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INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO.: M-388-MSREE-2021-2024

Performance Enhancement of Radial Distribution Network with Optimal Placement of Capacitor Bank: A Case study of Butwal West Distribution Feeder with Scenario Study of Electric Vehicle Charging Station

By

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(PUL/078/MSREE/017)

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THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

JUNE, 2024

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Performance Enhancement of Radial Distribution Network with Optimal Placement of Capacitor Bank: A Case study of Butwal West Distribution Feeder with Scenario Study of Electric Vehicle Charging Station"** submitted by Subash Pandey (078MSREE017) in partial fulfillment of the requirement for the degree of Masters of Science in Renewable Energy Engineering.

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ACKNOWLEDGEMENT

I want to express my deep gratitude to my supervisors, Associate Professor Mahammad Badrudoza, Department of Electrical Engineering, and Assistant Professor Sanjaya Neupane, Department of Mechanical and Aerospace Engineering from Pulchowk Campus, Tribhuvan University for their exceptional guidance, constant encouragement, and careful mentoring throughout my thesis work which has been extremely valuable.

I am also extremely grateful to Associate Professor Dr. Hari Bahadur Darlami, the MSc. Program Coordinator for MSREE, and Assistant Professor Dr. Sudip Bhattarai, the Head of the Department of Mechanical and Aerospace Engineering at Pulchowk Campus, IOE, TU, for their wonderful support and guidance. I am grateful for the helpful input from Assistant Professor, Sahabuddin Khan during this study. Additionally, I am thankful to Rabindra Maharjan Ph.D., Director at Equagen Engineers for his valuable support and guidance during this project.

I would like to extend my thankfulness to the Engineer of Butwal DCS Er. Binod Sharma for providing support with the necessary data and elaboration required for the modeling of the system. I would like to thank Er. Manoj Joshi and Er. Prashanta Poudel for their valuable support during this project. Moreover, I am thankful for and fortunate enough to get continuous encouragement, support, and guidance from all Teaching staff of the Department of Mechanical and Aerospace Engineering and Department of Electrical Engineering, Pulchowk Campus, IOE, TU which helped me in this study.

Finally, I extend my sincere appreciation to all my acquaintances, colleagues, family members, and individuals who have directly or indirectly contributed their valuable support, suggestions and guidance in the course of this research.

ABSTRACT

Minimization of Power Loss, enhancing cost savings, and improving the performance of the distribution network are important areas in the power system due to degrading power quality on consumers' end, financial loss of utility due to heavy power loss and unbalance of reactive power in the distribution network. One of the best method to enhance the efficiency and performance of the distribution system is by optimal sizing and placement of a capacitor bank. In this thesis, the Particle Swarm Optimization (PSO) algorithm is used to determine the size of the capacitor bank and candidate bus for placement of the capacitor. The objective function is adopted to minimalize the total cost of energy and enhance the cost saving.

Initially, the standard IEEE 33 bus radial distribution system is considered without compensation (without capacitor bank) and Load Flow analysis is carried out using the PSO algorithm and ETAP software and the performance of the distribution network is determined. Then, the optimal sizing and placement of the capacitor bank are determined using the PSO algorithm based on LSI values. Now, the simulation is performed with compensation, and the performance of the system is analyzed and compared with and without compensation cases. Finally, a similar procedure is implemented in the Butwal West Radial distribution feeder with and without considering the Electric Vehicle (EV) charging station present in the feeder. The improvement in voltage profile, Power Loss reduction and Voltage regulation were compared and analyzed after the placement of the capacitor bank in the actual Feeder.

The result obtained by the proposed approach has been found to enhance the performance of the Butwal West distribution Feeder by reducing voltage drop, power losses and improving the voltage regulation of the feeder. The test was performed in two cases for the IEEE 33 bus system ie with and without compensation. In Butwal West Feeder, Case I: Without EV charging Loads and Case II: Considering EV charging Loads was taken into consideration. In the IEEE 33 bus system, active and reactive power loss reduction was obtained to be 30.33% and 28.39% respectively after compensation. Similarly, after compensation Voltage Regulation was improved to 5.3% from 9.62%. Likewise, In Case I of Butwal West feeder minimum voltage of 83.4% in Bus 71 was improved to 95.2% after compensation. Active power and Reactive power loss were reduced by 10.19% and 10.74% respectively after compensation. Voltage Regulation was improved from 13.93% to 3.93% after compensation. In case II of the Butwal west feeder, the voltage at bus 71 was 83.0% before compensation which was improved to 95.5% after compensation. Likewise, Voltage regulation was found to improve from 14.25% to 3.63% after the placement of capacitor bank. The financial analysis was carried out for Case II of Butwal West Distribution Feeder to determine the financial feasibility of the project. The financial metrics such as BC Ratio, IRR, and Discounted Payback period were found to be 2.45, 18%, and 4.15 years respectively. The sensitivity analysis indicates that the cost of power savings and the cost of capacitor banks were the most sensitive parameters affecting the financial performance of capacitor bank installations. Likewise, the Monte Carlo Simulation analysis provided confidence in the investment decision highlighting financial benefits for the optimal placement of the capacitor bank in the Butwal West Radial Distribution Feeder.

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LIST OF ABBREVIATIONS

FY	Fiscal Year
NEA	Nepal Electricity Authority
kV	Kilo Volt
kVAr	Kilo Volt Ampere Reactive
MW	Mega Watt
kW	Kilo Watt
MATLAB	Matrix Laboratory
IEEE	Institute of Electrical and Electronics Engineers
PSO	Particle Swarm Optimization
BIBC	Branch Injection to Branch Current
BCBV	Branch Current to Branch Voltage
ETAP	Electrical and Transient Analysis Program
P_{best}	Personal Best
G_{best}	Global Best
BFS	Backward Forward Sweep
KVL	Krichoff's Voltage Law
KCL	Krichoff's Current Law
LSI	Loss Sensitivity Index
EV	Electric Vehicle
AC	Alternating Current
DC	Direct Current
SLD	Single Line diagram
pu	Per Unit
NPV	Net Present Value
BCR	Benefit Cost Ratio
IRR	Internal Rate of Return
DG	Distributed Generation

CHAPTER ONE: INTRODUCTION

1.1 Background

A Power system refers to the interconnected network that facilitates the generation, transmission, and distribution of electrical energy from power plants to end-users. Generating stations such as hydropower plants, solar, thermal, nuclear, wind, etc are the major sources of electrical energy. The transmission system provides an electrical path to transmit power generated at the generating station to distribution centers. Distribution systems are responsible for carrying out electrical power to different levels of consumers. So, it is a great challenge to supply electricity to the highest possible quality and reliability in a country like ours as the generating station and load center are distantly located from each other leading to higher system loss.

Generation is the first stage where the electrical energy is generated from hydropower plants, thermal stations, solar PV, wind farms, etc. According to NEA, in FY 2079/080 the country's existing generation capacity is 2759 MW which is 491.28 MW more than FY 2078/079. Over a year, the country successfully, integrated electricity from 21 hydropower and 6 solar power plants into the transmission system. Several projects with a combined capacity of around 5000 MW are under construction. At present, the total installed capacity for the generation of electrical energy is 2,189,918 KW which comprises hydropower 2,081,788 kW, Thermal 53,410 kW, and Solar 54,720 kW (both NEA and IPP). [1]

The transmission line carries electrical energy at high voltage from the generating station to the load center. It bridges an important link between the generation and distribution system. The transmission line ranges from 66 kV to 400 kV in Nepal. The first ever 400 kV transmission line has played a major role in the Power Trade Agreement (PTA) between Nepal and India. In fiscal year 2079/080, the total length of transmission lines (includes 66 kV, 132 kV, 220 kV and 400 kV) reached 5742 km which was 5329 km in FY 2078/079. Likewise, the capacity of the substation was increased by 1718 MVA in FY 2079/080 in comparison to FY 2078/079. Besides these, NEA is increasing the total installation capacity of the capacitor bank to 748.644 MVAr. This improves the reliable transmission of electrical energy to various levels of consumers through a distribution system. [1]

The distribution system carries transmitted electrical energy to several consumers through various feeders. According to the annual report of NEA 2080, the total number of consumers is 5,134,058 and annual energy sales comprise 9,365.40 GWh. In FY 2079/080, the distribution losses were reduced by a narrow margin to 9.76 % which was 10.86% in FY 2078/079. Domestic consumers are the largest electricity-consuming group in the country. Increasing the use of modernized cooking practices, heating and cooling systems, EVs, etc in large numbers demands the upgradation of the distribution network, installation of reactive power compensators such as Capacitor banks to maintain the voltage drop within permissible limit and enhance the quality and reliability of electrical energy.

It is crucial to supply quality electrical energy to all the consumers with a higher degree of reliability and efficiency. As set by NEA, the standard voltage tolerance level in the distribution system is 5% and that of frequency is 2.5%. Good power factor and voltage regulation are necessary to maintain the quality of the power supply. This results in a lower voltage drop and the losses are minimal. If the losses in the distribution system are higher, then compensating techniques must be implemented to maintain power quality within set standards.

Voltage regulation is the important parameters that determine the quality of electrical energy at the distribution level. It is desirable to have a value of voltage regulation as low as possible to maintain the quality of supply. Generally, Voltage regulation of 10% or below is considered a good voltage regulation from a power quality point of view.

In alternating current (AC) systems, both active (real) and reactive power play crucial roles. Active power performs useful work or generates heat, while reactive power maintains electric and magnetic fields in equipment like motors and generators. Lack of reactive power can lead to voltage collapse and system failures, highlighting its importance for system reliability. Reactive power also enhances the delivery efficiency of active power to consumers. As reactive power flows through distribution feeders alongside active power, it increases total current flow and causes voltage drop and losses. By reducing reactive power flow, system losses decrease, and line capacity increases without requiring infrastructure upgrades. Various sources such as synchronous condensers, generators, and transmission equipment provide reactive power, which can be compensated using capacitors and other devices. To enhance voltage profile and the quality of electrical energy, the installation of a capacitor bank near the load center is essential. The size of the capacitor and its placement in distribution should be optimal otherwise, it may result in undercompensation or overcompensation of reactive power in the network which is not desirable for better power quality. So optimal allocation of capacitor banks helps to limit reactive power flow, lower losses, and improve voltage profiles, enhancing system efficiency. In summary, reactive power management is crucial for maintaining system stability, reducing losses, and improving efficiency in AC power systems. By strategically compensating for reactive power, voltage levels can be enhanced, and system performance optimized without the need for extensive infrastructure upgradation.

1.2 Problem Statement

The demand for electrical energy is growing day by day. Due to this most of the Nepalese distribution feeders are facing huge technical and non-technical losses resulting in inefficiencies in system operation. The increase of several significant loads at the consumer's premises directly impacts the performance of the distribution system. This has increased the consumption of electrical energy, increasing line current and thus increasing the power loss in the conductor. This further results in Poor voltage regulation, degrading power quality, more voltage drop, and thus resulting poor Voltage profile. These types of effects are more pronounced in the case of the Radial distribution network. This demands for the enhancement and upgradation of transmission and distribution capability. In Nepal, almost all the distribution nature are of the Radial type which mostly experiences problems of power loss and voltage drop largely below the standard limit generally at the extreme ends of the distribution system.

As per NEA, the standard Voltage tolerance level in the distribution system is 5%. Similarly, the voltage regulation of the distribution system should not deviate by more than 10 % of its normal value to maintain power quality. However, the voltage regulation of the Butwal West Distribution feeder often fails to meet the standard set by NEA resulting in a larger voltage drop in the consumer's end especially in the far end of the substation. The several problems that consumers constantly face with large voltage drops are equipment damage, inefficient performance of electrical devices, and issues of power quality. At the same time, the utility also faces huge power loss resulting in uneconomic performance of the power system. So to cope with this problem, compensating devices such as Capacitor bank plays a vital role. These capacitor banks are installed in the load centers. The capacitor bank to be placed in the distribution network should be of optimal size and their placement should be optimal otherwise, it might result in the problem of under compensation or over compensation in the distribution network degrading the power quality.

1.3 Objectives

1.3.1 Main Objectives

The main objective of this research is to enhance the performance of the Butwal West Radial distribution feeder by optimal sizing and placement of capacitor bank along with a scenario study considering EV charging stations.

1.3.2 Specific Objectives

The specific objectives of this research include;

- To determine the optimal bus and size of capacitor bank for the IEEE 33 bus system and Butwal West distribution Feeder.
- To study voltage drop, Voltage profile and Voltage Regulation of the distribution feeder.
- To study the total power losses and improve the power quality of the distribution Network.
- To perform financial analysis after the optimal allocation of the capacitor bank in the actual distribution Feeder.

1.4 Rationale

At present, the major challenges that electrical utilities are facing while supplying electrical energy at consumer ends from distribution substations are high voltage drop, power loss, poor voltage regulations, poor voltage profile, low reliability and poor power quality. So it is of prime importance to enhance the performance of the distribution network to maintain the power quality within standard limits. The improvement in voltage profile, power quality, and reduction in losses can be achieved with several techniques such as optimal placement of capacitor bank, installation of compensating devices such as FACTs, upgradation, reconfiguration of distribution feeder, and load balancing in the transformer. [2]

The study performs the technical as well as economic analysis of optimal sizing and allocation of capacitor bank in distribution feeder to minimize the total power loss, enhance voltage profile, improve voltage regulation, reduce voltage drop, and improve power quality. Butwal west Radial distribution feeder is considered in this thesis to enhance the system performance.

1.5 Limitations

The limitations of this thesis include;

- The study does not consider the no load case and variation of load over different periods.
- This study is confined to a 3-phase distribution system and does not consider load growth patterns.
- The cost of capacitor, maintenance & installation cost, and cost of energy may vary with market price with some margins.
- The reliability assessment of the distribution feeder was not performed before and after compensation.

CHAPTER TWO: LITERATURE REVIEW

2.1 Optimization

The optimization method is a influential tool to obtain the accurate and anticipated design parameters with the best sets of operating conditions. This helps to reduce the possible errors and risks during the design and operation of various engineering works. It refers to determining the values of decision variables which assists in determining the maximum & minimum values of desired objectives. The accuracy and reliability of the solution obtained from the optimization depend upon the objective function and optimization technique selected. To describe and predict the process model it requires a mathematical model. Optimization search helps to determine the unknown parameters in case of complex non-linear processes. A robust optimization process can determine the uncertainty variables in a dynamic process. The efficiency of design & operation, engineering, and manufacturing activities cannot be achieved without the implementation of optimization. [3]

The application of optimization techniques helps in finding better designs a& decisions, faster designs & evaluations, automating routine decisions and useful for trade-off analysis, Non-intuitive designs may be found. A schematic diagram showing the working of the design process in MATLAB is represented below.

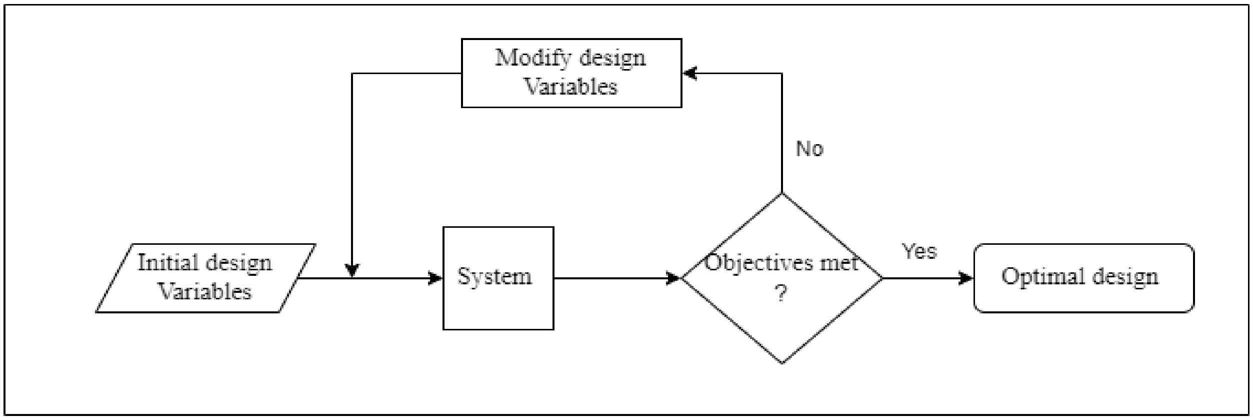


Figure 2.1: Block representation of design process using Optimization Technique [4]

2.2 Methods of Computation Techniques

This paper presented a newer approach for the optimal allocation of DG and DSTATCOM in the radial distribution system. The objective function was expressed with equality and inequality constraints to minimalize the total power losses in the network. Voltage stability index (VSI) &loss sensitivity factor (LSF) were considered to determine the placement of DSTATCOM and DG respectively. The optimal size of DG and DSTATCOM was obtained using the Cuckoo Search algorithm. In this research, five different cases were considered for the system i.e.; without DG & DSTATCOM units, with only DG, with only DSTATCOM, single DG and DSTATCOM, and multiple DG & DSTATCOM to assess the effectiveness of the proposed technique. To determine the feasibility, the proposed method is tested on IEEE 34 bus, 12 bus & 69 bus systems. The obtained results were then compared with other existing techniques. [5]

In this paper, the IEEE 10 bus system was employed as a test bus system for validation by comparing outcomes with other published research papers. The same methodology was implemented in the Jomsom distribution feeder to improve the performance of the distribution feeder with optimal allocation of the capacitor and analyzed the impact of injection of grid-connected wind power plant and solar PV system. The bus voltage at every node, voltage regulation, Voltage profile, Power losses and total annual costs were compared for both cases with and without the application of capacitor bank and DERs. The annual cost saving was computed in both cases. The power losses were found to be reduced by 18.5% & 14.5% for the IEEE 10 bus system and Jomsom feeder with the optimal allocation of the capacitor bank in the feeder. For the IEEE 10 bus system, the voltage regulation was found to improve from 16.25% to 11.63% and for the Jomsom feeder, it was improved from 18.24% to 5.54% after the optimal allocation of the capacitor bank. The saving in annual cost was found to be $23,955.084 for the IEEE bus system and $3,806 for the Jomsom feeder after the optimal allocation of the capacitor bank in the distribution system. Similarly, the injection of DERs in the distribution system was found to enhance the voltage profile & reduce the power loss in the system. [6]

A good quality power system must have a small power loss and remain within the tolerance limit. The tolerable voltage limit is considered between 1.05 and 0.95 Pu. Here, this paper aims to enhance the power quality of of Bosowa cement factory by implementation of capacitor bank. Here, the focus is on determining the optimal placement and allocation of the capacitor bank to improve the voltage profile and reduce power loss by implementing a Genetic Algorithm (GA). A model is presented to allocate the capacitor bank to compensate for the reactive power in the network. Several simulation for power flow is carried out with and without compensation to optimize the size and placement of the capacitor bank with financial analysis. The simulation yield requirement of 7.4 kVar of 73 capacitors with each capacitor size of 100 kVar to enhance the power quality of the Bosowa cement factory. The placement of a capacitor bank reduced the power loss of 100 kW from 901 kW to 801 kW. [7]

This paper highlighted the performance of the radial distribution network after the incorporation of single and multiple PV systems in the network with various levels of load. The system voltage profile was enhanced and total power losses were reduced significantly with the best location & size of PV in the system. A loss sensitivity factor and an Augmented gray wolf optimizer algorithm were implemented to determine the PV placement. The IEEE 69 bus system was used to validate the proposed algorithm in the radial distribution system. The proposed algorithm was implemented in a MATLAB environment at different loading conditions such as light load, nominal load, and peak load conditions. For 3 number of PV, the system power loss was found to be 652.102 kW without DG and 181.73 kW with DG system. The obtained result showed the accuracy & effectiveness of the proposed algorithm in the system. [8]

[9] The paper presents an approach for load flow analysis in radial distribution system, focusing on the development and application of the BIBC matrix. Previous studies have explored various methods for load flow analysis, such as Gauss-Seidel and Newton-Raphson, which are not well-suited for distribution systems due to their unique characteristics. The proposed method utilizes a forward-backward sweep (BFS) technique, which is particularly suitable for radial systems. Initial versions of BFS were designed for radial systems with constant complex power nodes. Subsequent enhancements have allowed for the solution of weakly meshed systems, voltage-dependent loads, and systems with distributed generation. The BFS method has also been extended to handle three-phase systems and various load models, including constant impedance, constant current & composite (ZIP) loads. The BIBC matrix, derived through the application of Kirchhoff's current law during the Backward sweep, establishes a direct relationship between node current injections and branch currents. This matrix facilitates the calculation of branch currents based on node injections, enabling efficient load flow evaluation. The algorithm outlined in the paper involves steps for calculating the BIBC matrix, along with the BCBV matrix, to determine branch currents and node voltages iteratively. The method is tested on an IEEE 85 bus system without tie lines, demonstrating convergence and efficiency in load flow calculations. Overall, the paper contributes

to the advancement of load flow analysis methodologies for distribution networks, emphasizing the utility and effectiveness of the BIBC matrix in facilitating accurate and efficient solutions.

Due to the advantages of environmentally friendly nature, improvement of voltage profile, system upgradation postponement & enhancement reliability, the integration of DG in the electrical power network is increasing these days. This paper discussed the application of a hybrid technique for optimizing the size and position of DG units to reduce losses in the distribution network. Here, both the CS & GOA were combined and executed and were termed as hybrid techniques. The optimization behavior of the GOA technique was improved by the CS technique. The proposed method determined the optimal position of the DG unit concerning voltage profile, line power flow & power loss. The proposed technique directed the limit of DG concerning the cost of enhancing the dynamic execution. The proposed technique was implemented to determine the optimal DG capacity for minimizing power loss and enhancing the voltage profile of the distribution network. The simulation of the proposed technique was performed in a MATLAB/Simulink environment. The proposed method was implemented and tested in IEEE 33 bus & IEEE 69 bus systems. The several load state was considered to observe the stability of the distribution network with a reduction in system loss. Several existing techniques were compared and analyzed with the proposed system.[10]

This paper highlighted the procedure to determine the optimal size and allocation of the capacitor bank in the distribution system to improve its performance. The sensitivity analysis determines the nodes for the placement of the capacitor. The sensitivity index determined the power losses in each node in terms of reactive power. The suitable point for the allocation of the capacitor in the distribution system was identified using the sensitivity index. An Ant Colony Algorithm (ACO) was implemented to determine the placement of the capacitor to improve the economic and technical advantages of the distribution network. In this research, the load flow analysis was performed with the BFS algorithm. The analysis was done initially on the IEEE 24 bus and 15 bus radial distribution system. The obtained outcome outlined the ability of the proposed system to locate the optimal placement of the capacitor bank in the distribution system in comparison to the uncompensated system with a reduction in the system losses. Likewise, the economical solution with minimum operating generation cost was achieved. Similarly, the comparative and competitive analysis was performed to determine the performance of the proposed system with the comparison of the result of previously published literature. [11]

This paper presented the optimal allocation of DG in the radial type of distribution network using particle swarm optimization (PSO) for enhancing the performance of the system with loss reduction. A single DG was considered for its placement & sizing in the distribution network. The proposed method was implemented in the 26-bus radial system and observed the network performance with and without the application of the DG in the distribution network. The original real & reactive power loss in the system was 11.68 kW & 26.08 kVAr respectively. The optimal size and location of the DG were determined with PSO in which the population size was considered to be 100. The DG was placed in each bus of the network and power loss was computed. In doing so the minimum loss was found to be in bus 14 of 26 bus radial system. The power loss was found to be 4.56 KW & 10.20 kVAr. The proposed method was found to reduce loss by around 61% in compared to that of original loss. The overall load flow analysis was performed using the forward-backward method. The proposed method was found to reduce maximum power loss in the system by a considerable amount. [12]

This paper presented the load flow study performed in the ETAP software. IEEE33 test bus system was selected to perform the load flow analysis. Several line data such as Rated kV, Active power, Reactive power, Resistance and Reactance of each branch and bus were inputted in the model developed in the ETAP software. The simulation was performed and several results were observed in the form of active & reactive power losses and voltage drop in several buses. By utilizing the suggested load flow solution techniques, it was possible to obtain a significant reduction in the execution steps necessary to obtain a stable state. As for the topology of the static networks, the uses of the proposed scheme make time savings; it suggests, that as network topology undergoes dynamic reconfiguration for the network management factors, this phase was found to contribute to several distinct static system topologies. The saving in time required for the analysis of load flow for all the network topologies would been a remarkable number for each of the static topologies. [13]

This paper aimed to improve the performance of radial distribution feeders with the optimal installation of a capacitor bank in the system. Here, a GA was implemented to determine the optimal placement and sizing of the capacitor. The technical and economic impact of the placement of capacitor bank as per regulation of NEA & optimal placement was compared. In the case of the IEEE-33 bus system, the minimum voltage was observed to be 0.924 pu and 0.921 pu with an optimal scenario and NEA regulation respectively. The active power loss was observed to be 154.43 kW and 163.28 kW with optimal scenario and NEA guidelines respectively. Melamchi feeder was considered for the study in the thesis. With the optimal installation of the capacitor and NEA's regulation, the minimum voltage was observed to be 0.817 pu and 0.774 pu respectively. The financial study was carried out to determine the viability of the project for both cases. For the optimal scenario IRR, discounted payback period and BCR were found to be 23.76%, 4.41 years, and 2.46 respectively. Similarly, for NEA guidelines, IRR, discounted payback period and BCR were found to be 19.78%, 4.96 years, and 2.20 respectively. From the analysis, it was observed that the optimal placement of the capacitor bank was more cost-effective than that of NEA guidelines. [14]

This research paper focused on overcoming the problem of low voltage & reducing the power loss in the distribution network with the optimal capacitor placement and sizing. The optimal location and sizing of the capacitor bank were carried out employing a GA and ETAP software. Here the Alkaherat distribution network of Iran was considered in the study. Medium voltage transmission lines of 11 kV, 5 MVA, 50 Hz, and low voltage transmission lines of 0.4 kV, and 250 kVA were considered in the study. The simulation was performed to determine the power loss at various load levels. The financial analysis was carried out with Cost-Benefit to determine the financial viability of the project. The result showed that the voltage loss can be reduced and 99% of the rated voltage but this demands for large number of capacitor banks which gives rise to more power loss. So the minimum power loss, suitable operating voltage, and minimum capacitor are considered to determine the optimal sizing and location of the capacitor bank. [15]

This paper presented the methodology and techniques to determine the optimal placement of capacitor banks in radial distribution system. Here the optimization of the capacitor bank was carried out based on the location, size, and cost to compensate the amount of reactive power form the load. ETAP software was implemented to determine the optimal allocation based on the maximum cost saving in the radial distribution network. The IEEE 10 bus system was considered to demonstrate the proposed method. The power factor, voltage profile and power losses of each node were computed for both with and without compensation. From the result, the power factor was found to improve form 0.9294 to 0.9871, and active power loss reduction was observed to be 702.7 kW form 783.8 kW. An annual profit of Rs.806266.5 was obtained for a life expectancy of 5 years. [16]

The application of a capacitor bank in a distribution network can considerably reduce the total power loss & enhance the performance of the system. Generally, a significant amount of power loss takes place in the distribution transformer present in the distribution system. In this study, a method is proposed to determine the optimal placement of a capacitor bank in a distribution transformer to reduce the overall power loss in the system. The location of the capacitor bank is considered in the low voltage side of the transformer. NPV is computed to determine the financial viability of the installation of a capacitor bank. Initially, the power loss in the distribution network is computed using an explicit formula. Then Mixed-Integer-Programming technique is adopted to determine the optimal placement of the capacitor bank. The commercial MIP package is implemented to solve the model and local remote switching is implemented to control the operation of the capacitor bank. This methodology was implemented in the Macau distribution network and the result showed a considerable reduction in power loss with positive NPV. [17]

2.3 Load Flow Analysis

Load flow study plays an significant role in the planning and problem-solving during the operation of the power system. The load flow analysis determines the nodal voltages and branch power flow in the power system network. It involves non-linear algebraic equations as the mathematical model and solving those equations provides information on node voltage, power flow, and power angle. It defines the economic condition, stability, and reliability of the power system from generation to distribution. For proper operation of the power system, the generation should meet the total power demand & fulfill the system losses. The operation of the generation unit should be limited to the rated active & reactive power. The bus voltages should be within the rated ranges for steady operation of the power system. [18]

There are various approaches to perform the load flow analysis which are the Gauss-Seidel method, Newton Raphson Method & Fast Decoupled Method. Different optimization algorithms such as PSO, GA, Forward-Backward algorithm, Novel sweep algorithm, ACO, etc can be implemented in several software programs such as ETAP, MATLAB, DigSilent, NEPLAN, etc to perform the load flow analysis of the power distribution system to determine the flow of power and voltage at each load buses.

