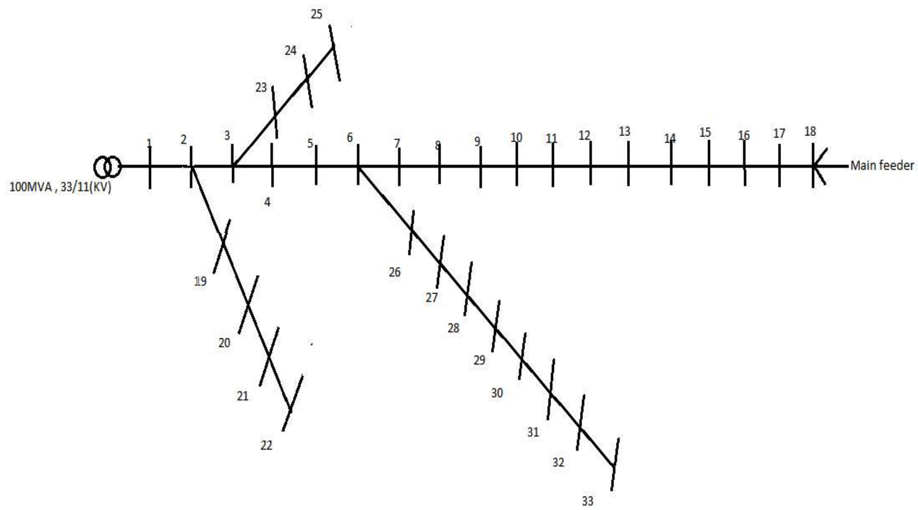

Figure 5.1 Layout of the 33-Bus Radial Distribution System with Lateral Branches

5.2 Results of Loss sensitivity Factor for Bus Selection

The busses are selected and arranged in decreasing order of loss sensitivity factor. The potential buses which were selected upon using the loss sensitivity factor were [12, 13,11, 10, 15, 16, 17]. With this, the capacitor sizes are taken in discrete values. The allowable range for capacitor is 10 -50 kVAr according to IEEE standard. The six buses with the highest loss sensitivity values are selected as the candidate buses and the capacitor sizes are now determined using a genetic algorithm to reduce the losses. A comparison will be made between the losses with and without capacitors. X (1), X (2), X(3) (X4), X (5), and X (6) are the capacitors to be put across candidate buses. Their values vary from 10-50 (u farad) in the genetic algorithm discussed in chapter four. For each combination, the program calculates the fitness function's value, which is the loss with capacitor and without capacitors. The values selected are those values with minimum loss as shown in table 5.3 and 5.4.

