OPTIMAL CAPACITOR PLACEMENT IN RADIAL DISTRIBUTION SYSTEM FOR LOSS MINIMIZATION USING PARTICLE SWARM OPTIMIZATION

By

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A Project submitted to the Department of Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of M.Eng. in Electrical and Electronic Engineering

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Declaration

It is hereby declared that

1. The thesis submitted is my own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

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Approval

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Abstract

The primary goal of the project is to minimize the system's power loss. In general, power systems are three - stage process: generation, transmission, and distribution. The distribution system is the final component of the system, it is responsible for providing power to the load. It frequently suffers from excessive power loss, which results in a variety of problems, including unbalanced lines, overloaded transformers, and bypassing meter connections. The distribution system power loss can be decreased by equipping it with capacitor banks. However, the issue is how to choose the optimal capacitor bank and bus for the system. This project presents a particle swarm optimization for capacitor placement in a radial distribution system with the goal of reducing the system active and reactive power losses losses and improving the system voltage profile; prior to installing the capacitor banks in the power system, a power flow analysis was performed to determine the system's power loss and to observe the power losses due to different buses. Particle Swarm Optimization determines the location of the capacitor bank on the node. before installing capacitor banks the Active and reactive power losses increase to 6024.85 kW and 3822.68 Mvar, respectively. The particle swarm optimization algorithm selected 10 power system buses and their capacitor banks. After installing the capacitor bank, the active and reactive power losses of the system decrease to 852.8 kW and 440 kVAr, respectively. as a result, the voltage profile of all the system buses is enhanced.

Keywords: Particle Swarm Optimization (PSO), Radial distribution system, Optimal Capacitor Placement (OCP)

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Chapter 1: Introduction

1.1 Background

Population and economic growth boost global demand for electricity. Electricity is essential to life [1]. Most equipment we use requires electricity. Power-based technologies are also growing quickly. Industrial advancement and social growth have boosted energy consumption. The electricity system should be dependable, economical, and clean. Fig. 1.1 shows the electrical power system divided into three sections: high-voltage generation, high-medium transmission, and medium-low distribution. A customer-focused distribution system is a key part of the system. Voltage is scaled down for consumer usage. Big loads reduce the voltage, increasing power system losses. Modern lifestyles have caused various power grid problems in the recent decade. Because distribution had a larger X/R ratio than transmission, it was responsible for 70% of power losses [2]. This causes power loss and voltage violations, expensive, and unstable power systems. Electric utilities reduce power losses to boost competitiveness. System losses impact deregulated energy costs. In tightly managed markets like ours, everyone should avoid losses. Effective optimization may minimize consumer end losses and energy costs. Researchers have long looked at shunt capacitors in distribution feeders. Inductive loads cause current and line losses. Capacitive devices may minimize distribution system power loss by providing reactive power. The system's principal source can't cover all reactive power needs and losses. Reactive electricity in distribution system branches may be reduced. Capacitors improve power factor, bus voltage management, power and energy losses, feeder and system capacity, and power quality in all distribution systems. Capacitors may be allocated and managed to achieve the following advantages under different loading circumstances. The optimization of capacitor location should be based on loss minimization and other technical restrictions. After that, use the right solution methodologies to identify the ideal capacitor number, position, and size.

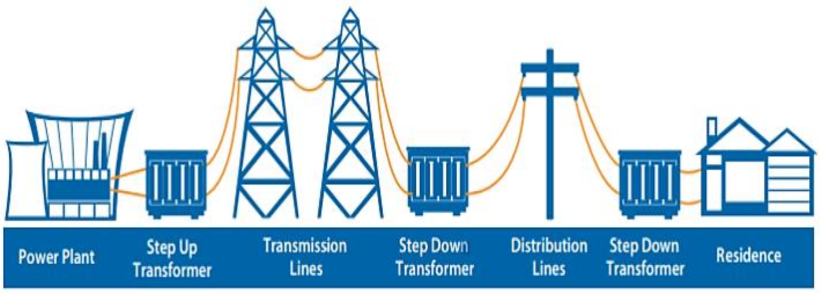


Fig. 1.1 Electrical transmission and distribution system

The goal of this project is to decrease reactive loss in the electric power distribution networks by employing artificial intelligence to install shunt capacitors on chosen feeders.

1.2 Somaliland electricity

In a 2015 assessment by the African Development Bank Group, "the inadequate access of Somaliland to modern energy (especially electricity) is a concern that affects living and limits production," the report said. Voltage dips and frequent outages hamper the public electrical supply in cities, which is restricted in quantity, quality, and dependability. There are considerable obstacles to Somaliland economic development, according to the National Development Plan 2017-2019, which was published in December 2016. Nearly 80% to 90% of Somaliland energy requirements are met by locally available charcoal and firewood, leading in overexploitation of these basic energy sources. Access, cost, and dependability are only now being addressed in the Somaliland area when it comes to broad-based electricity, which has three major issues. Access to electricity is limited to a small fraction of the country's population and varies greatly from place to location and settlement design. 32.7 percent of Somaliland has power, an increase from 29.1 percent last year, according to World Bank estimates, which are based on a limited amount of credible data. There are 2,076,677 homes in the United Nations Population Fund (UNFPA) 2014 population report, which means that there should be around 679,073 power connections in the area. The picture is less pleasant when looking at alternative computations. More than a quarter of the population does not have access to electricity, according to the African Energy Outlook 2014. If that wasn't bad enough, according to a recent evaluation of energy needs by the African Development Bank (AFDB), there are 270,000 homes and businesses in the Somaliland area with access to power. Only 13% of Somaliland's 12.3 million people have access to electricity. Based on current best estimates, the range of feasible connections is between 13.7% and 32.7.7% access to electricity. Overall, Somaliland has an installed and operating producing capacity of 80 to 85 MW, with an anticipated 250,000 connections, says the National Development Plan (NDP) for the period of 2017 to 2019. It's not uncommon for voltage to fluctuate, and the supply is only available for 4 to 5 hours each day at the moment. Most small generators lose 40 to 50 percent of their power while operating at low tension (480/220 V) across quite long distances. "In urban regions, electrification varies greatly by location," according to a Shuraako research published in May 2016 [3].

1.3 Statement of the problem

The term "distribution power losses" encompasses both technical and non-technical losses. The heat generated is proportional to the material qualities and electrical current flow resistance, which determine the technical losses. Distribution lines and transformers are the most obvious examples of power losses, because of their inherent electrical resistance.

1.4 The most common cause of technical failures

1.4.1 Distribution lines that are extensive

In reality, 11kV and 380-volt cables are carried across long distances in rural areas to provide power to loads that are dispersed over a wide geographic area. As a result, main and secondary distribution lines in rural areas are generally radial in nature and often cover long distances to reach their destinations. As a result, there is significant line resistance and, as a result, significant I^2R losses in the line. Unpredictable expansion of sub-transmission and distribution networks into new geographic areas. Power on a big scale in rural areas, including lengthy 11kV and LT transmission lines

1.4.2 Inadequate distribution line conductor size

However, since rural loads are often distributed and supplied by radial feeders, it is important to pick conductor sizes that are equivalent to the kVA×km capacity of a conventional conductor to provide adequate voltage control in the area served. The diameters of the conductors in these feeders should be sufficient.

1.4.3 Additional potential sources of technical failures

Large neutral currents are produced by the L.T system's unequal load distribution throughout three phases.

- Power leaking and loss
- Lines that are overloaded
- Unusual operating conditions in which power and distribution transformers are used
- Low voltages at consumer terminals induce inductive loads to draw more current.
- Poor equipment quality in agricultural pumps in rural areas, colder air conditioners, and industrial loads in metropolitan areas.

1.5 Network loss quantification

According to the study's findings, more than 75% of network losses are caused by Distribution transformers, LV networks, and HV networks. Overall, LV networks are responsible for 36-47 percent of overall losses. As shown Fig. 1.2, the electrical network losses can be divided into two parts, technical and non-technical losses. Distribution transformer load-related losses account for 9-13 percent of total losses. Distribution transformer no-load losses account for 7–10% of losses. HV networks cover 7-27 percent of the population [4]. non-technical losses, often known as "commercial losses," are particularly significant since they frequently result in the utility not paying for a considerable amount of the electricity used. Metering issues, including broken meters, erroneously read meters, and projected usage owing to meter absence, are all major sources of non-technical losses. Unauthorized connections and administrative failures are two more potential causes of non-technical losses. The vast majority of non-technical losses are associated with low-voltage distribution networks. Non-technical losses in medium voltage distribution are mostly caused by defective meters and measuring transformer manipulation.

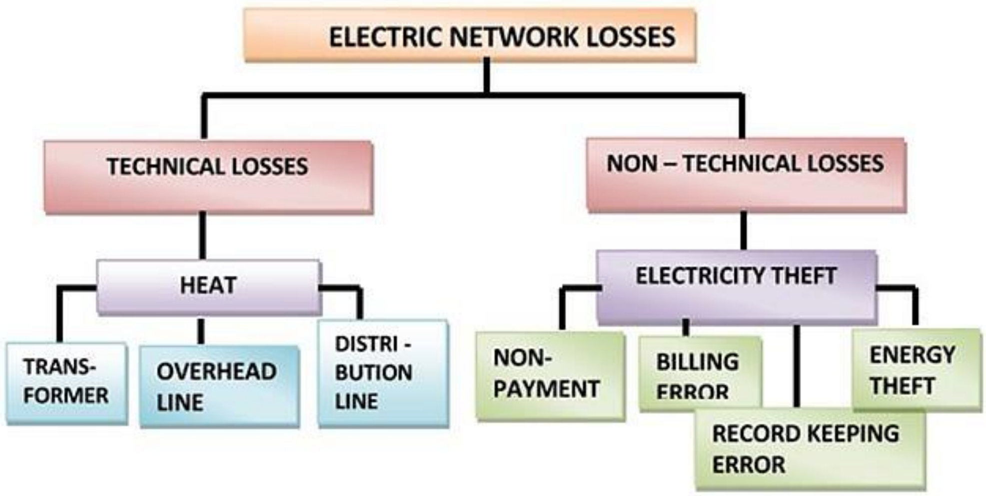


Fig. 1.2 Classification of losses

Non-technical losses are rare at the transmission level and may go unnoticed. It is currently 40 percent, with the bulk of the power loss in the distribution system due to rising inductive load demand, transformer overloading, and the great distance of loads with distribution transformers. Because of the lower voltage magnitude, electric power losses are significant in Burao City's distribution system. The following are the most often used ways for reducing the losses mentioned above:

- Capacitor positioning
- Reorganization of feeders
- Configuration of distributed generation

On the main distribution feeders, standard-size shunt capacitor banks are preferable. On the other hand, installing capacitors has the drawback of necessitating the use of protective equipment and may result in some disruptions. Nonetheless, they are easy to set up and inexpensive. Furthermore, installing shunt capacitor banks is crucial for enhancing power factor, optimizing feeder voltage profile, reducing power loss, and boosting available feeder capacity.

1.6 Objectives of the project

The purpose of this study was to establish and develop a technique to find the optimal positions and sizes of capacitors for minimizing power loss by balancing the reactive power, to offer a reason for the requirement of decreasing voltage during reactive power adjustment, and to establish the ideal voltage setting at the substation regulator.

1.7 Scope

The scope of the research and the scope of the activity must be determined in order to achieve the desired outcome. The goal of the research is to discover how capacitor banks may improve the quality of the distribution system's power, how to develop a program using MATLAB, and how a mathematical algorithm can determine the optimal position for the capacitor banks' number. These are all part of the overall study. Once the research has identified the scope of the project, it will be possible to group the results.

We'll use a mathematical approach and MATLAB software to code everything. Many iterations are required to get optimal results in an algorithm that uses a particle swarm optimization approach. The number of times something has been done. Objective functions and operational limitations are essential for iterative development. Use MATLAB for this project. MATLAB output may then be used to figure out the appropriate number of capacitor banks once all functions have been defined and implemented into code.

1.8 Expected outcomes

This project's intended goal is the achievement of the optimum number of capacitor banks in the distribution system. In addition, the technique approach, Particle swarm optimization, is projected to provide findings that improve the distribution system's power quality.

1.9 Thesis outline

Chapter 1: address motivation of this project, problem of the statement, Expected outcome, electricity in Somaliland.

Chapter 2: review of the relevant literature

Chapter 3: discusses and recommends alternative solutions to the problem. Calculating the bus voltage and branch power is accomplished via the use of a technique known as backward forward load flow. PSO optimization methods are presented in order to acquire the best possible locations and the right size of capacitors.

Chapter 4: describes the information needed to address the issue being studied. Shown are bus numbers to be compensated as well as bus numbers after appropriate capacitor placement.

Chapter 5: summarizes the findings of this study and outlines its future work.

Chapter 2: Literature Review

2.1 Introduction

The voltage level of each customer bus must be kept within the permissible limit by the system operator of a power system. Many standards have been created to give requirements or recommendations for ensuring adequate voltage profiles in distribution networks A distribution system's voltage fluctuations should be limited to a range of -13 percent to 7 percent, as specified by ANSI standard C 84.1 [5].

This chapter offers review of literature in the following area:

1. Radial distribution system
2. Power flow methods
3. Optimization techniques
4. Optimal capacitor placement and sizing

2.2 Radial distribution system

Radial distribution feeders differ from other types in that power is sent from the distribution substation to each individual customer in a single path. A typical distribution system will contain one or more distribution substations, each of which has one or more "feeders." The following components could be found in the feeder:

1. Primary "main" feeder with three phases
2. laterals that are three-phase, two-phase ("V"), and single-phase
3. voltage regulators of the step-type
4. In-line transformers
5. Distribute capacitor banks
6. electrical distribution transformers
7. Secondary
8. Three-phase, dual-phase, and single-phase loads

An unbalanced distribution feeder is the result of supplying a high number of single-phase loads that are not distributed equally. A further imbalance is introduced by the non-equilateral conductor spacings of the three-phase overhead and subterranean lines. Power flow and short-circuit analyses for transmission systems are not adequate because of the distribution system's complexity. Such programs have weak convergence characteristics for radial systems. A single-phase equivalent system is utilized since the programs presume a perfectly balanced system. A distribution engineer must model the distribution feeder as well as possible in order to conduct accurate power flow and short-circuit analyses. Essentially, this implies that a major model is a three-phase model [6].