2.4 Particle Swarm Optimization (PSO)

The intelligence and movement of swarms are considered in the PSO algorithm. The concepts of social interaction are applied in the PSO technique. It was developed by Russell Eberhart and James Kennedy. It is the system model which makes groups for some purpose such as searching for food. In food searching or victim, all birds in the group fly in one direction, and the bird at the shortest distance to the food i.e.; the leader bird will be the best fitness & the remaining bird follows the leader. The fitness values are considered for the modeling of the PSO algorithm. The solution of fitness values is represented with particles. The particle velocity is an important property in food searching for birds which they use to set the direction for movement. Then all the particles improve their direction related to the best ability of particle direction. This outcome helps to set the most appropriate direction for the particles. PSO consists of several particles in a group moving in the space searching for the optimal solution. These particles are represented with s vector of length n to indicate the position with velocity vector v used to adjust its flying as per their flying experience as well as other particles. Each particle tracks its coordinates in the solution space which are associated with best fitness. This personal optimal solution is known as Pbest. Another best solution is obtained by PSO by adjusting the particle position with the neighbor particle. This solution is called Gbest. Each particle in the swarm modifies its position using the information of the current position, velocities, and distances between the current position of pbest and gbest with the flowchart of the PSO algorithm.[12]

2.5 Forward/Backward Sweep (BFS) Algorithm

The BFS is one of the widely used methods to perform load flow analysis in distribution networks due to its robust, simple, fast, efficient, and accurate properties. This method mainly consists of three basic steps which are based on Krichoff's voltage law (KVL) and Krichoff's current law (KCL). [19]

The three major steps involved in BFS for low flow analysis are nodal current calculation, backWard sweep & forward sweep and these steps are repeated until the set convergence is reached. [20]

2.6 IEEE Bus System

In an electrical system, the IEEE bus system is normally used for communication between different components of the system, such as protection relays, meters, and control systems. The IEEE bus system can be used to integrate these components into a larger system and allow for centralized control and monitoring. For example, in a power distribution system, protective relays are used to detect faults and initiate protective actions to isolate the faulty part of the system. The relay can communicate with each other and with a central control system through the IEEE bus system. This allows for faster detection and isolation of faults, reducing the impact on the system and improving reliability. Similarly, the IEEE bus system can be used in the control system for power generation, transmission, and distribution. The control system can communicate with each other and with field devices such as switches and transformers allowing for coordinated control of the system. Overall, the IEEE bus system plays an significant role in the integration and control of different components in electrical systems, improving their reliability and performance. The algorithm or methods developed can be checked first in the IEEE bus system and then can be implemented in the real bus system. [21]

2.7 ETAP (Electrical Transient & Analysis Program)

It is software used in the design, operation & analysis of electrical power systems. It is widely used in industries such as power generation, transmission & distribution, renewable energy & industrial facilities. ETAP offers a wide range of features for modeling and analyzing electrical systems, including load flow study, short circuit analysis, protective device coordination, arc flash analysis, motor analysis, transient stability analysis, and more. The software is capable of analyzing both AC and DC systems as well as hybrid systems. One of the key benefits of using ETAP is its ability to simulate different scenarios and what-if analyses which can help engineers and operators identify potential issues and optimize the performance of their electrical systems. ETAP can also generate comprehensive reports and diagrams allowing users to easily communicate their findings and recommendations to stakeholders. Overall, ETAP is a powerful tool for designing and analyzing electrical systems and is widely used in the industry for its reliability and versatility. [22]

2.8 Financial Analysis

The initial investment cost was considered as the installation cost of the capacitor bank in the optimal place with the optimal size. The total revenue was considered as the total amount saved from the installation of the capacitor bank. The total energy cost was considered as Rs. 10/kWh while the life expectancy of the capacitor bank was considered to be 20 years. The capital budgeting of the capacitor bank was analyzed with Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR), and discounted payback period. The financial viability for the installation of the capacitor bank was determined with these indicators of capital budgeting. [24]

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Methodology

The thesis work is carried out to improve the performance of the Radial distribution feeder by reducing the power loss and enhancing voltage profile with optimal placement of the capacitor bank considering the loads of Electric Vehicle (EV) charging station in the actual feeder thus minimizing the total cost of energy and maximizing total cost saving. The research work begins with an in-depth literature review of a similar research paper related to the optimal allocation of capacitor banks in distribution feeders to gain necessary insight and procedures into the project work. The research work is based on several technical aspects such as reduction of losses in the feeder, improving voltage profile thus reducing voltage drop, and total cost saving after implication of capacitor bank in radial distribution network. MATLAB-based PSO algorithm is implemented to determine the candidate bus for optimal placement of capacitor thus determining the capacitor size to be placed in the distribution network. The line and bus data of the distribution feeder are simulated in the ETAP software to compare the performance of the distribution system at both the pre-and post-compensation stages.

Literature review work is followed by the collection of necessary data such as line parameters and Bus parameters of the standard IEEE 33 Radial distribution feeder and 77 bus Butwal West distribution feeder. These data are considered during the study of this research. The MATLAB-based PSO algorithm is implemented to determine the candidate buses for placement of the capacitor bank and determine the optimal size of the capacitor bank. This algorithm calculates the Loss Sensitivity Index (LSI) of each buses of the distribution network and selects the candidate bus as per LSI values. The bus with a higher value of LSI is preferred to compute the optimal bus for placement of the capacitor bank. Similarly, the algorithm also suggests the standard size of the capacitor based on the reactive power requirement in the system. The proposed PSO algorithm computes the load flow analysis to determine the optimal location for the placement of the capacitor bank. The simulation is then performed in ETAP software to determine the bus voltages, Power losses (both active and reactive power), and voltage Regulation of the system. The several system performance parameters such as Voltage profile, power loss and voltage regulation are analyzed for both the pre and post-compensation stages.

For the actual distribution feeder, the analysis is carried out both with and without compensation considering the load of the EV charging station separately and finally with the installation of a capacitor bank in the distribution network. Here, the simulation is performed in two cases: in case I the simulation is performed without considering the EV charging station load, and in case II simulation is carried out considering the EV charging station load. Likewise, financial analysis is carried out for case II to determine the financial viability of project after the optimal placement of the capacitor bank. Besides these, Sensitivity analysis and Monte Carlo Simulation is carried out to determine the confidence and risk in the investment of the project.

The general flow diagram that illustrates the methodology of this research work is shown in *Figure 3.1*.

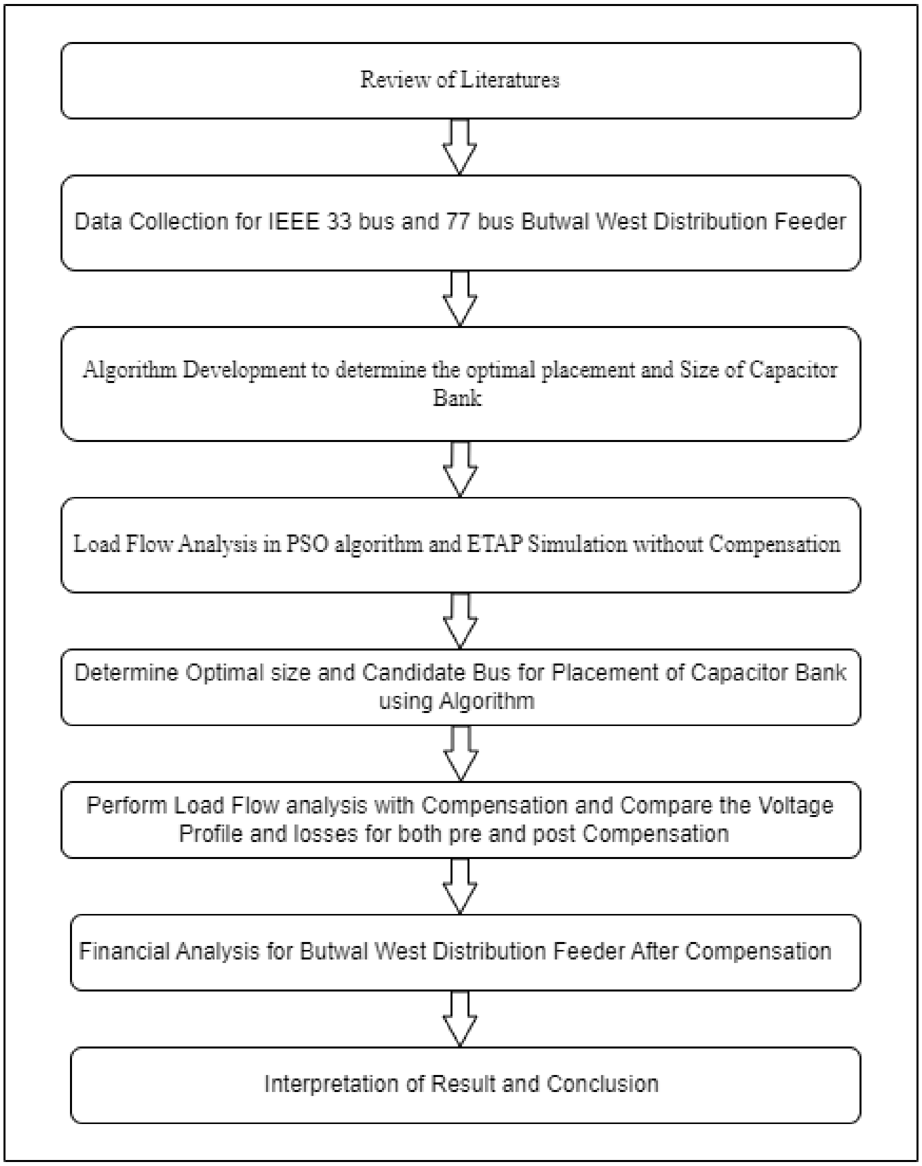


Figure 3.1: Flowchart showing the general Methodology of Research

3.2 Flowchart of PSO Algorithm

The Particle Swarm Optimization (PSO) algorithm initiates with initialization of a swarm of particles, each representing a potential solution within the search space. The next step involves evaluating the fitness of each particle considered based on a predefined objective. Subsequently, particles adjust their positions and velocities according to their individual and neighborhood best-known positions, guided by both local and global information. This iterative process goes on until termination criterion is met, such as attaining a specified number of iterations or reaching satisfactory convergence. Throughout the optimization process, the flowchart illustrates how particles update their velocities and positions dynamically, converging towards promising regions of the search space. Additionally, the algorithm includes details on how parameters such as inertia weight, and cognitive, and social components influence the movement of particles. Finally, the global best (gbest) value is determined and based on that value the optimal selection of candidate bus and sizing of the capacitor bank is performed. The general flow diagram showing the steps involved in MATLAB based PSO algorithm is shown below;

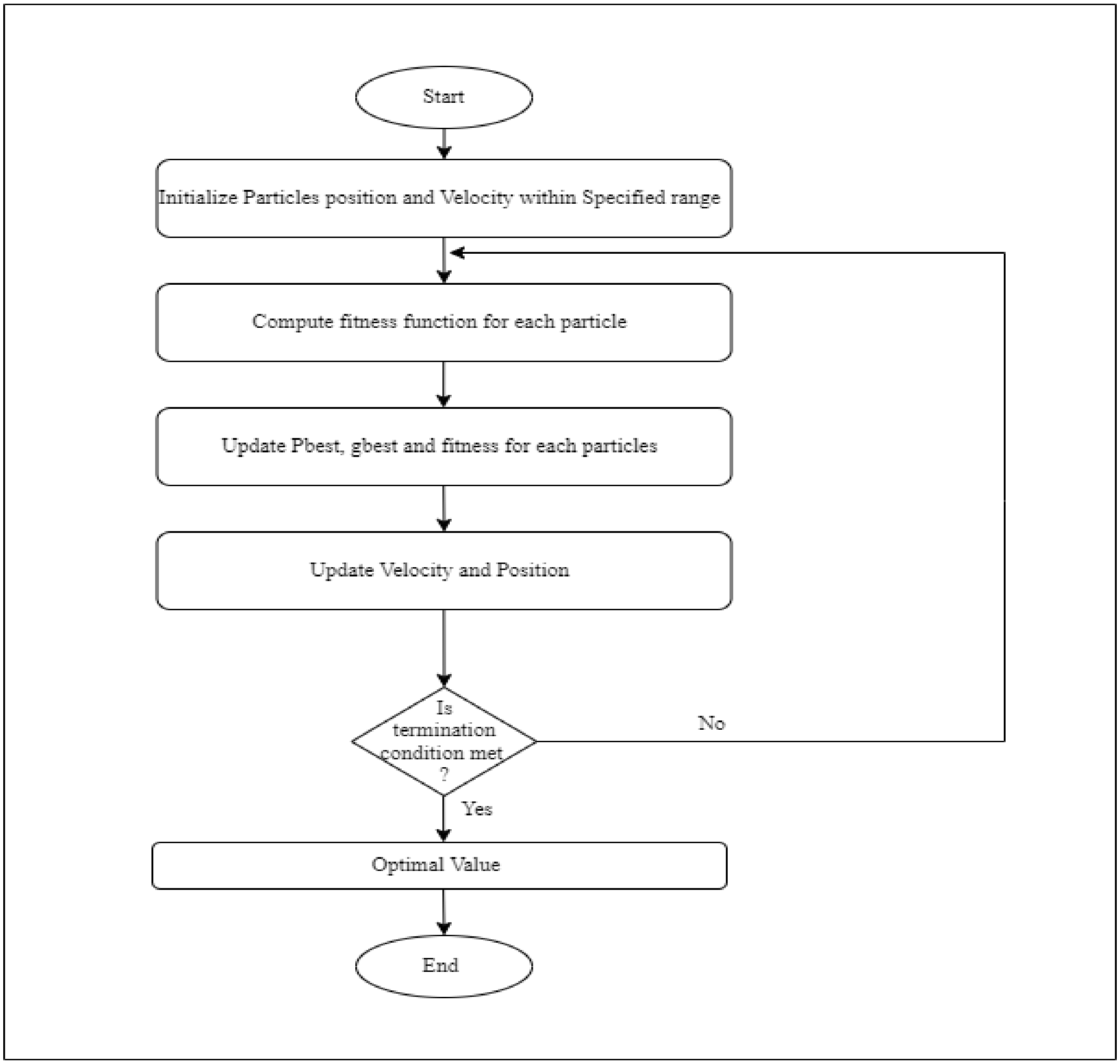


Figure 3.2: Flowchart of MATLAB-based PSO Algorithm

Initially, the line & bus data of the IEEE 33 bus and 77 Bus Butwal West distribution feeder are taken into consideration as the input parameters to initiate the load flow analysis. The load flow analysis is carried out in both MATLAB and ETAP software. The average life expectancy of capacitor bank, cost of energy per unit, kVAr cost per unit ie; cost of the capacitor bank is taken as the input parameters in objective function. The function is set to penalize the fitness function if the voltage tolerance is violated. The Base MVA and base KV of the feeder are chosen for each radial distribution feeder to determine the per-unit values of line and bus parameters. On choosing the size of the capacitor bank, a standard practice for selecting the capacitor bank that varies between 150 kVAr - 1200 kVAr with a difference of 150 kVAr each is adopted in this thesis. If the upper & lower limit of reactive power falls between 0 and 0.05 then a 150 kVAr capacitor is selected. Similarly, for the 0.125 and 0.25 ranges, a 300 kVAr capacitor is preferred. 450 kVAr of capacitor bank is chosen for the lower and upper range of 0.25 and 0.375. Likewise, for the values falling between 0.375 and 0.5, the 600 kVAr size of the capacitor is preferred. For values falling in between 0.5 - 0.625 and 0.625 – 0.75, 750 and 900kVAr size of the capacitor is considered. Similarly, for 1050 kVAr size of capacity, the values should fall between 0.75 and 0.875. For values above 0.875, 1200 kVAr of the capacitor bank is chosen as the optimal size. A mathematical formula is set in the algorithm to calculate the power loss (both active and reactive power) of the radial feeder. The value of LSI is computed for each bus of the feeder and is arranged in descending order of magnitude to select the bus for optimal placement of the capacitor bank. The load flow analysis is performed also in ETAP software to obtain the power loss, voltage drop, voltage regulation and voltage profile of the distribution network for both Pre and Post compensation cases.

After this Financial analysis is performed for the actual feeder to determine the financial feasibility of the project. Besides this, Sensitivity Analysis and Monte Carlo Simulation Analysis are performed to carry out the risk analysis of the project.

Minimization Function

The objective function aims to minimize total cost of energy and enhance the savings in the radial distribution feeder.

Min Z = Kp*PT_{Loss} + $\sum_{j=1}^{J} Kc * Q_{Total}$ 3. 1

Where,

Z = Fitness Function ie; Total Cost

Kp = Per unit annual cost of Power Loss in the feeder $/kW year

PT_{Loss} = Total Active Power Loss

Q_{Total} = Total reactive Power supplied by Capacitor Banks

Kc = Per kVAr cost of capacitor bank $/kVAr

j = Bus number

J = Number of candidate buses for allocation of capacitor bank

The annual cost of capacitor bank is computed as;

$$\text{Total Capacitor Cost} = \frac{Kc * Q_{Total}}{Life\ Expectancy\ of\ Capacitor\ Bank}\ \$/\text{year} \qquad \text{.......................................3. 2}$$

The inequality constraints considered in the PSO algorithm to determine the optimal allocation and sizing of the capacitor bank is;

$$V_{min} \leq V_j \leq V_{max} \ \text{..3. 3}$$

Where j represents the bus number. The Voltage considered for the IEEE 33 Bus and 77 Bus Butwal West distribution feeder is $0.95 \leq V_j \leq 1.05$ pu. This is also the standard voltage tolorences level considered by NEA.

$$Q^{C}_{max} \leq Q_{total} \ \text{..3. 4}$$

Where, Q_{total} is the total reactive power supplied by the capacitor bank & Q^{C}_{max} is the maximum size of capacitor bank allowed.

3.3 Loss Sensitivity Index (LSI)

The LSI is an important parameter to determine the candidate bus for the placement of the capacitor bank in the electrical distribution networks. [23] The value of LSI for all the buses is calculated and sorted in descending order. The descending order of LSI will indicate the sequence in which the buses are to be considered for capacitor placement. Let us consider a radial distribution network connecting two buses ‘p’ & ‘q’.

Then loss of active power in the kth line joining two buses can be calculated as;

$P_{line\ loss}[q]$ = {(P_{eff}^2[q] + (Q_{eff}^2[q])*R[k]}/(V^2[q]) 3.5

Now, LSI can be computed as;

$$\frac{\delta P_{line\ loss}}{\delta Q_{eff}} = \frac{2Q_{eff\ [q]}}{V^2[q]} * \text{R[k]} \quad \text{..3.6}$$

Where, Peff[q] = Total active power (effective) supplied beyond bus q

Qeff[q] = Total reactive power (effective) supplied beyond bus q

3.4 Voltage Regulation

Voltage regulation is defined as the change in magnitude of voltage of the sending and receiving end with respect to the sending end of the power system network. The voltage regulation gives a clear idea about the voltage drop that occurs in the distribution network. It is desirable to have a lesser value of voltage regulation for better performance of the electrical network. The higher the value of voltage regulation, the lower the performance of the power system. It is generally expressed in percentage. The formula to calculate the voltage regulation of the power system network is given by;

$$\text{Voltage Regulation} = \frac{Vs-Vr}{Vs} *100\% \quad \text{...3. 7}$$

Where, Vs = Sending end Voltage

Vr = Receiving end Voltage

3.5 Power Loss

The power loss mainly occurs due to the resistive and reactive parameters present in the distribution network. Resistive components are responsible for active power loss while reactive power loss is caused due to inductive components present in the line. The percentage of Active and Reactive power loss reduction after placement of the capacitor bank is calculated as;

Active Power Loss Reduction =

$$\frac{P_{loss}\ before\ compensation - P_{loss}\ after\ compensation}{P_{loss}\ before\ compensation} *100\% \quad \text{...3. 8}$$

Reactive Power Loss Reduction =

$$\frac{Q_{loss}\ before\ compensation - Q_{loss}\ after\ compensation}{Q_{loss}\ before\ compensation} * 100\% \text{...} 3.9$$

Where, P_{loss} = Active Power loss and Q_{loss} = Reactive Power Loss

3.6 Data Collection

In this Project work, the Butwal West Distribution feeder is considered to analyze and improve the performance of the feeder with the optimal allocation of capacitor banks. The analysis is carried out for both with and without EV charging stations. Data related to the loading of the transformer, the distance between the distribution transformer, the type of conductors used, operating power factor, etc were acquired from direct interaction with the Member of Butwal DCS, NEA. Data's related to the capacity and location of EV charging stations were acquired from respective stations and the official website of Charging station Nepal. Likewise, the single-line diagram (SLD) of the feeder was acquired from Butwal DCS. In order to compute line parameters ie; resistance and reactance between each bus, the technical specification of the ACSR conductor is utilized which is tabulated in the Appendix. The ACSR conductors used for the distribution of electrical power in this feeder are Dog, Weasel, and Rabbit Conductor. Besides these, the bus parameters ie; Active & Reactive power of the feeder at each bus are computed using the loading of the transformer and their respective operating power factor.

3.7 Electric Charging Station

There are altogether five Electric vehicle charging stations located in the Butwal West distribution feeder which is considered in this thesis as shown in Google map in Appendix A. The total capacity of the charging station is taken as AC or DC load as per the nature of the charging station located in the respective bus bar and finally simulated in ETAP software to determine the voltage profile, total losses, Voltage regulation of the distribution feeder with and without considering electric charging station. The value of the power factor for both AC and DC fast chargers is considered to be 0.9 lagging. The location of the charging station along with type and rating is listed in the table below;

Table 3.1: Rating and Location of EV charging station

Bus No.	**Type and Rating of EV Charger**
2	30 kW AC charger

9	30 kW AC charger
10	30 kW DC fast charger
28	120 kW DC charger and 22 kW AC charger
23	30 kW AC charger

3.8 Financial Analysis

The financial viability of this research work is computed by using different techniques of capital budgeting ie; IRR, NPV, BC Ratio, and Discounted Payback Period. Likewise, sensitivity analysis is performed to determine the impact of various variables such as interest rate, maintenance cost, incremental rate in maintenance cost, cost of power loss, and cost of capacitor. To carry out the analysis, the life expectancy of the capacitor bank is considered as 20 years, and the annual inflation rate is 10%. The capacitor cost is considered as 5 \$/kVAr, the installation cost of the capacitor bank as \$1000, the Cost of power loss as 168 \$/kW-year, the compounding factor of maintenance cost as 8% annually, and the maintenance cost of capacitor bank as 322.42 \$/year. [25]

3.8.1 Internal Rate of Return

The Internal Rate of Return (IRR) is a financial metric used to evaluate the attractiveness of an investment by calculating the discount rate at which net present value (NPV) of all cash flows associated with the investment equals zero. A higher IRR typically signifies a higher profitable investment opportunity, as it represents that the return of project surpass the capital cost. The IRR is calculated using the formula;

NPV = $\sum_{t=0}^{n} Rt/(1+i)^{t}$ = 0 ....3. 10

Where Rt represents cash flow in time t, i represents discount rate and n is the total time period.

3.8.2 Benefit Cost Ratio

The Benefit Cost Ratio (BCR) is also a financial metric used to determine the desirability of an investment or project by comparing the present value of its probable benefits to the present value of its costs. A BCR greater than 1 indicates that the benefits of project outweigh its costs, signaling a potentially favorable investment.

$$\text{BCR} = \frac{\sum_{t=0}^{n} Rb/(1+i)^t}{\sum_{t=0}^{n} Rc/(1+i)^t} \quad \text{...} 3.\ 11$$

Rb and Rc denote the net benefits and net cash outflow during a period t, i represents discount rate and t is number of time periods.

3.8.3 Discounted Payback Period

The Discounted Payback Period is used to assess the time period it takes for an investment to return its initial cost, considering the time value of money through discounting future cash flows. It involves calculating the time required for the sum of the discounted cash flows to equal initial investment. A lower payback period indicates more quicker investment recovery.

3.8.4 Sensitivity Analysis

Sensitivity analysis is used to analyze the influence of several independent variables or factors on the dependent variables under certain conditions. It reveals how much the output will change upon certain changes in input variables. Here, the benefit-cost ratio is computed for several values of input variables such as capacitor bank cost, Cost of power loss, maintenance cost, interest rate, and compounding factor of maintenance cost. The sensitivity graph is plotted for different values of input variables. The steeper the slope, the more sensitive the BC ratio to a change in particular Variables. [26]

3.8.5 Monte Carlo Simulation Analysis

The risk analysis is determined by Monte Carlo Simulation. Here, the defined assumptions are the Capacitor Bank’s cost, Cost of Power Loss, Annual Maintenance Cost, percentage increment in maintenance cost, and Interest Rate. The IRR and BC Ratio are taken for Forecast.