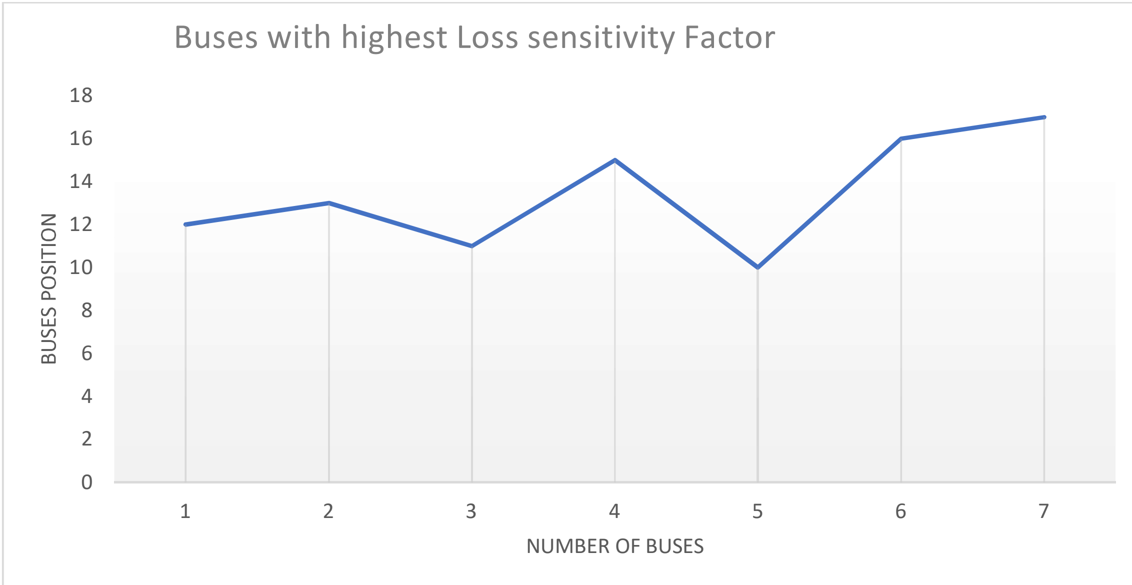

Figure 5.2 Graph of buses with the highest loss sensitivity factor

5.3 Results of Load Flow Analysis

The results Table 5.1 for the voltage and their angles were obtained from the 33-line data in Appendix A and load data in Appendix B. The real and reactive power and impendence are known, hence the voltages and currents with their angles can be calculated. The currents and their angles in Table 5.2 are calculated using the impedances and the power. The change in voltage is also calculated by multiplying DLF and current in kilowatts. The abs values of the voltages are taken in consideration by substituting the change in voltage from the base voltage.

Table 5.1 Base Caseload flow of 33-bus RDS without Capacitor

Bus Number	Voltage magnitude in kV	Angle in degrees
1	11	0
2	10.956	0.00032613
3	10.739	0.0023414
4	10.609	0.003903
5	10.477	0.0055895
6	10.157	0.002262
7	10.105	-0.0033452
8	9.8698	-0.0074739
9	9.7569	-0.0095452
10	9.672	-0.011152
11	9.6595	-0.010985
12	9.6382	-0.010665
13	9.5488	-0.012735
14	9.5157	-0.014579
15	9.4898	-0.015475
16	9.4727	-0.01615
17	9.449	-0.017881
18	9.4431	-0.018103
19	10.948	7.52E-05
20	10.896	-0.0014788
21	10.885	-0.0019286
22	10.876	-0.0024016
23	10.705	0.0018723
24	10.645	0.00066885
25	10.597	-0.00035293
26	10.119	0.0031969
27	10.08	0.0045551
28	9.9055	0.0064479
29	0.0064479	0.0082278
30	9.722	0.01089
31	9.5875	0.013156
32	9.5694	0.012312
33	9.5564	0.011467

Table 5.2 Node Currents of the 33-bus RDS without Capacitor Placement

Bus number	Current magnitude in kA	Angle in degrees
1	0	0
2	10.859	-0.53808
3	9.2837	-0.41432
4	13.766	-0.58241
5	6.6044	-0.46139
6	6.2588	-0.3251
7	22.656	-0.47112
8	22.918	-0.47319
9	6.539	-0.3329
10	6.5475	-0.33274
11	5.6114	-0.59867
12	7.2745	-0.54081
13	7.2997	-0.54265
14	15.198	-0.60348
15	6.4214	-0.1813
16	6.6934	-0.33963
17	6.6975	-0.33985
18	8.9961	-0.41815
19	9.0393	-0.4197
20	9.0478	-0.42015
21	9.0556	-0.42063
22	9.2	-0.41635
23	9.6715	-0.50643
24	43.9	-0.44477
25	45.973	-0.44122
26	6.4486	-0.39024
27	6.562	-0.38834
28	6.4664	-0.31352
29	14.29	-0.51718
30	65.966	-1.2359
31	17.298	-0.42432
32	24.339	-0.43295

Minimum bus voltage = 9.4431 kV obtained from Table 5.1

The losses are obtained from the impendences from Appendix A, currents in Table 5.2 and the voltages obtained in Table 5.1 to obtain the total real power and reactive losses.

Real power loss = 928.9 kW

Reactive power loss = 818.72 kVAr

Energy loss Cost = Real Power Losses x Energy rate

$$\text{Energy Loses Cost} \;=\; 928.9\text{ kW x }0.834562\,\frac{GH₵}{\text{kWh}} = \;GH₵\;775.224\;/\text{h}$$

This means that with 928.9 kW of power loss the company losses an amount of GH₵ 775.22 in an hour.

5.4 Results of Genetic Algorithm for Capacitor Placement, and Sizes

Table 5.3 is the combination (string) of capacitors that are used to minimize losses. This was obtained using the candidate buses corresponding to their various losses calculated using the genetic algorithm approach from Figure 4.4 in chapter four. From this string the best combination of string is chosen as the best capacitor combination as shown in Table 5.4.