2.3 Power flow system

2.3.1 Brief history of loaf flow

Load-flow solutions were found with the help of network analyzers before and for a while after digital computers were invented. [7] Network analyzers were used to figure out how to get the load to flow. The first really useful automatic digital solution methods were published in 1956, and since then, many more have been made [8].

2.3.2 Load flow system

Load flow (also known as power flow) is the steady-state solution of an electrical power network in the terminology of power systems. Except for the inherent limits of power systems, it does not vary much from other network solutions. Specifically, the non-linear nature of the formulation necessitates an iterative solution [9]. In power systems, the load flow analysis is a numerical analysis of the flow of electric power in a networked system.

Focusing on AC power characteristics such as voltages, voltage angles, real power, and reactive power, a power-flow analysis sometimes employs simpler notation, such as a one-line diagram. Power systems in steady-state operation are investigated. It is applied in both operational and planning phases of power system analysis. Numerous power flow methods have been created due to the unique characteristics of distribution systems (high R/X ratios, radial or loosely meshed architecture, and numerous branches and nodes). Some of these techniques are Newtonian, while others are Gaussian. However, the radial topology of distribution networks is used in certain techniques. These approaches are based on the backward/forward sweeps technique. The following is a list of the most common power flow solutions for unbalanced radial distribution systems (unbalanced-RDS). Other strategies that may still be discovered in the literature include the following:

2.3.3 Ladder network method

In 1975, Kersting suggested a solution for dealing with the power flow problem that depended on basic electric circuit concepts such as Ohm's law, the KCL and KVL laws. In this method, First, nodes are ideally arranged based on the source node. At initially, it is believed that the voltage at the receiving end is identical to the voltage at the transmitting end. Calculating branch currents and nodal voltages using KCL and KVL The method is repeated until the difference between the stated sending-end voltage and the estimated receiving-end voltage falls within a certain tolerance. Because the currents flowing through the branches are approximated using the complex power provided at each node, current branch equations are nonlinear [10].

2.3.4 Newton power flow method improved

Tinney developed a Newton-based power flow approach in 1967 [11]. The Newtonian technique necessitates those direct solutions be found for the derivative power flow equations. Jacobian matrices are used to demonstrate the relationship between changes in real and reactive powers at each node and changes in nodal voltage angles and magnitudes. The Jacobian matrix is LU factorized to adjust nodal voltage angles and magnitudes. In Newton's method, the backward/forward sweep strategy was employed to replace the LU factorization and forward/backward substitution procedures. The derivative of power flow equations is not necessary to calculate the real and reactive power mismatches. Instead, the Jacobian matrix is approximated by assuming that the voltage difference between two adjacent nodes is small and that a node's self-admittance is equal to the negative of the sum of all admittances related to it. Shunt components such as shunt capacitors and line section shunt capacitances are thus neglected. The branches are then stacked in layers distant from the source node (i.e., the main substation). Once the Jacobian matrix has been determined, the power mismatch equations are solved using the backward/forward sweep method.

2.3.5 Substitution method (Backward/Forward)

The reverse sweep is simply a current or power flow solution with possible voltage updates. It starts with the branches in the last layer and works its way up to the branches associated with the root node. Backward propagation calculates each branch's updated effective power flows by using the node voltages from the previous iteration. It indicates that the voltage values gained in the forward route are constant throughout backward propagation. That updated power flows in each branch are carried backward via the feeder utilizing the backward path. This means that backward propagation starts at the far end node and progresses towards the source node. There are three basic types of the forward/backward sweep method, which differ from one another based on the kind of electric values calculated at each iteration, starting with the terminal nodes and going up to the source node (backward sweep) [12].

2.4 Evolutionary optimization techniques

In recent years, there has been a lot of progress in developing evolutionary optimization approaches. This section looks at how evolutionary optimization approaches have evolved and how they may be used to solve an optimum water flow issue in general.

The application of Evolutionary Programming (EP) to solve the optimum reactive power dispatch problem and regulate the voltage profile in power systems was described. The technique was shown to be beneficial in overcoming global optimization difficulties in large-scale power systems [13].

Q H Wu, Y J Cao, and J Y Wen suggested An Adaptive Genetic Algorithm (AGA) was developed to handle the optimal reactive problem dispatch issue and voltage profile control in power systems. The crossover and mutation probabilities were varied in the evolution process using the proposed Adaptive Genetic Algorithm (AGA) method based on the objective functions of the solutions and the normalized fitness distances between the solutions to prevent premature convergence and improve the convergence performance of genetic algorithms [14].

Abido proposed (TS), This study provides a Tabu Search (TS)–based technique to solving the Optimum Power Flow (OPF) issue that is both efficient and reliable. The suggested method uses the TS algorithm to find the best settings for the OPF problem's control variables. The computational load of solving the OPF problem using TS as a derivative-free optimization approach is greatly reduced. The TS algorithm's resistance to parameter settings and the initial solution is one of its key features. Furthermore, TS is distinguished by its ability to minimize entanglement in the best local solution and to avoid cycle by using flexible search history memory. [15]

A Genetic Algorithm (GA)-based approach for improving Reactive Power Dispatch (RPD) in power networks, including voltage stability restrictions. The voltage stability monitoring method is based on the L-index of load buses. The control variables include bus voltage magnitudes, transformer tap settings, and capacitor bank reactive power output. This difficult optimization problem is addressed using a binary-coded GA with tournament selection, two-point cross-over, and bit-wise mutation [16].

Alterations are made to the transformer taps and the proper position and management of a Unified Power Flow Controller (UPFC) to simultaneously lower both the actual power losses and the Voltage Stability Limit (VSL) of a mesh power network. This is a nonlinear optimization problem with constraints based on equality and inequality, and the objective function considers both the actual power loss and the VSL. An innovative evolutionary method called bacteria foraging is used to solve the multi-objective, multi-variable issue. The variables in this method are the UPFC position, its series injected voltage and the transformer tap positions. The identical issue may be handled successfully using the Interior Point Successive Linearization Program (IPSLP) approach, the LINPROG tool in MATLAB, and a simple aim of merely actual power loss [17].

Devaraj presented. describes an improved Genetic Algorithm (GA) approach for dealing with the multi-objective reactive power dispatch problem. The aims have been decided to be loss reduction and increased voltage stability margin. The voltage stability level is determined by the system's maximum L-index. There are three optimization variables: generator terminal voltages, reactive power production from capacitor banks, and tap altering transformer settings. There are floating-point numbers for voltage magnitudes, but integers for tap-setting and reactive power output for capacitor banks in the proposed Generalized Autonomous (GA). Binary-coded GAs can't handle real or integer variables with more than 25 possible values, but with this approach, those problems are gone. Multivariate crossover and mutation operators have been suggested [18].

Optimal Reactive Power Dispatch (ORPD) is an optimization problem with a nonlinear objective function and many local minima that calls for combinatorial solutions. Several Ant Colony Optimizations (ACO) approaches to solve the reactive power dispatch issue. Using the initial ant colony optimization technique, the Ant System (AS), as well as its immediate descendants, the Elite Ant System (EAS), the rank-based ant system (ASrank), and the Max-Min Ant System (MMAS), the reactive power dispatch issue may be solved with the use of these systems [19].

The problem of optimal reactive power dispatch in power systems has had a growing impact on the secure and economical functioning of power systems. This issue, on the other hand, is commonly acknowledged as a nonlinear, multimodal, and mixed-variable problem. Previously, computational intelligence-based methodologies such as Genetic Algorithms (GAs), Differential Evolution (DE) algorithms, and Particle Swarm Optimization (PSO) algorithms, among others, were commonly used to achieve this goal. This research proposes a reactive power dispatch system based on a Seeker Optimization Algorithm (SOA). The SOA is based on the act of human searches being replicated. The empirical gradient is used to determine the search direction by evaluating the behavior to location changes. The step length is determined by applying uncertainty reasoning and a simple Fuzzy rule [20].

One of the most important roles in the operation and administration of power systems is Reactive Power Dispatch (RPD). This paper presents an effective and dependable evolutionary-based technique for dealing with RPD. The proposed method employs a Differential Evolution (DE) algorithm to find optimal sets of RPD control variables [21].

The Artificial Bee Colony (ABC) algorithm is an optimization approach based on the honeybee swarm's intelligent foraging activity. This study investigates the Optimal Reactive Power Flow (ORPF) based on the ABC algorithm in order to minimize active power loss in power systems. The ABC algorithm has the advantage of not requiring these parameters since it is difficult to quantify external variables such as cross-over rate and mutation rate, as in the case of genetic algorithms and differential evolution. The second advantage is that the algorithm's global search capability is enhanced by including a neighborhood source formation mechanism similar to the mutation process. Because of these characteristics, the ABC algorithm has attracted a lot of attention in recent years and has been used successfully in a variety of fields [22].

Reactive power optimization-based multi-level system. The created approach is designed to solve the infeasibility of addressing the fuel cost minimization issue (at a particular operating point) when a conventional method, such as the Interior Point Method (IPM), is used. As a starting point for addressing the fuel cost reduction issue, it is suggested to use the optimum reactive power planning problem while maintaining voltage stability. The issue of load voltage variation is used to enhance the voltage profile of the system. The reactive power planning and load voltage deviation reduction challenges are tackled using a novel optimization approach, the Differential Search Algorithm (DSA), in order to achieve great results (DSA). In addition, IPM is used to solve the issue of lowering fuel costs. The potential locations of compensating devices for the optimum reactive power planning issue are determined using the Fast Voltage Stability Index (FVSI), a unique voltage stability measure [23].

The Honey Bees Optimization (HBO) method is used to address the problem of reactive power in a power system. The Honey Bees Optimization (HBO) approach is a nature-inspired algorithm that replicates the mating behavior of bees and is used to handle reactive power challenges. Optimization parameters include generator terminal voltages, capacitor bank reactive power generation, and tap changing transformer configuration [24].

A fuzzy and Particle Swarm Optimization (PSO) approach for locating capacitors on the major feeders of radial distribution systems in order to decrease power losses and enhance voltage profiles. The optimum capacitor placement issue is solved in two stages. In the first step, the fuzzy technique is employed to discover the ideal capacitor positions. The Particle Swarm Optimization approach is utilized in the second step to determine the capacitor sizes [25].

2.5 Optimal capacitor placement and sizing

The issue for power system designers and researchers was precisely finding and rating shunt capacitors in distribution networks. As a result, several published papers and reports in the literature were discovered. Several solutions to the capacitor location and size challenge have been offered. This challenging complex issue was solved using a number of strategies. The existence of harmonic sources in distribution networks, as well as imbalanced operating situations, complicates the capacitor location and size issue even more. As a result, they have received little attention in different capacitor optimization research. Duran introduced the approach for evaluating the appropriate number, location, and size of shunt capacitors in a radial distribution feeder with discrete lumped loads to achieve overall savings, including capacitor cost, in 1968. When capacitors are not economically justifiable, the program assesses this as well. The optimization process is seen as a multistage decision process with the requisite Markovian characteristic, and several strategies are created to get the optimal response. When no capacitor cost, cost proportional to installed capacity, and cost proportional to installed capacity plus a fixed cost per installed bank are analyzed, unusual cases are investigated, and solutions are developed. The techniques are suited for developing efficient solutions in a digital computer [26]. The problem of capacitor placement on radial distribution systems is described, and a solution approach is proposed. The issue addresses the location, type, and size of capacitors, voltage limits, and load variations. The goal of capacitor placement is to reduce peak power and energy loss while keeping capacitor cost in mind. The problem is described as a mixed-integer programming problem. The power fluxes in the system are clearly displayed, and the voltage limitations are integrated. The recommended solution strategy divides the problem into two parts: a master problem and a slave problem. The master problem is used to calculate the location of the capacitors. The master problem uses the slave problem to determine the kind and size of capacitors installed on the system. An effective phase I - phase II strategy is used to handle the slave problem [27]. Presents a unique approach for determining the appropriate location and size of capacitors on radial distribution networks to improve voltage profile and reduce active power loss. Loss Sensitivity Factors and Particle Swarm Optimization are used to locate and size capacitors, respectively. The concept of Loss sensitivity factors may be considered as a unique contribution in the realm of distribution systems [28]. Total distribution system losses must be reduced to increase overall power delivery efficiency. This may be accomplished by finding ideal capacitor values in radial distribution systems. A fuzzy-genetic approach has been presented as a technique. The ideal position for the capacitor is discovered using fuzzy set theory, and the size of the capacitor is selected using a genetic algorithm. The goal function is to deploy the optimum value of capacitors in the best places, maximizing net savings in the distribution system [29].

According to the reviews above, artificial intelligence provides a faster and more accurate solution to an optimization problem than existing conventional methodologies. Particle Swarm Optimization is the most popular optimization technique because it is easy to implement, has a low computing load, and has a fast convergence. PSO is effective at solving tough problems. The position of the buses where the capacitors should be placed in this project is determined by a series of algorithm criteria based on sizing and selected using Particle Swarm Optimization.

2.6 Summary

This chapter looked at previously published work that was linked to the research for this thesis. This chapter was divided in to three parts

The first part of this series covered power flow solution techniques for radial distribution systems.

The second part of the series focused on power flow solution algorithms for power systems.

Part three of the series covered the best capacitor placement and size strategies.

Chapter 3: Methodology

3.1 Introduction

In this chapter, we are addressing the mathematical formulation of the objective function and power flow equations to a single line diagram of a radial distribution network system. thus, every choice to modify or add a capacitor in the network hinges on analysis from power flow

3.2 Problem formulation

The primary purpose of reactive power optimization is to reduce actual system power losses and enhance power quality by controlling capacitor location and loss. Unbalanced operation, high R/X ratios, and distribution generation are three of the downsides of radial distribution networks. Due to these obstacles, Newton Raphson, Gauss-seidel, and other standard techniques for predicting load flow in distribution networks are ineffective [8].