After defining the assumption variables, the nature of the considered variables is defined. Maintenance cost and Cost of Power Loss are taken as Normal type of distribution considering data to be clustered around average value. The cost of a Capacitor bank is considered to be uniform distribution. Likewise, Interest rate and compound rate are considered to be Triangular distribution as they are mostly bounded in between some ranges. The simulation aims to forecast key financial metrics such as the IRR and the BCR, providing a comprehensive risk assessment by evaluating how these input uncertainties affect the overall economic performance of the capacitor bank placement strategy. The results were then aggregated and analysis was made for risk evaluation.

3.9 Tools Used during Research

The thesis was undertaken using MATLAB-based PSO algorithm and ETAP software for overall simulation and load flow analysis. MS Excel was used to perform the financial analysis while risk analysis was carried out through Monte-Carlo Simulation. The graphical representation of the observed results related to the system performance is performed using Origin Lab software. The SLD of the IEEE 33 Bus system and 77 Bus Butwal West Radial Feeder is carried out in AutoCAD software. The overall analysis is undertaken in Intel(R) Core(TM) i5-1035G1 CPU @ 1.00GHz 1.19 GHz system.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 IEEE 33 Bus System

At first, the analysis is carried out for the IEEE 33 bus system for both cases with and without the optimal placement of the capacitor bank in the radial distribution system.

4.1.1 Single Line Diagram

A Single line diagram (SLD) of the IEEE 33 Bus System is shown in *Figure 4.1*. A base voltage of 12.66 kV is taken and carried out load flow analysis to determine the performance of the system. [27]

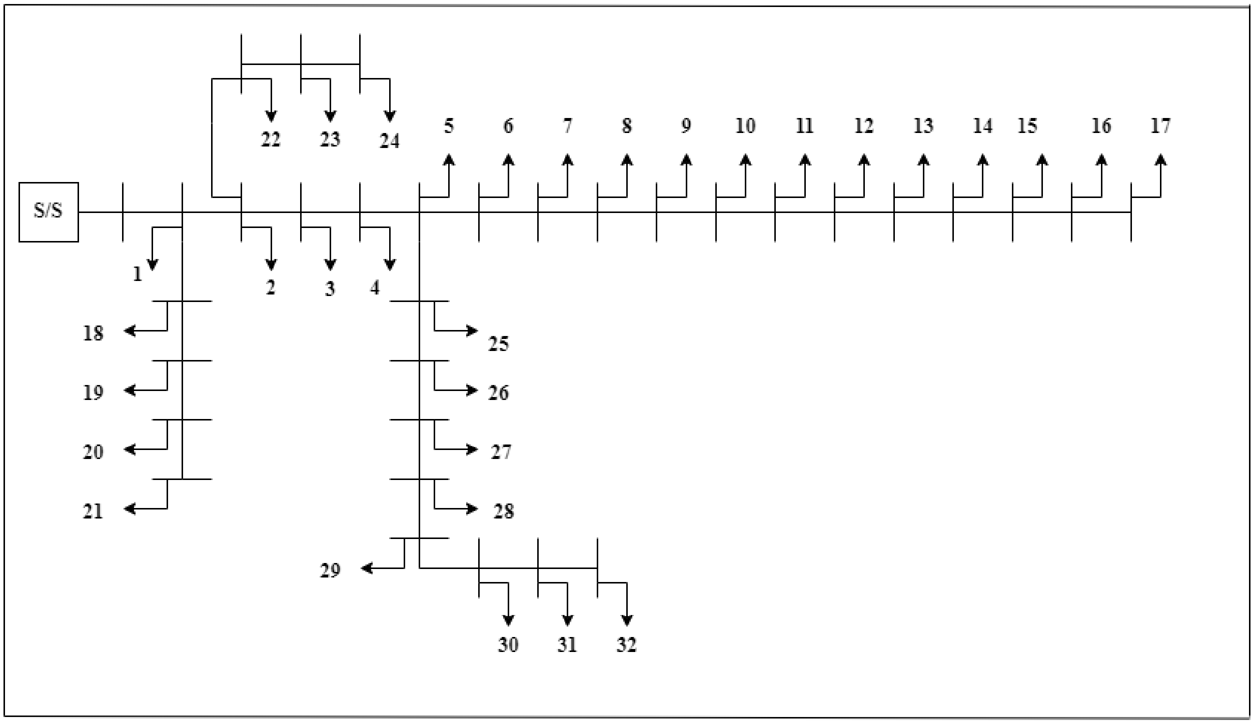


Figure 4.1: Single Line diagram of IEEE 33 Bus System

4.1.2 Load Flow Analysis

The several line parameters of the IEEE 33 bus system in *Table A-1* which is simulated in ETAP software and PSO algorithm. The outcome of several bus voltages obtained from the algorithm and simulation is represented in *Table 4.1*.

Table 4.1: Result of Bus Voltages obtained from PSO algorithm and ETAP simulation

Bus No.	**MATLAB Algorithm**	**ETAP Simulation**
1	1	1
2	0.9969	0.997
3	0.9832	0.983
4	0.9753	0.975
5	0.9679	0.968
6	0.9494	0.949
7	0.9459	0.946
8	0.9323	0.932
9	0.9259	0.926
10	0.9200	0.920
11	0.9192	0.919
12	0.9177	0.918
13	0.9115	0.912
14	0.9092	0.909
15	0.9078	0.908
16	0.9064	0.906
17	0.9044	0.904
18	0.9038	0.904
19	0.9962	0.996
20	0.9929	0.993

Bus No.	MATLAB Algorithm	ETAP Simulation
21	0.9927	0.992
22	0.9915	0.992
23	0.9793	0.979
24	0.9726	0.973
25	0.9691	0.969
26	0.9475	0.948
27	0.9449	0.945
28	0.9335	0.934
29	0.9253	0.925
30	0.9217	0.922
31	0.9176	0.918
32	0.9166	0.917
33	0.9164	0.916

The IEEE 33 bus system is modeled in ETAP software along with their respective line & bus parameters. The load flow analysis carried out in ETAP software for the IEEE 33 bus system is shown in *Figure 4.2*.

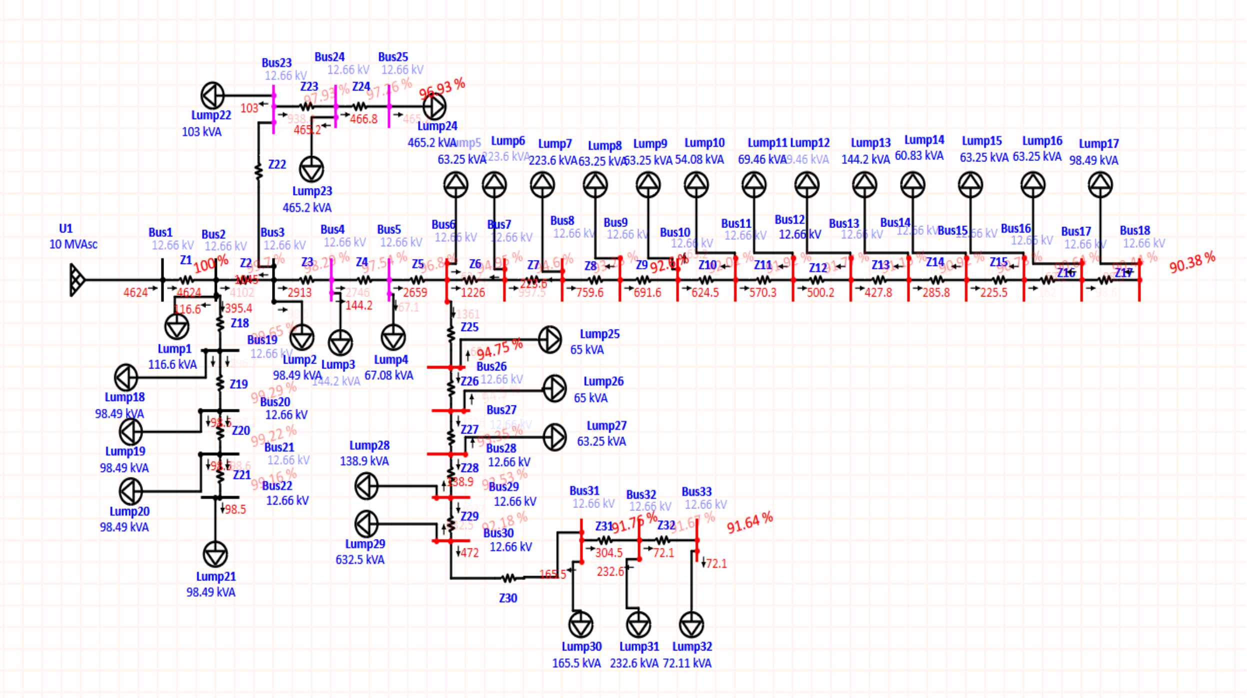


Figure 4.2: Load Flow analysis of IEEE 33 Bus System (Before Compensation)

From the above simulation performed in ETAP software the voltage at each bus is found to decrease while moving from the sending end to the farthest receiving end of the feeder. A minimum voltage of 90.38 % is observed in Bus 18 of the IEEE 33 bus feeder. The bus voltage is computed using both ETAP Simulation and the proposed PSO algorithm to validate the obtained results from MATLAB. The voltage at the sending (max.) and receiving end (min.) is found to be 1 pu and 0.904 pu respectively. A maximum voltage drop of 9.6% was observed between the sending and receiving end of the IEEE 33 bus system. A graph showing the voltage magnitude ie; Voltage Profile obtained by both the PSO algorithm and ETAP simulation is shown in *Figure 4.3*.

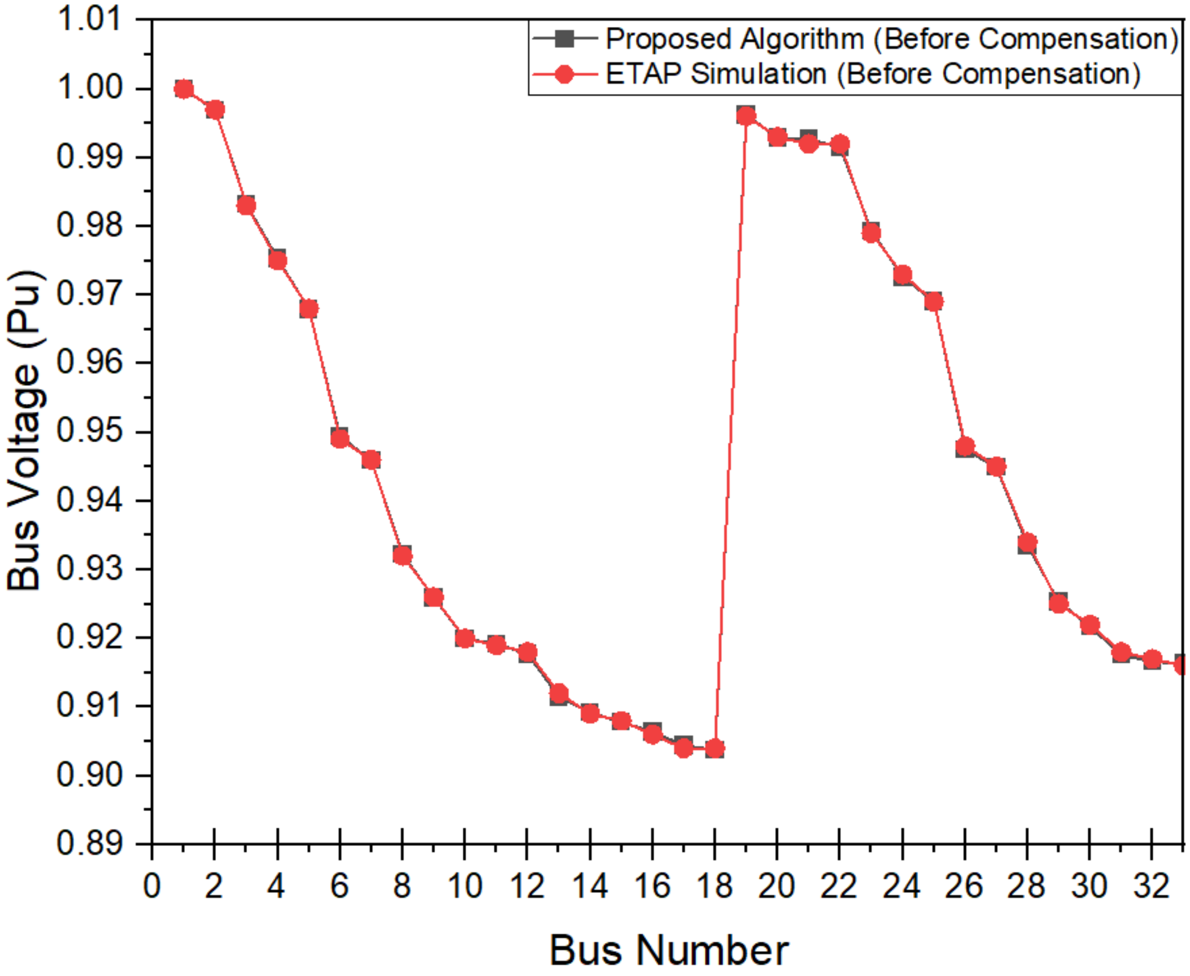
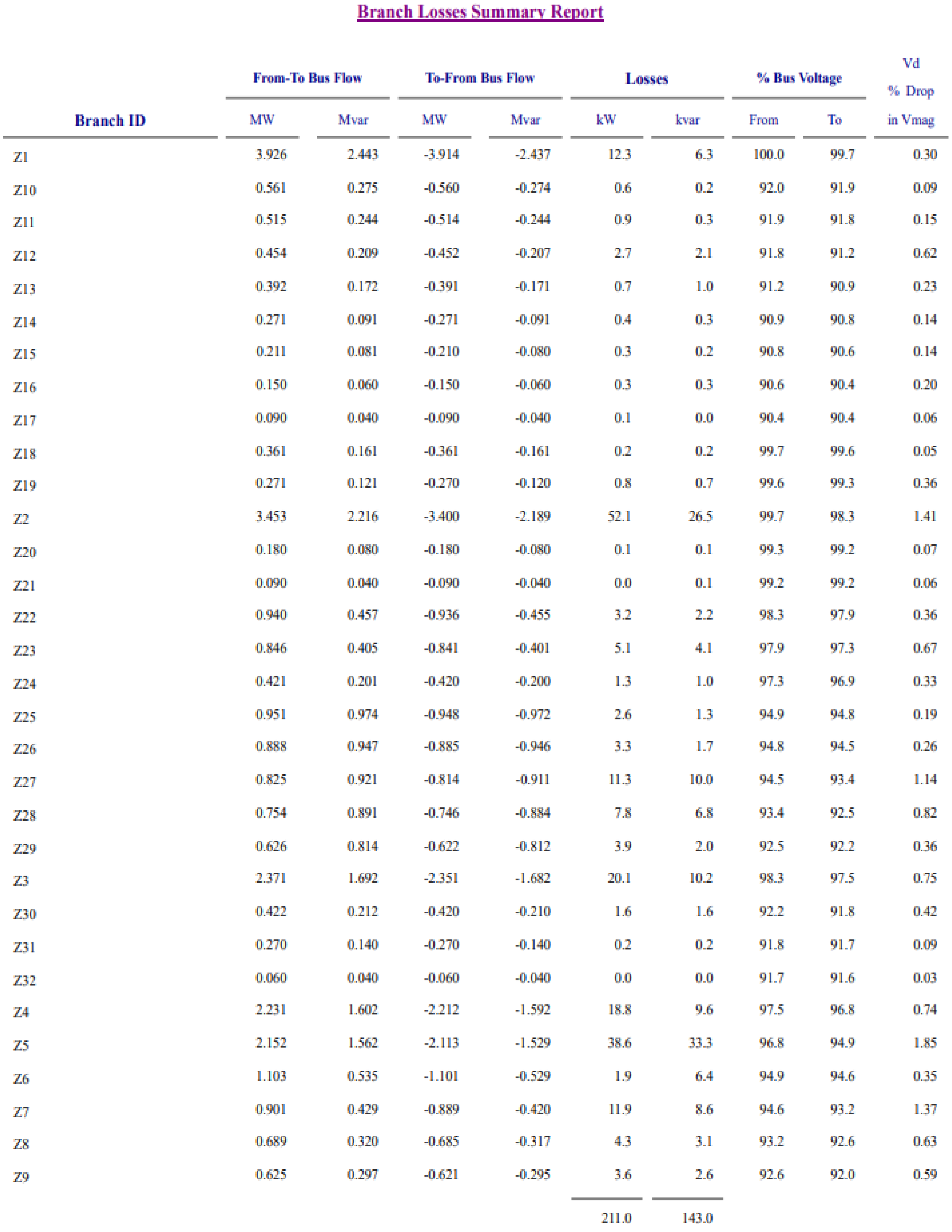


Figure 4.3: Voltage Profile of IEEE 33 bus system (Before Compensation)

Table 4.2: Result of Load Flow analysis (Before Compensation)



Branch Losses Summary Report

	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
Branch ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Z1	3.926	2.443	-3.914	-2.437	12.3	6.3	100.0	99.7	0.30
Z10	0.561	0.275	-0.560	-0.274	0.6	0.2	92.0	91.9	0.09
Z11	0.515	0.244	-0.514	-0.244	0.9	0.3	91.9	91.8	0.15
Z12	0.454	0.209	-0.452	-0.207	2.7	2.1	91.8	91.2	0.62
Z13	0.392	0.172	-0.391	-0.171	0.7	1.0	91.2	90.9	0.23
Z14	0.271	0.091	-0.271	-0.091	0.4	0.3	90.9	90.8	0.14
Z15	0.211	0.081	-0.210	-0.080	0.3	0.2	90.8	90.6	0.14
Z16	0.150	0.060	-0.150	-0.060	0.3	0.3	90.6	90.4	0.20
Z17	0.090	0.040	-0.090	-0.040	0.1	0.0	90.4	90.4	0.06
Z18	0.361	0.161	-0.361	-0.161	0.2	0.2	99.7	99.6	0.05
Z19	0.271	0.121	-0.270	-0.120	0.8	0.7	99.6	99.3	0.36
Z2	3.453	2.216	-3.400	-2.189	52.1	26.5	99.7	98.3	1.41
Z20	0.180	0.080	-0.180	-0.080	0.1	0.1	99.3	99.2	0.07
Z21	0.090	0.040	-0.090	-0.040	0.0	0.1	99.2	99.2	0.06
Z22	0.940	0.457	-0.936	-0.455	3.2	2.2	98.3	97.9	0.36
Z23	0.846	0.405	-0.841	-0.401	5.1	4.1	97.9	97.3	0.67
Z24	0.421	0.201	-0.420	-0.200	1.3	1.0	97.3	96.9	0.33
Z25	0.951	0.974	-0.948	-0.972	2.6	1.3	94.9	94.8	0.19
Z26	0.888	0.947	-0.885	-0.946	3.3	1.7	94.8	94.5	0.26
Z27	0.825	0.921	-0.814	-0.911	11.3	10.0	94.5	93.4	1.14
Z28	0.754	0.891	-0.746	-0.884	7.8	6.8	93.4	92.5	0.82
Z29	0.626	0.814	-0.622	-0.812	3.9	2.0	92.5	92.2	0.36
Z3	2.371	1.692	-2.351	-1.682	20.1	10.2	98.3	97.5	0.75
Z30	0.422	0.212	-0.420	-0.210	1.6	1.6	92.2	91.8	0.42
Z31	0.270	0.140	-0.270	-0.140	0.2	0.2	91.8	91.7	0.09
Z32	0.060	0.040	-0.060	-0.040	0.0	0.0	91.7	91.6	0.03
Z4	2.231	1.602	-2.212	-1.592	18.8	9.6	97.5	96.8	0.74
Z5	2.152	1.562	-2.113	-1.529	38.6	33.3	96.8	94.9	1.85
Z6	1.103	0.535	-1.101	-0.529	1.9	6.4	94.9	94.6	0.35
Z7	0.901	0.429	-0.889	-0.420	11.9	8.6	94.6	93.2	1.37
Z8	0.689	0.320	-0.685	-0.317	4.3	3.1	93.2	92.6	0.63
Z9	0.625	0.297	-0.621	-0.295	3.6	2.6	92.6	92.0	0.59
					211.0	143.0			

4.1.3 Sizing of Capacitor

The LSI value of each buses is computed using the PSO algorithm and the candidate buses for the allocation of the capacitor is obtained. Candidate buses obtained for capacitor bank placement are 7, 14, 18, 23, 31, 30, 24, 25, 8, 32, 4, 29, 3, 2, 20, 22. These candidate buses are arranged in the descending order of magnitude as per the Value of LSI and the optimal size of the capacitor bank is obtained using the proposed algorithm. These capacitor bank is chosen as per the standard practices which are generally taken in between 150 and 1200 kVAr with the difference of 150 kVAr. The optimal size of the capacitor bank obtained is shown in *Table 4.3*.

Table 4.3: Optimal Capacitor size and respective buses for IEEE 33 Bus System

Bus Number	**Capacitor Size (kVAr)**
7	900
14	150
18	300
23	1200
31	750

4.1.4 Comparison of Voltage Profile Before and After Compensation

The above obtained capacitor size along with their optimal location is considered and the ETAP model of the IEEE 33 bus system is updated. The model after placement of the capacitor bank in the respective buses then ran to perform the load flow analysis and observed the bus voltages & losses in each node of model. The result of load flow study after the compensation is presented in *Figure 4.4*. Thus obtained result after compensation is then compared with the result before compensation and found that the voltage at each bus is enhanced with a significant reduction in the line losses. The detail of bus voltages per unit (pu) value before and after the placement of the capacitor bank is tabulated in *Table 4.4*. The data on bus voltages also shows that the voltage profile of the IEEE 33 bus system is improved after compensation in comparison to the same IEEE 33 bus system before compensation.

Table 4.4: Bus Voltage's IEEE 33 Bus System (After Compensation)

Bus No.	MATLAB Algorithm	ETAP Simulation
1	1	1
2	0.997	0.998
3	0.986	0.989
4	0.981	0.984
5	0.977	0.979
6	0.968	0.970
7	0.970	0.972
8	0.959	0.962
9	0.955	0.957
10	0.953	0.954
11	0.951	0.953
12	0.949	0.952
13	0.947	0.949
14	0.947	0.949
15	0.946	0.948
16	0.946	0.948
17	0.947	0.949
18	0.947	0.949
19	0.996	0.997
20	0.992	0.994

Bus No.	MATLAB Algorithm	ETAP Simulation
21	0.991	0.993
22	0.990	0.989
23	0.986	0.988
24	0.979	0.981
25	0.970	0.970
26	0.968	0.969
27	0.965	0.967
28	0.958	0.960
29	0.954	0.955
30	0.952	0.953
31	0.952	0.953
32	0.950	0.952
33	0.950	0.952

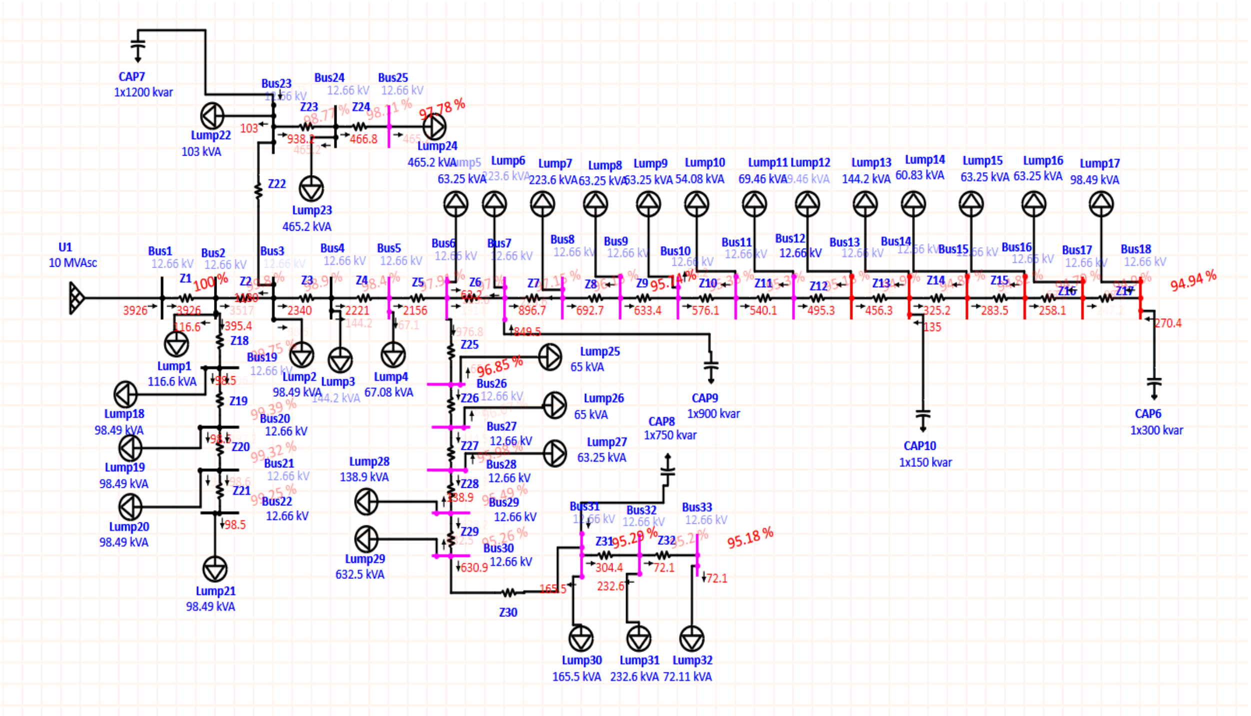


Figure 4.4: Load Flow analysis of IEEE 33 bus system (After Compensation)

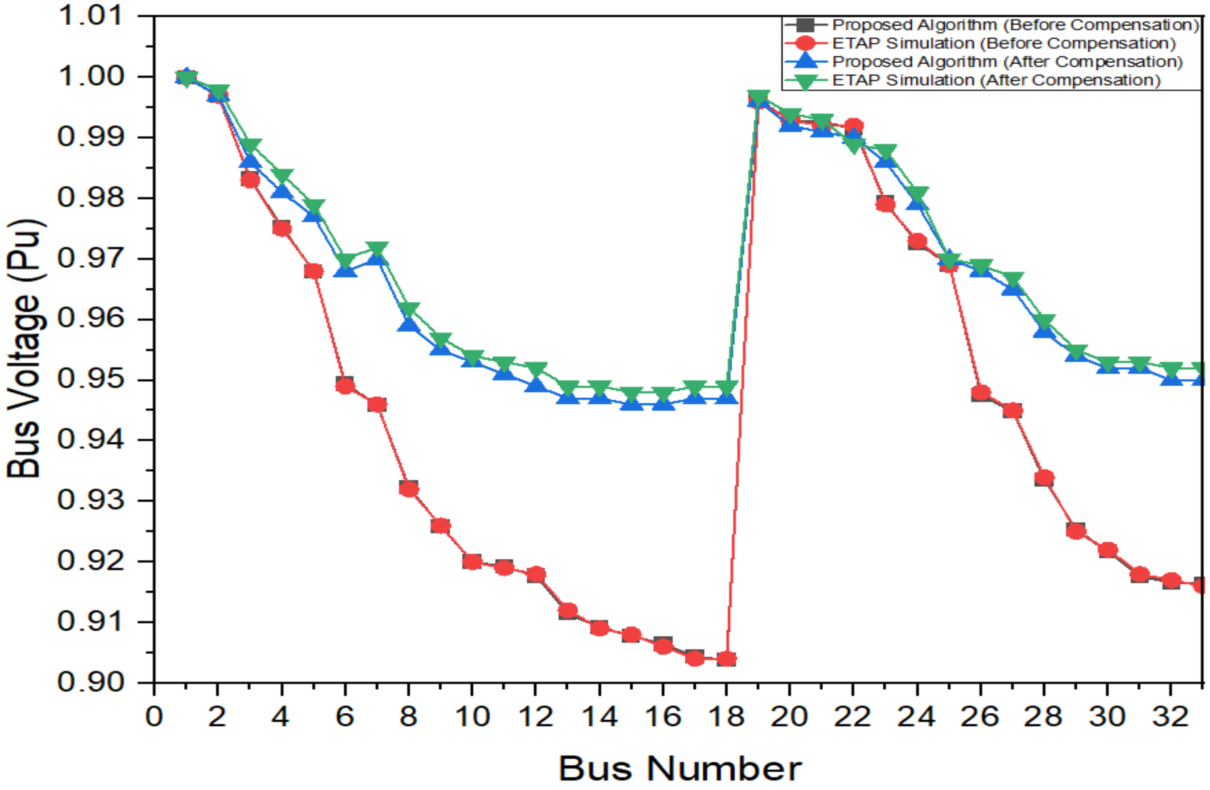


Figure 4.5: Voltage Profile of IEEE 33 bus system (After Compensation)

4.1.5 Power Losses

The total active power losses in each branches of network are determined in ETAP simulation for both before & after compensation stages. Before compensation, the total active power loss was observed to be 211.0 kW. Likewise, after the optimal allocation of capacitor banks in the respective candidate bus, the total active power loss was reduced to 147.3 kW which is also represented in the table below. Similarly, total reactive power loss in the system is determined to be 143.0 kVAr before compensation. After compensation, the reactive power loss was reduced to 102.4 kVAr. This shows a significant reduction in the total power loss of system.