Table 5.3 Comparison of losses with and without capacitors: Genetic Algorithm output

X (1)	X (2)	X (3)	X (4)	X (5	X (6)	Losses without capacitor	Losses with capacitors
47	23	16	49	33	43	928.9	918.2
41	38	18	37	33	39	928.9	917.2
25	35	21	25	31	18	928.9	918.1
18	40	28	38	41	50	928.9	917.4
48	18	26	48	37	47	928.9	917.3
18	37	20	23	38	35	928.9	918.3
36	48	26	32	45	41	928.9	916.3
15	18	19	32	44	16	928.9	950.1
48	42	17	20	43	16	928.9	917.9

35	30	45	29	35	11	928.9	915.8
22	33	29	29	37	37	928.9	917
33	17	21	43	11	18	928.9	919.2
30	20	23	39	28	19	928.9	918.2
22	22	41	44	38	20	928.9	789.3
38	49	13	18	22	31	928.9	917.9
16	17	26	28	33	30	928.9	918.7
20	36	25	35	21	14	928.9	932.3
48	14	30	47	36	34	928.9	917.2
38	35	30	49	22	25	928.9	804.7
34	22	23	29	42	16	928.9	918.1

Table 5.4 Optimal Capacitor Placement Results

X (1)	X (2)	X (3)	X (4)	X (5)	X (6)	Losses without capacitor	Losses with Capacitor
22	22	41	44	38	20	928.9	789.3

After the loss sensitivity factor has selected the candidate buses, the capacitor sizes are determined by genetic algorithm and places at the selected positions as shown in Table 5.5

and Figure 5.2. The optimally placed capacitors have lower losses as shown in Figure 5.3.

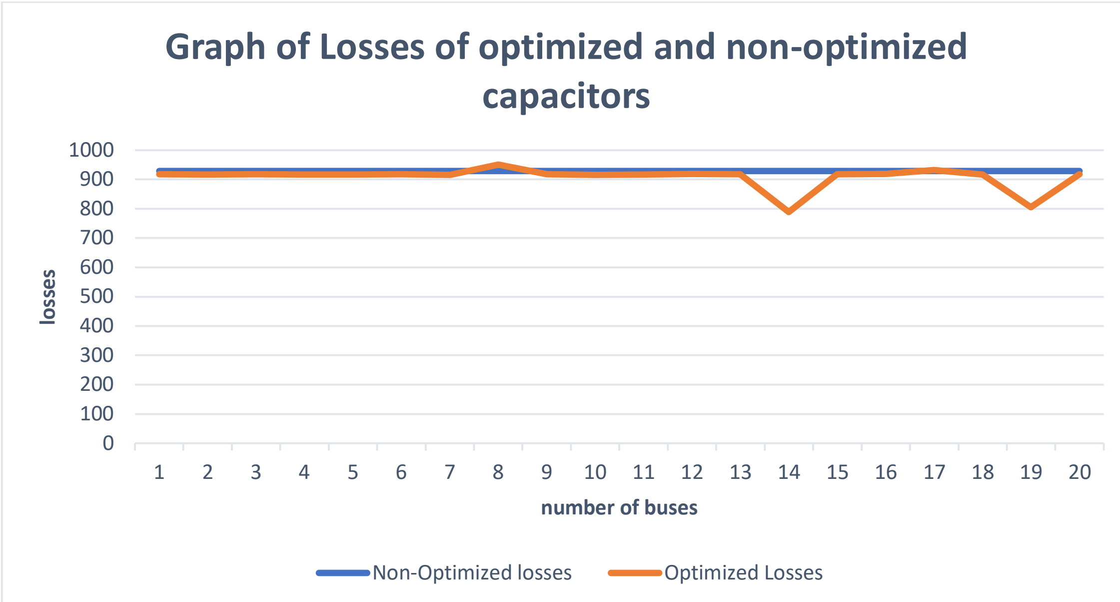

Figure 5.3 Graph of Losses of optimized and non-optimized capacitors

Table 5.5 Load flow solution of RDS (with capacitors placed at their candidate buses)

Bus number	Voltage magnitude in kV	Angle in degrees	Capacitor Value Q kVAr
1	11	0	0
2	10.957	0.00017039	0
3	10.746	0.0013311	0
4	10.62	0.0022366	0
5	10.493	0.003222	0
6	10.189	-0.0016137	0
7	10.15	-0.0075066	0