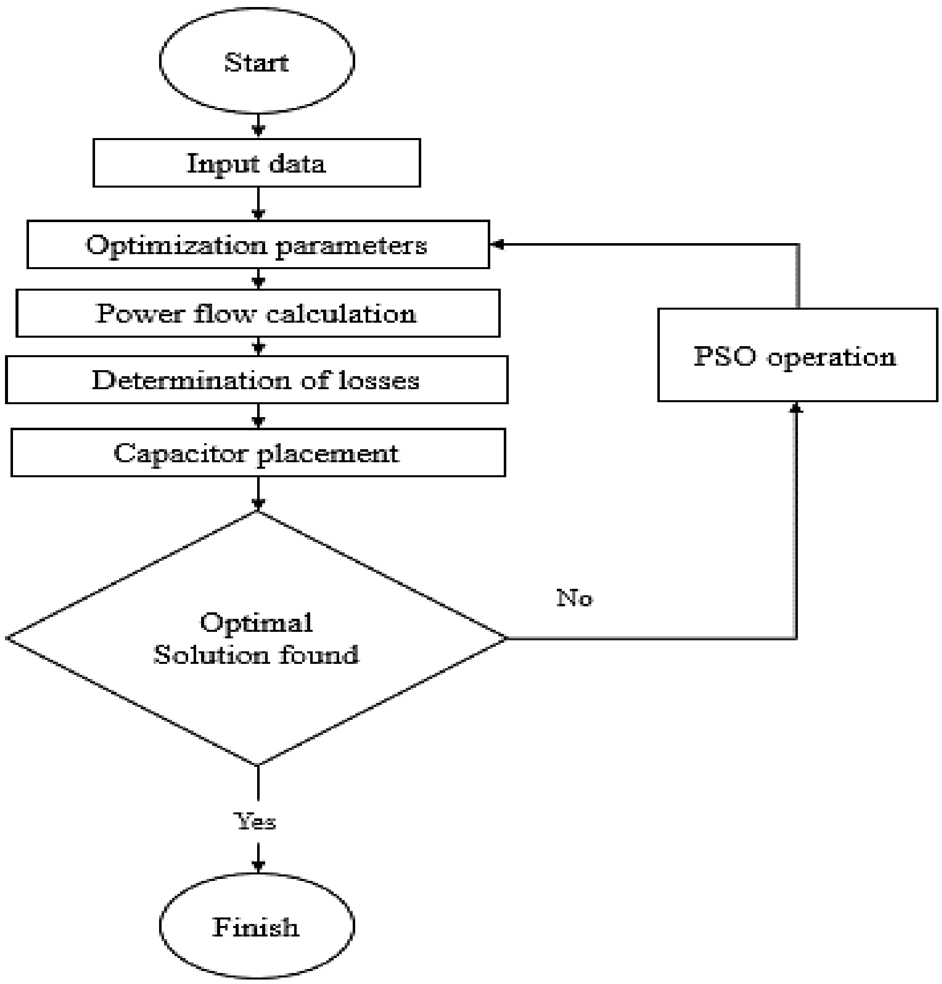


Fig. 3.1 Flow chart of the proposed method

3.3 Flow chart of the project

First-time collection of essential data, including line data and bus data as shown in fig 3.1. The load flow algorithm was built in MATLAB using the backward and forward sweep technique. Load flow was used to calculate the overall power loss of the system, and then MATLAB code was used to execute Particle Swarm Optimization in order to pick the needed capacitors and capacitor sizes for the buses.

3.4 Equations for line power flow

As explained below, power flow may be analyzed in one of two directions: forward from the first to the last node or backward from the first to the preceding node [30]. Fig. 3.2, The single line graphic below was used to calculate the forward and reverse power flow equations shown in this chapter.

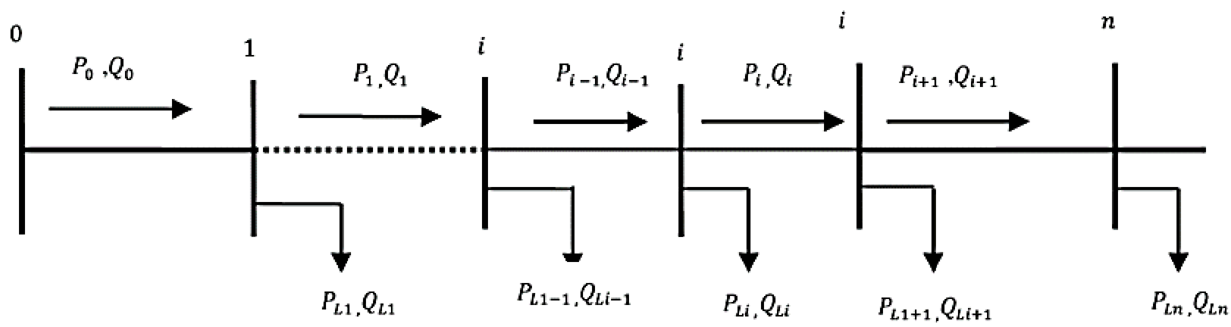


Fig. 3.2 Single line diagram of radial system

Like forwarding branch equations, distribution flow branch equations use the real power, reactive power, and voltage at the branch's sending end to express the same values at the branch's receiving end. They may be used to represent the flow of power in a radial distribution system.

$$P_i = P_{i+1} + R_{i,i+1}\left|\frac{P_i^2 + Q_i^2}{V_i^2}\right| + P_{L,i+1} \tag{3.1}$$

$$Q_i = Q_{i+1} + X_{i,i+1}\left|\frac{P_i^2 + Q_i^2}{V_i^2}\right| + Q_{L,i+1} \tag{3.2}$$

$$\left|V_{i+1}^2\right| = |V_i|^2 - 2(R_{i,i+1} \times P_i^2 + X_{i,i+1} \times Q_i^2) + (R^2_{i,i+1} + X^2_{i,i+1}) \times \left|\frac{P_i^2 + Q_i^2}{V_i^2}\right| \tag{3.3}$$

The distribution flow branch equation may be written backward by taking into account the real power, reactive power, and voltage at the receiving end of a branch in order to compute the classification values at the sending end of the branch.

$$P_{i-1} = P_i + R_i \times \left|\frac{{P_i'}^2 + {Q_i'}^2}{{V_i}^2}\right| + P_{Li} \tag{3.4}$$

$$Q_{i-1} = Q_{i+1} + R_{i,i-1} \times \left|\frac{{P_i'}^2 + {Q_i'}^2}{{V_i}^2}\right| + Q_L \tag{3.5}$$

$$|V_{i-1}|^2 = {V_i}^2 - 2(R_{i,i+1} \times {P_i'}^2 + X_{i,i+1} \times {Q_i'}^2) + ({R^2}_{i,i+1} + {X^2}_{i,i+1}) \times \left|\frac{{P_i'}^2 + {Q_i'}^2}{{V_i}^2}\right| \tag{3.6}$$

Where $P_i' = P_i + P_{Li}$ and $Q_i' = Q_i + Q_{Li}$

Power loss in distribution system

$$P_{loss(i,j)} = R_{i,i+1} \times \left|\frac{{P_i}^2 + {Q_i}^2}{{V_i}^2}\right| \tag{3.7}$$

$$Q_{loss(i,j)} = X_{i,j+1} \times \left|\frac{{P_i}^2 + {Q_i}^2}{{V_i}^2}\right| \tag{3.8}$$

3.4.1 The distribution flow mechanism has been simplified

The quadratic components in the distribution flow branch equations indicate the branch losses, which are much less than the branch power values P_i and Q_i, suggesting that the branch losses are substantial. Power flow equations are of the type if the second order factors are left out of the estimations. As shown in figure 3.3 We can make a one-line diagram for power flow analysis to make the equations more manageable.

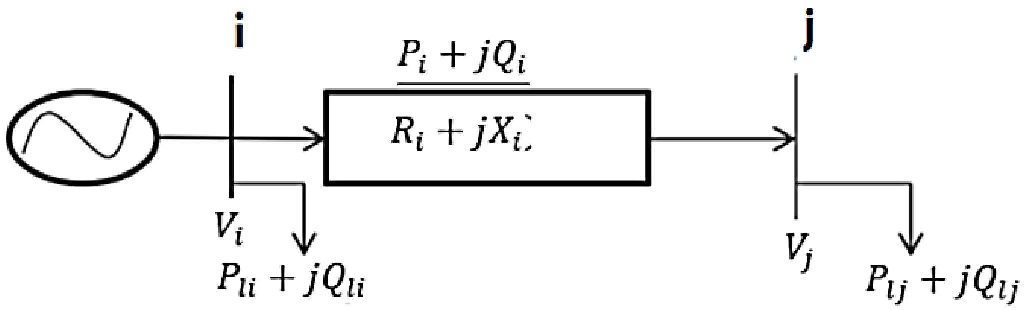


Fig. 3.3 Single line diagram infinite bus system

The terminal voltage can be calculated

$$V_j = V_i - I_i \times (R_i + JX_i) \tag{3.9}$$

Equation 3.8 find the I_i

$$I_i = \left(\frac{V_i - V_j}{R_i + JX_i}\right) \tag{3.10}$$

Current of each line

$$I_i = \left(\frac{P_i + jQ_i}{V_i}\right) \tag{3.11}$$

Power loss of the system can be calculated using this equation

$$P_{loss(i,j)} = I_i^{\,2} \times R_i \tag{3.12}$$

This is the last power loss modified

$$P_{loss} = \left(\frac{V_i - V_j}{R_i + jX_i}\right)^2 \times R_i \tag{3.13}$$

$$Q_{loss} = \left(\frac{V_i - V_j}{R_i + jX_i}\right)^2 \times X_i \tag{3.14}$$

Appendix a show the electrical specifications for conductors used to simulate Burao feeder, derived from standard books and catalogs. The feeder is a three-phase 11 KV system with constant base loads and a 1.5 MVA base.

$$Z_{base} = \frac{(11\text{kV})^2}{1.5\text{MVA}} = 80.67 \text{ Ohm}$$

$$I_{base} = \frac{1.5\ \text{MVA}}{\sqrt{3} \times 11\ \text{kV}} = 78.73\ \text{A}$$

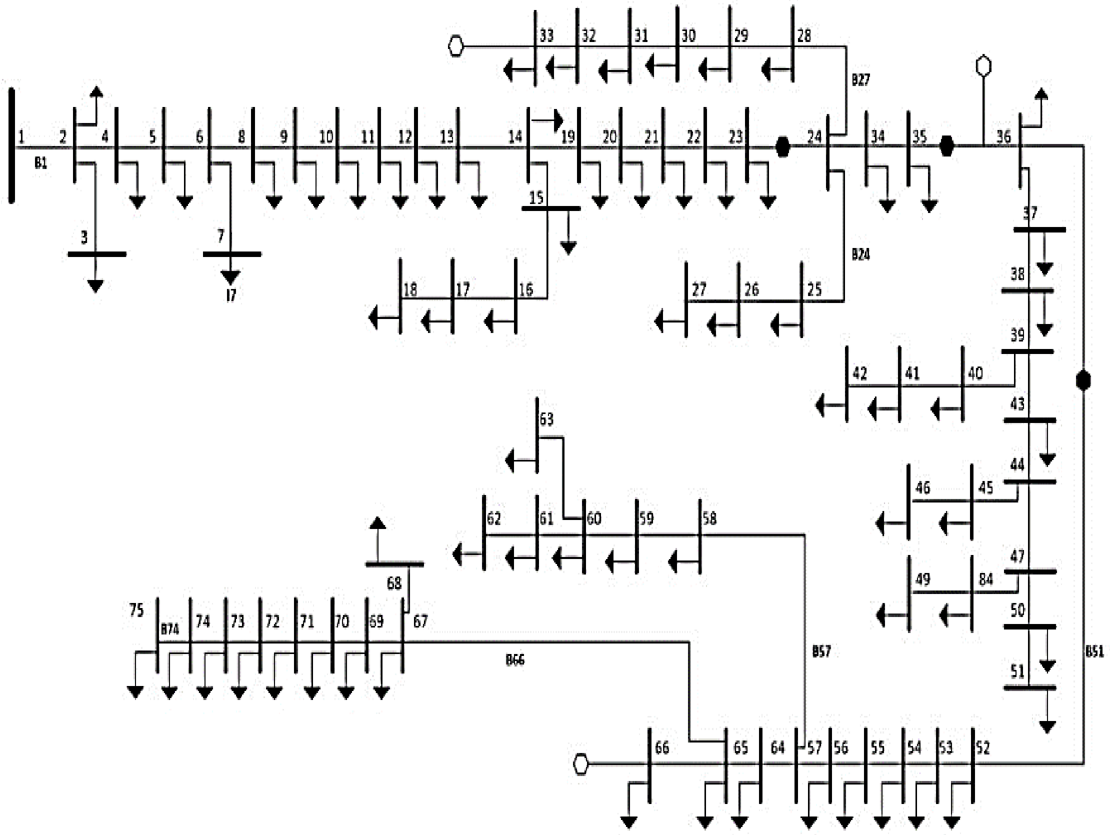


Fig. 3.4 Single line diagram of the distribution system

A single line diagram of the system is seen in figure 3.4. This diagram reveals that the system is made up of 74 buses, linked to 5 distributed generators, with a rated voltage of 11 kV and a capacity of 8 MW.