The calculation showing the reduction of power loss is;

Active Power Loss reduction = $\frac{P_{loss}\ before\ compensation - P_{loss}\ after\ compensation}{P_{loss}\ before\ compensation}$*100%

$= \frac{211.0-147.3}{211.0}$ *100%

= 30.33 %

Reactive power Loss reduction = $\frac{Q_{loss}\ before\ compensation - Q_{loss}\ after\ compensation}{Q_{loss}\ before\ compensation}$*100%

$= \frac{143.0-102.4}{143.0}$ *100%

= 28.39 %

Hence, after optimal allocation of the capacitor bank in the respective candidate buses, the active power losses was reduced by 30.33%, and reactive power losses was reduced by 28.39% for the IEEE 33 bus system.

4.1.6 Voltage Regulation

Here, the voltage regulation of the IEEE 33 bus system for both before and after compensation is computed and compared.

Before Compensation:

The voltage at bus 1 ie; the sending end is found to be 1 pu and that in bus 18 ie; receiving end is found to be 0.9038 pu. The voltage regulation without compensation is then calculated as

Voltage Regulation (V.R) = $\frac{Sending\ end\ voltage - Receiving\ end\ voltage}{Sending\ end\ Voltage}$*100%

= $\frac{1-0.9038}{1}$*100%

= 9.62 %

After Compensation:

The voltage at bus 1 ie; the sending end is found to be 1 pu and the voltage at bus 18 ie; the receiving end voltage is found to be 0.947 pu. The voltage regulation after compensation is then computed as;

Voltage Regulation (V.R) = $\frac{Sending\ end\ voltage - Receiving\ end\ voltage}{Sending\ end\ Voltage}$*100%

= $\frac{1-0.947}{1}$*100%

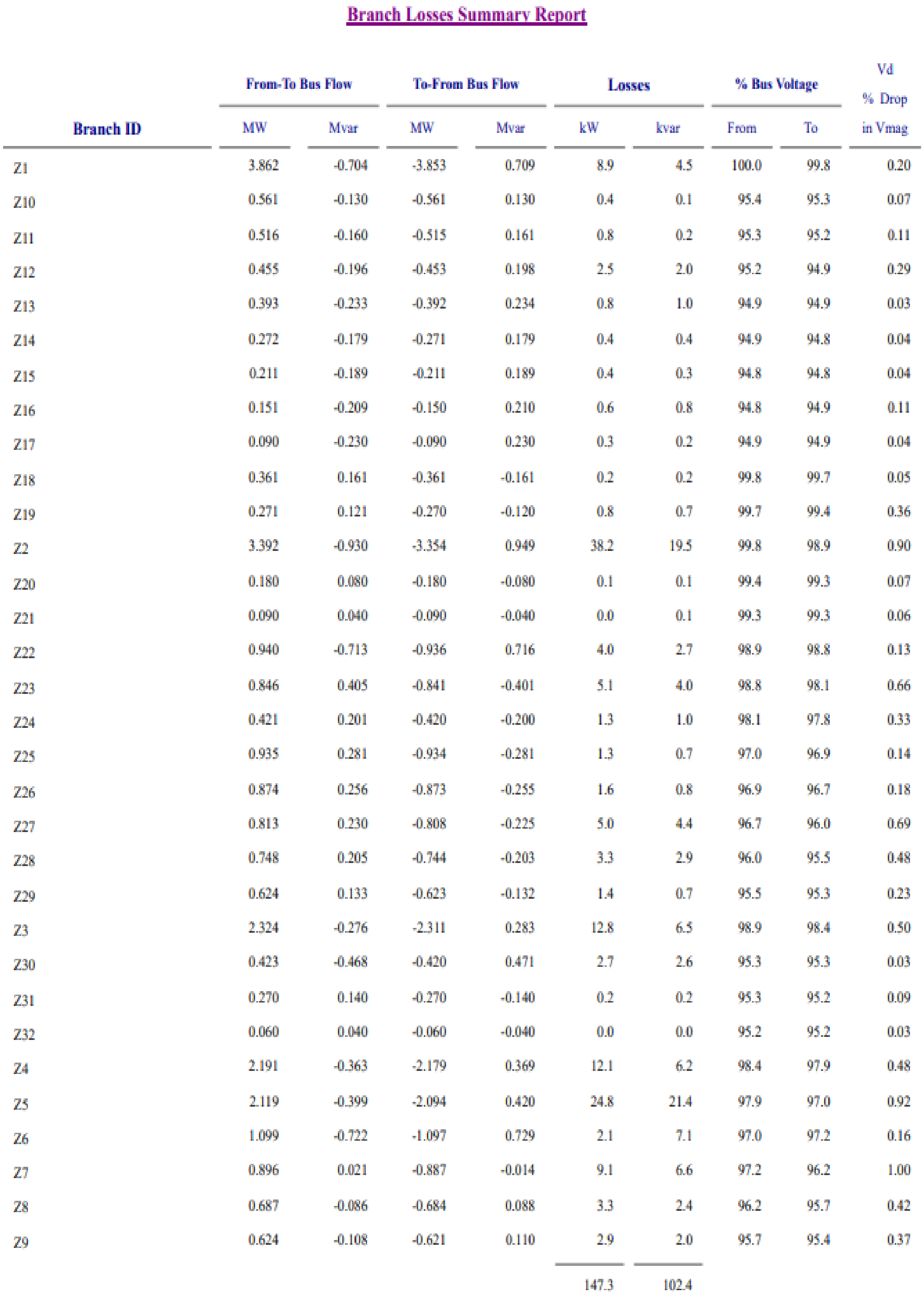
= 5.3 %

From the above calculation, after optimal placement of the capacitor bank in candidate buses the voltage regulation of the system is found to improve in comparison to the case without compensation.

4.1.7 Validation of Research

Here, the result obtained before and after the allocation of the capacitor bank is compared with the previously published research paper. This [28] paper used two stage process of Loss Sensitivity Factor (LSF) & Cuckoo Search Algorithm (CSA) to determine the optimal placement and size of the capacitor bank. For the standard IEEE 33 bus system, the loss of active power before and after compensation was found to be 210.99 kW and 138.65 kW. In this research, the active power loss before and after compensation was observed to be 211.0 kW and 147.3 kW respectively. Similarly, the maximum and minimum voltage obtained before compensation in the published paper is 1 and 0.9044 pu respectively. In this research, the maximum and minimum voltage obtained before compensation are 1 and 0.904 pu respectively. This shows that the voltage magnitude before compensation in this thesis and the previously published paper are almost the same. This proposed method is now implemented in the 77 Bus Butwal West Distribution Radial Feeder to evaluate optimal sizing and placement of the capacitor bank.

Table 4.5: Result of Load Flow Analysis of IEEE 33 Bus System (After Compensation)



Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Z1	3.862	-0.704	-3.853	0.709	8.9	4.5	100.0	99.8	0.20
Z10	0.561	-0.130	-0.561	0.130	0.4	0.1	95.4	95.3	0.07
Z11	0.516	-0.160	-0.515	0.161	0.8	0.2	95.3	95.2	0.11
Z12	0.455	-0.196	-0.453	0.198	2.5	2.0	95.2	94.9	0.29
Z13	0.393	-0.233	-0.392	0.234	0.8	1.0	94.9	94.9	0.03
Z14	0.272	-0.179	-0.271	0.179	0.4	0.4	94.9	94.8	0.04
Z15	0.211	-0.189	-0.211	0.189	0.4	0.3	94.8	94.8	0.04
Z16	0.151	-0.209	-0.150	0.210	0.6	0.8	94.8	94.9	0.11
Z17	0.090	-0.230	-0.090	0.230	0.3	0.2	94.9	94.9	0.04
Z18	0.361	0.161	-0.361	-0.161	0.2	0.2	99.8	99.7	0.05
Z19	0.271	0.121	-0.270	-0.120	0.8	0.7	99.7	99.4	0.36
Z2	3.392	-0.930	-3.354	0.949	38.2	19.5	99.8	98.9	0.90
Z20	0.180	0.080	-0.180	-0.080	0.1	0.1	99.4	99.3	0.07
Z21	0.090	0.040	-0.090	-0.040	0.0	0.1	99.3	99.3	0.06
Z22	0.940	-0.713	-0.936	0.716	4.0	2.7	98.9	98.8	0.13
Z23	0.846	0.405	-0.841	-0.401	5.1	4.0	98.8	98.1	0.66
Z24	0.421	0.201	-0.420	-0.200	1.3	1.0	98.1	97.8	0.33
Z25	0.935	0.281	-0.934	-0.281	1.3	0.7	97.0	96.9	0.14
Z26	0.874	0.256	-0.873	-0.255	1.6	0.8	96.9	96.7	0.18
Z27	0.813	0.230	-0.808	-0.225	5.0	4.4	96.7	96.0	0.69
Z28	0.748	0.205	-0.744	-0.203	3.3	2.9	96.0	95.5	0.48
Z29	0.624	0.133	-0.623	-0.132	1.4	0.7	95.5	95.3	0.23
Z3	2.324	-0.276	-2.311	0.283	12.8	6.5	98.9	98.4	0.50
Z30	0.423	-0.468	-0.420	0.471	2.7	2.6	95.3	95.3	0.03
Z31	0.270	0.140	-0.270	-0.140	0.2	0.2	95.3	95.2	0.09
Z32	0.060	0.040	-0.060	-0.040	0.0	0.0	95.2	95.2	0.03
Z4	2.191	-0.363	-2.179	0.369	12.1	6.2	98.4	97.9	0.48
Z5	2.119	-0.399	-2.094	0.420	24.8	21.4	97.9	97.0	0.92
Z6	1.099	-0.722	-1.097	0.729	2.1	7.1	97.0	97.2	0.16
Z7	0.896	0.021	-0.887	-0.014	9.1	6.6	97.2	96.2	1.00
Z8	0.687	-0.086	-0.684	0.088	3.3	2.4	96.2	95.7	0.42
Z9	0.624	-0.108	-0.621	0.110	2.9	2.0	95.7	95.4	0.37
					147.3	102.4			

4.2 Butwal West Distribution Feeder

Yogikuti Substation is located in Butwal, Rupandehi District of Lumbini Province. This substation supplies Power to all over Butwal city including neighboring places through 8 different distribution feeders. The different feeders fed from the Yogikuti substation are Butwal East, Butwal West, Chauraha Paschim, Chauraha Purba, Devinagar, Nayamil Paschim, Nayamil Purba and Saljhandi Feeder. Among them, the Butwal West distribution feeder is considered in this Thesis. This is an 11 kV radial distribution feeder with 77, 11/0.4 kV distribution transformer. Here all the distribution transformers are taken as load bus. The line conductors used in this distribution feeder are Dog, Weasel, and Rabbit conductors. Generally, the end parts of this feeder use Rabbit and Weasel Conductors. The single-line diagram of this distribution feeder is shown in *Figure 4.6*. The location of the transformer and routing of the line is represented in the Google map as shown in *Figure 4.7*. The Bus parameters ie; Active & Reactive power and line parameters ie; Resistance & Reactance of the Butwal west feeder *Table B.1* and *Table B.2*.

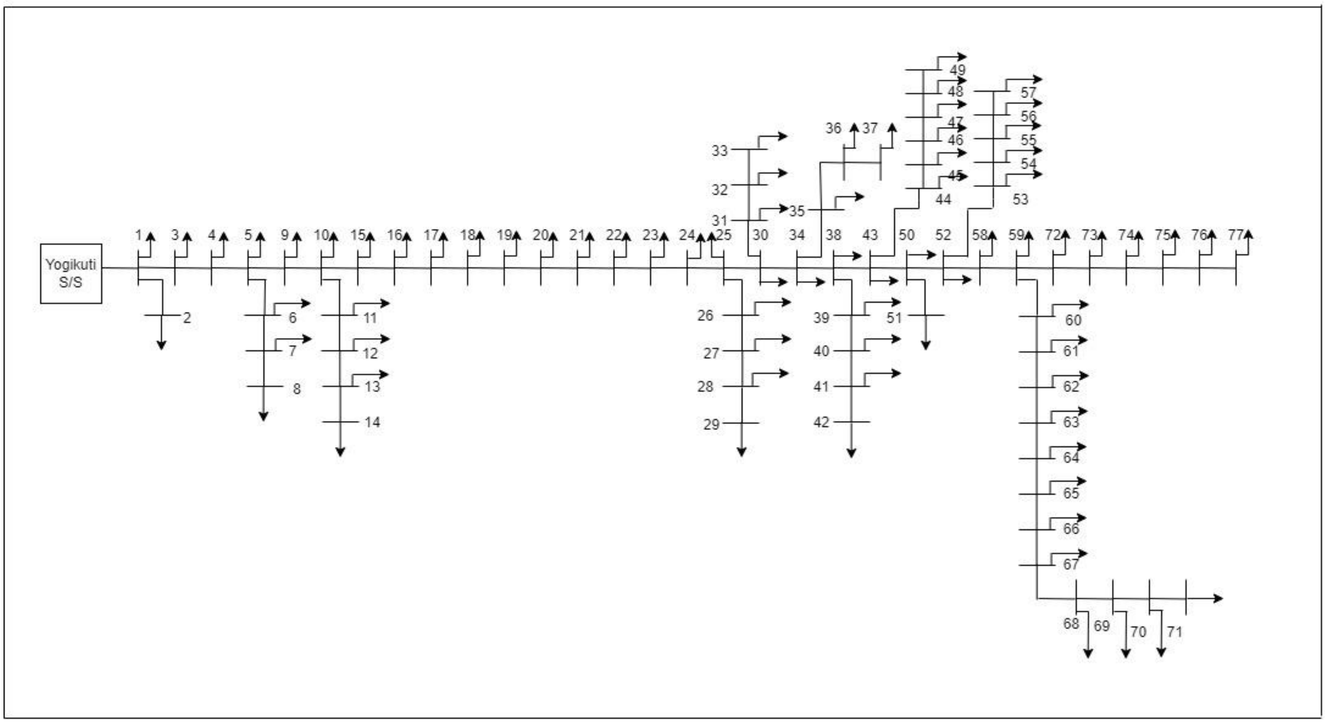


Figure 4.6: Single Line diagram of 77 Bus Butwal West Distribution Feeder

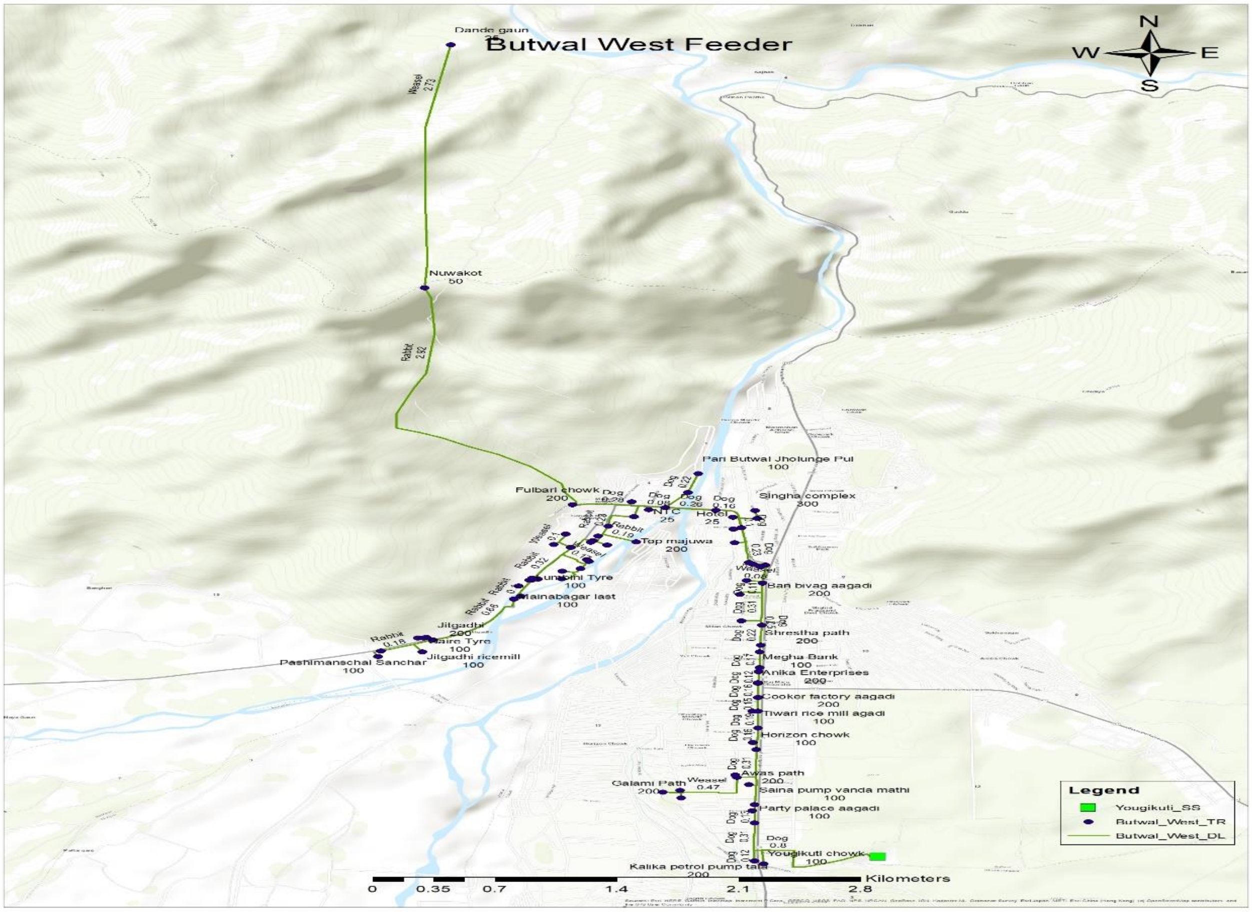


Figure 4.7: Google Map showing line routing and location of transformer in Butwal West Distribution Feeder

4.2.1 Load Flow Analysis

The Load Flow analysis of the 77 Bus Butwal West Distribution feeder with line and bus parameters is modeled in ETAP software to examine the performance of feeder observing Voltage drop and Power losses in each bus bar. Here, the load flow analysis is carried out in two Cases: Case I and II. In case I, load flow analysis is performed without considering the load of the EV charging station while in case II, the load of EV charging stations are considered and evaluated the line performance through load flow analysis.

4.2.2 Case I: Without EV Charging Station

The load flow analysis of the Butwal West feeder without considering the EV charging station is shown in *Figure 4.8*. Initially, the simulation is performed without the placement of a capacitor bank. The result of each bus voltage after simulation in ETAP software is tabulated below. The bus voltage decreases gradually while moving from sending end to receiving end of the feeder. The maximum voltage of 96.9% is observed in Bus 1 while the minimum voltage of 83.4% is observed in Bus 71. A voltage drop of 13.5% is observed while moving from sending end to receiving end of the feeder.

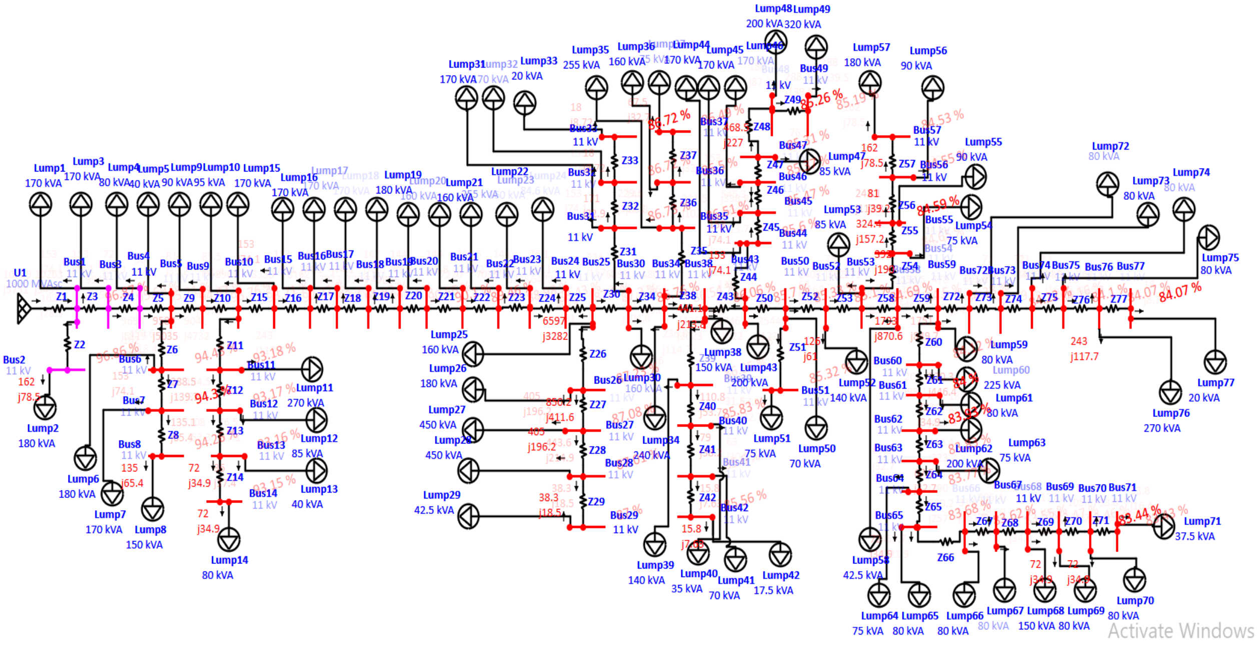


Figure 4.8: Load Flow analysis of 77 Bus Butwal West Distribution Feeder (Before Compensation)

Now, the LSI for each bus is computed using the PSO algorithm to determine the optimal size and candidate buses for the placement of the capacitor bank. The optimal buses obtained for placement of capacitor bank are arranged in descendent order as per the magnitude of LSI which are 76, 26, 35, 34, 43, 62, 10, 57, 6, 20, 36, 38, 25, 70, 19, 27, 28, 49, 22, 3, 11, 60, 18, 16, 15, 21, 48, 23, 17, 30, 45, 46, 44, 2, 31, 7, 32, 68, 9 using PSO algorithm. Similar to the standard IEEE 33 bus, the size of the capacitor bank is considered as per the standard practices which is generally considered in between 150 - 1200 kVAr. The size of the capacitor bank obtained is shown in Table 4.6.

Table 4.6: Optimal Capacitor Size and Respective Buses for Butwal West Feeder

Bus Number	Capacitor Size (kVAr)

76	1200
26	1200
35	1050
34	1200
43	300
62	1200
10	1200
57	1200
6	1200
20	1200

4.2.2.1 Comparison of Voltage Profile Before and After Compensation

The obtained candidate bus and optimal size of the capacitor bank are considered and Butwal West Feeder is modeled in the ETAP software as shown in *Figure 4.9*. The model is run to observe the Voltage drop & Power losses associated with each bus of the feeder. The Voltage magnitude in the percentage of each bus before and after the placement of the capacitor bank is tabulated below. The voltage profile for before & after compensation is compared and found significant enhancement in the voltage profile after optimal allocation of the capacitor bank which is shown in *Figure 4.10*.