8	9.9419	-0.014963	0
9	9.8452	-0.019095	0
10	9.7765	-0.022822	0
11	9.7655	-0.023069	22
12	9.747	-0.023541	22
13	9.6825	-0.028657	41
14	9.6623	-0.031414	44
15	9.6435	-0.033063	38
16	9.6321	-0.03448	20
17	9.6193	-0.036973	0
18	9.615	-0.037377	0
19	10.949	-8.05E-05	0
20	10.897	-0.0016342	0
21	10.886	-0.0020839	0
22	10.877	-0.0025568	0
23	10.712	0.00086264	0
24	10.653	-0.00033922	0

25	10.604	-0.0013596	0
26	10.151	-0.00068489	0
27	10.112	0.00066443	0
28	9.9384	0.002545	0
29	9.8141	0.004313	0
30	9.7556	0.0069569	0
31	9.6216	0.009207	0
32	9.6035	0.0083686	0

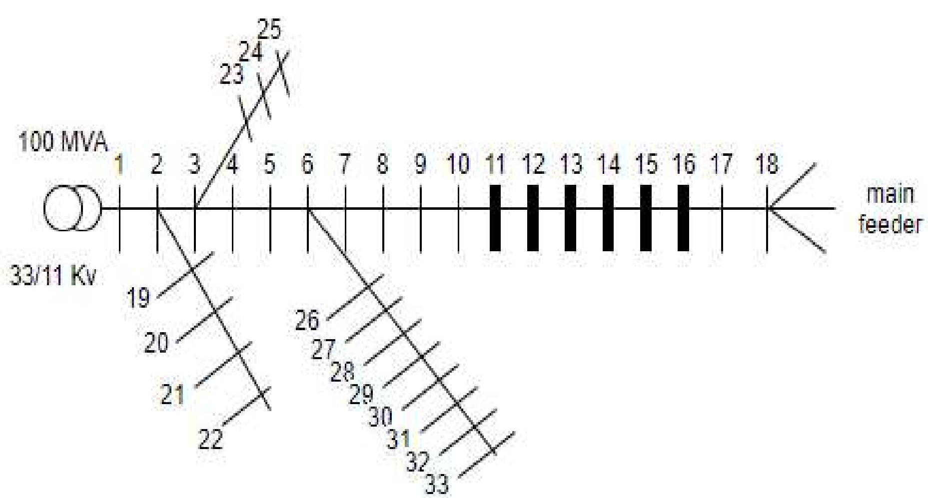

Figure 5.4 Layout of a 33-bus radial distribution system with optimally placed capacitors

The final real and minimum voltages are now calculated after the capacitor placement has been done as indicated in Table 5.5 and Figure 5.2

Real power loss = 789.3 kW

Minimum voltage = 9.5905 kV

The initial Real power loss = 928.9 kW and final Real power loss = 789.3 kW

Net power savings = $928.9 - 789.3 = 139.6\ kW$

The initial Minimum bus voltage = 9.4431 kV and final Minimum voltage = 9.5905 kV

Net voltage improvement $= 9.5905 - 9.4431 = 0.1474\ kV$

Energy loss Cost = Real Power Losses x Energy rate

$$\text{Energy Loses Cost} = 789.3\text{ kW x }0.834562\frac{GH₵}{\text{kWh}} = GH₵\,658.72/\text{h}$$

$$\text{Net energy cost saving} = GH₵\,775.224 - GH₵\,658.72 = GH₵166.50/\text{h}$$

It can be observed that after placing the suitable capacitor sizes at the candidate buses, there is a significant loss reduction of 139.6 kW and an improvement of voltage at the various buses and thus an improvement in the voltage profile by 0.147 kV. The company saves an amount of $GH₵$ 166.50 per hour.

Chapter 6: Conclusion, Limitation and Future Work

6.1 Conclusion

With reduced technical losses in the distribution system, utility providers will obtain enough revenue for future expansion. This will ensure the security and reliability of supply. Therefore, this project presents a technique for minimizing the power losses in the flow of reactive power in the distribution system by using shunt capacitor compensation at some specific locations in the network. This is to achieve maximum loss reduction and annual savings. This method is applied to 1 single-phase 11 kV 50 HZ radial distribution system. Heuristic techniques are used to analyse both the optimal placement of capacitors and the distribution system ratings. To achieve this, the solution is examined as a set of critical nodes termed candidate buses. The candidate buses are chosen based on the losses that occur in the system by the reactive component of the load current using sensitivity analysis. The capacitor banks are then installed at the candidate buses to achieve minimization in the distribution system. From the study, the following conclusion is made. The algorithm's implementation involves selecting capacitors' locations for different numbers of candidate buses and different capacitor sizes. Hence there is a general increase in voltage profile and loss reduction.