3.5 Backward and forward power flow method

The fundamental load flow analysis is the most important aspect of electric power system management and planning. Always considered a three-phase system with a balanced output, the transmission system is seen as a balanced output. In contrast, the balanced analysis technique is inappropriate for uneven distribution systems. Consequently, load flow evaluations of distribution system loads and flows need three-phase methods. In the previous several decades, a range of approaches have been developed by researchers for assessing distribution load flow. Each proposed strategy has its own advantages and disadvantages. The forward/backward sweep strategy and the ladder iteration method provide the best outcomes, according to a comprehensive assessment of the aforementioned approaches and their accompanying simulation results on several levels [30]. Two inputs give the electrical network parameters necessary for load flow analysis. The two inputs are the line data and the load data. By aggregating the active power injections and active/reactive power consumption at each node, load data may be derived [31]. Forward/backward sweep algorithms refer to these approaches that use radial network design and include forward or reverse sweep procedures. The forward sweep of the feeder and laterals focuses on calculating node voltage from the sending end to the far end, while the reverse sweep is concerned with calculating the branch current or power from the far end to sender. The backward sweep and the forward sweep make up this strategy's two phases. Using the KVL and KCL values, a current is computed in a backward sweep by dividing it by the distance between the furthest and source nodes. In forward sweep, the downstream voltage is calculated starting at the source node. Provided are the node-branch oriented data used as input to this approach. Fundamental data that must be gathered include active and reactive powers, nomenclature for transmitting and receiving nodes, and an impedance model for all branches. Following is a summary of the essential steps of the recommended solution approach, along with the needed equations. Two matrices are applied to calculate power flow solutions. The bus-injection to branch-current (BIBC) and the branch-current to bus-voltage (BCBV) matrices are the two types. For each radial bus, an injection of node currents is shown in this figure to explain how branch currents travel and their links to node currents. Si is the symbol used to represent the bus's complicated load.

$$S_i = P_i + JQ_i \tag{3.15}$$

3.5.1 Backward sweep

The branch currents from the loads to the origin are added at each iteration k-th. Before we can compute the branch current, we must first calculate the current injected at each bus and the bus-injection to branch current (BIBC), which represents the relationship between the bus injected current and the branch current. Injection of current at the k-th repetition of the i-th bus is expressed as a function of time by Equation (3.15).

$$I_{i\,k} = (V_i{}^{k}) \times I_i{}^{r} + (V_i{}^{K}) \times jI_i{}^{k} = \frac{P_i + jQ_i}{V_{i\,k}} \tag{3.16}$$

It specifies the voltage and equivalent current of the i-th bus at the kth time as $V_{k,i}$ and $I_{k,i}$. At the kth iteration, $I_{r,i}$ and $I_{i,i}$ are the real and imaginary sections of bus I equivalent current injection, as shown below:

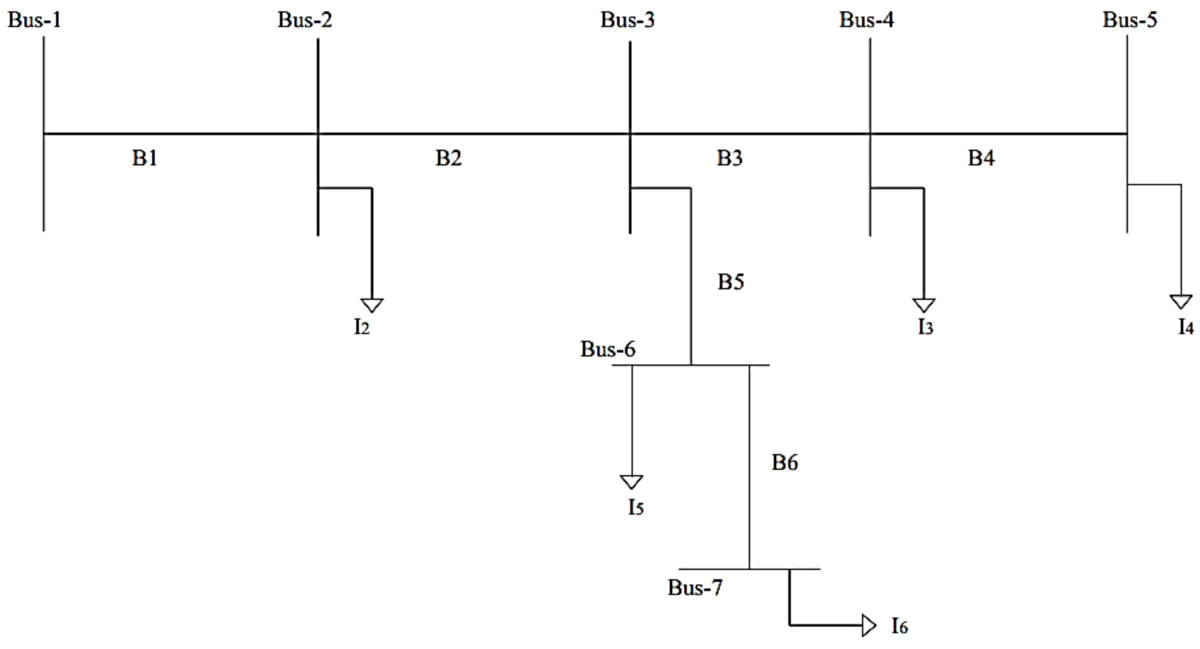


Fig. 3.5 Simple radial system

When Kirchhoff's current law (KCL) is applied to the distribution network, equation is obtained. (3.15), which determines the injected currents. Fig. 3.5, depicts an elementary distribution system. Consequently, branch currents may be represented as functions of comparable current injections. For instance, the branch currents B_1, B_2, B_3 up to B_6 may be stated in the following manner:

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 + I_7$$

$$B_2 = I_3 + I_4 + I_5 + I_6 + I_7$$

$$B_3 = I_4 + I_5$$

$$B_4 = I_4$$

$$B_5 = I_6 + I_7$$

$$B_6 = I_7$$

The relationship between injected current and branch current can be expresses like this

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \\ B_6 \end{bmatrix} = \begin{bmatrix} 1\ 1\ 1\ 1\ 1\ 1 \\ 0\ 1\ 1\ 1\ 1\ 1 \\ 0\ 0\ 1\ 1\ 0\ 0 \\ 0\ 0\ 0\ 1\ 0\ 1 \\ 0\ 0\ 0\ 0\ 1\ 1 \\ 0\ 0\ 0\ 0\ 0\ 0 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \end{bmatrix} \tag{3.17}$$

Equation (3.16) may be represented as a matrix formula (3.17)

$$[B] = [BIBC]\ [I] \tag{3.18}$$

A bus injection into the brunch current matrix is referred to as a BIBC. The top triangle matrix, BIBC, contains nothing but zeros and ones.

3.5.2 Forward sweep

According to Kirchhoff's voltage laws (KVL), a nodal voltage vector V is updated from the origin to the loads based on the previously calculated branch currents vector B and branch current to bus voltage vector B. (BCBV). As seen in Fig. 3.4, branch currents and bus voltages are connected. To put it another way, you may say,

$$V_2 = V_1 - B_1 Z_{12} \tag{3.19}$$

$$V_3 = V_2 - B_2 Z_{23} \tag{3.20}$$

$$V_4 = V_3 - B_3 Z_{34} \tag{3.21}$$

$$V_5 = V_4 - B_4 Z_{45} \tag{3.22}$$

$$V_6 = V_3 - B_5 Z_{45} \tag{3.23}$$

$$V_7 = V_6 - B_6 Z_{67} \tag{3.24}$$

Bus voltage and line impedance are both important variables to understand. Substituting (3.19), (3.20) and (3.21) into (3.22) can be rewritten as

$$V_6 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \tag{3.25}$$

Using the formula in (3.18) it is possible to express the bus voltage in terms of the branch current, line characteristics, and substation voltage. Bus voltage and current relationships may be described in the following way for any number of buses that have undergone similar operations:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \end{bmatrix} = \begin{bmatrix} Z_{12} & Z_{23} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{35} & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{45} & Z_{37} \end{bmatrix} \tag{3.26}$$

The generic version of equation (3.25) may be expressed as follows:

$$[\Delta V] = [BCBV][B] \tag{3.27}$$

3.5.3 Topology-based load flow method: algorithm for implementation [32]

1. Analyze the system data,

2. Construct the BIBC matrix as shown in equation (3.17).

3. Transpose BIBC and multiply with impedances to generate the BCBV matrix as shown in equation (3.25).

4. Initialize the iteration count to 1. Calculate equivalent current injections using the equation (3.15). Considering a homogeneous voltage profile of 1 pu across all buses.

5. Using the equation, compute the V matrix (3.26).

6. Measure the voltages at each node.

7. Determine the amount of current that was injected by utilizing a new set of voltages.

8. If the difference in currents between the current iteration currents and the previous iteration currents is more than 0.001, then output the result; otherwise, increase the count and repeat the operation starting at step 1. (4).

As previously discussed in the preceding sections, there are two critical phases in this algorithm that must be completed: [B] = [BIBC] = [BIBC] [I]: current injections are represented by the matrix [I]. Branched currents are represented as a function of the bus current injection rate.

[ΔV] = [BCBV] [B] Branched currents are used to represent voltage variations in the form of branch currents.

3.5.4 Backward and forward load flow algorithm

3.6 Basic Particle swarm optimization

This section a theoretical overview of the PSO algorithm and its parameter selection techniques is provided, as well as a geometrical representation and neighborhood topology, as well as a mathematical explanation of PSO's advantages and drawbacks.

3.7 Introduction

Particle Swarm Optimization is a technique that can optimize a non-linear and multi-dimensional problem, and it often achieves excellent results while needing little parameterization. In 1995, James Kennedy and Russel Ebhart proposed the method and its notion of "Particle Swarm Optimization" (PSO). [33] PSO is a population-based algorithm influenced by bird flocking and fish schooling, as are other evolutionary techniques. PSO was originally designed to address continuous nonlinear optimization issues. Since then, more research has been conducted to expand the initial version of the PSO method to address restricted nonlinear optimization problems with both discrete and continuous variables [34]. It is derived from swarm intelligence, which is based on the study of the movement of bird and fish congregations. While seeking for food, the birds can disperse or congregate until they discover a source of food. There is always a bird that can smell the food extremely well, indicating that the bird is wise of the location where the food can be located due to its superior food resource knowledge. This is because while birds migrate from one location to another in search of food, there is always a bird that can smell the food extremely well.

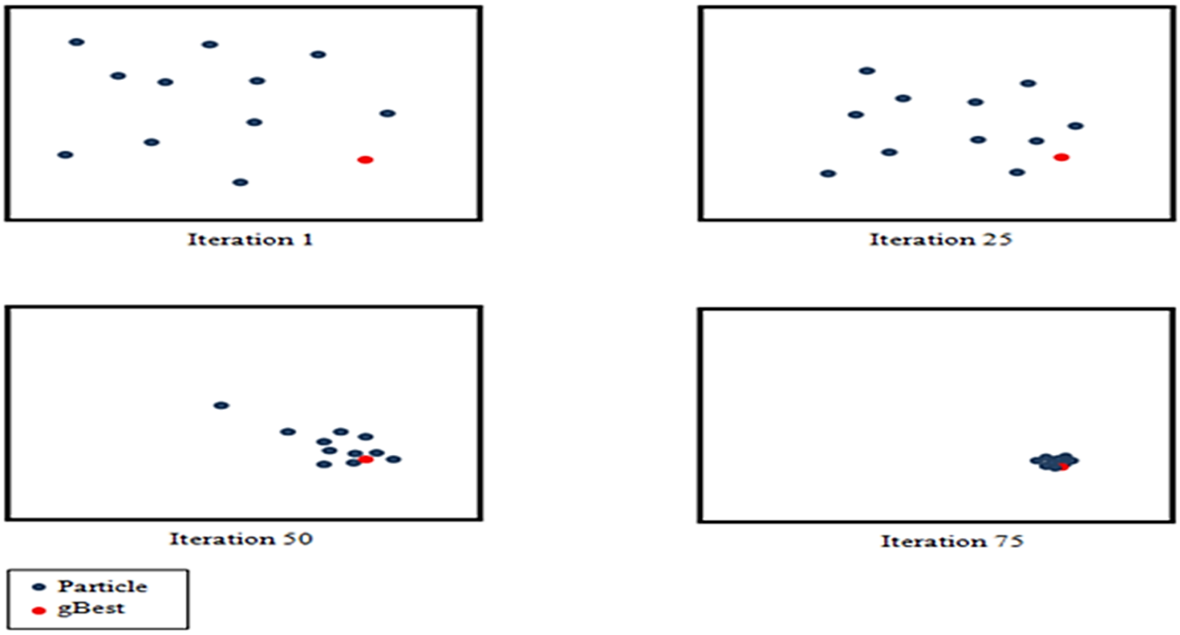


Fig. 3.6 Swarm behavior of particles

In the end, the birds will migrate to the area where food can be obtained since they are constantly exchanging information, particularly excellent information, while searching for food in other regions. Particle swarm optimization compares the solution swarm to a flock of birds; the birds' movement from one location to another corresponds to the development of the solution swarm; good information corresponds to the most optimistic solution, and food resources correspond to the most optimistic solution over time. As shown in Fig. 3.6, Each individual's engagement in the particles swarm optimization procedure may lead to the discovery of the most optimum solution. Each individual particle is represented by a particle devoid of quality and volume. In addition, each particle's core behavioral pattern is modified so that the complexity of the swarm may be shown. Originally, particle swarms were intended to emulate the social behavior of groups such as flocks of birds or schools of fish. For the first iteration of PSO, only continuous non - linear optimization problems were studied. However, several advancements in the development of PSO have increased its capacity to tackle a broad class of complicated optimization issues encountered in engineering and research.

3.8 Constant improvement of the particle swarm

Personal experience (Pbest), global experience (Gbest), and the present motion of the particles all assist the algorithm in determining the future locations of the particles inside the search space. Additionally, the experience is accelerated by two factors c_1 and c_2 and created random integers between [0, 1], while the current movement is multiplied by an inertia factor W changing between [Wmin. Wmax].