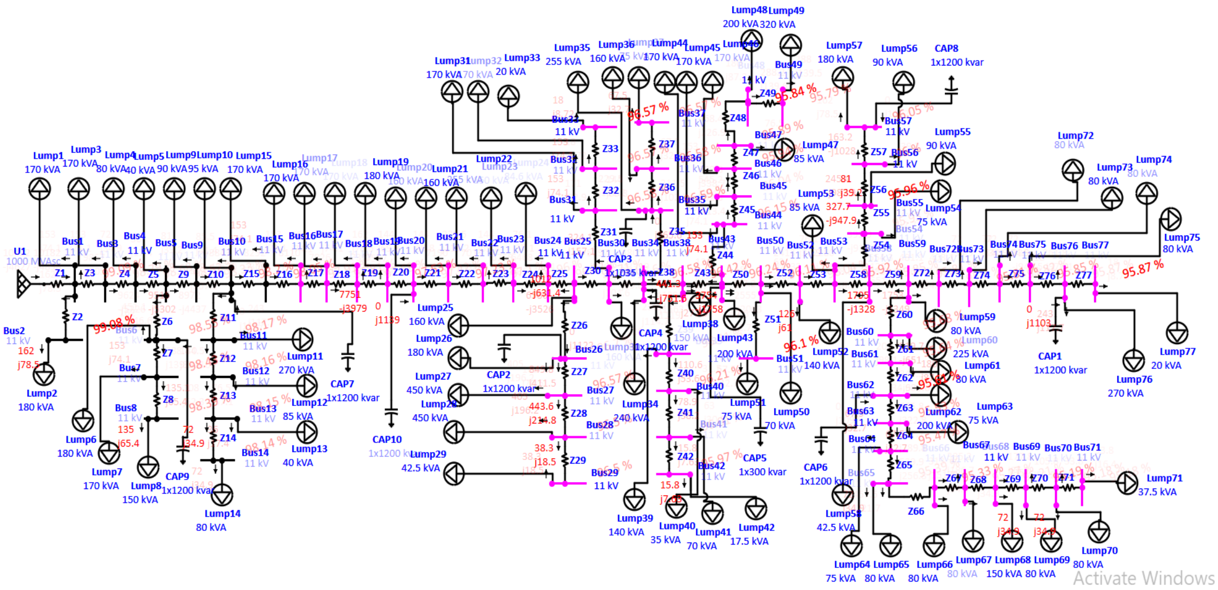


Figure 4.9: Load Flow analysis of 77 Bus Butwal West Distribution Feeder (After Compensation)

Table 4.7: Result of Bus Voltages obtained from ETAP simulation

Bus No.	Bus Voltage in % (Before Compensation)	Bus Voltage in % (After Compensation)
1	96.9	99.1
2	96.9	99.1
3	95.7	98.8
4	95.2	98.7
5	94.5	98.5
6	94.4	98.6
7	94.3	98.4
8	94.3	98.4
9	93.8	98.3

Bus No.	Bus Voltage in % (Before Compensation)	Bus Voltage in % (After Compensation)
10	93.2	98.2
11	93.2	98.2
12	93.2	98.2
13	93.2	98.1
14	93.2	98.1
15	92.7	98.1
16	92.2	97.9
17	91.8	97.8
18	91.3	97.7
19	90.7	97.5
20	90.1	97.4
21	89.5	97.2
22	89.0	97.1
23	88.4	97.0
24	87.6	96.8
25	87.3	96.7
26	87.2	96.7
27	87.1	96.6
28	87.0	96.5
29	87.0	96.5

Bus No.	Bus Voltage in % (Before Compensation)	Bus Voltage in % (After Compensation)
30	86.8	96.6
31	86.7	96.6
32	86.7	96.6
33	86.7	96.6
34	86.5	96.6
35	86.5	96.6
36	86.5	96.6
37	86.5	96.6
38	86.1	96.4
39	86.0	96.4
40	85.8	96.2
41	85.6	96.0
42	85.6	96.0
43	85.7	96.2
44	85.6	96.1
45	85.5	96.0
46	85.4	95.9
47	85.3	95.9
48	85.3	95.8
49	85.2	95.8

Bus No.	Bus Voltage in % (Before Compensation)	Bus Voltage in % (After Compensation)
50	85.3	96.1
51	85.3	96.1
52	85.1	96.0
53	84.7	95.9
54	84.7	95.9
55	84.6	96.0
56	84.6	96.0
57	84.5	96.1
58	84.5	95.9
59	84.4	95.8
60	84.1	95.7
61	84.0	95.6
62	83.9	95.6
63	83.8	95.5
64	83.8	95.5
65	83.7	95.4
66	83.6	95.3
67	83.5	95.3
68	83.5	95.2
69	83.5	95.2

Bus No.	**Bus Voltage in % (Before Compensation)**	**Bus Voltage in % (After Compensation)**
70	83.4	95.2
71	83.4	95.2
72	84.3	95.8
73	84.2	95.8
74	84.2	95.8
75	84.1	95.8
76	84.1	95.8
77	84.1	95.9

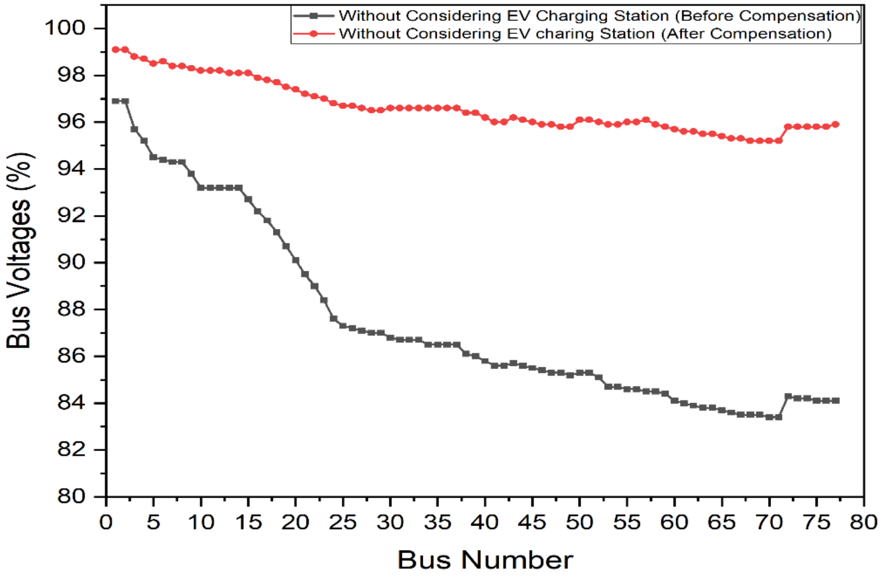


Figure 4.10: Voltage Profile of 77 bus Butwal West Distribution Feeder (Case I)

4.2.2.2 Power Losses and Voltage Regulation

The active and reactive power losses in each branch of the network are obtained from ETAP simulation for both before & after compensation. Before compensation, the active power loss and reactive power loss are found to be 1062.7 kW and 1164.6 kVAr respectively. Likewise, after compensation, these active and reactive power losses in the feeder are reduced to 954.4 kW and 1039.5 kVAr respectively. After placement of the capacitor bank, the percentage reduction of active and reactive power loss is found to be 10.19% and 10.74% respectively. Before compensation, the maximum voltage of 96.9% was observed in Bus 1, and the minimum voltage was found to be 83.4% in Bus 71. Likewise, after compensation, the maximum & minimum voltage are observed to be 99.1% and 95.2% in Bus 1 and Bus 71 respectively. The voltage regulation before and after compensation is found to be 13.93% and 3.93% respectively.

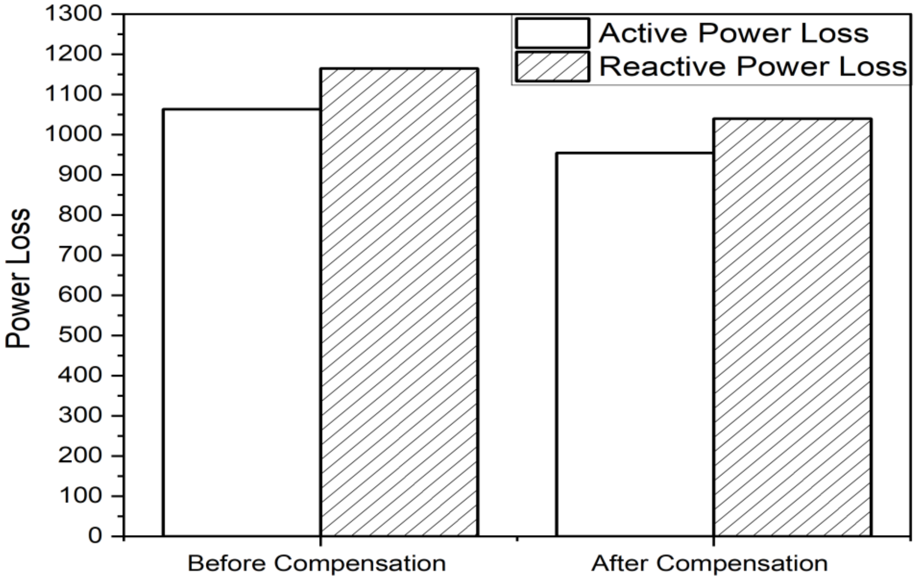


Figure 4.11: Power Loss (Case I)

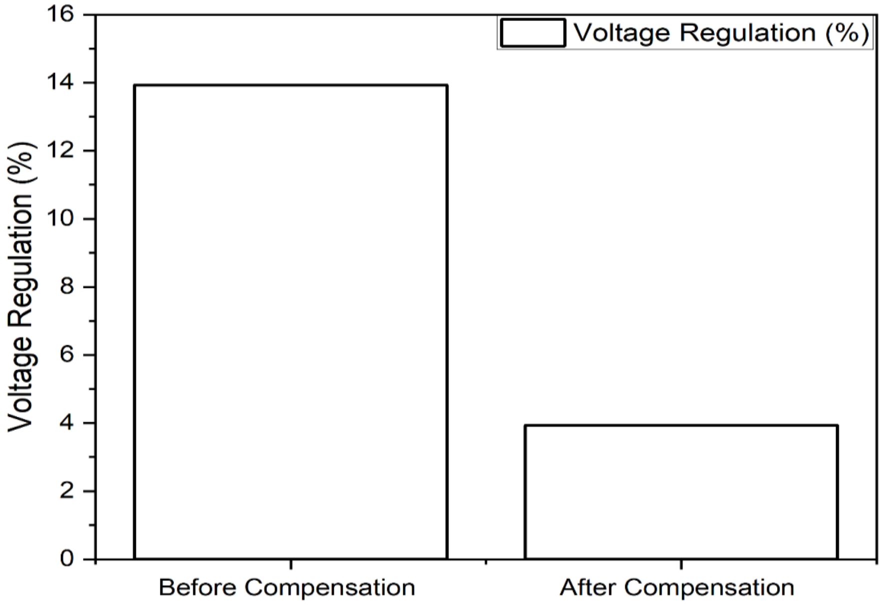


Figure 4.12: Voltage Regulation (Case I)

4.2.3 Case II: Considering EV Charging Station

In this case, the load of 5 different EV charging stations present in the Butwal West Radial Distribution Feeder is considered and the performance of the feeder is analyzed. The load of each charging stations is injected into their respective buses as per their location and simulated in ETAP software as shown in *Figure 4.13*. The result of each bus voltage after simulation in ETAP software is tabulated below. Similar to Case I, the bus voltage is found to gradually decrease from sending end to receiving end of the feeder. The maximum voltage of 96.8% and minimum voltage of 83.0% are observed in Bus 1 and Bus 71 respectively. A maximum voltage drop of 13.8% is observed between the sending and receiving ends of the feeder. The loads of EV charging station that are injected into the respective buses are presented in *Table 4.8*.

Table 4.8: EV Charging Station's Load

Bus No.	EV Charging Stations Load
2	30 kW, 14.52 kVAr

9	30 kW, 14.52 kVAr
10	30 kW, 14.52 kVAr DC
28	120 kW, 58.08 kVAr (DC) and 22 kW, 14.52 kVAr
23	30 kW, 14.52 kVAr

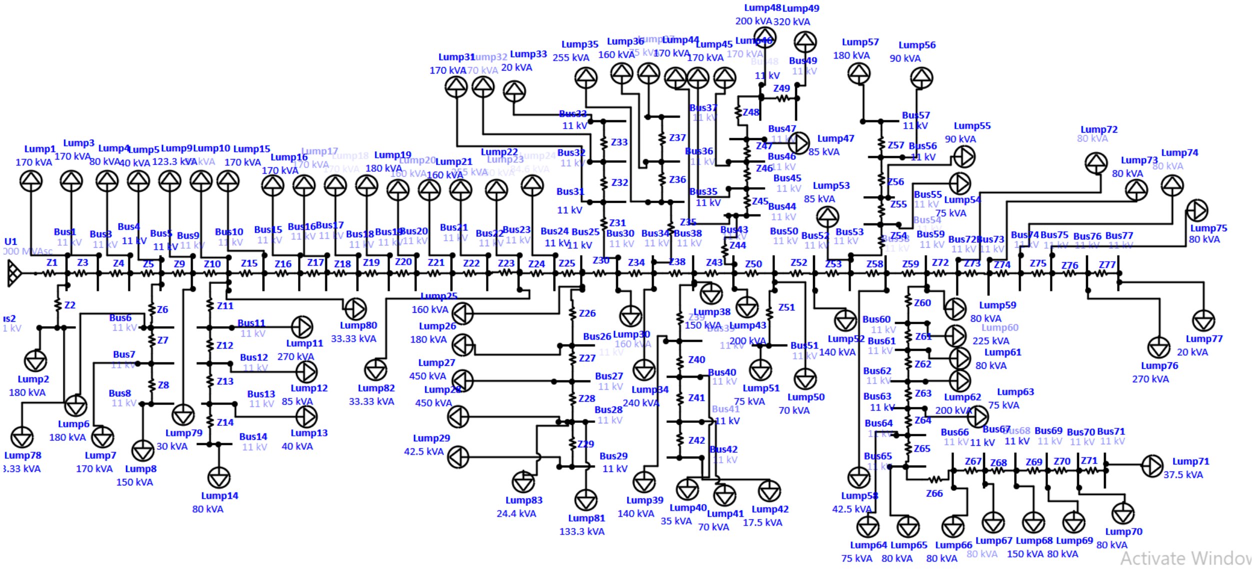


Figure 4.13: Load Flow analysis of Butwal West feeder for case II (Before compensation)

Now, the LSI for each bus are computed using the PSO algorithm to determine the optimal size and candidate buses for the placement of the capacitor bank. The optimal buses obtained for placement of capacitor bank are arranged in descending order according to LSI values which are 20, 70, 49, 3, 43, 76, 30, 10, 6, 45, 26, 35, 34, 62, 57, 36, 38, 25, 19, 27, 28, 22, 11, 60, 18, 16, 15, 48, 23, 17, 46, 44, 2, 31, 7, 32, 68, 9 using PSO algorithm. Similar to the IEEE 33 bus system, the size of the capacitor bank is considered as per the standard practice which are generally taken from 150 – 1200 kVAr. The optimal size of the capacitor bank obtained through the PSO algorithm is presented in *Table 4.9*.

Table 4.9: Optimal Capacitor Size and Bus for Butwal West Radial Feeder

Bus Number	**Capacitor Size (kVAr)**

20	1200
70	1200
49	1200
3	1200
43	1200
76	1200
30	1200
10	900
6	1200
45	1200

4.2.3.1 Comparison of Voltage Profile Before and After Compensation

After determining the candidate bus and size of the capacitor bank, load flow analysis is performed in ETAP software to determine the performance of the feeder after compensation as shown in *Figure 4.14*. After carrying out the simulation, the voltage drop and line losses associated with each feeder are determined. The result of voltage percentage before and after compensation is tabulated below. The voltage profile of the feeder before & after compensation is compared and significant enhancement in voltage profile is shown in *Figure 4.16*.

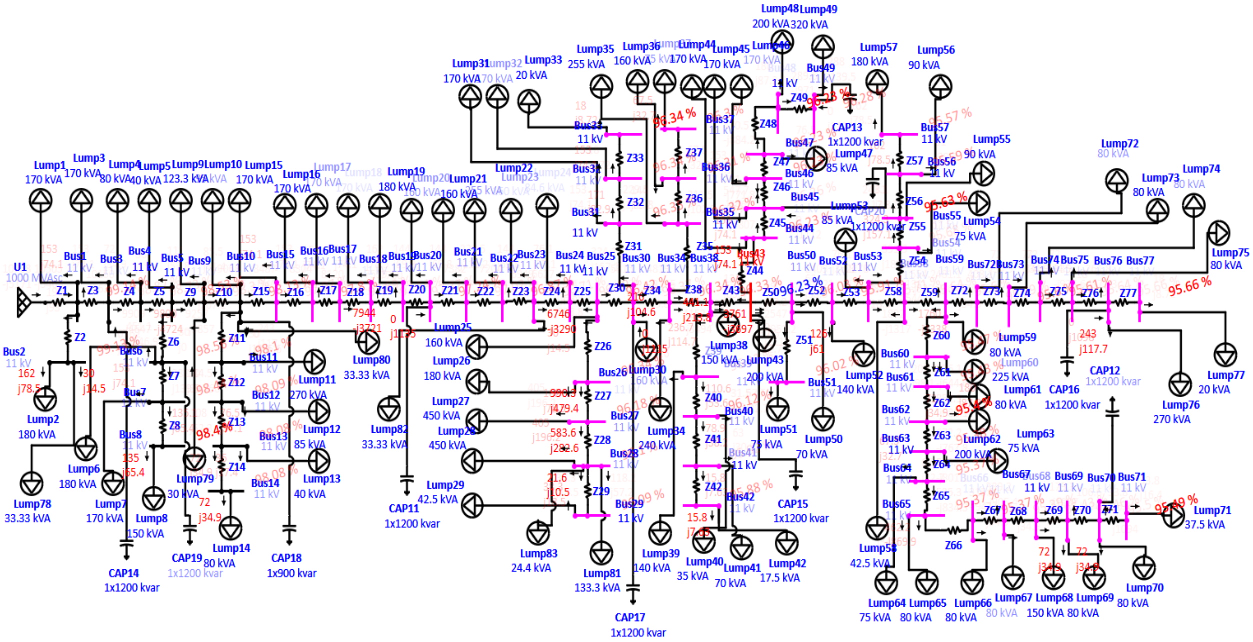


Figure 4.14: Load Flow analysis of Butwal West feeder for case II (After compensation)

Table 4.10: Result of Bus Voltage after ETAP Simulation

Bus No.	Bus Voltage in % (Before Compensation)	Bus Voltage in % (After Compensation)
1	96.8	99.1
2	96.8	99.1
3	95.6	98.9
4	95.1	98.7
5	94.3	98.5
6	94.2	98.6
7	94.1	98.5
8	94.1	98.4
9	93.6	98.3

Bus No.	**Bus Voltage in % (Before Compensation)**	**Bus Voltage in % (After Compensation)**
10	93.0	98.2
11	93.0	98.1
12	93.0	98.1
13	92.9	98.1
14	92.9	98.1
15	92.5	98.0
16	92.0	97.8
17	91.6	97.7
18	91.0	97.5
19	90.4	97.4
20	89.8	97.2
21	89.1	97.0
22	88.6	96.9
23	88.1	96.7
24	87.2	96.5
25	86.9	96.4
26	86.8	96.3
27	86.7	96.2
28	86.6	96.1
29	86.6	96.1

Bus No.	**Bus Voltage in % (Before Compensation)**	**Bus Voltage in % (After Compensation)**
30	86.4	96.4
31	86.4	96.3
32	86.3	96.3
33	86.3	96.3
34	86.2	96.3
35	86.1	96.3
36	86.1	96.3
37	86.1	96.3
38	85.7	96.3
39	85.7	96.3
40	85.4	96.1
41	85.2	95.9
42	85.2	95.9
43	85.3	96.2
44	85.2	96.2
45	85.1	96.3
46	85.0	96.2
47	84.9	96.2
48	84.9	96.2
49	84.8	96.3

Bus No.	**Bus Voltage in % (Before Compensation)**	**Bus Voltage in % (After Compensation)**
50	85.0	96.0
51	84.9	96.0
52	84.7	95.9
53	84.3	95.7
54	84.3	95.7
55	84.2	95.6
56	84.2	95.6
57	84.1	95.6
58	84.1	95.6
59	84.0	95.6
60	83.7	95.5
61	83.6	95.4
62	83.5	95.4
63	83.4	95.4
64	83.4	95.4
65	83.3	95.4
66	83.2	95.4
67	83.2	95.4
68	83.1	95.4
69	83.1	95.5

Bus No.	**Bus Voltage in % (Before Compensation)**	**Bus Voltage in % (After Compensation)**
70	83.1	95.5
71	83.0	95.5
72	83.9	95.6
73	83.8	95.6
74	83.8	95.6
75	83.7	95.6
76	83.7	95.7
77	83.7	95.7

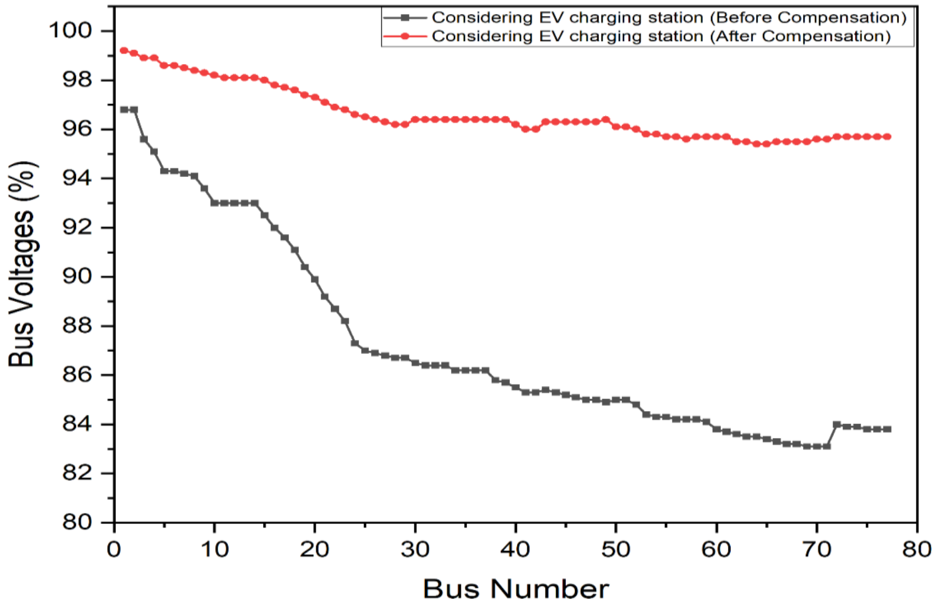


Figure 4.15: Voltage Profile of 77 Bus Butwal West Distribution Feeder (Case II)

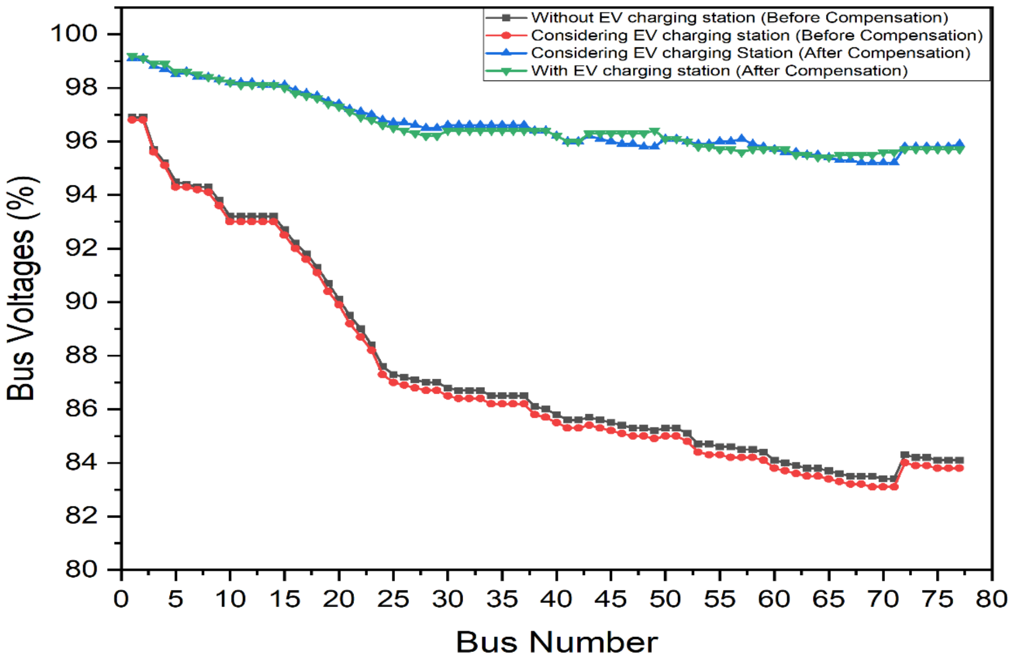


Figure 4.16: Comparison of Voltage Profile of Butwal West Feeder for both Cases I and II

4.2.3.2 Power Losses and Voltage Regulation

The total power losses ie; active & reactive power losses at each branches of the feeder are observed in ETAP software for both with and without compensation considering the electric charging station. Before compensation, the active power loss is found to be 1121.6 kW and the reactive power loss to be 1230.2 kVAr. Similarly, after optimal allocation of the capacitor bank, the active and reactive power loss are found to be reduced to 1011.3 kW & 1099.3 kVAr respectively. After compensation, the percentage reduction in active & reactive power loss is evaluated as 9.83% and 10.64% respectively. Before compensation, the maximum voltage of 96.8% is observed in bus 1, and the minimum voltage is found to be 83.0% in bus 71. Likewise, after compensation, the maximum and minimum voltage is observed to be 99.1% and 95.5% in Bus 1 and Bus 71 respectively. The voltage regulation before and after compensation is computed to be 14.25% and 3.63% respectively.