6.2 Limitations

As the project progresses, data from Volta River Authority were needed and this took a long time to get the data. This slowed down the project because the data was needed to test the code and improve on the efficiency of the code. Most of the information such as capacitor installation cost could not be obtained while time was fast moving. Also, the time taken to learn the concept of genetic algorithm took a while and caused the project to slow down. All these limitations prevented the possibility of further analysis such as capacitor cost.

6.3 Future Work

Upon completing this project, it opens an avenue for work in many other related areas. Some areas which could be considered for future works include:

1. This same project could be extended to the 69-bus system and any other bus system.
2. This project considered a balanced distribution system. The capacitor allocation can be extended to the unbalanced distribution system.

Reference

[1] Maximum losses for distribution, power, and dry-type transformers. (1994). Rexdale, Ont.: Canadian Standards Association.

[2] Montano, J. C., Salmeron, P., & Prieto, J. (2005). Cable losses resulted of instantaneous compensation with shunt active power filters. *2005 IEEE Russia Power Tech*. doi:10.1109/ptc.2005.4524615

[3] Lakervi, E., & Holmes, E. J. (1995). *Electricity distribution network design*. London: P. Peregrinus on behalf of the Institution of Electrical Engineers.

[4] Pansini, A. J. (2005). *Guide to electrical power distribution systems*. Lilburn, Géorgie: Boca Raton. Flor.

[5] Burkhardt, F., & Persnger, M. (1980). Economic evaluation of losses to electric power Utilities caused by ash fouling. final technical report, November 1, 1979-April 30, 1980. doi:10.2172/6563408

[6] Berrah, N. (2007). *Sustainable energy in China: The closing window of opportunity*. Washington, DC: World Bank.

[7] Zhang, J., Adu, D., Fang, Y., Antwi, E. O., & Kyekyeku, S. O. (2018). Renewable energy situation in Ghana and future prospect. *Journal of Clean Energy Technologies, 6*(4), 284-288. doi:10.18178/jocet.2018.6.4.475

[8] Distribution system and distributed energy resources. (2017). *Modernizing America's Electricity Infrastructure*. doi:10.7551/mitpress/11045.003.0018

[9] Ghana Energy Situation - energypedia.info. (n.d.). Retrieved September 16, 2019, from https://energypedia.info/wiki/Ghana_Energy_Situation.

[10] How to improve power system reliability in Ghana. (2016). *International Journal of Science and Research (IJSR), 5*(5), 1341-1345. doi:10.21275/v5i5.nov163607

[11] Turkson, J. K. (1999). *Power sector reform in Sub-Saharan Africa*. New York: St. Martin's Press.

[12] Black, M., Mcdonald, S., & Nicholson, M. (2009). Using strategic models in electricity distribution investment planning. *IET Conference Publications*. doi:10.1049/cp.2009.0816

[13] Das. (n.d.). Feeder reconfiguration for loss reduction. *Power Distribution Automation,* 127-151. doi:10.1049/pbpo075e_ch5.

[14] Distribution feeder reconfiguration for service restoration and load balancing. (2009). *Power System Restoration*. doi:10.1109/9780470545607.ch86

[15] Distributed generation: Understanding issues and barriers. (2011). In *Distributed generation: Understanding issues and barriers*. Melbourne: Victorian Government Department of Sustainability and Environment.

[16] Yasin, A. A. (2000). *Optimal capacitor placement in distribution systems using heuristic techniques*. Ann Arbor, MI: UMI.

[17] Ng, W. Y. (n.d.). Application of optimization-based methods in control system design. *System Modelling and Optimization,* 52-59. doi:10.1007/bfb0042773

[18] Wood, A. J. (1976). *Application of optimization methods in power system engineering*. Piscataway, NJ: IEEE Service Centre.

[19] Goyal, N. and Singh, P., 2014. Optimal Placement of Capacitors in Radial Distribution System to Minimizes the Losses at Variable Load Levels. *International Journal on Recent and Innovation Trends in Computing and Communication*, *2*(8), pp.2246-2249.