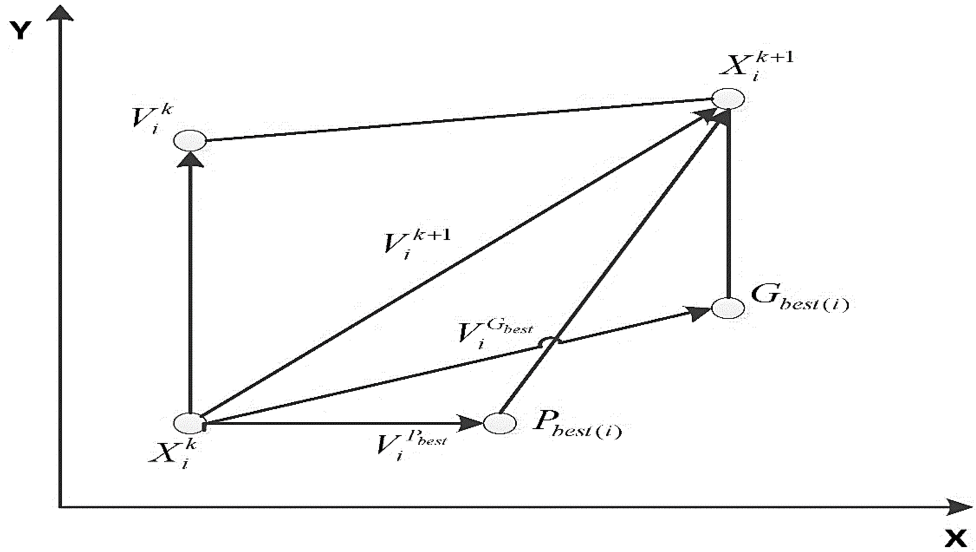


Fig. 3.7 PSO search mechanism in multidimensional search space

As seen in Figure (4.2) above, the position update process from x_i^k to x_i^{k+1} given the x_i^{k+1} velocity update is shown in this figure. In order to conduct optimization, the PSO algorithm relies on this connection and this process. The agent's position may be adjusted by combining its current location with its velocity. The following are some examples of PSO search methods based on the aforementioned concept: Agents work together to accomplish a certain goal. Each agent is aware of its current best value (pbest) and where it stands in relation to other agents. Each agent also has a working knowledge of the group's best value (gbest), which is the best value that the group has produced so far. Equation (4.1) shows how to compute the modified velocity of each agent using the current velocity and the distance form.

Based on the illustration, we can derive the velocity update equation (4.2)

$$v_i^{k+1} = \omega \times v_i^k + c_1 \times rand()\left[Pbest_i - x_i^k\right] - c_2 \times rand()\left[gbest_i - x_i^k\right] \qquad (3.28)$$

Where the i^{th}particle in the swarm is located

The position of i^{th} particle in the swarm

$$s = [x_1,\ x_1 \dots \dots \dots x_{n-1}] = \begin{bmatrix} x_{11} & \cdots & x_n \\ \vdots & \ddots & \vdots \\ x_{1n} & \cdots & x_{n-1} \end{bmatrix} \qquad (3.29)$$

$$x_i = [x_{i1},\ x_{i1} \dots \dots \dots \dots \dots, x_{in}] \tag{3.30}$$

Where the i^{th} paricle's velocity is defined as

$$v_i = [v_{i1},\ v_{i1} \dots \dots \dots, v_{in}] \tag{3.31}$$

Where

$$i = 1, 2 \dots \dots \dots, d$$

The term

$$c_1 \times rand(\,)\big[Pbest_i - \ x_i^k\big]$$

And

$$c_2 \times rand(\,)\big[gbest_i - \ x_i^k\big]$$

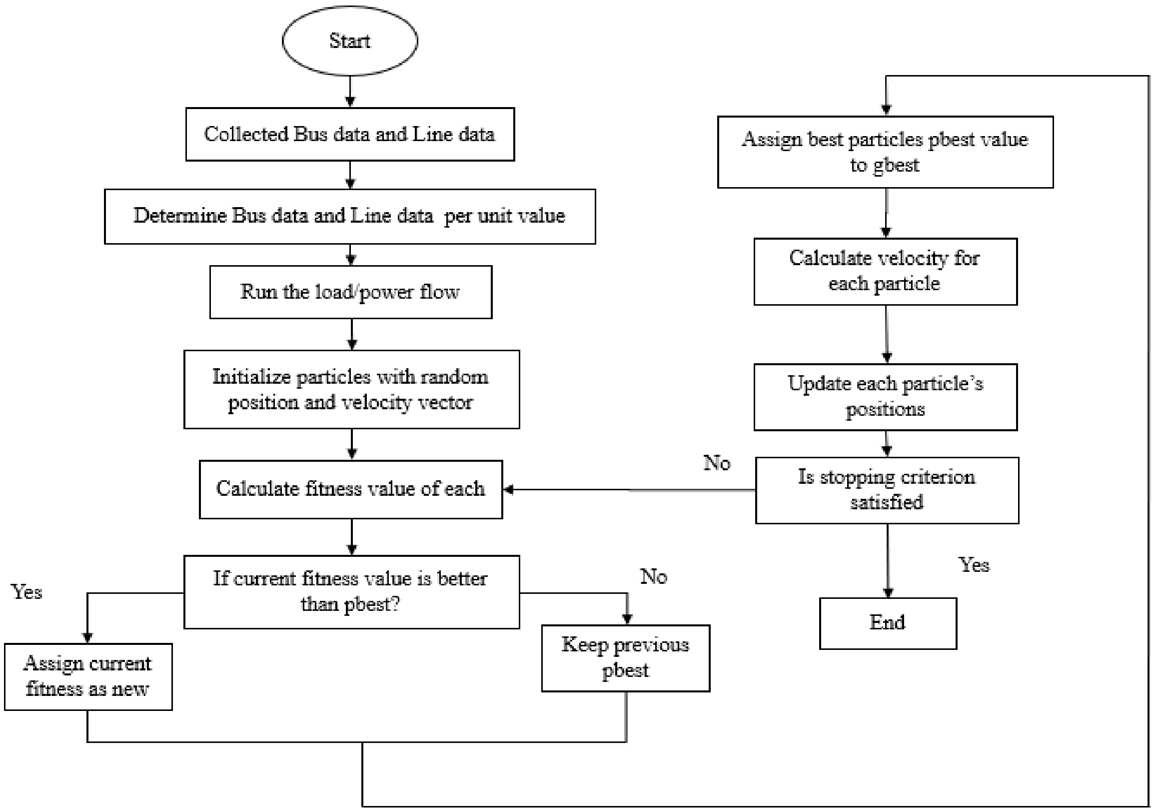
Particles' cognitive and social behavior is taken into consideration. Even while these extra variables have an enormous impact on the average impacts of each particle's movement and direction, it doesn't indicate the present location will improve. Scaling factors $c_1 \times rand(\,)$ and $c_2 \times rand(\,)$. determine the average heaviness. As accelerating factors, $c_1$and c_2 work to pull x 1 in one of two directions: $Pbest_i$ or $gbest_i$. For c_1 and c_2 to be scaled without using an absolute procedure, the $rand(\,)$ function generates two random values between [0, 1].

3.9 Particle swarm optimization parameters

PSO's tuning parameters include inertia weight w, particle number m, accelerate constants c_1 and c_2, maximum limiting velocity Vmax, maximum iteration number Tmax, and calculated precision ε. When it comes to choosing which parameters to utilize as controlling parameters, it's common to employ a combination of them. This is especially true when deciding whether or not to iterate further. [35]

3.10 Implementation of PSO

There is a random number generator in PSO, an evolutionary algorithm. The PSO algorithm's performance is influenced by the produced numbers' quantity and quality. The first iteration



is carried out throughout the whole search space. Fig.3.8 depicts the simplest form of PSO.

Fig. 3.8 Flow diagram illustrating the particle swarm optimization algorithm

The PSO algorithm uses the following steps:

1. Initiate the particles by setting their velocity and location in the search space to arbitrary values.
2. Begin computing the swarm particle fitness function's associated value.
3. Evaluate a particle's fitness using its best. If the current value is better, set pbest to the current n-dimensional position.
4. After that, compare the fitness value to the prior all-time high. If current value is better than gbest, reset gbest to the particle's array index and value.
5. Finally, apply these values to the swarm particle's respective location and velocity.

3.10.1 Advantages and disadvantages of PSO

1. As with other heuristic optimization approaches, PSO is a derivative-free method.
2. Using PSO is easier than using other heuristic optimization approaches.
3. PSO has a lesser sensitivity to the nature of the goal function than normal mathematical procedures and other heuristic methods.
4. The only parameters that PSO has in contrast to other heuristic optimization techniques are the inertia weight factor and two acceleration coefficients. According to some, the influence of parameters on replies is less sensitive than in other heuristic approaches.
5. If the convergence process is robust, PSO appears to be less reliant on an initial set of points than other evolutionary algorithms.
6. In comparison to other stochastic approaches, PSO techniques can produce high-quality solutions in a shorter amount of time with more steady convergence characteristics.

One of the main drawbacks of PSO is that it lacks an adequate mathematical basis for analysis. The development of ethical theories may help overcome this problem in the future. For real-time emergency department (ED) applications like 5-minute dispatch, the PSO is a stochastic optimization strategy that needs a longer calculation time than mathematical algorithms. The PSO-based method is expected to be useful for offline ED settings like day-ahead electricity markets. Other heuristic approaches, such as PSO, are regarded to have less impact on the final solution than those based on PSO.

However, it still has the drawbacks of depending on the starting point and parameters, establishing their optimal design parameters, and stochastic outcomes [36].

3.11 Summary

This chapter emphases the system modeling, this chapter divided into three parts

1. Mathematical modeling of the system
2. Design and implementation of the backward and forward sweep load-power flow system
3. Algorithm and working principle of the Particle Swarm Optimization

Chapter 4: Result and Discussion

4.1 Pre-compensation load flow

The data required for this study was collected from one electrical provider in the capital city of Burao. The electrical distribution system consists of 74 buses, and among those 74 buses, only five are connected with sources. The rest are connected to load and 71 transformers. The rated voltage of the feeders is 11 kV. So that we may know the power loss in the distribution system, we use one kind of load flow analysis called backward and forward. The table shown in the appendix, Table A:1, and Table A:2, displays the data for each feeder.

Before installing the capacitor shunt in the system, the bus data and line data are supplied in Table A:1 and Table A:2 shown in the appendix, respectively, as input for the MATLAB backward and forward load flow calculations. As shown in Table A.1, the distribution feeders directly monitor each transformer's active and reactive power. Unbalanced transformers are present. At the remaining nodes, the voltage exceeds the permitted limit (+/- 8 percent). Large distribution radial networks offer load buses located far from the substation with extremely low voltage. These low voltages will result in significant power losses and a decrease in load power factor. This radial distribution system node voltage limit violation may be minimized by putting shunt capacitors on distribution feeders. As depicted in Fig. 4.1 and Fig. 4.2, the active power and reactive power losses resulting from the system's total active power loss and reactive power loss are 6024.85 kW 3226.118 kVAr. The total apparent power loss in the system is 6834.22 kVA, which causes numerous issues, such as an increase in the cost of electricity.

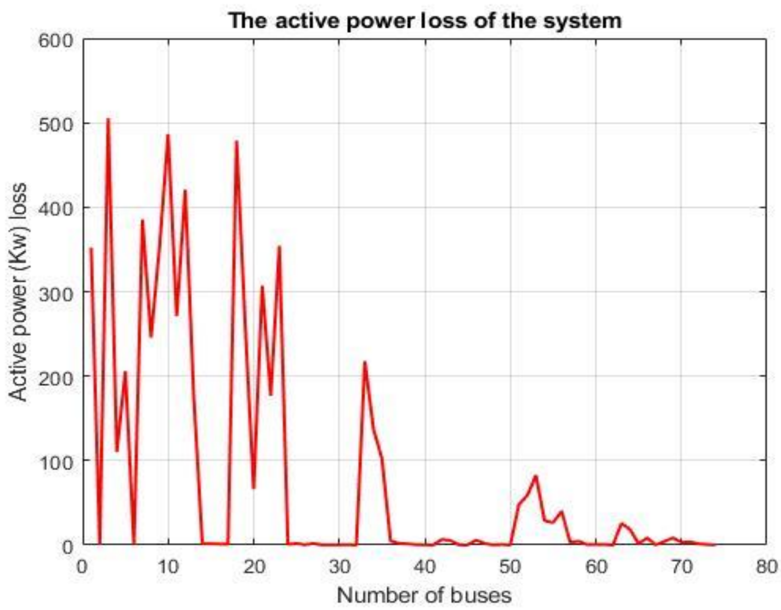


Fig. 4.1 Active power losses of the system

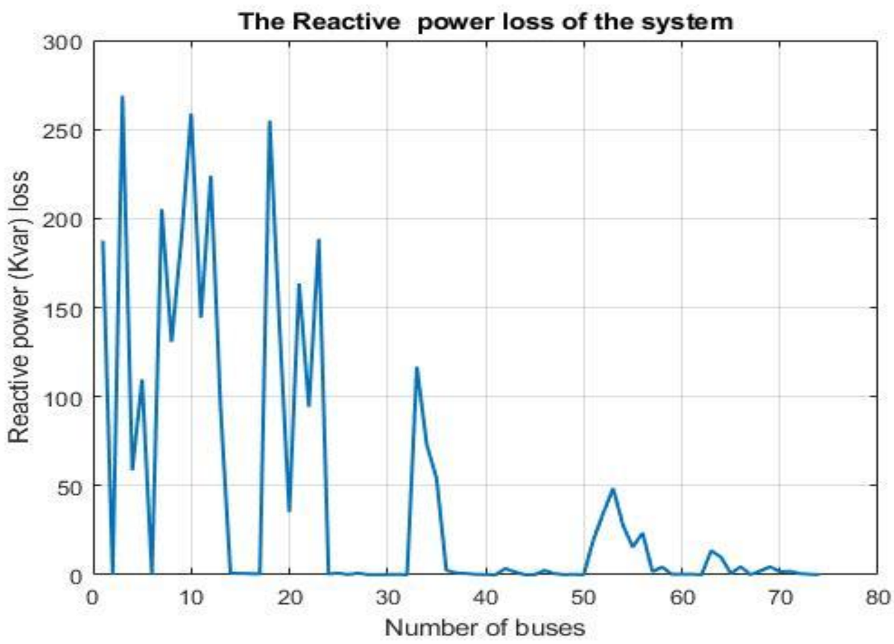


Fig. 4.2 Reactive power losses of the system

The overall system active and reactive power losses are Table A:3 shown in the appendix. Because of the connected loads, the losses at different system nodes are not similar. While some losses are tolerable, the majority surpasses a specific threshold, creating an economic concern due to the price differential between power transmitting and receiving. The system loses 6024.85 kW of active power and 3226.118 kVAr of reactive power.