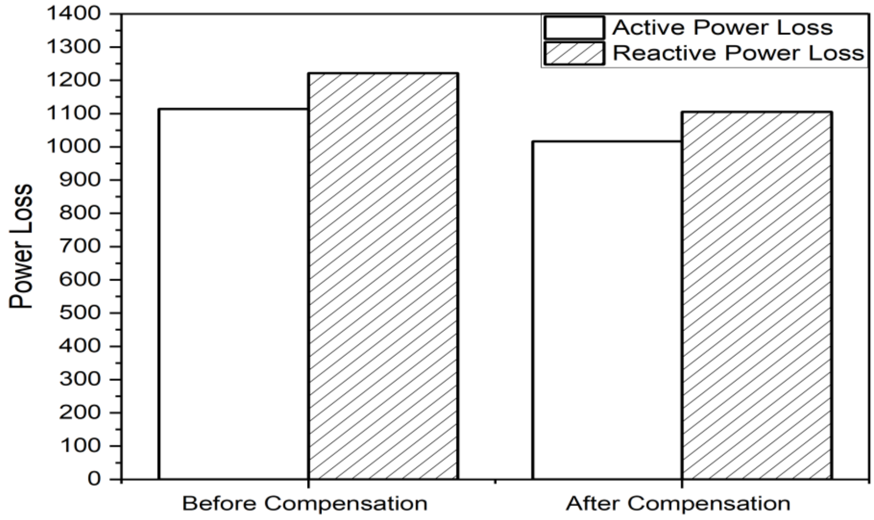


Figure 4.17: Power Loss (Case II)

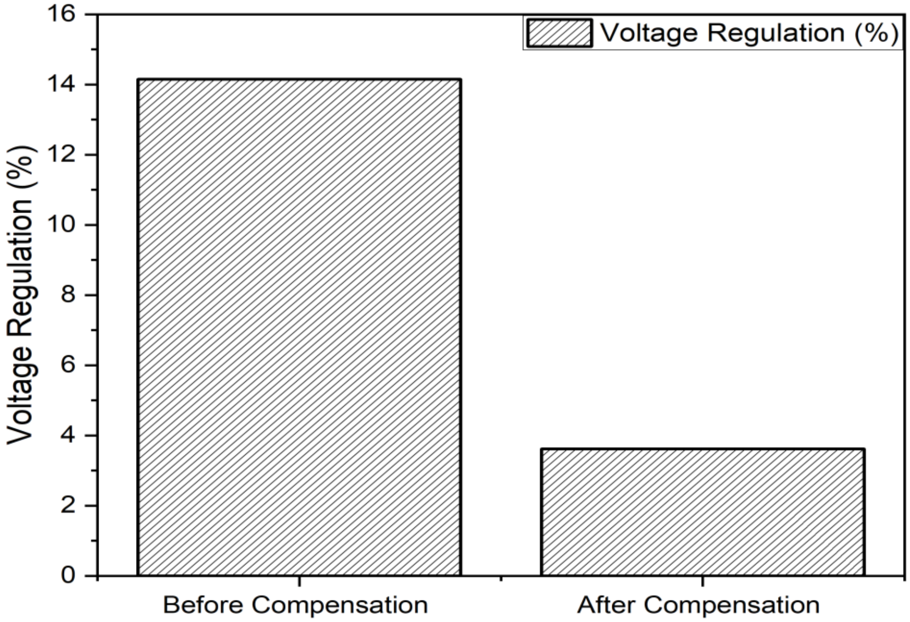


Figure 4.18: Voltage Regulation (Case II)

4.2.4 Financial Analysis

The financial analysis after the installation of the capacitor bank considering the EV charging station in this thesis was carried out considering an annual interest rate of 10% p.a. and the life expectancy of the capacitor bank of 20 years. The cost of capacitor bank and installation cost of the capacitor bank were taken as 5 \$/year and 1000\$ respectively. A total capacitor bank of size 11700 kVAr was installed in the feeder to achieve the active power loss reduction of 110.3 kW. Here, the total capital cost is considered as the sum of total capacitor cost and its installation which is \$59,500. The detailed financial analysis was carried out in MS Excel which is shown in Appendix *Table B.7*.

From financial analysis, the total annual return was evaluated to be \$ 18,530.40 which was greater than the total annual cost. The BC ratio is evaluated to be 2.45. The higher value of the BC ratio indicates that the total revenue is 2.45 times of total cost of the project. Likewise, the IRR is evaluated as 18% which is much greater than that of considered interest rate of the project. This suggests that the project is more profitable from a financial perspective view. Similarly, the discounted payback period of the project is evaluated as 4.15 years. This indicates that at 4.15 years total initial cost associated with the project is overcome and the project yields profit beyond this period. From the financial examination, it can be inferred that the optimal allocation of a capacitor bank is financially justifiable. The BC ratio, IRR, and discounted Payback period computed are represented in *Figure 4.19*.

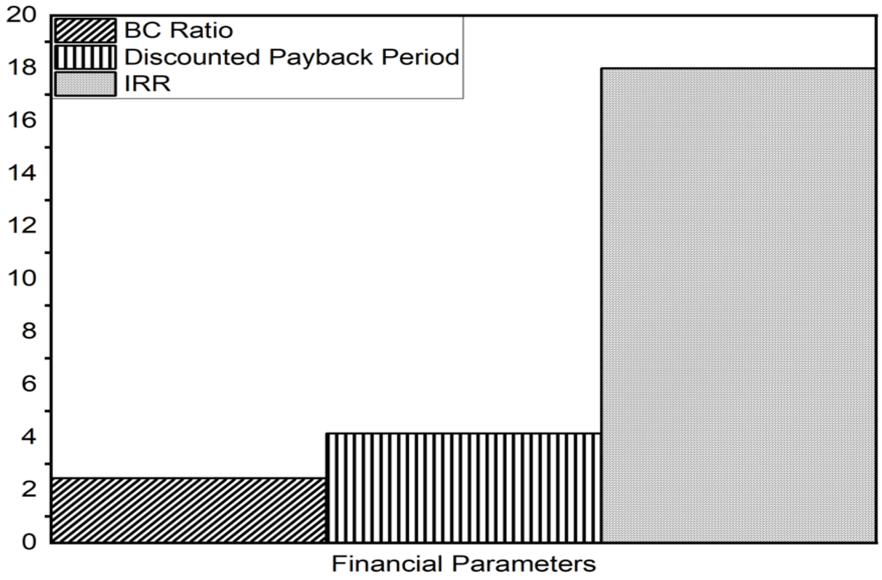


Figure 4.19: Financial Indicators after Placement of Capacitor Bank for Case II

4.2.5 Sensitivity Analysis

After Capital budgeting, sensitivity analysis is carried out to assess the impact of change in various input parameters on the BCR analysis of the project after installation of the capacitor bank considering loads of EV charging station. From the result, the BC ratio is found to decrease with the increase in interest rate. For -30% variation of interest rate BC ratio was found to be 2.970 while for +30% variation, it was found to be 2.055. Similarly, for -30% variation, the BC ratio was 1.713, for +30% variation, the BC ratio was found to be 3.182 for cost of power loss. The graph for variable cost of power loss was found to be steeper in comparison to other input variables considered. This indicates that the cost of power saving has the most substantial impact on the BC ratio, emphasizing the importance of cost of power loss in financial feasibility for the installation of a capacitor bank. The graph showing the impact of variation in various input parameters is represented in *Figure 4.20*.

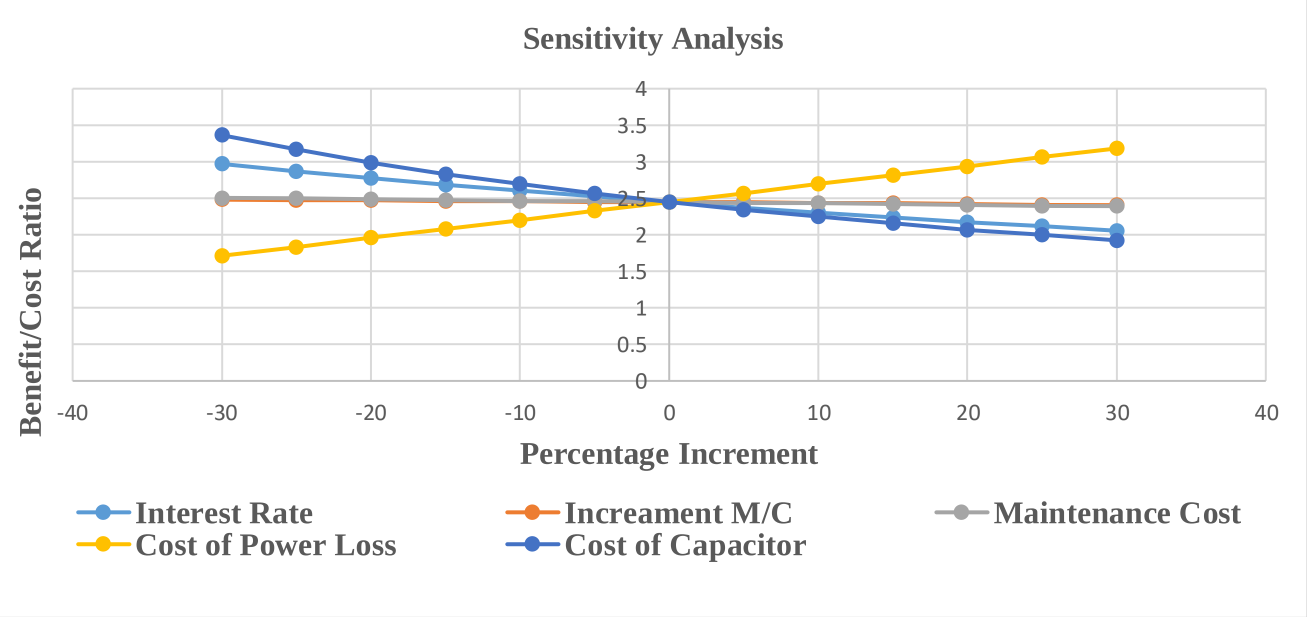
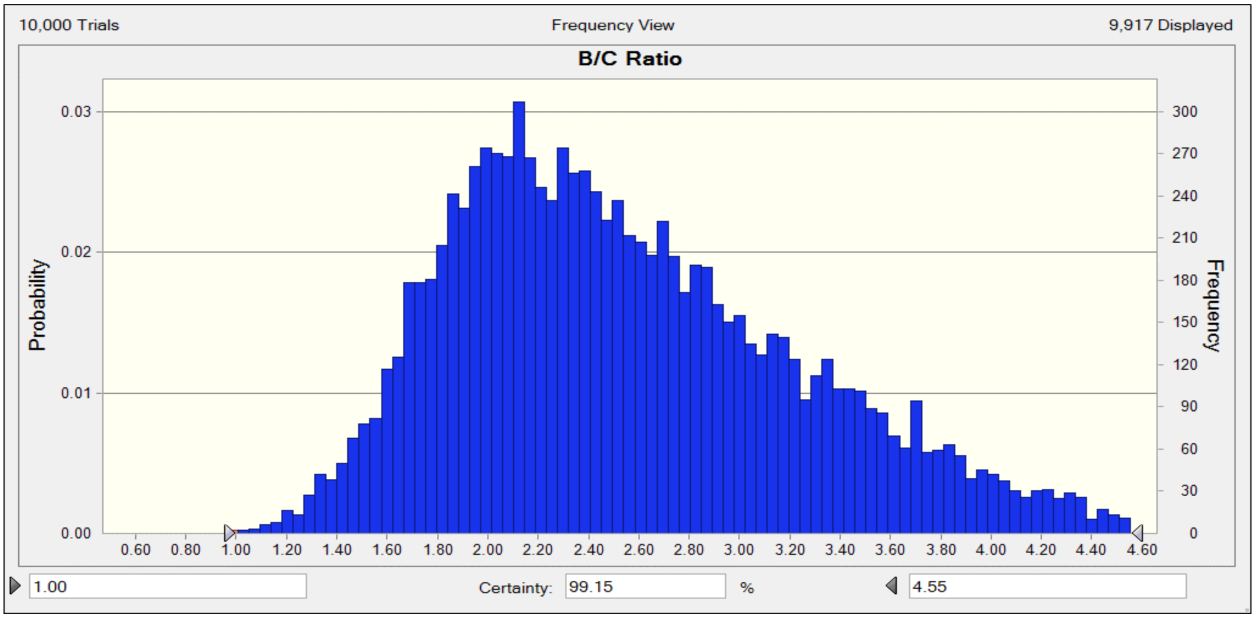


Figure 4.20: Sensitivity Analysis

The sensitivity analysis indicates that cost of power savings and cost of capacitor banks are the most sensitive parameters affecting the financial performance of capacitor bank installations. These parameters exhibit the most significant variations in the BC ratio when altered, highlighting their critical role in the decision-making process for optimal capacitor placement. Conversely, the increment rate in maintenance cost shows the least sensitivity, indicating a minor impact on the overall financial assessment.

4.2.6 Monte Carlo Simulation Analysis

In the Monte Carlo simulation for risk analysis of the optimal allocation of capacitor banks in an actual feeder, several input parameters with specific probabilistic distributions are considered to account for uncertainty & variability. The Cost of the capacitor bank is modeled as a uniform distribution with a minimum value of \$3 per kVar and a maximum value of \$7 per kVar, reflecting the variability in market prices. The Cost of power loss is assumed to follow a normal distribution with a mean of \$168 per kW-year & a standard deviation of \$26.12, capturing the fluctuating nature of power savings due to varying load conditions and operational efficiencies. The Maintenance cost of the capacitor bank is also normally distributed, with a mean of \$322.42 per year & a standard deviation of \$50.12, accounting for potential deviations in maintenance expenses over time. The Interest rate is represented by a triangular distribution, with a minimum of 8%, a maximum of 12%, and a most likely value of 10%, reflecting the range of potential interest rates influenced by economic conditions. Similarly, the incremental rate of maintenance cost. follows a triangular distribution with a minimum of 5%, a maximum of 12%, and a likeliest value of 8%, considering the possible growth rates in maintenance costs. The IRR and BC Ratio are considered as Forecast parameters to evaluate the impact of input uncertainties to the overall financial performance of optimal installation of capacitor bank.



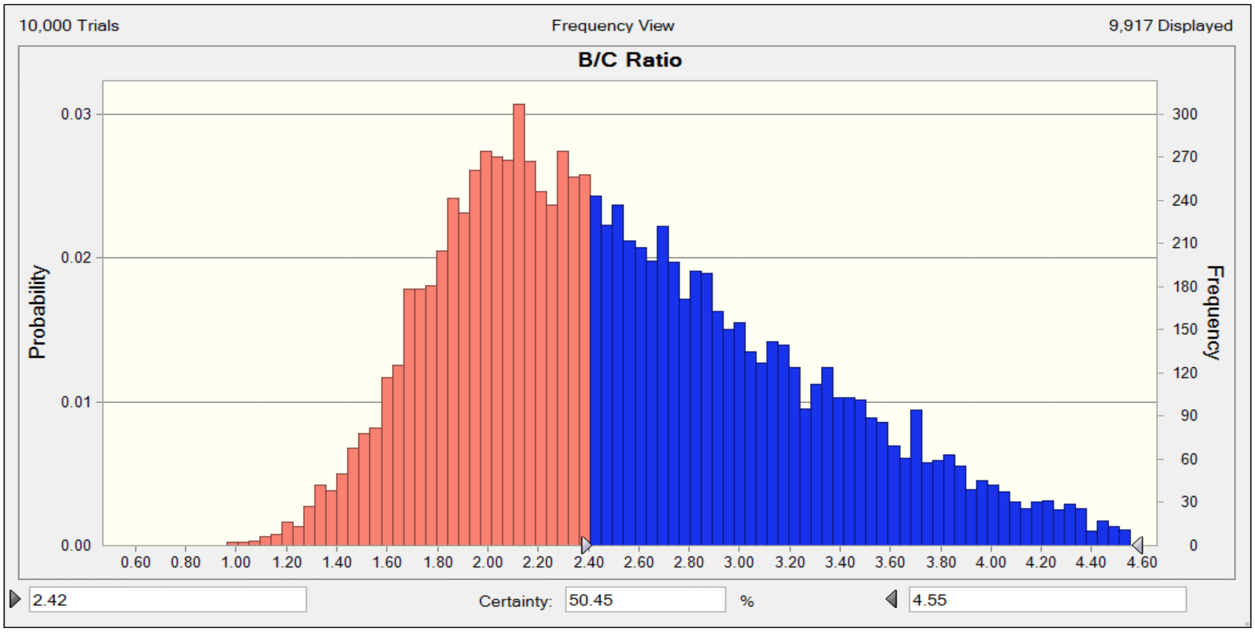
1.00

Certainty: 99.15 %

4.55

Figure 4.21: Probability of Breakeven B/C Ratio

This result indicates that there is a 99.15% probability that the B/C ratio will be at least 1. A BCR of 1 means that benefits from the capacitor bank installation (such as cost savings from reduced power losses) are equal to the costs incurred (including installation, maintenance, and other expenses). This high certainty level suggests that it is almost guaranteed that the project will at least break even, making it a financially safe investment.



2.42 Certainty: 50.45 % 4.55

Figure 4.22: Probability for B/C ratio Computed

For a B/C ratio of 2.42, there is a 50.45% probability that the benefits will be 2.42 times greater than the costs. This implies that there is roughly a 50-50 chance that the project will be highly profitable. This ratio indicates a significantly positive return on investment, reflecting a favorable economic outcome under typical conditions.

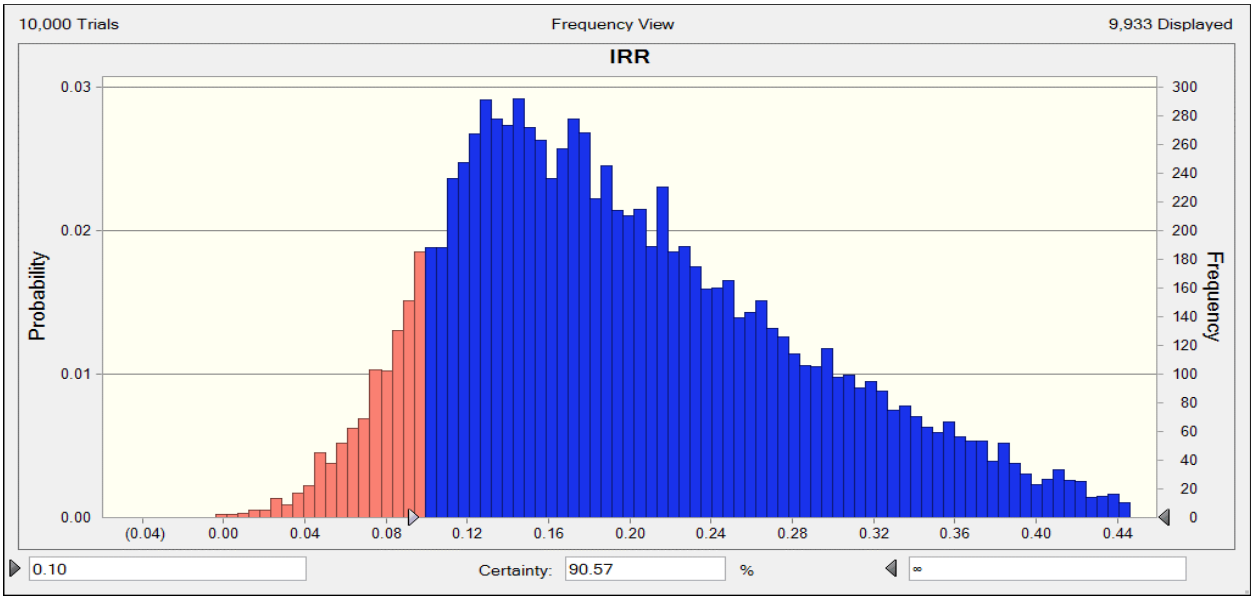


Figure 4.23: Probability of Breakeven IRR

The certainty level of 90.57% for an IRR of 10% shows a high likelihood that the project will achieve at least a 10% return on investment, which is often considered the breakeven point where the project justifies its cost of capital. This high probability underscores the project's robustness in achieving a minimum acceptable return, reinforcing its financial viability.

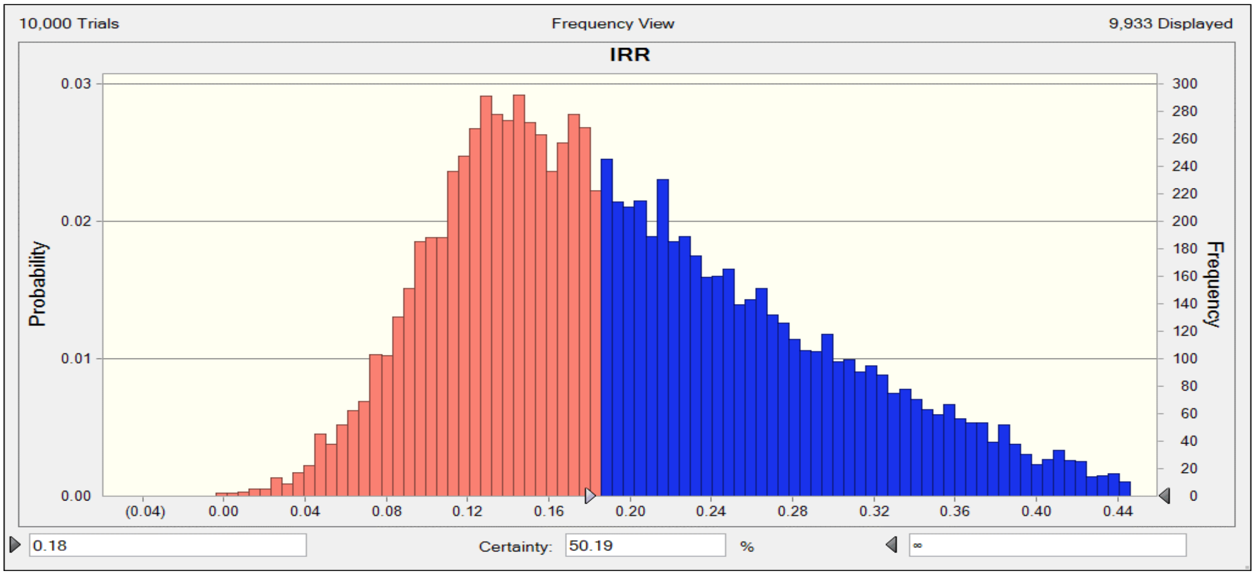


Figure 4.24: Probability of IRR Computed

For an IRR of 18%, the certainty is 50.19%, indicating an even chance that the project will yield a return of 18% or higher. An IRR of 18% reflects a strong performance, significantly above the typical cost of capital rates, suggesting substantial profitability. This result portrays the project as potentially very lucrative, but with a balanced risk of achieving such high returns.

Overall, the Monte Carlo Simulation analysis provides confidence in the investment decision, highlighting the financial benefits while also acknowledging the inherent risks & variability.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Different types of inherent losses take place while electrical energy is transferred from generating stations to distribution networks through transmission & distribution networks. In this thesis, two different feeder ie; Standard IEEE 33 Bus and 77 Bus Butwal West Practical feeders are considered. In a practical feeder, the system is simulated for both cases considering and without considering the loads of the EV charging station in the system. The optimal size and allocation of the capacitor bank are determined with the PSO algorithm and the feeder performance in Power loss, Voltage Profile & cost-saving with and without compensation.

The following conclusions are drawn from this research work;

- The improvement and reduction in overall loss of the radial distribution system are achieved with the optimal installation of a capacitor bank in the distribution network. In the case of the IEEE 33 bus system, before compensation, the active & reactive power losses are found to be 211.0 kW and 143.0 kVAr respectively. After the installation of the capacitor bank, the active & reactive power losses were reduced to 147.3 kW and 102.4 kVAr respectively. Likewise, Voltage regulation was improved from 9.62% to 5.3%.
- In the case of the Butwal West Distribution feeder without considering the electric charging station (Case I), the active & reactive power loss before compensation was found to be 1062.7 kW and 1164.6 kVAr respectively. This active & reactive power loss was reduced to 954.4 kW and 1039.5 kVAr after placement of the capacitor bank. The percentage reduction in active & reactive power loss was found to be 10.19% and 10.74% respectively. Likewise, Voltage regulation was improved from 13.93% to 3.93% resulting in an enhancement in the voltage profile of the distribution network.
- Similarly, after considering loads of EV charging stations in the Butwal west distribution feeder (Case II), the active & reactive power loss of 1121.6 kW and 1230.2 kVAr was found before the optimal placement of the capacitor bank. After the Placement of the capacitor bank, these active & reactive power losses were reduced to 1011.3 kW & 1099.3 kVAr respectively.

Likewise, a significant improvement in voltage regulation was observed from 14.15% to 3.62% after the placement of the capacitor bank.

- The financial examination indicates that the installation of a capacitor bank is highly financially viable. The financial metrics such as BC Ratio, IRR, and Discounted Payback Period were found to be 2.45, 18%, and 4.15 years respectively. The sensitivity analysis indicates that cost of power savings and cost of capacitor banks were the most sensitive parameters affecting the financial performance of capacitor bank installations. Likewise, the Monte Carlo Simulation analysis provided confidence in the investment decision highlighting financial benefits for the optimal allocation of the capacitor bank in the Butwal West Distribution Feeder.

5.2 Recommendations

This thesis can be extended further to encounter limitations that are realized while carrying out the research work. In this study, the optimal placement and sizing of the capacitor bank is determined considering that the system always runs at full load. But in actual practice, the load in the system varies timely and is not constant. In future research, variable loads can be considered and determine the size & placement of the capacitor bank. Besides the capacitor bank, several compensators such as FACTs devices and static VARs compensators can be considered in the future to reduce the losses and enhance feeder performance.

Likewise, other optimization techniques can be adopted to determine the optimal allocation of capacitor banks in future research to obtain the best possible results.