[20] Zayandehroodi, Hadi, Moslem Amirinejad, Hamzeh Afzalynia and Ali Abdul-Elah Noori. "sParticle Swarm Optimization Algorithm for Optimal Capacitor Placement on Electric Power Distribution Networks." (2014).

[21] Siddiqui, A.S. and Rahman, F., 2012. Optimal capacitor placement to reduce losses in distribution system. *Wseas Transactions On Power Systems*, *7*(1), pp.12-17.

[22] Gnanasekaran, N., Chandramohan, S., Kumar, P.S. and Imran, A.M., 2016. Optimal placement of capacitors in radial distribution system using shark smell optimization algorithm. *Ain Shams Engineering Journal*, *7*(2), pp.907-916.

[23] Mahela, O.P., Ola, S.R. and Goyal, L., 2013. Optimal capacitor placement for loss reduction in radial distribution feeder. *IOSR Journal of Electrical and Electronics Engineering*, *4*(6), pp.43-48.

[24] Baysal, Yesim A. and Ismail H. Altas. "Power Quality Improvement Via Optimal Capacitor Placement In Electrical Distribution Systems Using Symbiotic Organisms Search Algorithm." (2017).

[25] Reddy, M. Damodar and V. C. Veera Reddy. "Capacitor Placement Using Fuzzy And Particle Swarm Optimization Method For Maximum Annual Savings." (2008).

[26] Nawaz, Sarfaraz & Singh, Sonali & Awasthi, Supriya. (2018). Power Loss Minimization in Radial Distribution System using Network Reconfiguration and Multiple DG Units. European Journal of Scientific Research. 148. 474-483.

[27] Distribution system and distributed energy resources. (2017). *Modernizing America's Electricity Infrastructure*. doi:10.7551/mitpress/11045.003.0018.

[28] Ekwue, A., & Macqueen, J. (1991). Comparison of load flow solution methods. *Electric Power Systems Research, 22*(3), 213-222. doi:10.1016/0378-7796(91)90008-b

[29] Teng, J.H., 2003. A direct approach for distribution system load flow solutions. *IEEE Transactions on power delivery*, *18*(3), pp.882-887.

[30] Electric power transmission and distribution (t&d) losses. (2014). doi:10.1787/eco_surveys-ind-2014-graph35-en

[31] Li, S., Wang, X., Han, X., & Ge, L. (2014). Analysis on losses of distribution network and countermeasures to reduce losses. *Advances in Communication Technology and Systems*. doi:10.2495/iccts140811

[32] Sallam, A.A., Desouky, M. and Desouky, H., 1994. Shunt capacitor effect on electrical distribution system reliability. *IEEE transactions on reliability*, *43*(1), pp.170-176.

[33] Reddy, P. and Prasad, D., 2013. Application of Loss Sensitivity Factor and Genetic Algorithm for Capacitor placement for Minimum Loss in radial distribution system. *International Journal of Engineering Sciences & Research Technology*, *9*, pp.2400-2403.

[34] Pencheva, T., Atanassov, K. and Shannon, A., 2009. Modelling of a roulette wheel selection operator in genetic algorithms using generalized nets. *Int. J. Bioautomation*, *13*(4), pp.257-264.

[35] Public utilities Regulatory Commission. (n.d.). Retrieved April 16, 2021, from https://www.ghanayello.com/company/26794/Public_Utilities_Regulatory_Commission.

Appendix

Appendix A: Line data for 33 bus radial distribution system

Branch Number	Sending end bus	Recieving end bus	Branch resistance (Ω)	Branch reactance (Ω)
1	1	2	0.0922	0.0477
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.0300	0.7400
9	9	10	1.0400	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129

14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8980	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630

31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Appendix B: Load data for 33 bus radial distribution system

Bus number	P(kW)	Q(kVAr)
1	0	0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80