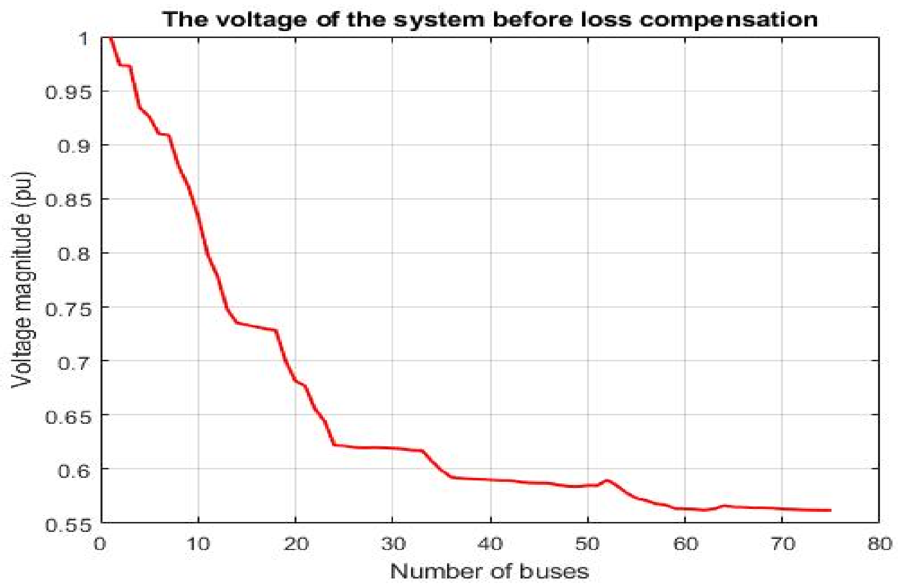


Fig. 4.3 Voltage magnitude before installed capacitor bank of the system

Table A:1 in the appendix reveals that certain transformers exceed their rated kVA and suffer from severe power losses, indicating that they are overloaded. With a total of 8223.19 KVA, the feeder has a total power consumption of 3822,68 MVAR. The voltage profiles of most buses, which are smaller than 0.8pu, may be shown in Table A:4 in the appendix and Fig. 4.3. The voltage exceeded the allowable threshold, resulting in a terrible position economically, with the cost of power equal to 0.67 US/kWh. To resolve this issue, the system required a technique of reactive power compensation that would minimize the system losses.

4.2 Load flow after compensation

The particle swarm optimization will identify the most suitable buses for the capacitor installation. The PSO selected 10 system buses to install the capacitor to compensate for the system reactive power loss. The value of the capacitors given in the Table 4.3 are the capacitors that the PSO selected for the system, but these capacitors are not available to the market. The rated standard is 900, 300, 500, 50, 750, 750, 700, 850, 1200, 1200. the best location the capacitor rated installed in the buses in the system is 3, 7, 9, 18, 25, 27, 52, 66, 71, and 74.

Table 4.1 Sizes of the capacitor system

Bus no	size of the capacitor (pu)	Size of the capacitor kVAr
3	0.5881	882.15
7	0.2325	348.75
9	0.2997	449.55
18	0.0421	63.15
25	0.5029	754.35
27	0.5054	758.1
52	0.4801	720.15
66	0.5662	849.3
71	0.7972	1195.8
74	0.8057	1208.55

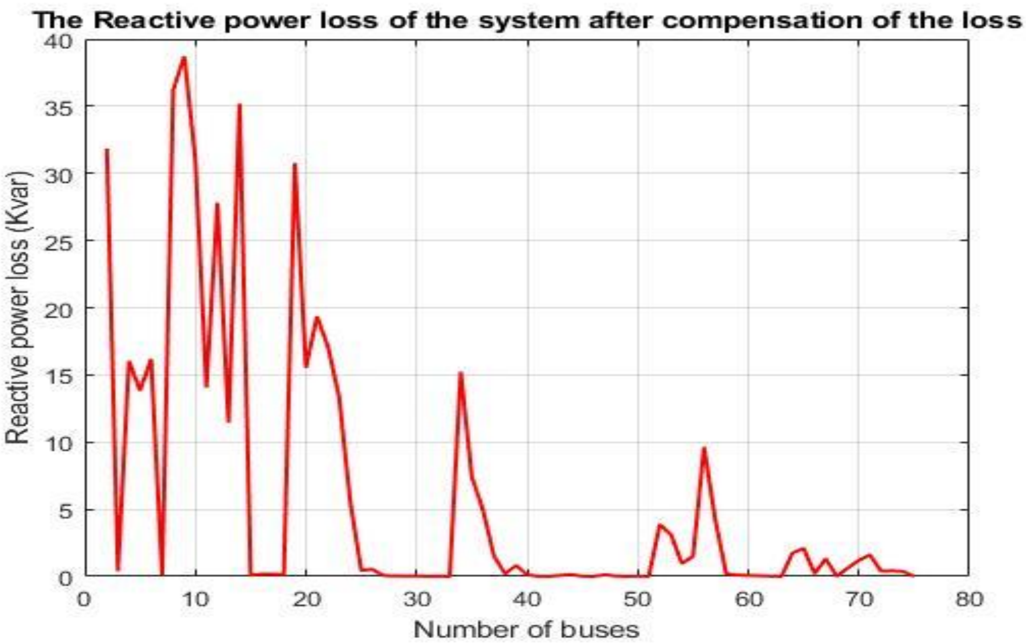


Fig. 4.4 Active power losses of the system after connected capacitor bank

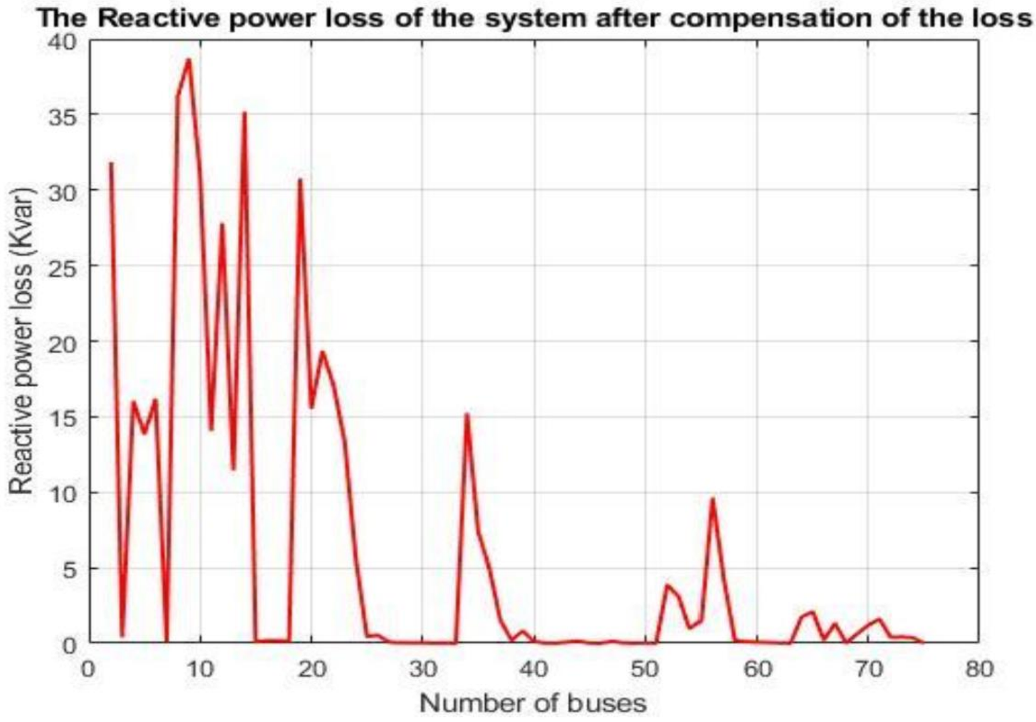


Fig. 4.5 Reactive power losses of the system after connected capacitor bank

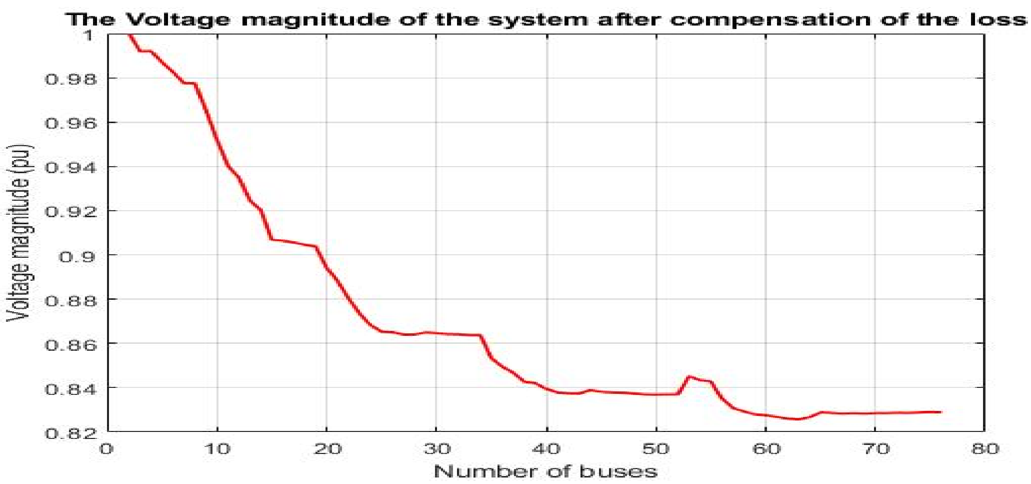


Fig. 4.6 Voltage magnitude of system after loss compensation

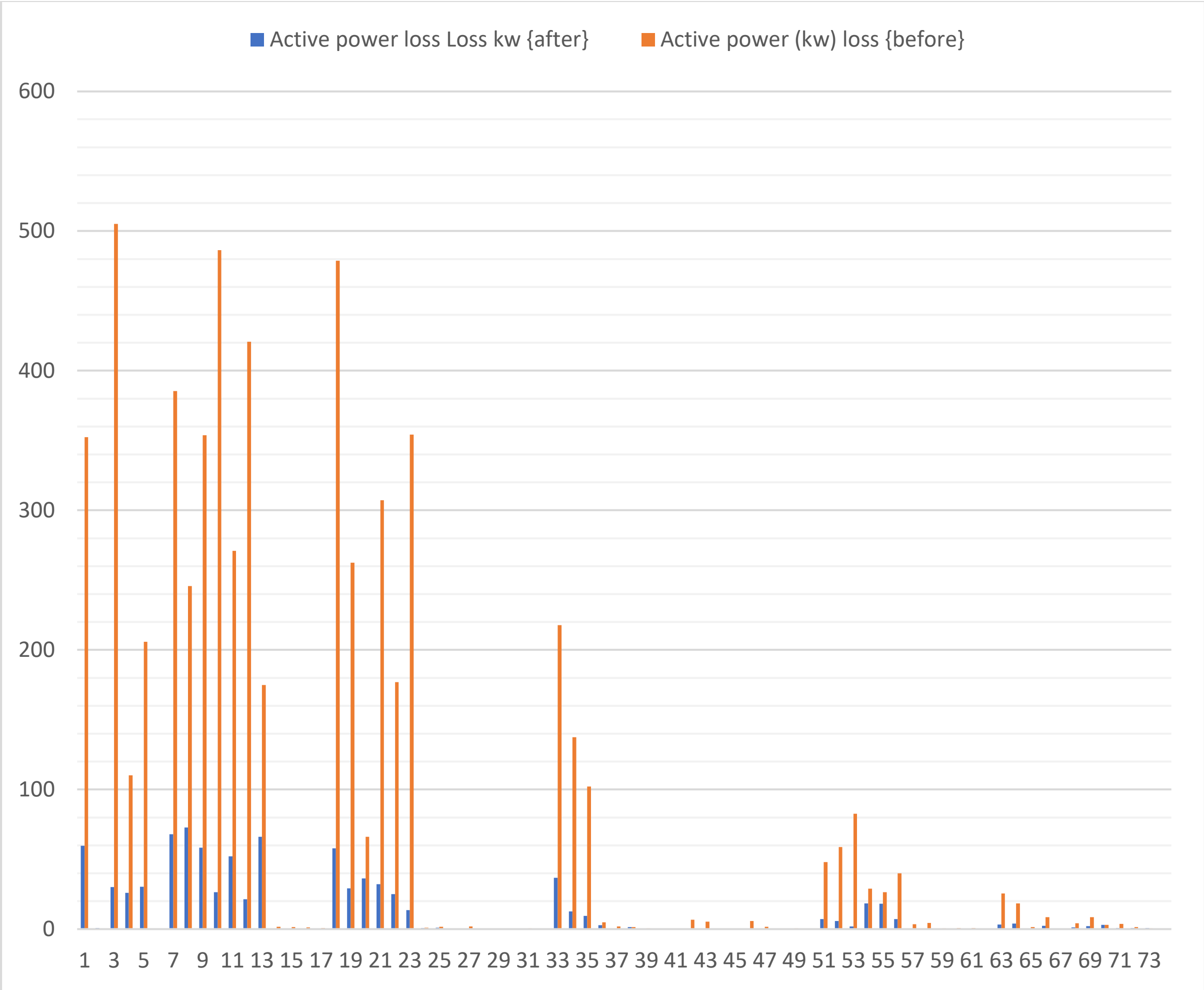


Fig. 4.7 Comparison of the active power before and after installing capacitor banks