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APPENDIX A

Table A.1: Line Parameters of IEEE 33 Bus System

Branch No.	From	To	R (Ω)	X (Ω)	P (kW)	Q (kVAr)
1	1	2	0.0922	0.0470	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	1.7114	1.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	18	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	22	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	25	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40

APPENDIX B

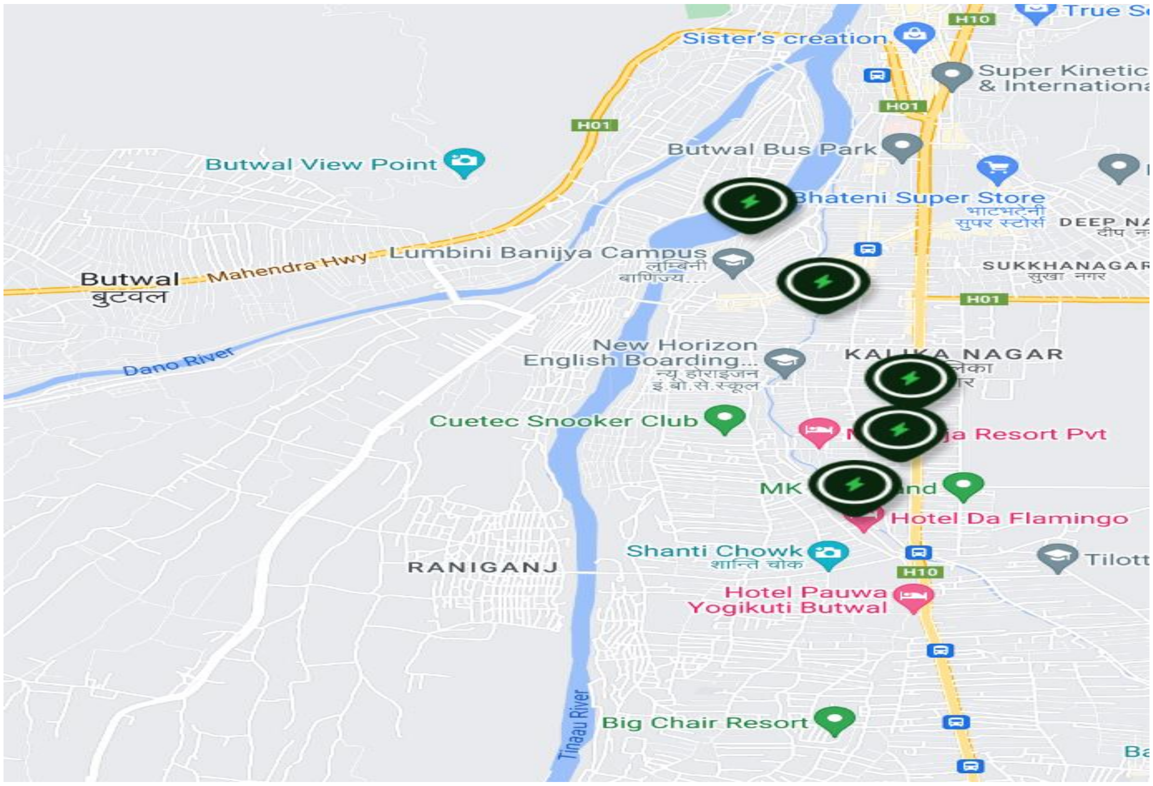


Figure B.1: Google Map Showing the Location of Electric Charging Station

Table B.1: Bus Parameter of Butwal West Distribution Feeder, Butwal

Bus No.	**Rating of Transformer**	**Transformer Loading**	**P(kW)**	**Q(kVAr)**
1	200	170	153	74.12
2	200	180	162	78.48
3	200	170	153	74.12
4	100	80	72	34.88
5	50	40	36	17.44
6	200	180	162	78.48
7	200	170	153	74.12
8	200	150	135	65.4
9	100	90	81	39.24
10	100	95	85.5	41.42
11	300	270	243	117.72
12	100	85	76.5	37.06
13	50	40	36	17.44
14	100	80	72	34.88

Bus No.	Rating of Transformer	Transformer Loading	P(kW)	Q(kVAr)
15	200	170	153	74.12
16	200	170	153	74.12
17	200	170	153	74.12
18	200	170	153	74.12
19	200	180	162	78.48
20	200	160	144	69.76
21	200	160	144	69.76
22	300	255	229.5	111.18
23	200	160	144	69.76
24	100	85	76.5	37.06
25	200	160	144	69.76
26	200	180	162	78.48
27	500	450	405	196.2
28	500	450	405	196.2
29	50	42.5	38.25	18.53
30	200	160	144	69.76
31	200	170	153	74.12
32	200	160	144	69.76
33	25	20	18	8.72
34	300	240	216	104.64
35	300	255	229.5	111.18
36	200	160	144	69.76
37	100	75	67.5	32.7
38	200	150	135	65.4
39	200	140	126	61.04
40	50	35	31.5	15.26
41	100	70	63	30.52
42	25	17.5	15.75	7.63
43	250	200	180	87.2
44	200	170	153	74.12
45	200	170	153	74.12
46	200	170	153	74.12
47	100	85	76.5	37.06
48	250	200	180	87.2
49	400	320	288	139.52
50	100	70	63	30.52
51	100	75	67.5	32.7
52	200	140	126	61.04
53	100	85	76.5	37.06
54	100	75	67.5	32.7
55	100	90	81	39.24
56	100	90	81	39.24

Bus No.	Rating of Transformer	Transformer Loading	P(kW)	Q(kVAr)
57	200	180	162	78.48
58	50	42.5	38.25	18.53
59	100	80	72	34.88
60	300	225	202.5	98.1
61	100	80	72	34.88
62	250	200	180	87.2
63	100	75	67.5	32.7
64	100	75	67.5	32.7
65	100	80	72	34.88
66	100	80	72	34.88
67	100	80	72	34.88
68	200	150	135	65.4
69	100	80	72	34.88
70	630	535.5	481.95	233.478
71	50	37.5	33.75	16.35
72	100	80	72	34.88
73	100	80	72	34.88
74	100	80	72	34.88
75	100	80	72	34.88
76	300	270	243	117.72
77	25	20	18	8.72

Table B.2: Line Parameter of 77 Bus Butwal West Distribution System

Sending End	Receiving End	Line Length (KM)	R(Ω)	X(Ω)	Conductor Type
0	1	0.8	0.22336	0.252	Dog
1	2	0.12	0.033504	0.0378	Dog
1	3	0.31	0.086552	0.09765	Dog
3	4	0.13	0.036296	0.04095	Dog
4	5	0.2	0.05584	0.063	Dog
5	6	0.24	0.067008	0.0756	Dog
6	7	0.47	0.436583	0.16215	Dog
7	8	0.3	0.27867	0.1035	Weasel
5	9	0.2	0.05584	0.063	Weasel
9	10	0.16	0.044672	0.0504	Dog
10	11	0.19	0.053048	0.05985	Dog
11	12	0.15	0.04188	0.04725	Dog
12	13	0.21	0.058632	0.06615	Dog
13	14	0.22	0.061424	0.0693	Dog

Sending End	Receiving End	Line Length (KM)	R(Ω)	X(Ω)	Conductor Type
14	15	0.15	0.04188	0.04725	Dog
15	16	0.16	0.044672	0.0504	Dog
16	17	0.12	0.033504	0.0378	Dog
17	18	0.17	0.047464	0.05355	Dog
18	19	0.21	0.058632	0.06615	Dog
19	20	0.19	0.053048	0.05985	Dog
20	21	0.22	0.061424	0.0693	Dog
21	22	0.17	0.047464	0.05355	Dog
22	23	0.2	0.05584	0.063	Dog
23	24	0.31	0.086552	0.09765	Dog
24	25	0.11	0.030712	0.03465	Dog
25	26	0.18	0.050256	0.0621	Dog
26	27	0.17	0.157913	0.05865	Weasel
27	28	0.15	0.139335	0.05175	Weasel
28	29	0.19	0.176491	0.06555	Weasel
25	30	0.25	0.0698	0.07875	Dog
30	31	0.21	0.058632	0.06615	Dog
31	32	0.15	0.04188	0.04725	Dog
32	33	0.12	0.033504	0.0378	Dog
30	34	0.11	0.030712	0.03465	Dog
34	35	0.15	0.04188	0.04725	Dog
35	36	0.12	0.033504	0.0378	Dog
36	37	0.26	0.072592	0.0819	Dog
37	38	0.28	0.078176	0.0882	Dog
38	39	0.14	0.039088	0.0469	Dog
39	40	2.92	1.613008	0.9782	Rabbit
40	41	2.73	2.535897	0.91455	Rabbit
41	42	2.7	2.50803	0.9315	Rabbit
38	43	0.14	0.077336	0.0469	Weasel
43	44	0.15	0.08286	0.05025	Rabbit
44	45	0.21	0.116004	0.07035	Rabbit
45	46	0.22	0.121528	0.0737	Rabbit
46	47	0.15	0.08286	0.05025	Rabbit
47	48	0.17	0.093908	0.05695	Rabbit
48	49	0.32	0.176768	0.1072	Rabbit
49	50	0.21	0.116004	0.07035	Rabbit
50	51	0.22	0.121528	0.0737	Rabbit
50	52	0.14	0.077336	0.0469	Rabbit
52	53	0.26	0.143624	0.0871	Rabbit
53	54	0.15	0.08286	0.05025	Rabbit
54	55	0.26	0.143624	0.0871	Rabbit
55	56	0.22	0.121528	0.0737	Rabbit

Sending End	Receiving End	Line Length (KM)	R(Ω)	X(Ω)	Conductor Type
56	57	0.23	0.127052	0.07705	Rabbit
52	58	0.15	0.08286	0.05025	Rabbit
58	59	0.1	0.05524	0.0335	Rabbit
59	60	0.33	0.182292	0.11055	Rabbit
60	61	0.18	0.099432	0.0603	Rabbit
61	62	0.12	0.066288	0.0402	Rabbit
62	63	0.21	0.116004	0.07035	Rabbit
63	64	0.16	0.088384	0.0536	Rabbit
64	65	0.22	0.121528	0.0737	Rabbit
65	66	0.21	0.116004	0.07035	Rabbit
66	67	0.26	0.143624	0.0871	Rabbit
67	68	0.33	0.182292	0.11055	Rabbit
68	69	0.14	0.077336	0.0469	Rabbit
69	70	0.15	0.08286	0.05025	Rabbit
70	71	0.41	0.226484	0.13735	Rabbit
59	72	0.23	0.127052	0.07705	Rabbit
72	73	0.21	0.116004	0.07035	Rabbit
73	74	0.22	0.121528	0.0737	Rabbit
74	75	0.25	0.1381	0.08375	Rabbit
75	76	0.15	0.08286	0.05025	Rabbit
76	77	0.13	0.071812	0.04355	Rabbit

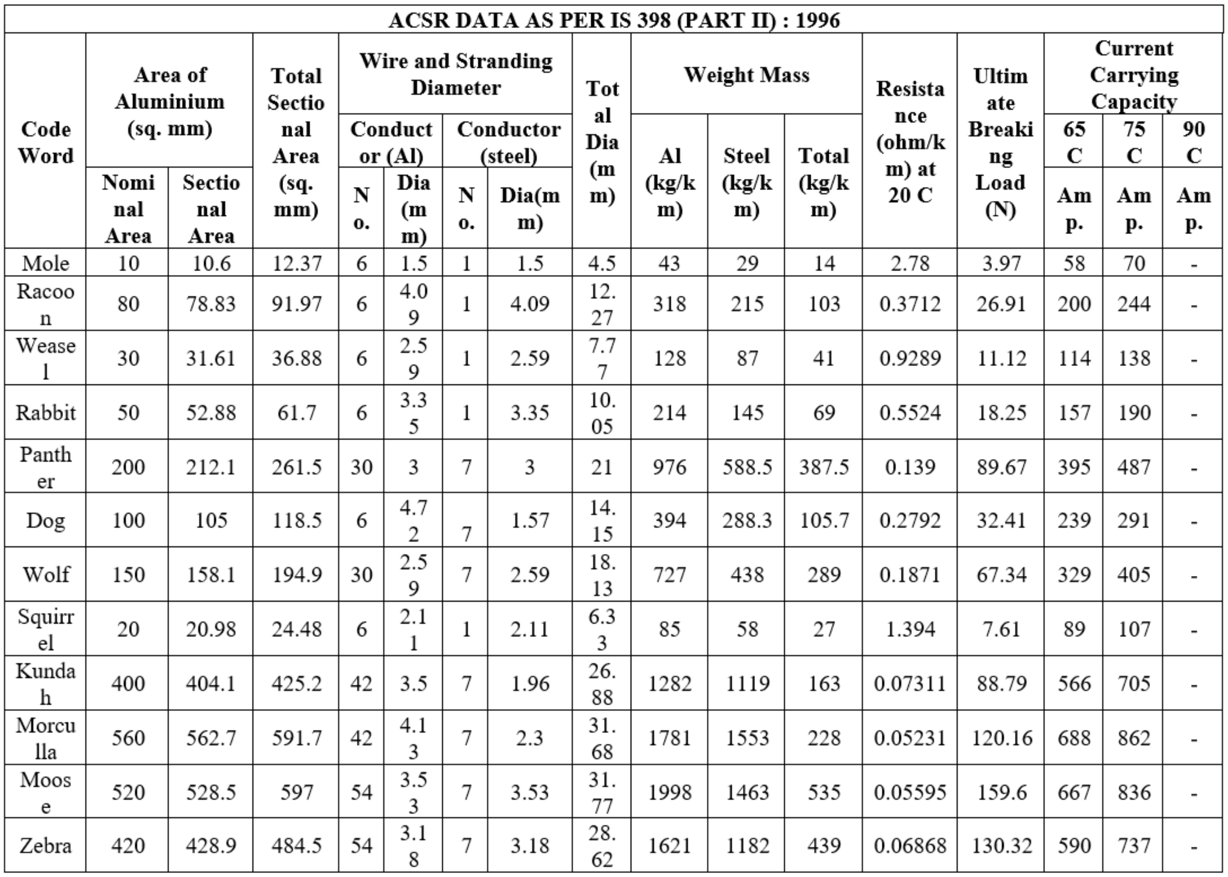
Table B.3: LF Analysis of 77 Bus Butwal West Distribution feeder without considering EV Charging Station (Before Compensation)

<table>
<tr><th colspan="10">Branch Losses Summary Report</th></tr>
<tr><th>Branch ID</th><th>MW</th><th>Mvar</th><th>MW</th><th>Mvar</th><th>kW</th><th>kVAr</th><th>From</th><th>To</th><th>Vd % Drop in Vmag</th></tr>
<tr><td>Z1</td><td>-10.295</td><td>-5.468</td><td>10.562</td><td>5.769</td><td>267.4</td><td>301.7</td><td>96.9</td><td>100.0</td><td>3.14</td></tr>
<tr><td>Z10</td><td>8.906</td><td>4.633</td><td>-8.864</td><td>-4.585</td><td>42.3</td><td>47.8</td><td>93.7</td><td>93.2</td><td>0.56</td></tr>
<tr><td>Z11</td><td>0.428</td><td>0.207</td><td>-0.428</td><td>-0.207</td><td>0.1</td><td>0.1</td><td>93.2</td><td>93.2</td><td>0.03</td></tr>
<tr><td>Z12</td><td>0.185</td><td>0.089</td><td>-0.185</td><td>-0.089</td><td>0.0</td><td>0.0</td><td>93.2</td><td>93.1</td><td>0.01</td></tr>
<tr><td>Z13</td><td>0.108</td><td>0.052</td><td>-0.108</td><td>-0.052</td><td>0.0</td><td>0.0</td><td>93.1</td><td>93.1</td><td>0.01</td></tr>
<tr><td>Z14</td><td>0.072</td><td>0.035</td><td>-0.072</td><td>-0.035</td><td>0.0</td><td>0.0</td><td>93.1</td><td>93.1</td><td>0.01</td></tr>
<tr><td>Z15</td><td>8.351</td><td>4.336</td><td>-8.315</td><td>-4.296</td><td>35.3</td><td>39.8</td><td>93.2</td><td>92.7</td><td>0.49</td></tr>
<tr><td>Z16</td><td>8.162</td><td>4.222</td><td>-8.126</td><td>-4.181</td><td>36.3</td><td>40.9</td><td>92.7</td><td>92.2</td><td>0.51</td></tr>
<tr><td>Z17</td><td>7.973</td><td>4.107</td><td>-7.947</td><td>-4.078</td><td>26.2</td><td>29.6</td><td>92.2</td><td>91.8</td><td>0.38</td></tr>
<tr><td>Z18</td><td>7.794</td><td>4.004</td><td>-7.758</td><td>-3.963</td><td>35.7</td><td>40.3</td><td>91.8</td><td>91.3</td><td>0.53</td></tr>
<tr><td>Z19</td><td>7.605</td><td>3.889</td><td>-7.563</td><td>-3.841</td><td>42.4</td><td>47.9</td><td>91.3</td><td>90.6</td><td>0.64</td></tr>
</table>

Z2	0.162	0.078	-0.162	-0.078	0.0	0.0	96.9	96.8	0.01
Z20	7.401	3.763	-7.364	-3.721	36.8	41.5	90.6	90.1	0.56
Z21	7.220	3.651	-7.179	-3.605	40.9	46.2	90.1	89.4	0.64
Z22	7.035	3.536	-7.004	-3.501	30.4	34.3	89.4	89.0	0.48
Z23	6.775	3.390	-6.742	-3.352	33.5	37.8	89.0	88.4	0.55
Z24	6.598	3.282	-6.548	-3.226	49.7	56.1	88.4	87.6	0.83
Z25	6.472	3.189	-6.455	-3.170	17.2	19.4	87.6	87.3	0.29
Z26	1.013	0.491	-1.012	-0.490	0.7	0.9	87.3	87.2	0.08
Z27	0.850	0.412	-0.849	-0.411	1.5	0.6	87.2	87.1	0.15
Z28	0.444	0.215	-0.443	-0.215	0.4	0.1	87.1	87.0	0.07
Z29	0.038	0.019	-0.038	-0.019	0.0	0.0	87.0	87.0	0.01
Z3	9.980	5.315	-9.883	-5.205	97.5	110.0	96.9	95.7	1.18
Z30	5.298	2.609	-5.271	-2.579	26.4	29.8	87.3	86.7	0.54
Z31	0.324	0.157	-0.324	-0.157	0.1	0.1	86.7	86.7	0.03
Z32	0.171	0.083	-0.171	-0.083	0.0	0.0	86.7	86.7	0.01
Z33	0.018	0.009	-0.018	-0.009	0.0	0.0	86.7	86.7	0.00
Z34	4.803	2.353	-4.794	-2.342	9.6	10.9	86.7	86.5	0.22
Z35	0.441	0.214	-0.441	-0.214	0.1	0.1	86.5	86.5	0.03
Z36	0.212	0.102	-0.212	-0.102	0.0	0.0	86.5	86.5	0.01
Z37	0.068	0.033	-0.068	-0.033	0.0	0.0	86.5	86.5	0.01
Z38	4.136	2.023	-4.118	-2.003	18.3	20.6	86.5	86.0	0.48
Z39	0.237	0.115	-0.237	-0.115	0.0	0.0	86.0	86.0	0.01
Z4	9.730	5.131	-9.690	-5.086	39.6	44.7	95.7	95.2	0.49
Z40	0.111	0.054	-0.110	-0.053	0.3	0.2	86.0	85.8	0.22
Z41	0.079	0.038	-0.079	-0.038	0.2	0.1	85.8	85.6	0.23
Z42	0.016	0.008	-0.016	-0.008	0.0	0.0	85.6	85.5	0.05
Z43	3.746	1.822	-3.731	-1.813	15.0	9.1	86.0	85.7	0.36
Z44	1.008	0.489	-1.006	-0.488	1.2	0.7	85.7	85.6	0.10
Z45	0.853	0.414	-0.852	-0.413	1.2	0.7	85.6	85.5	0.12
Z46	0.699	0.339	-0.698	-0.338	0.8	0.5	85.5	85.3	0.11
Z47	0.545	0.264	-0.545	-0.264	0.3	0.2	85.3	85.3	0.06
Z48	0.468	0.227	-0.468	-0.227	0.3	0.2	85.3	85.2	0.06
Z49	0.288	0.140	-0.288	-0.140	0.2	0.1	85.2	85.2	0.06
Z5	9.618	5.051	-9.558	-4.983	60.1	67.8	95.2	94.4	0.74
Z50	2.544	1.238	-2.533	-1.231	10.5	6.3	85.7	85.3	0.37
Z51	0.068	0.033	-0.068	-0.033	0.0	0.0	85.3	85.3	0.01
Z52	2.403	1.168	-2.397	-1.164	6.3	3.8	85.3	85.1	0.23
Z53	2.271	1.103	-2.260	-1.097	10.4	6.3	85.1	84.7	0.41
Z54	0.392	0.190	-0.392	-0.190	0.2	0.1	84.7	84.6	0.04
Z55	0.324	0.157	-0.324	-0.157	0.2	0.1	84.6	84.6	0.06
Z56	0.243	0.118	-0.243	-0.118	0.1	0.1	84.6	84.5	0.04

Z57	0.162	0.079	-0.162	-0.078	0.0	0.0	84.5	84.5	0.03
Z58	1.793	0.871	-1.789	-0.868	3.8	2.3	84.7	84.5	0.19
Z59	1.751	0.850	-1.749	-0.848	2.4	1.5	84.5	84.4	0.12
Z6	0.451	0.218	-0.450	-0.218	0.2	0.2	94.4	94.4	0.04
Z60	1.126	0.547	-1.123	-0.545	3.3	2.0	84.4	84.1	0.26
Z61	0.920	0.446	-0.919	-0.446	1.2	0.7	84.1	84.0	0.12
Z62	0.847	0.411	-0.846	-0.410	0.7	0.4	84.0	83.9	0.07
Z63	0.666	0.323	-0.666	-0.323	0.7	0.5	83.9	83.8	0.10
Z64	0.598	0.290	-0.598	-0.290	0.5	0.3	83.8	83.7	0.07
Z65	0.530	0.257	-0.530	-0.257	0.5	0.3	83.7	83.7	0.08
Z66	0.458	0.222	-0.457	-0.222	0.4	0.2	83.7	83.6	0.07
Z67	0.385	0.187	-0.385	-0.187	0.3	0.2	83.6	83.5	0.07
Z68	0.313	0.152	-0.313	-0.152	0.3	0.2	83.5	83.4	0.07
Z69	0.178	0.086	-0.178	-0.086	0.0	0.0	83.4	83.4	0.02
Z7	0.288	0.140	-0.288	-0.140	0.4	0.2	94.4	94.3	0.13
Z70	0.106	0.051	-0.106	-0.051	0.0	0.0	83.4	83.4	0.01
Z71	0.034	0.016	-0.034	-0.016	0.0	0.0	83.4	83.4	0.01
Z72	0.551	0.267	-0.550	-0.267	0.6	0.3	84.4	84.3	0.09
Z73	0.478	0.232	-0.478	-0.231	0.4	0.2	84.3	84.2	0.07
Z74	0.406	0.197	-0.405	-0.196	0.3	0.2	84.2	84.1	0.06
Z75	0.333	0.161	-0.333	-0.161	0.2	0.1	84.1	84.1	0.06
Z76	0.261	0.126	-0.261	-0.126	0.1	0.0	84.1	84.1	0.03
Z77	0.018	0.009	-0.018	-0.009	0.0	0.0	84.1	84.0	0.00
Z8	0.135	0.065	-0.135	-0.065	0.1	0.0	94.3	94.2	0.04
Z9	9.071	4.748	-9.017	-4.686	54.2	61.2	94.4	93.7	0.70
					1066.4	1168.8			

Table B.4: Specification of ACSR Conductor



ACSR DATA AS PER IS 398 (PART II) : 1996																
Code Word	Area of Aluminium (sq. mm)		Total Sectional Area (sq. mm)	Wire and Stranding Diameter				Total Dia (mm)	Weight Mass			Resistance (ohm/km) at 20 C	Ultimate Breaking Load (N)	Current Carrying Capacity		
				Conductor (Al)		Conductor (steel)			Al (kg/km)	Steel (kg/km)	Total (kg/km)			65 C	75 C	90 C
	Nominal Area	Sectional Area		No.	Dia (mm)	No.	Dia(mm)							Amp.	Amp.	Amp.
Mole	10	10.6	12.37	6	1.5	1	1.5	4.5	43	29	14	2.78	3.97	58	70	-
Racoon	80	78.83	91.97	6	4.09	1	4.09	12.27	318	215	103	0.3712	26.91	200	244	-
Weasel	30	31.61	36.88	6	2.59	1	2.59	7.77	128	87	41	0.9289	11.12	114	138	-
Rabbit	50	52.88	61.7	6	3.35	1	3.35	10.05	214	145	69	0.5524	18.25	157	190	-
Panther	200	212.1	261.5	30	3	7	3	21	976	588.5	387.5	0.139	89.67	395	487	-
Dog	100	105	118.5	6	4.72	7	1.57	14.15	394	288.3	105.7	0.2792	32.41	239	291	-
Wolf	150	158.1	194.9	30	2.59	7	2.59	18.13	727	438	289	0.1871	67.34	329	405	-
Squirrel	20	20.98	24.48	6	2.11	1	2.11	6.33	85	58	27	1.394	7.61	89	107	-
Kundah	400	404.1	425.2	42	3.5	7	1.96	26.88	1282	1119	163	0.07311	88.79	566	705	-
Morculla	560	562.7	591.7	42	4.13	7	2.3	31.68	1781	1553	228	0.05231	120.16	688	862	-
Moose	520	528.5	597	54	3.53	7	3.53	31.77	1998	1463	535	0.05595	159.6	667	836	-
Zebra	420	428.9	484.5	54	3.18	7	3.18	28.62	1621	1182	439	0.06868	130.32	590	737	-

S/N	ACSR conductor	Resistance at 20 C	Current Rating (A)	Nominal Al Area (Sq. mm)	Inductive Reactance (ohm/km)	Weight (kg/km)
1	Squirrel	1.374	76	20	0.355	80
2	Weasel	0.9116	95	30	0.345	128
3	Rabbit	0.5449	135	50	0.335	214
4	Dog	0.2792	205	100	0.315	394

Table B.5: LF Analysis of 77 Bus Butwal West Distribution feeder considering EV Charging Station (Before Compensation)

Branch Losses Summary Report									
Branch ID	MW	Mvar	MW	Mvar	kW	kVAr	From	To	Vd % Drop in Vmag
Z1	-10.589	-5.620	10.872	5.939	283.3	319.7	96.8	100.0	3.24

Z10	9.126	4.754	-9.081	-4.704	44.6	50.4	93.6	93.0	0.57
Z11	0.428	0.207	-0.428	-0.207	0.1	0.1	93.0	93.0	0.03
Z12	0.185	0.089	-0.185	-0.089	0.0	0.0	93.0	93.0	0.01
Z13	0.108	0.052	-0.108	-0.052	0.0	0.0	93.0	92.9	0.01
Z14	0.072	0.035	-0.072	-0.035	0.0	0.0	92.9	92.9	0.01
Z15	8.538	4.441	-8.501	-4.399	37.1	41.8	93.0	92.5	0.50
Z16	8.348	4.325	-8.310	-4.282	38.1	43.0	92.5	92.0	0.53
Z17	8.157	4.208	-8.129	-4.177	27.6	31.1	92.0	91.6	0.39
Z18	7.976	4.102	-7.939	-4.060	37.6	42.5	91.6	91.0	0.54
Z19	7.786	3.986	-7.741	-3.935	44.7	50.5	91.0	90.4	0.65
Z2	0.192	0.093	-0.192	-0.093	0.0	0.0	96.8	96.8	0.01
Z20	7.579	3.857	-7.540	-3.813	38.8	43.8	90.4	89.8	0.58
Z21	7.396	3.743	-7.353	-3.694	43.2	48.8	89.8	89.1	0.66
Z22	7.209	3.625	-7.177	-3.588	32.1	36.3	89.1	88.6	0.50
Z23	6.947	3.477	-6.912	-3.437	35.4	40.0	88.6	88.1	0.57
Z24	6.738	3.353	-6.686	-3.294	52.2	58.9	88.1	87.2	0.85
Z25	6.610	3.257	-6.591	-3.237	18.1	20.4	87.2	86.9	0.30
Z26	1.149	0.557	-1.148	-0.556	0.9	1.1	86.9	86.8	0.09
Z27	0.986	0.477	-0.984	-0.476	2.1	0.8	86.8	86.7	0.17
Z28	0.579	0.280	-0.578	-0.280	0.6	0.2	86.7	86.6	0.09
Z29	0.038	0.019	-0.038	-0.019	0.0	0.0	86.6	86.6	0.01
Z3	10.244	5.453	-10.141	-5.337	102.9	116.1	96.8	95.6	1.21
Z30	5.299	2.610	-5.272	-2.580	26.6	30.0	86.9	86.4	0.55
Z31	0.324	0.157	-0.324	-0.157	0.1	0.1	86.4	86.4	0.03
Z32	0.171	0.083	-0.171	-0.083	0.0	0.0	86.4	86.3	0.01
Z33	0.018	0.009	-0.018	-0.009	0.0	0.0	86.3	86.3	0.00
Z34	4.804	2.353	-4.794	-2.342	9.7	11.0	86.4	86.2	0.22
Z35	0.441	0.214	-0.441	-0.214	0.1	0.1	86.2	86.1	0.03
Z36	0.212	0.102	-0.212	-0.102	0.0	0.0	86.1	86.1	0.01
Z37	0.068	0.033	-0.068	-0.033	0.0	0.0	86.1	86.1	0.01
Z38	4.137	2.024	-4.119	-2.003	18.5	20.8	86.2	85.7	0.48
Z39	0.237	0.115	-0.237	-0.115	0.0	0.0	85.7	85.7	0.01
Z4	9.988	5.262	-9.946	-5.215	41.9	47.2	95.6	95.1	0.50
Z40	0.111	0.054	-0.110	-0.053	0.3	0.2	85.7	85.4	0.22
Z41	0.079	0.038	-0.079	-0.038	0.2	0.1	85.4	85.2	0.23
Z42	0.016	0.008	-0.016	-0.008	0.0	0.0	85.2	85.2	0.05
Z43	3.747	1.823	-3.732	-1.814	15.1	9.2	85.7	85.3	0.36
Z44	1.008	0.489	-1.006	-0.488	1.2	0.7	85.3	85.2	0.10
Z45	0.853	0.414	-0.852	-0.413	1.2	0.7	85.2	85.1	0.12
Z46	0.699	0.339	-0.698	-0.338	0.8	0.5	85.1	85.0	0.11