15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100

Appendix C: MATLAB Code for the Project

Main Load Flow

```
%clear
clc

ch = input('Specify the bus system \n\n PRESS 6 TO RUN 6_bus system data
\n\n PRESS 33 TO RUN 33 bus sytem data\n');
while ch ~= 6 && ch ~= 33
    fprintf('Invalid Input try again\n');
    ch = input('Enter the bus system no.\n 6. 6_bus system \n 33. 33 bus
sytem\n');
end

switch ch
    case 6
        six_bus_data = importdata('six_bus_data.csv');
        data = six_bus_data.data(:,(2:7));
    case 33
        the = importdata('the_new_33_data.csv');
        data = the.data(:,(2:7));
end
Lower_limit = 0.86; %for per unit values
Upper_limit = 1.01;  %for per unit values

Time_period = 1;
Energy_rate = 0.834562;% Kilowatt hour in GH cedis.
Cci = 200; %constant_installation
Ccv = 3; %rate_of_capacitor
lowerLimit = 10;
upperLimit = 50;
maximum_generation = 20;
population_size = 100;



n_bus = size(data,1);
Base_voltage = (11 +0i)*ones(1,n_bus)';
tolerance = 1.00e-05;

I = zeros(n_bus,1);
initialVoltage = Base_voltage;

buses = [data(:,1) data(:,2)];
BIBC = eye(n_bus);
BCBV = zeros(n_bus);
impedance = [data(:,3) data(:,4)];
BCBV(1) = data(1,3) + 1j*data(1,4);

BIBC = calculate_BIBC(buses,n_bus,BIBC);


csvwrite('BIBC.csv',BIBC);

BCBV = calculate_BCBV(n_bus,impedance,buses,BCBV);
```

```
csvwrite('BCBV.csv',BCBV);

DLF = BCBV*BIBC;

csvwrite('DLF.csv',DLF);

[currentVoltage, I] =
calculate_FinalBusVoltages(I,n_bus,data,initialVoltage,DLF,Base_voltage,tol
erance);

csvwrite('FIRST_CURRENT.csv',[abs(I),angle(I)]);
csvwrite('FirstVoltage.csv',[abs(currentVoltage),angle(currentVoltage)]);

[TRPLoss, energy_loss, TQPLoss] =
calculatePowerLosses(I,n_bus,impedance,data,currentVoltage,Time_period);
losses_data = [TRPLoss,TQPLoss];

csvwrite('losses_data.csv',losses_data);

EnergyLossCost = energy_loss*Energy_rate;

BusPosition = calculate_bpos(n_bus,data,currentVoltage,impedance);

csvwrite('BusPosition.csv',BusPosition)

candidate_bus =
calculate_candidatebuses(n_bus,currentVoltage,Base_voltage,Lower_limit,Uppe
r_limit);
string_length = length(candidate_bus);

csvwrite('candidate_bus.csv',candidate_bus);

GEN =
initialize_population(string_length,maximum_generation,population_size,lowe
rLimit,upperLimit);

csvwrite('initial_capacitor_values.csv',GEN);

data1 = data;
Table0 = [];
for i = 1:maximum_generation
    ncap = GEN(i,:);
    for j = 1:length(candidate_bus)
        data1(candidate_bus(j),6) = data1(candidate_bus(j),6)- ncap(j);
    end
    currentVoltage =
calculate_FinalBusVoltages(I,n_bus,data1,initialVoltage,DLF,Base_voltage,to
lerance);
    [TRPLoss, energy_loss, TQPLoss] =
calculatePowerLosses(I,n_bus,impedance,data1,currentVoltage,Time_period);
    Table0(i,:) = [TRPLoss, energy_loss, TQPLoss];
    data1 = data;
end
csvwrite('Table0.csv',Table0);

csvwrite('second_CURRENT.csv',[abs(I),angle(I)]);
csvwrite('secondVoltage.csv',[abs(currentVoltage),angle(currentVoltage)]);
```

```
fprintf('BEFORE GENETIC ALGORITHM\n')
best_capacitor_values(GEN,Table0(:,1))

[Objective_func,fit_func,total_fit,family,select_pool,crossed_values,temp]
=
GA(lowerLimit,upperLimit,maximum_generation,EnergyLossCost,string_length,Cc
i,Ccv,GEN);
for i = 1:length(temp)
    GEN(temp(i),:) = crossed_values(i,:);
end

data1 = data;
Table1 = [];
for i = 1:size(crossed_values,1)
    ncap = crossed_values(i,:);
    for j = 1:length(candidate_bus)
        data1(candidate_bus(j),6) = data1(candidate_bus(j),6)- ncap(j);
    end
    currentVoltage =
calculate_FinalBusVoltages(I,n_bus,data1,initialVoltage,DLF,Base_voltage,to
lerance);
    [TRPLoss, energy_loss, TQPLoss] =
calculatePowerLosses(I,n_bus,impedance,data1,currentVoltage,Time_period);

    Table1(i,:) = [TRPLoss, energy_loss, TQPLoss];
    data1 = data;
    csvwrite('Table1.csv',Table1);
end

csvwrite('third_CURRENT.csv',[abs(I),angle(I)]);
csvwrite('thirdVoltage.csv',[abs(currentVoltage),angle(currentVoltage)]);
fprintf('AFTER GENETIC ALGORITHM\n')
best_capacitor_values(GEN,Table1(:,1))

% Table
```