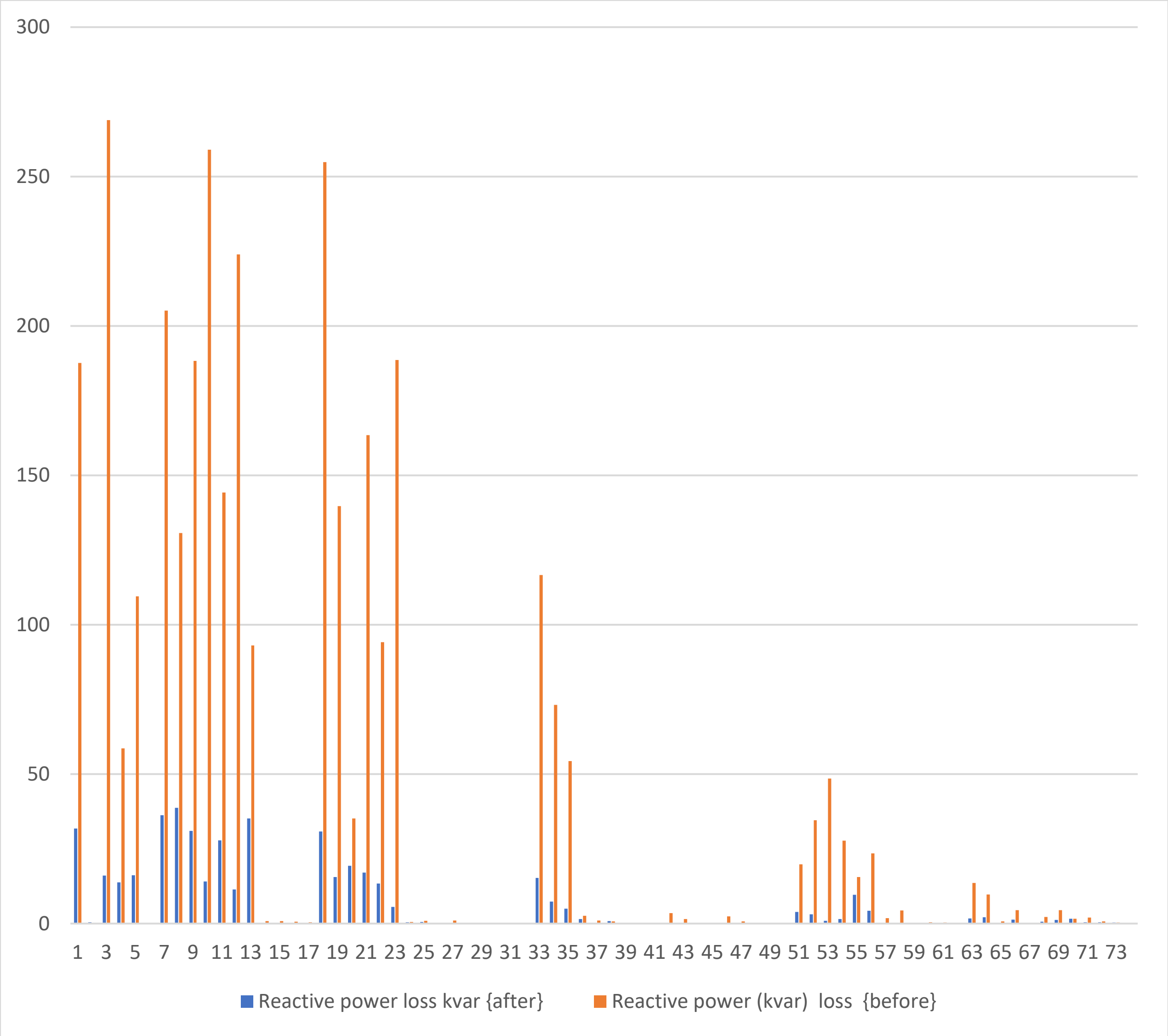


Fig. 4.8 Comparison of the reactive power before and after installing capacitor banks

Table A:3 and Table A:5 shown in the appendix illustrate the active and reactive power before and after the connected shunt capacitor. The power loss of the after-compensation of the losses is significantly less than the power loss before the shunt capacitor is connected. Fig 4.8 and Fig 4.9 illustrate the power loss difference before and after the shunt capacitor is connected and the voltage. The voltage profile of each bus in the system after the capacitor is installed shown in Table A:6. After correcting the system's power, the system's active and reactive power losses are 852.8 kW and 440 kVAr, respectively. Fig. 10 compares voltage change before and after installing capacitors in the distribution system. The total apparent power loss after compensation becomes 959.6 kVA.

Consequently, the 7229.85 kVar total shunt capacitor saves a total of 5,172 kW of power. The percentage amount improving the system became 85.95%. This result suggests that the capacitor has a good effect on the system; the system performs better once the capacitor is installed.

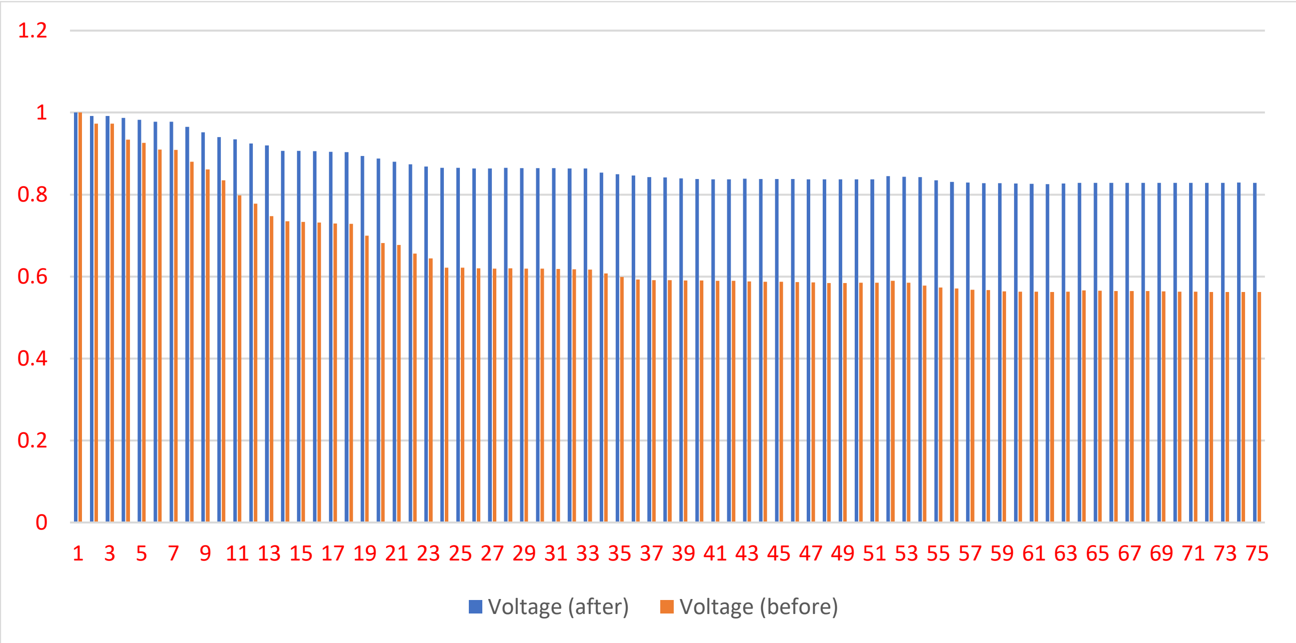


Fig. 4.9 Comparison of the voltage before and after installing capacitor banks

4.3 Analysis of the energy costs

Here is an explanation of how the feeder's cost is evaluated both before and after compensation. The following billing information is used for the purposes of the investigation.

a) In this study, only fixed capacitors are used maintenance, and operation costs are not included.
b) Electricity rate is 0.69/kwh for residential and commercial
c) Expenses associated with installing capacitors 700 USD
d) Life span 6 years

4.3.1 Expenses incurred due to energy waste

The energy loss of each bus of the system before capacitor installed in the system

Cost of energy loss = ∑ power loss × duration of time (in hours) ×

The cost of energy (per kWh)

Cost of energy loss = 6024.85 × 365 × 24 ×0.69 usd/kWh

Cost of energy loss = 36416603 USD

4.3.2 Capital expenses capacitor costs

The cost of a capacitor is divided into two categories: the fixed installation cost and the variable cost. The cost of a capacitor is stated as

$$\text{CECC} = \sum_{i=1}^{n} \text{ICC} + \text{C}_P \times \text{Q}_c$$

CECC = Capital expenses capacitor costs

ICC = Installation capacitor cost

C_P = Capacitor price per kVAr

Q_c = Capacitor rating of bus k in kVAr

Table 4.2 Selected buses and Capacitor rating

Selected buses	3	7	9	18	25	27	52	66	71	74
Capacitor rating kVAr	900	300	500	50	750	750	700	850	1200	1200

Table 4.3 Expenses of the capacitors

Bus no	Expenses of the capacitors
3	$ 4,300.00
7	$ 1,900.00
9	$ 2,700.00
18	$ 900.00
25	$ 3,700.00
27	$ 3,700.00
52	$ 3,500.00
66	$ 4,100.00
71	$ 6,200.00
74	$ 6,200.00
Total	$ 37,200.00

Cost of energy loss with capacitor = $852.8 \times 365 \times 24 \times 0.69$ =5154664 USD

Total cost after installing capacitor = 5154664+37200 = 5191864 USD

The system's overall cost savings

Saving = 36416603-5191864 = 31224739 USD

31224739 USD is saving per annum.

Chapter 5: Conclusion and Future Work

5.1 Conclusion

Shunt capacitors are commonly used in distribution systems to gain cost and operational advantages. Such advantages are very dependent on how and where these capacitors are positioned in the system. Shunt capacitors, although they minimize power losses, and enhance voltage profiles.

The issue of capacitor location and size was presented as a nonlinear integer optimization problem. It was thought about the discrete character of commercially accessible capacitor sizes. This project's study examined one goal of optimum capacitor bank location and size. Particle swarm optimization tackled the capacitor location and size challenge (PSO).

The simulation results reveal that when particle swarm optimization (PSO) is used in the system, 5874.66 kVA of power is saved. The use of shunt capacitors to reduce loss improves the voltage profile of the system. By installing 7229.85 kVAr shunt capacitors on the system's ten different buses, these power losses were reduced from 6834.22 kVA to 959.6 kVA. The percentage value decreases in the loss of the system after connecting the capacitor bank in the system became 85.95%, which was beneficial to both the company and the consumer.

It was discovered that using particle swarm optimization (PSO) to optimum capacitor placement on a radial distribution system may greatly minimize loss.

5.2 Future work

Future study will attempt to identify where the algorithm falls short in order to grasp any limits and apply it to the appropriate scenarios.

1. The PSO algorithm is quite good at searching, although it has a tendency to fall into local minimum solutions. More study is needed to consider ways to prevent issues before they occur.

2. The code takes seven minutes to execute on the laptop. The MATLAB code's efficiency will be improved in the future.

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Appendix A

Table A: 1 Bus data

Bus	P (kW)	Q (kVAr)	Transformer kVA	P(pu)	Q(pu)
1	0	0	0	0	0
2	132.4	49.2	300	0.088266667	0.0328
3	394.5	183.5	600	0.263	0.122333333
4	145.6	47.23	300	0.097066667	0.031486667
5	74.4	46.7	200	0.0496	0.031133333
6	0	0	0	0	0
7	217.2	107.5	300	0.1448	0.071666667
8	44.24	19.56	70	0.029493333	0.01304
9	163.2	59.1	300	0.1088	0.0394
10	87	19.2	100	0.058	0.0128
11	128.3	58.8	300	0.085533333	0.0392
12	90.1	44.5	300	0.060066667	0.029666667
13	161.23	70.12	300	0.107486667	0.046746667
14	90.2	49.7	300	0.060133333	0.033133333
15	96.4	49.4	200	0.064266667	0.032933333
16	52.2	21.1	100	0.0348	0.014066667
17	18.8	8.1	25	0.012533333	0.0054
18	425.12	230.5	630	0.283413333	0.153666667
19	78.23	29.1	300	0.052153333	0.0194
20	124.1	60.8	300	0.082733333	0.040533333
21	119	61.1	300	0.079333333	0.040733333
22	82.5	34.6	300	0.055	0.023066667
23	142.2	67.6	315	0.0948	0.045066667
24	0	0	0	0	0
25	230.1	84.1	500	0.1534	0.056066667
26	307.1	132.6	500	0.204733333	0.0884
27	236	124	300	0.157333333	0.082666667
28	86.1	35.2	200	0.0574	0.023466667
29	34.2	14.7	100	0.0228	0.0098
30	29.25	16.5	100	0.0195	0.011
31	56.3	27.39	100	0.037533333	0.01826
32	84.23	50.45	200	0.056153333	0.033633333
33	46.9	28.7	50	0.031266667	0.019133333
34	134.2	68.25	315	0.089466667	0.0455
35	125.1	70.43	315	0.0834	0.046953333
36	81.34	47.23	200	0.054226667	0.031486667
37	131.8	60.7	315	0.087866667	0.040466667
38	53.2	24.3	100	0.035466667	0.0162
39	0	0	0	0	0

40	145.1	75.1	200	0.096733333	0.050066667
41	58.45	24.2	100	0.038966667	0.016133333
42	77.2	37	100	0.051466667	0.024666667
43	18.6	9.1	25	0.0124	0.006066667
44	0	0	0	0	0
45	38	18.19	100	0.025333333	0.012126667
46	72.5	43.23	100	0.048333333	0.02882
47	54.4	31.1	100	0.036266667	0.020733333
48	56.3	30.2	100	0.037533333	0.020133333
49	152.5	80.1	200	0.101666667	0.0534
50	147.1	84	100	0.098066667	0.056
51	54.6	26.8	100	0.0364	0.017866667
52	373.6	134	800	0.249066667	0.089333333
53	96.1	35.5	100	0.064066667	0.023666667
54	85	40.1	300	0.056666667	0.026733333
55	94	47	200	0.062666667	0.031333333
56	95	47	200	0.063333333	0.031333333
57	0	0	0	0	0
58	24	11.5	30	0.016	0.007666667
59	145	64.6	200	0.096666667	0.043066667
60	0	0	200	0	0
61	112.4	50.4	300	0.074933333	0.0336
62	157.2	52.7	100	0.1048	0.035133333
63	88.2	42.8	200	0.0588	0.028533333
64	119	51	200	0.079333333	0.034
65	83.2	33.1	200	0.055466667	0.022066667
66	460	221	1600	0.306666667	0.147333333
67	26.5	15.3	100	0.017666667	0.0102
68	66.4	34.3	100	0.044266667	0.022866667
69	46.7	28.1	100	0.031133333	0.018733333
70	63.2	25.2	100	0.042133333	0.0168
71	233.1	103	630	0.1554	0.068666667
72	167	83	300	0.111333333	0.055333333
73	70.1	31	100	0.046733333	0.020666667
74	194	81	300	0.129333333	0.054
75	46	30.1	100	0.030666667	0.020066667