Z47	0.545	0.264	-0.545	-0.264	0.3	0.2	85.0	84.9	0.06
Z48	0.468	0.227	-0.468	-0.227	0.3	0.2	84.9	84.9	0.06
Z49	0.288	0.140	-0.288	-0.140	0.2	0.1	84.9	84.8	0.06
Z5	9.874	5.180	-9.811	-5.109	63.5	71.7	95.1	94.3	0.76
Z50	2.544	1.238	-2.534	-1.231	10.5	6.4	85.3	85.0	0.37
Z51	0.068	0.033	-0.068	-0.033	0.0	0.0	85.0	84.9	0.01
Z52	2.403	1.168	-2.397	-1.164	6.3	3.8	85.0	84.7	0.23
Z53	2.271	1.103	-2.260	-1.097	10.5	6.4	84.7	84.3	0.41
Z54	0.392	0.190	-0.392	-0.190	0.2	0.1	84.3	84.3	0.04
Z55	0.324	0.157	-0.324	-0.157	0.2	0.1	84.3	84.2	0.06
Z56	0.243	0.118	-0.243	-0.118	0.1	0.1	84.2	84.2	0.04
Z57	0.162	0.079	-0.162	-0.078	0.0	0.0	84.2	84.1	0.03
Z58	1.793	0.871	-1.789	-0.868	3.8	2.3	84.3	84.1	0.19
Z59	1.751	0.850	-1.749	-0.848	2.4	1.5	84.1	84.0	0.12
Z6	0.451	0.218	-0.450	-0.218	0.2	0.2	94.3	94.2	0.04
Z60	1.126	0.547	-1.123	-0.545	3.3	2.0	84.0	83.7	0.26
Z61	0.920	0.446	-0.919	-0.446	1.2	0.7	83.7	83.6	0.12
Z62	0.847	0.411	-0.846	-0.410	0.7	0.4	83.6	83.5	0.07
Z63	0.666	0.323	-0.666	-0.323	0.8	0.5	83.5	83.4	0.10
Z64	0.598	0.290	-0.598	-0.290	0.5	0.3	83.4	83.4	0.07
Z65	0.530	0.257	-0.530	-0.257	0.5	0.3	83.4	83.3	0.08
Z66	0.458	0.222	-0.457	-0.222	0.4	0.2	83.3	83.2	0.07
Z67	0.385	0.187	-0.385	-0.187	0.3	0.2	83.2	83.2	0.07
Z68	0.313	0.152	-0.313	-0.152	0.3	0.2	83.2	83.1	0.07
Z69	0.178	0.086	-0.178	-0.086	0.0	0.0	83.1	83.1	0.02
Z7	0.288	0.140	-0.288	-0.140	0.4	0.2	94.2	94.1	0.13
Z70	0.106	0.051	-0.106	-0.051	0.0	0.0	83.1	83.1	0.01
Z71	0.034	0.016	-0.034	-0.016	0.0	0.0	83.1	83.0	0.01
Z72	0.551	0.267	-0.550	-0.267	0.6	0.3	84.0	83.9	0.09
Z73	0.478	0.232	-0.478	-0.231	0.4	0.2	83.9	83.8	0.07
Z74	0.406	0.197	-0.405	-0.196	0.3	0.2	83.8	83.8	0.06
Z75	0.333	0.161	-0.333	-0.161	0.2	0.1	83.8	83.7	0.06
Z76	0.261	0.126	-0.261	-0.126	0.1	0.0	83.7	83.7	0.03
Z77	0.018	0.009	-0.018	-0.009	0.0	0.0	83.7	83.7	0.00
Z8	0.135	0.065	-0.135	-0.065	0.1	0.0	94.1	94.1	0.04
Z9	9.324	4.873	-9.267	-4.808	57.5	64.8	94.3	93.6	0.73
					1121.6	1230.2			

Table B.6: LF Analysis of 77 Bus Butwal West Distribution feeder considering EV Charging Station (After Compensation)

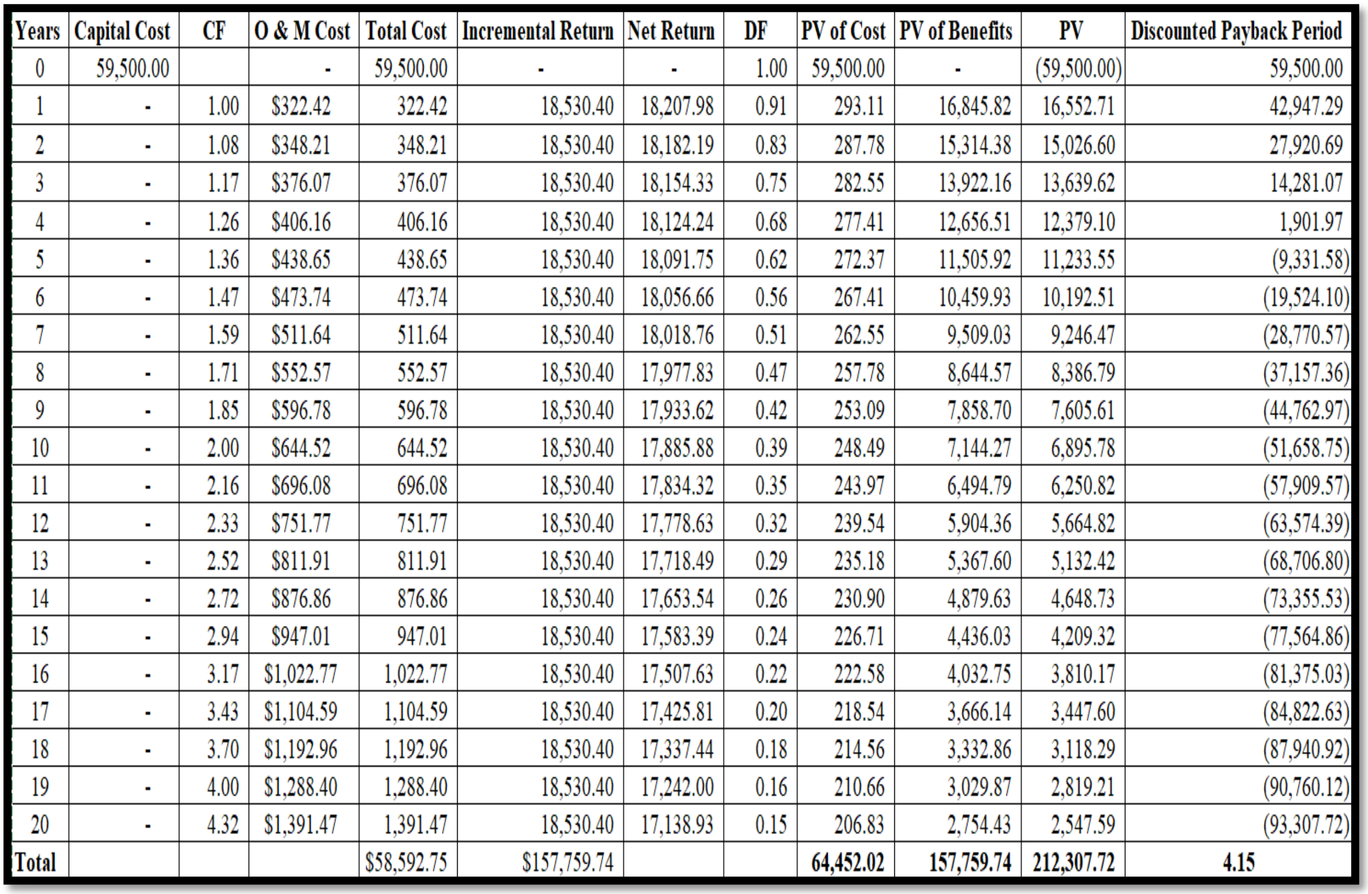
Branch Losses Summary Report									
Branch ID	**MW**	**Mvar**	**MW**	**Mvar**	**kW**	**kVAr**	**From**	**To**	**Vd % Drop in Vmag**
Z1	-10.505	5.468	10.768	-5.171	263.4	297.2	99.1	100.0	0.86
Z10	9.068	-3.965	-9.031	4.007	37.4	42.2	98.3	98.1	0.17
Z11	0.428	0.207	-0.428	-0.207	0.1	0.1	98.1	98.1	0.03
Z12	0.185	0.089	-0.185	-0.089	0.0	0.0	98.1	98.1	0.01
Z13	0.108	0.052	-0.108	-0.052	0.0	0.0	98.1	98.1	0.01
Z14	0.072	0.035	-0.072	-0.035	0.0	0.0	98.1	98.1	0.01
Z15	8.487	-3.404	-8.457	3.438	30.1	33.9	98.1	98.0	0.16
Z16	8.304	-3.512	-8.273	3.547	31.3	35.3	98.0	97.8	0.16
Z17	8.120	-3.621	-8.097	3.647	22.9	25.8	97.8	97.7	0.11
Z18	7.944	-3.721	-7.913	3.757	31.6	35.7	97.7	97.5	0.15
Z19	7.760	-3.831	-7.721	3.874	38.1	43.1	97.5	97.4	0.17
Z2	0.192	0.093	-0.192	-0.093	0.0	0.0	99.1	99.1	0.01
Z20	7.559	-3.953	-7.526	3.991	33.6	38.0	97.4	97.2	0.14
Z21	7.382	-2.926	-7.348	2.964	33.8	38.2	97.2	97.0	0.21
Z22	7.204	-3.034	-7.179	3.062	25.5	28.7	97.0	96.9	0.15
Z23	6.949	-3.174	-6.920	3.206	28.7	32.4	96.9	96.7	0.16
Z24	6.746	-3.290	-6.703	3.339	43.1	48.6	96.7	96.5	0.22
Z25	6.627	-3.376	-6.612	3.393	15.1	17.0	96.5	96.4	0.07
Z26	1.153	0.559	-1.152	-0.558	0.7	0.9	96.4	96.3	0.08
Z27	0.990	0.479	-0.989	-0.479	1.7	0.6	96.3	96.2	0.16
Z28	0.584	0.283	-0.583	-0.282	0.5	0.2	96.2	96.1	0.08
Z29	0.038	0.019	-0.038	-0.019	0.0	0.0	96.1	96.1	0.01

Z3	10.160	-5.635	-10.062	5.746	98.2	110.8	99.1	98.9	0.27
Z30	5.315	-4.022	-5.288	4.053	27.6	31.1	96.4	96.4	0.04
Z31	0.324	0.157	-0.324	-0.157	0.1	0.1	96.4	96.3	0.03
Z32	0.171	0.083	-0.171	-0.083	0.0	0.0	96.3	96.3	0.01
Z33	0.018	0.009	-0.018	-0.009	0.0	0.0	96.3	96.3	0.00
Z34	4.819	-3.165	-4.810	3.175	9.1	10.2	96.4	96.3	0.03
Z35	0.441	0.214	-0.441	-0.214	0.1	0.1	96.3	96.3	0.02
Z36	0.212	0.102	-0.212	-0.102	0.0	0.0	96.3	96.3	0.01
Z37	0.068	0.033	-0.068	-0.033	0.0	0.0	96.3	96.3	0.01
Z38	4.153	-3.494	-4.133	3.517	20.5	23.1	96.3	96.3	0.01
Z39	0.237	0.115	-0.237	-0.115	0.0	0.0	96.3	96.3	0.01
Z4	9.909	-4.647	-9.872	4.689	36.7	41.5	98.9	98.7	0.14
Z40	0.111	0.054	-0.110	-0.053	0.2	0.1	96.3	96.1	0.20
Z41	0.079	0.038	-0.079	-0.038	0.2	0.1	96.1	95.9	0.20
Z42	0.016	0.008	-0.016	-0.008	0.0	0.0	95.9	95.9	0.04
Z43	3.761	-3.697	-3.742	3.708	19.2	11.6	96.3	96.2	0.10
Z44	1.015	-1.731	-1.012	1.733	3.0	1.8	96.2	96.2	0.00
Z45	0.859	-1.807	-0.855	1.810	4.1	2.5	96.2	96.3	0.02
Z46	0.702	-0.772	-0.701	0.773	1.2	0.7	96.3	96.2	0.02
Z47	0.548	-0.847	-0.547	0.847	0.8	0.5	96.2	96.2	0.00
Z48	0.470	-0.884	-0.470	0.885	0.8	0.5	96.2	96.2	0.01
Z49	0.290	-0.972	-0.288	0.973	1.6	1.0	96.2	96.3	0.05
Z5	9.800	-4.724	-9.744	4.787	56.0	63.2	98.7	98.5	0.21
Z50	2.547	-0.953	-2.539	0.958	7.7	4.6	96.2	96.0	0.20
Z51	0.068	0.033	-0.068	-0.033	0.0	0.0	96.0	96.0	0.01

Z52	2.409	-1.021	-2.404	1.024	4.7	2.9	96.0	95.9	0.12
Z53	2.278	-1.085	-2.270	1.090	8.2	5.0	95.9	95.7	0.20
Z54	0.392	0.190	-0.392	-0.190	0.1	0.1	95.7	95.7	0.04
Z55	0.324	0.157	-0.324	-0.157	0.2	0.1	95.7	95.6	0.05
Z56	0.243	0.118	-0.243	-0.118	0.1	0.0	95.6	95.6	0.03
Z57	0.162	0.079	-0.162	-0.078	0.0	0.0	95.6	95.6	0.02
Z58	1.802	-1.317	-1.798	1.319	3.7	2.3	95.7	95.6	0.07
Z59	1.760	-1.338	-1.757	1.339	2.4	1.5	95.6	95.6	0.05
Z6	0.451	-0.947	-0.450	0.948	0.6	0.7	98.5	98.6	0.03
Z60	1.131	-0.545	-1.129	0.546	2.6	1.6	95.6	95.5	0.13
Z61	0.926	-0.645	-0.925	0.645	1.1	0.7	95.5	95.4	0.05
Z62	0.853	-0.680	-0.852	0.681	0.7	0.4	95.4	95.4	0.03
Z63	0.672	-0.768	-0.671	0.768	1.1	0.7	95.4	95.4	0.02
Z64	0.604	-0.801	-0.603	0.802	0.8	0.5	95.4	95.4	0.01
Z65	0.535	-0.834	-0.534	0.835	1.1	0.7	95.4	95.4	0.00
Z66	0.462	-0.870	-0.461	0.870	1.0	0.6	95.4	95.4	0.01
Z67	0.389	-0.905	-0.388	0.906	1.3	0.8	95.4	95.4	0.02
Z68	0.316	-0.941	-0.314	0.942	1.6	1.0	95.4	95.4	0.04
Z69	0.179	-1.007	-0.179	1.008	0.7	0.4	95.4	95.5	0.03
Z7	0.288	0.140	-0.288	-0.140	0.4	0.1	98.6	98.4	0.12
Z70	0.107	-1.043	-0.106	1.043	0.8	0.5	95.5	95.5	0.04
Z71	0.034	0.016	-0.034	-0.016	0.0	0.0	95.5	95.5	0.01
Z72	0.554	-0.829	-0.553	0.830	1.1	0.7	95.6	95.6	0.01
Z73	0.481	-0.865	-0.480	0.865	1.0	0.6	95.6	95.6	0.00
Z74	0.408	-0.900	-0.407	0.901	1.1	0.7	95.6	95.6	0.01
Z75	0.335	-0.936	-0.334	0.936	1.2	0.7	95.6	95.6	0.03

Z76	0.262	-0.971	-0.261	0.972	0.8	0.5	95.6	95.7	0.02
Z77	0.018	0.009	-0.018	-0.009	0.0	0.0	95.7	95.7	0.00
Z8	0.135	0.065	-0.135	-0.065	0.1	0.0	98.4	98.4	0.04
Z9	9.257	-3.857	-9.209	3.911	47.8	53.9	98.5	98.3	0.23
					1011.3	1099.3			

Table B.7: Financial Analysis for actual feeder after Compensation



Years	Capital Cost	CF	O & M Cost	Total Cost	Incremental Return	Net Return	DF	PV of Cost	PV of Benefits	PV	Discounted Payback Period
0	59,500.00		-	59,500.00	-	-	1.00	59,500.00	-	(59,500.00)	59,500.00
1	-	1.00	$322.42	322.42	18,530.40	18,207.98	0.91	293.11	16,845.82	16,552.71	42,947.29
2	-	1.08	$348.21	348.21	18,530.40	18,182.19	0.83	287.78	15,314.38	15,026.60	27,920.69
3	-	1.17	$376.07	376.07	18,530.40	18,154.33	0.75	282.55	13,922.16	13,639.62	14,281.07
4	-	1.26	$406.16	406.16	18,530.40	18,124.24	0.68	277.41	12,656.51	12,379.10	1,901.97
5	-	1.36	$438.65	438.65	18,530.40	18,091.75	0.62	272.37	11,505.92	11,233.55	(9,331.58)
6	-	1.47	$473.74	473.74	18,530.40	18,056.66	0.56	267.41	10,459.93	10,192.51	(19,524.10)
7	-	1.59	$511.64	511.64	18,530.40	18,018.76	0.51	262.55	9,509.03	9,246.47	(28,770.57)
8	-	1.71	$552.57	552.57	18,530.40	17,977.83	0.47	257.78	8,644.57	8,386.79	(37,157.36)
9	-	1.85	$596.78	596.78	18,530.40	17,933.62	0.42	253.09	7,858.70	7,605.61	(44,762.97)
10	-	2.00	$644.52	644.52	18,530.40	17,885.88	0.39	248.49	7,144.27	6,895.78	(51,658.75)
11	-	2.16	$696.08	696.08	18,530.40	17,834.32	0.35	243.97	6,494.79	6,250.82	(57,909.57)
12	-	2.33	$751.77	751.77	18,530.40	17,778.63	0.32	239.54	5,904.36	5,664.82	(63,574.39)
13	-	2.52	$811.91	811.91	18,530.40	17,718.49	0.29	235.18	5,367.60	5,132.42	(68,706.80)
14	-	2.72	$876.86	876.86	18,530.40	17,653.54	0.26	230.90	4,879.63	4,648.73	(73,355.53)
15	-	2.94	$947.01	947.01	18,530.40	17,583.39	0.24	226.71	4,436.03	4,209.32	(77,564.86)
16	-	3.17	$1,022.77	1,022.77	18,530.40	17,507.63	0.22	222.58	4,032.75	3,810.17	(81,375.03)
17	-	3.43	$1,104.59	1,104.59	18,530.40	17,425.81	0.20	218.54	3,666.14	3,447.60	(84,822.63)
18	-	3.70	$1,192.96	1,192.96	18,530.40	17,337.44	0.18	214.56	3,332.86	3,118.29	(87,940.92)
19	-	4.00	$1,288.40	1,288.40	18,530.40	17,242.00	0.16	210.66	3,029.87	2,819.21	(90,760.12)
20	-	4.32	$1,391.47	1,391.47	18,530.40	17,138.93	0.15	206.83	2,754.43	2,547.59	(93,307.72)
Total				$58,592.75	$157,759.74			**64,452.02**	**157,759.74**	**212,307.72**	**4.15**

APPENDIX C

6/4/24, 7:04 PM Pulchowk Campus, Institute of Engineering, Tribhuvan University Mail - Review Request: Article for Publication in Journal

Pulchowk Campus
Institute of Engineering
Tribhuvan University

SUBASH PANDEY <078msree017.subash@pcampus.edu.np>

Review Request: Article for Publication in Journal

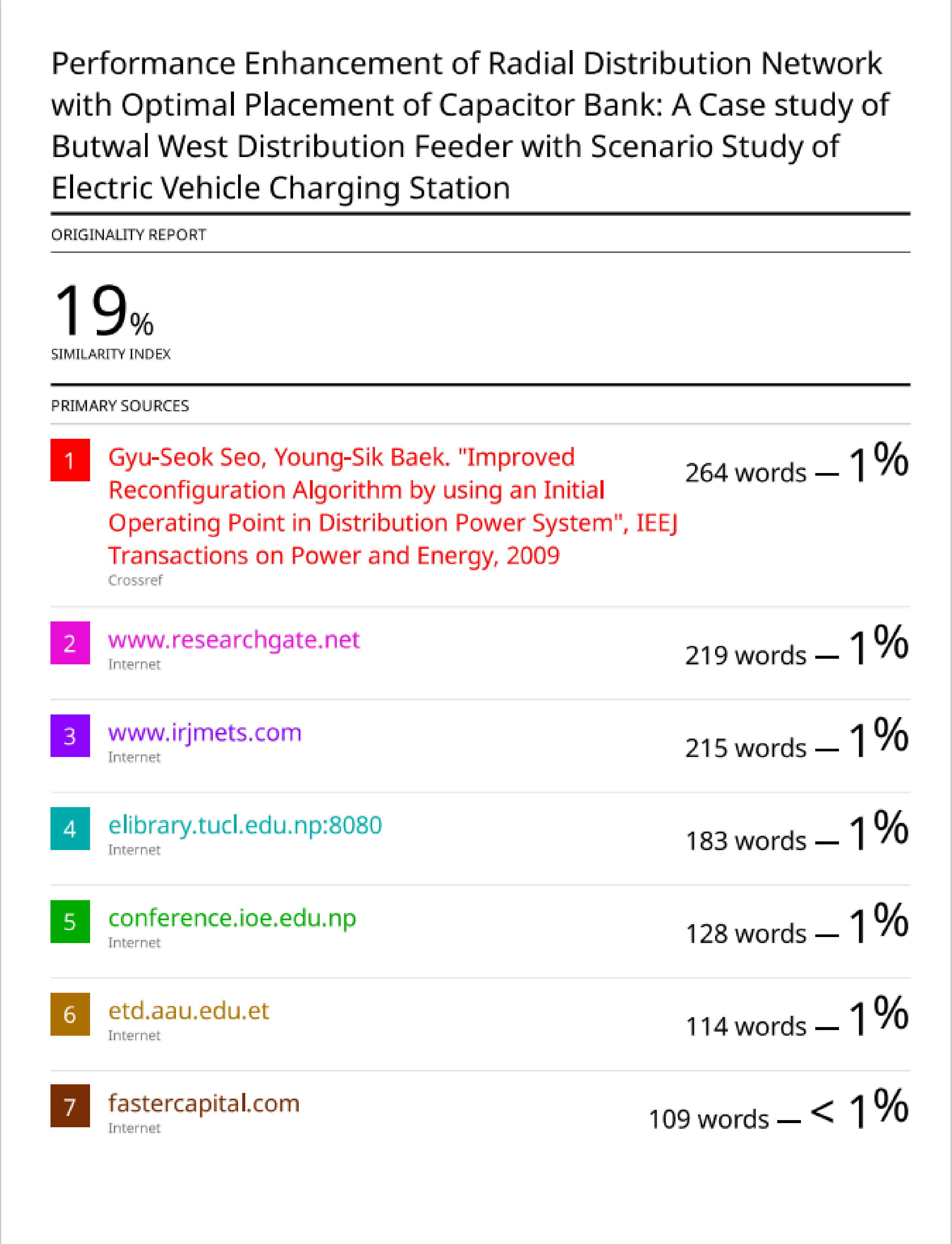
jacem advanced <jacem@acem.edu.np> Mon, Jun 3, 2024 at 6:28 PM
To: SUBASH PANDEY <078msree017.subash@pcampus.edu.np>

Dear Author,

Your Journal Paper titled"
Performance Enhancement of Radial Distribution Network with Optimal Placement of Capacitor Bank: A Case Study of Butwal West Distribution Feeder with Scenario Study of Electric Vehicle Charging Station"
has been accepted for the Journal of Advanced College of Engineering and Management (JACEM) for Vol.10, 2024. However, there are some minor changes that need to be done. Please look at the website for the format. We will contact you for further changes.

On Fri, 31 May 2024 at 10:37 SUBASH PANDEY <078msree017.subash@pcampus.edu.np> wrote:

> Dear Sir/Mam,
> I would like to request you to review the Manuscript of My thesis (Masters in Renewable Energy Engineering, Pulchowk Campus) attached herewith. The deadline for final defence is 10 June. Please, review it as soon as possible.
> Thank You for your valuable time and effort in the review process
>
> Sincerely,
> Subash Pandey
> Masters In Renewable Energy Engineering
> Supervisors: Mohammad Badrudhoza, Sanjaya Neupane
> subashpandey824@gmail.com
> 9867403491



Performance Enhancement of Radial Distribution Network with Optimal Placement of Capacitor Bank: A Case study of Butwal West Distribution Feeder with Scenario Study of Electric Vehicle Charging Station

ORIGINALITY REPORT

19%

SIMILARITY INDEX

PRIMARY SOURCES

1	Gyu-Seok Seo, Young-Sik Baek. "Improved Reconfiguration Algorithm by using an Initial Operating Point in Distribution Power System", IEEJ Transactions on Power and Energy, 2009 Crossref	264 words — 1%
2	www.researchgate.net Internet	219 words — 1%
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