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Techno-Economic Analysis of Impact on the Distribution Feeder with Capacitor Placement as per NEA's Regulations and Optimum Scenario

by

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A THESIS
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ABSTRACT

With the aim of distribution loss reduction, Nepal Electricity Authority has brought regulation to install the capacitor with size equivalent to approx. 30% of the load demand. Throughout the period of 5 years, the partial implementation of this regulation is practically achieved. This paper compares the techno-economic impact of the placement of the capacitor as per NEA's regulations and the other case for the optimal placement and sizing with the cost minimization function of genetic algorithm.

The voltage improvement and reduction in the overall loss can be achieved with the placement of the capacitor banks. In case of the IEEE-33 bus system, the voltage profile with optimal placement was better 0.924pu as compared to the case with NEA regulation which is 0.921pu. However, the overall system loss was lower for the optimal placement of the capacitor. With active loss being 163.28kW and 154.43kW respectively with the capacitor placed as per NEA’s guidelines and optimal scenario respectively. So, voltage can be better for the utility feeder dominated with the private consumers.

Melamchi feeder taken into account, the base case minimum voltage and loss was obtained as 0.732pu and 14.79% respectively. The minimum voltage with the capacitor placement as per NEA's regulation and Optimal capacitor placement (OCP) are 0.774pu and 0.817pu with loss 12.30% and 10.16% respectively. Moreover, from the financial analysis for the comparison of the two cases, it was evaluated that the IRR, BCR & discounted payback periods are 19.78%, 2.20 & 4.96 years and 23.76%, 2.46 & 4.41years for the placement with NEA’s guidelines and optimization respectively. This majorly indicates that the optimal placement of the capacitor is a bit more cost effective than the other case.

From both the techno-economic perspective, the capacitor placement in the distribution feeder at the optimal locations was determined more suitable than the installation at the private consumer’s point as per the NEA’s guidelines. So, the private consumers can aid the system voltage and mitigate loss with the collaborative evaluation of the optimal location and sizing of the capacitor in the utility’s distribution feeder.

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LIST OF ACRONYMS, SYMBOLS AND ABERRATIONS

BCR	Benefit to Cost Ratio
ETAP	Electrical Transient Analyzer Programme
GWh	Giga watt - hour
HP	Hydro Power
INPS	Integrated Nepal Power System
IRR	Internal Rate of Return
kV	kilo volt
LFA	Load Flow Analysis
MWh	Mega watt - hour
NEA	Nepal Electricity Authority
NPV	Net Present Value
OCP	Optimum Capacitor Placement
pf	power factor
pu	per unit
rpm	Revolutions per minute
SLD	Single Line Diagram
SS	Substation
SVC	Shunt VAR Compensator
VSI	Voltage Stability Index

CHAPTER ONE: INTRODUCTION

1.1 Background

The distribution system, being near to the consumers is often prioritized in case of quality power supply. The components of the qualitative power supply include the regulation of the system voltage along with the loss minimization. In addition, the distribution system has a huge investment to benefit cost as compared to the transmission systems. Therefore, the further investments need to be made considering the technical improvements and financial aspects associated with it.

With the flow of power in AC system, the electrical components produce as well as consumes the active or real power, responsible for the useful work or produces heat in the circuit, and the reactive power, which moves back and forth between the load and the source is used to produce and maintain the electric and magnetic fields in motors, generators, and other equipment.

Reactive power, on the other hand, is crucial for preserving the electrical system's voltage level and is essential for the system's reliable operation. The primary reason for the voltage collapse of various significant systems throughout the world has been a lack of reactive power in the system. Additionally, reactive power is necessary because it can increase the effectiveness with which real power is delivered to consumers (Sasson, 2005). Since it regulates steady-state and transient overvoltage and helps prevent system blackouts, reactive power must also be kept in the system.

Basically, proportionate inductive reactive power also passes along distribution feeders with the majority of the active element of power, increasing the total current flow. The voltage drop in the system gradually increases along with the I^2R loss due to this increased current flow. Therefore, as the demand rises, the inductive reactive power often rises in the same proportion, allowing more power to flow through the distribution system, which in turn causes a considerable decline in the efficiency and voltage level of the power lines. So, this reactive power flow when reduced will reduce the power/current flow through the distribution lines.