Table A: 2 Line data

Branch	Sending end	Receiving end	Conductor type	Length (km)	Resistance Ohm	Reactance Ohm	Resistance (pu)	Reactance (pu)
1	1	2	AAC-50	0.268	0.18224	0.097016	0.002259174	0.00120268
2	2	3	AAC-50	0.145	0.0986	0.05249	0.001222314	0.0006507
3	2	4	AAC-50	0.169	0.11492	0.061178	0.001424628	0.0007584
4	4	5	AAC-50	0.153	0.10404	0.055386	0.001289752	0.0006866
5	5	6	AAC-50	0.183	0.12444	0.066246	0.001542645	0.00082123
6	6	7	AAC-50	0.132	0.08976	0.047784	0.001112727	0.00059236
7	6	8	AAC-50	0.453	0.30804	0.163986	0.003818678	0.00203288
8	8	9	AAC-50	0.491	0.33388	0.177742	0.004139008	0.00220341
9	9	10	AAC-50	0.431	0.29308	0.156022	0.003633223	0.00193416
10	10	11	AAC-50	0.201	0.13668	0.072762	0.00169438	0.00090201
11	11	12	AAC-50	0.414	0.28152	0.149868	0.003489917	0.00185787
12	12	13	AAC-50	0.175	0.119	0.06335	0.001475207	0.00078533
13	13	14	AAC-50	0.565	0.3842	0.20453	0.00476281	0.0025355
14	14	15	AAC-50	0.134	0.09112	0.048508	0.001129587	0.00060134
15	15	16	AAC-50	0.355	0.2414	0.12851	0.002992562	0.0015931
16	16	17	AAC-50	0.453	0.30804	0.163986	0.003818678	0.00203288
17	17	18	AAC-50	0.356	0.24208	0.128872	0.003000992	0.00159759
18	14	19	AAC-50	0.622	0.42296	0.225164	0.005243306	0.00279129
19	19	20	AAC-50	0.321	0.21828	0.116202	0.00270595	0.00144052
20	20	21	AAC-50	0.413	0.28084	0.149506	0.003481488	0.00185338
21	21	22	AAC-50	0.375	0.255	0.13575	0.003161157	0.00168285
22	22	23	AAC-50	0.299	0.20332	0.108238	0.002520496	0.00134179
23	23	24	CU-25	0.121	0.113256	0.046827	0.001404	0.0005805
24	24	25	AAC-50	0.1269	0.086292	0.0459378	0.001069736	0.00056948
25	25	26	AAC-50	0.544	0.36992	0.196928	0.004585785	0.00244126
26	26	27	AAC-50	0.071	0.04828	0.025702	0.000598512	0.00031862
27	24	28	AAC-50	0.195	0.1326	0.07059	0.001643802	0.00087508
28	28	29	AAC-50	0.265	0.1802	0.09593	0.002233884	0.00118921
29	29	30	AAC-50	0.345	0.2346	0.12489	0.002908264	0.00154822
30	30	31	AAC-50	0.182	0.12376	0.065884	0.001534215	0.00081674
31	31	32	AAC-50	0.533	0.36244	0.192946	0.004493058	0.00239189
32	32	33	AAC-50	0.342	0.23256	0.123804	0.002882975	0.00153476
33	24	34	CU-25	0.644	0.602784	0.249228	0.007472529	0.0030896
34	34	35	AAC-95	0.37	0.2146	0.12617	0.002660331	0.00156409
35	35	36	AAC-50	0.243	0.16524	0.087966	0.00204843	0.00109049
36	36	37	AAC-50	0.871	0.59228	0.315302	0.007342314	0.0039087

37	37	38	AAC-50	0.143	0.09724	0.051766	0.001205455	0.00064173
38	38	39	AAC-50	0.68	0.4624	0.24616	0.005732231	0.00305157
39	39	40	AAC-50	1	0.68	0.362	0.012396694	0.0044876
40	40	41	AAC-50	0.632	0.42976	0.228784	0.005327603	0.00283617
41	41	42	AAC-50	0.262	0.17816	0.094844	0.002208595	0.00117575
42	39	43	AAC-25	0.138	0.184644	0.05244	0.002288975	0.00065008
43	43	44	AAC-50	0.264	0.17952	0.095568	0.002225455	0.00118473
44	44	45	AAC-50	0.697	0.47396	0.252314	0.005875537	0.00312786
45	45	46	AAC-50	0.121	0.08228	0.043802	0.00102	0.000543
46	44	47	AAC-50	0.372	0.25296	0.134664	0.003135868	0.00166939
47	47	48	AAC-50	0.471	0.32028	0.170502	0.003970413	0.00211366
48	48	49	AAC-50	0.0991	0.067388	0.0358742	0.000835388	0.00044472
49	47	50	AAC-50	0.372	0.348192	0.134664	0.00431643	0.00166939
50	50	51	CU-25	0.126	0.117936	0.048762	0.001462017	0.00060449
51	36	52	AAC-50	0.234	0.15912	0.084708	0.001972562	0.0010501
52	52	53	AAC-95	0.303	0.20604	0.109686	0.002554215	0.00135974
53	53	54	AAC-95	0.096	0.06528	0.034752	0.000809256	0.00043081
54	54	55	AAC-95	0.151	0.67592	0.054662	0.008379174	0.00067763
55	55	56	AAC-95	0.994	0.67592	0.359828	0.008379174	0.00446068
56	56	57	AAC-95	0.475	0.2755	0.161975	0.003415289	0.00200795
57	57	58	AAC-50	0.625	0.425	0.22625	0.005268595	0.00280475
58	58	59	AAC-50	0.194	0.13192	0.13192	0.001635372	0.00163537
59	59	60	AAC-50	0.523	0.35564	0.189326	0.00440876	0.00234702
60	60	61	AAC-50	0.716	0.48688	0.259192	0.006035702	0.00321312
61	61	62	AAC-50	0.7	0.476	0.2534	0.005900826	0.00314132
62	60	63	AAC-50	0.273	0.18564	0.098826	0.002301322	0.00122512
63	57	64	AAC-50	0.193	0.13124	0.069866	0.001626942	0.00086611
64	64	65	AAC-50	0.234	0.15912	0.084708	0.001972562	0.0010501
65	65	66	AAC-50	0.323	0.21964	0.116926	0.00272281	0.0014495
66	65	67	AAC-50	0.273	0.18564	0.098826	0.002301322	0.00122512
67	67	68	AAC-50	0.552	0.37536	0.199824	0.004653223	0.00247716
68	67	69	AAC-50	0.129	0.08772	0.046698	0.001087438	0.0005789
69	69	70	AAC-50	0.243	0.16524	0.087966	0.00204843	0.00109049
70	70	71	AAC-50	0.325	0.221	0.11765	0.002739669	0.00145847
71	71	72	AAC-50	0.341	0.23188	0.123442	0.002874545	0.00153027
72	72	73	AAC-50	0.339	0.23052	0.122718	0.002857686	0.0015213
73	73	74	AAC-50	0.291	0.19788	0.105342	0.002453058	0.00130589
74	74	75	AAC-50	0.252	0.17136	0.091224	0.002124298	0.00113088

Table A:3 Active power and reactive power losses before installing capacitor

Bus no	Active power (kW) loss	Reactive power (kVAr) loss
1	352.3014	187.5739
2	0.1405	0.0747
3	505.1985	268.883
4	110.1802	58.6485
5	205.8596	109.5579
6	0.2653	0.1412
7	385.2901	205.1545
8	245.6252	130.6939
9	353.7108	188.2596
10	486.4127	258.9758
11	270.964	144.2284
12	420.6855	223.9645
13	174.7595	93.0666
14	1.6063	0.855
15	1.4949	0.7958
16	1.2065	0.6424
17	0.8733	0.4649
18	478.7456	254.875
19	262.3988	139.684
20	66.0662	35.1837
21	307.0813	163.4839
22	176.82	94.1425
23	354.2699	188.6002
24	0.9713	0.5166
25	1.7421	0.9273
26	0.3231	0.1731
27	1.8466	0.9897
28	0.1055	0.0565
29	0.3034	0.1626
30	0.2978	0.1596
31	0.5063	0.2713
32	0.0147	0.0079
33	217.6828	116.6832
34	137.5348	73.2183
35	102.047	54.3492
36	4.8428	2.5777
37	1.9148	1.0197
38	1.3778	0.7323
39	0.5098	0.2714
40	0.2671	0.1422
41	0.0136	0.0073

42	6.6412	3.5353
43	5.351	1.5471
44	0.1353	0.0559
45	0.0804	0.0332
46	5.8821	2.4322
47	1.7545	0.7255
48	0.2068	0.0855
49	0.6312	0.2609
50	0.0364	0.0151
51	48.0201	19.8659
52	58.8419	34.5951
53	82.578	48.5478
54	28.8637	27.7608
55	26.5151	15.5971
56	39.9448	23.489
57	3.4073	1.8143
58	4.3768	4.3768
59	0.514	0.2736
60	0.7255	0.3863
61	0.6534	0.3478
62	0.0346	0.0184
63	25.5198	13.5838
64	18.3592	9.773
65	1.4	0.7454
66	8.468	4.5074
67	0.0681	0.0362
68	4.1939	2.2328
69	8.4923	4.5203
70	3.0992	1.6506
71	3.7854	2.0151
72	1.3757	0.7325
73	0.5981	0.3184
74	0.0433	0.0231

Table A:4 Voltage magnitude of the system before installed capacitor

Bus no	Voltage	Bus no	Voltage	Bus no	Voltage
1	1	26	0.8641	51	0.837
2	0.9919	27	0.8641	52	0.8452
3	0.992	28	0.865	53	0.8434
4	0.9869	29	0.8647	54	0.8429
5	0.9826	30	0.8643	55	0.8352
6	0.9775	31	0.8642	56	0.8308
7	0.9775	32	0.8638	57	0.8293
8	0.9651	33	0.8638	58	0.828
9	0.9519	34	0.8534	59	0.8276
10	0.9403	35	0.8496	60	0.8268
11	0.935	36	0.8467	61	0.8261
12	0.9245	37	0.8427	62	0.8257
13	0.9202	38	0.8421	63	0.8267
14	0.9068	39	0.8395	64	0.8289
15	0.9064	40	0.8379	65	0.8286
16	0.9055	41	0.8375	66	0.8283
17	0.9046	42	0.8374	67	0.8285
18	0.9038	43	0.8389	68	0.8283
19	0.8943	44	0.8382	69	0.8285
20	0.888	45	0.8379	70	0.8285
21	0.8803	46	0.8378	71	0.8287
22	0.8735	47	0.8374	72	0.8286
23	0.8683	48	0.837	73	0.8288
24	0.8653	49	0.8369	74	0.829
25	0.8651	50	0.837	75	0.8289

Table A:5 Active power loss and reactive power loss after installed the capacitor

Bus no	Active power (kW) loss	Reactive power (kVAr) loss
1	59.8211	31.8459
2	0.7394	0.3936
3	30.111	16.0297
4	25.9868	13.8342
5	30.3802	16.173
6	0.1149	0.0611
7	68.0532	36.2283
8	72.7113	38.7081
9	58.3369	31.0558
10	26.4161	14.0627
11	52.24	27.8101

12	21.4919	11.4413
13	66.0947	35.1857
14	0.1731	0.0921
15	0.3228	0.1718
16	0.3333	0.1774
17	0.2419	0.1288
18	57.8019	30.771
19	29.1674	15.5273
20	36.357	19.3547
21	32.1042	17.0907
22	25.1015	13.3629
23	13.5621	5.6074
24	0.8464	0.4506
25	0.9928	0.5285
26	0.119	0.0633
27	0.0758	0.0403
28	0.0589	0.0313
29	0.0581	0.0309
30	0.023	0.0122
31	0.034	0.0181
32	0.0028	0.0015
33	36.8426	15.233
34	12.5949	7.4049
35	9.3726	4.9895
36	2.8567	1.5208
37	0.362	0.1927
38	1.5352	0.8172
39	0.3315	0.12
40	0.0324	0.0173
41	0.0044	0.0024
42	0.287	0.0815
43	0.2622	0.1396
44	0.0257	0.0137
45	0.002	0.0011
46	0.2408	0.1282
47	0.0607	0.0323
48	0.0068	0.0036
49	0.0628	0.0243
50	0.0015	0.0006
51	7.259	3.8644
52	5.8423	3.1102
53	1.8035	0.9601
54	18.3583	1.4846
55	18.0859	9.6281

56	7.2682	4.2732
57	0.36	0.1916
58	0.1015	0.1015
59	0.1372	0.073
60	0.1047	0.0557
61	0.0338	0.018
62	0.0046	0.0025
63	3.2593	1.7351
64	3.9307	2.0925
65	0.3904	0.2078
66	2.4729	1.3165
67	0.0053	0.0028
68	1.1832	0.6299
69	2.2515	1.1986
70	3.0245	1.6101
71	0.7602	0.4047
72	0.7869	0.4189
73	0.692	0.3684
74	0.0013	0.0007

Table A:6 Voltage magnitude of the system after installed capacitor

Bus no	Voltage	Bus no	Voltage	Bus no	Voltage
1	1	26	0.8641	51	0.837
2	0.9919	27	0.8641	52	0.8452
3	0.992	28	0.865	53	0.8434
4	0.9869	29	0.8647	54	0.8429
5	0.9826	30	0.8643	55	0.8352
6	0.9775	31	0.8642	56	0.8308
7	0.9775	32	0.8638	57	0.8293
8	0.9651	33	0.8638	58	0.828
9	0.9519	34	0.8534	59	0.8276
10	0.9403	35	0.8496	60	0.8268
11	0.935	36	0.8467	61	0.8261
12	0.9245	37	0.8427	62	0.8257
13	0.9202	38	0.8421	63	0.8267
14	0.9068	39	0.8395	64	0.8289
15	0.9064	40	0.8379	65	0.8286
16	0.9055	41	0.8375	66	0.8283
17	0.9046	42	0.8374	67	0.8285
18	0.9038	43	0.8389	68	0.8283
19	0.8943	44	0.8382	69	0.8285
20	0.888	45	0.8379	70	0.8285

21	0.8803	46	0.8378	71	0.8287
22	0.8735	47	0.8374	72	0.8286
23	0.8683	48	0.837	73	0.8288
24	0.8653	49	0.8369	74	0.829
25	0.8651	50	0.837	75	0.8289