BIBC Function Code

```
 function BIBC = calculate_BIBC(buses,n_bus,BIBC)
for i = 2:n_bus
    bus_no = buses(i,:);
    end_bus = bus_no(2);
    start_bus = bus_no(1);
    BIBC(:,end_bus-1) = BIBC(:,start_bus-1);
    BIBC(end_bus-1,end_bus-1) = 1;
end
end
```

BCBV Function Code

```
function BCBV = calculate_BCBV(n_bus,impedance,buses,BCBV)
    for i = 2:n_bus
        bus_no = buses(i,:);
        br = impedance(i,:);
        new_row = bus_no(2);
        existing_row = bus_no(1);
        BCBV(new_row-1,:) = BCBV(existing_row-1,:);
        BCBV(new_row-1,new_row-1) = br(1) +1j*br(2);
    end
```

```
end
```

Bus Position Function Code

```
function BusPosition = calculate_bpos(n_bus,data,currentVoltage,impedance)
    check = [];
    for i= 1:n_bus
        SFP(i) = (2*impedance(i,1)*data(i,6)^2)/abs(currentVoltage(i))^2;
    end

    SFP_sort = sort(SFP,'descend');

    for i= 1:n_bus
        value = find(SFP == SFP_sort(i));
        [c,d]= size(value);
        if c == d == 1
            BusPosition(i)=(value);
            check(i) = SFP_sort(i);
        else
           if nnz(check == SFP_sort(i)) == 0
                BusPosition(i) = value(1);
                check(i) = SFP_sort(i);
           else
               BusPosition(i) = value(nnz(check == SFP_sort(i))+1);
               check(i) = SFP_sort(i);
           end
        end
    end
```

Candidate Bus Selection Function Code

```
function candidate_bus =
calculate_candidatebuses(n_bus,currentVoltage,Base_voltage,Lower_limit,Uppe
r_limit)
   candy = [];
    per_unit_volatage = currentVoltage./Base_voltage;
    normalised_voltage = abs(per_unit_volatage)./Lower_limit;
    for i=1:n_bus
        if normalised_voltage(i)< Upper_limit
        candy(length(candy)+1) = i;
        else
        end
    end
       candidate_bus = candy;
end
```

Power Losses Function Code

```
function [TRPLoss, energy_loss, TQPLoss] =
calculatePowerLosses(I,n_bus,impedance,data,currentVoltage,Time_period)
    P_loss=[];
    EL=[];
    Q_loss=[];
    for i= 1:n_bus
        P_loss(i) = impedance(i,1)*(data(i,5)^2 +
data(i,6)^2)/abs(currentVoltage(i))^2;
        EL(i) = (abs(I(i)))^2*impedance(i,1);
        Q_loss(i) = impedance(i,2)*(data(i,5)^2 +
data(i,6)^2)/abs(currentVoltage(i))^2;
    end
```

```
    TQPLoss = sum(Q_loss);
    TRPLoss = sum(P_loss);
    energy_loss = Time_period*sum(EL);
end
```

Final Bus Voltage Function Code

```
function [currentVoltage, finalCurrent]
=calculate_FinalBusVoltages(I,n_bus,data,initialVoltage,DLF,Base_voltage,to
lerance)
    while true
        for i = 1:n_bus
           I(i) = conj((data(i,5) + 1j*data(i,6))/initialVoltage(i));
        end
        finalCurrent = I;
        deltaV = (DLF*I)./1000;
        currentVoltage = Base_voltage - deltaV;
        errorVoltage = abs(currentVoltage - initialVoltage);
        if max(errorVoltage) <= tolerance
%              fprintf("Convergence occurs at the following node voltages
:)\n")
%              display(currentVoltage)
            break
        else
         initialVoltage = currentVoltage;
        end
   end
end
```