Reduced system losses (due to less current passing through the lines) and the release of extra capacity on the lines are both achieved with less reactive power flowing through the distribution lines. The capacity to transport electricity is increased via reactive compensation as a result, without the need for new infrastructures or conductors of a higher size. Reactive power can be supplied from a number of sources, including synchronous condensers, generators, and more often used transmission equipment including capacitors, reactors, and static var compensators. This inductive reactive component of power flow can be compensated for by reactive power. As it can limit the flow of reactive power in the distribution lines, resulting in lower loss and an improved voltage profile, reactive power compensation is typically performed at the distant level close to the load center. As a result, the power system uses capacitors to enhance voltage while also increasing efficiency.

In context of Nepal, Nepal Electricity Authority (NEA) is the major utility distributor. The voltage at the distribution feeders (11kV) are stepped-down to the required level (0.23/0.4kV) through the utility and privately owned distribution transformers. The private consumers get supply from either of these transformers and contributes in over 55% of the energy consumption. Acknowledging the importance of the reactive power management in the distribution system, NEA has recently issued a regulation stating that the private consumers with load demand higher than 5 KW should install the capacitor. The size of the capacitor to be placed is in variation according to the speed of the motor (presented in Annex D) and in average is around 30% of the load demand for motors of speed in range 1500-3000rpm.

In this research, the technical impact of this regulation is analyzed and is compared with the scenario of optimal capacitor placement. The technical impacts of system voltage and loss has been analyzed. Also, a comparison is made based on the financial analysis, about the suitability of the installation.

1.2 Problem Statement

The major utility of Nepal, NEA has recognized the importance of installation of the capacitor banks in distribution system and brought the regulations for installation of the capacitor with size nearly 30% of demand at all the private transformers exceeding load demand of 5kW. However, the study on the sizing of the capacitor and other alternatives has not carried out. Another feasible solution would have been the placement of the optimal size of the capacitor banks at some of the locations in the distribution feeder. The installation of large number of capacitor banks at the consumer end with proper protection devices would likely to increase investments for the installation of ancillary components.

1.3 Research Objectives

The main and specific objectives of this research are as follows:

1.3.1 Main Objective

- To perform techno-economic analysis of impact on the distribution feeder with capacitor placement as per NEA’s regulations and optimum scenario.

1.3.2 Specific Objectives

- To perform load flow analysis for the existing system of a distribution feeder.
- To analyze the effect on the voltage and loss of the system with the placement of the shunt capacitors as per NEA’s regulations
- To analyze the effect on the voltage and loss of the system with the optimum placement of the shunt capacitors
- To perform an financial analysis and compare the results for both cases

1.4 Limitations

The following are the limitations of the study:

The load has been considered for the distribution feeder at the time of the annual peak load and the optimizations are thus performed for the case of the most severe scenario.

For the optimum capacitor placement, the parameters of the cost of installation and maintenance was considered from the NEA as well as the energy savings cost from the average NEA tariff structure. The objective function of cost in the OCP will be the minimization of overall cost with increased voltage and increased energy savings. A comparative analysis with the capacitor placed in the various voltage level of the optimum location was carried out.

For the financial analysis, the benefit includes the benefit from the reduced system loss after the addition of the capacitors, the project lifetime was considered to be 20 years with annual interest rate of 10%. The cost of the capacitors, though considered from the NEA can vary with the market price by some margins. The financial analysis was carried out for the effect of a capacitor placed with the comparison of the financial parameters (IRR, BCR and discounted payback period).

1.5 Thesis Outline

This thesis report is divided into five chapters.

Chapter One presents the general introduction of the thesis work with its background and necessity of the study. This chapter covers the scope of the study and some assumptions and limitations.

Chapter Two focuses on the review of various literatures related with the study carried ahead. A brief summary of the techniques for the load flow and optimizations are presented in the chapter.

Chapter Three has illustrated the overall methodology followed in the course of study. The flowcharts of the methodology with the mathematical equations are described in this chapter.

Chapter Four presents the results obtained throughout the research for different scenarios with an analysis and illustrations of the outcomes.

Chapter Five presents the conclusion and recommendations.

The annex illustrates the data considered and the detail results.

CHAPTER TWO: LITERATURE REVIEW

For the thesis, a wide range of literatures was reviewed. These books presented a variety of methods for carrying out analysis that were relevant to the subject. Here is a brief summary of the various strategies that researchers have put up in recent years for the ideal placement of capacitors and load flow.

2.1 Power Flow Analysis

Due to economic growth and more access to energy, consumer demand for power is on the rise in Nepal (NEA, 2023). The entire flow of power via transmission/distribution lines rises concurrently with rising energy demand, increasing the need for reactive power. As a result, both the line loading and loss increase. Active loss reduction during electricity transfer is essential for the system to operate economically and consistently (Taylor, 2008).

A typical method to reduce loss is to transfer electricity at a higher voltage with a much larger conductor. As the power flowing through the system decreases, the amount of energy lost along the transmission lines also decreases. The active power, which the consumer is required to use, serves as the line's main purpose. As a result, it is possible to theoretically lessen the overall line loss by only reducing the reactive fraction of the power at the transmitting end. However, reactive power is a crucial requirement for maintaining the stability of the system voltage, and its shortage is the primary cause of system blackouts. (Edris & Mehraban, 1998).

A contingency in the system may also cause the reactive component of line loading to fluctuate greatly without appreciably altering the active component of the power (Leonardi & Ajjarapu, 2008). The reason for this is that as a result of component failure, the bus voltage drops and is accompanied by a reduction in reactive power generated by charging the line and shunt capacitors. Accordingly, there should be enough of a reserve to provide reactive power in the event of an irregularity (Edris & Mehraban, 1998). The easiest strategy to lessen line loss without compromising system stability is to generate reactive power at the load center and reduce the amount of reactive power that needs to flow via the distribution line.

Additionally, during a contingency in the system, the reactive component of line loading might change dramatically without the active component of the power significantly changing (Leonardi & Ajjarapu, 2008). The cause of this is that the generation of reactive power from charging the line and shunt capacitors diminishes along with the drop in bus voltage caused by component failure. This means that in the event of an irregularity, there should be a sufficient reserve to deliver reactive power (Edris & Mehraban, 1998). Reactive power generation at the load center and a reduction in the amount of reactive power required to flow via the distribution line are therefore the best ways to lower line loss without compromising system stability. Reactive power adjustment improves the stability of the power system by maintaining the necessary voltage level while also reducing active and reactive network power loss (K. Yang & Gong, 2015).

To understand a system, a load flow analysis is required. The system's steady-state status in terms of the active and reactive component of power can be ascertained using the amplitude and phase angle of the voltage at each bus (Alsulami & Kumar, 2017). Load flow studies are typically conducted for power system planning, operation, and control. Additionally, stability and dispatching optimization, emergency planning, and outage security assessment also employ data from load flow studies.

The non-linear algebraic equations of the load flow problem have been solved by various methods. The three iterative methods that are most frequently used are the Gauss Siedel, Newton-Raphson, and the Fast Decoupled approach. According to research comparing the load flow methods (Keyhani et al., 1989), the Newton-Raphson approach is reliable for higher voltage load flow analysis and is also quick in converge, but the Gauss-Siedel method is slower and at extreme ill conditions may even fail to converge. The load flow in the Electrical Transient Analyzer Program (ETAP) software will be used to conduct this investigation both before and after the reactive power compensation.

2.2 Reactive power compensation

There are numerous ways to generate reactive electricity. The primary ones include synchronous alternators, banks of static capacitors, synchronous compensators, and static VAR compensators. For the future scenarios of five and ten years (IPPs), research was done for the Integrated Nepal Power System (INPS) using the reactive power supplied by the synchronous alternators of the IPPs. The study shows that, with some payment to the IPPs, it would be technically and financially feasible (Poudel & Kumar Mishra, 2020).

Additionally, a study shows the effects of placing the Static VAR Compensator on the IEEE 14 Bus system to raise the voltage (Daw & Salih, 2019). Similar to this, a study was conducted to address the voltage drop and power loss issues at the Kalimantan electric power station in Indonesia. The study simulates the system with a 62 MVAR static var compensator installed among one of the substations, improving the voltage in all of the 150 kV buses by an average of 0.613 kV (Susilo et al., 2018). Additionally, a paper describes how to model and simulate the Distribution Static Synchronous Compensator (D-STATCOM) using the Sinusoidal Pulse Width (SPWM) Modulation Technique to address power quality issues including voltage sag (Madhusudan & Rao, 2012). Similar studies and research employing different reactive power compensation strategies have been done in numerous additional cases. Reactive power compensators should, in theory, be installed at each of the load centers to lower the flow of reactive power across the transmission lines. It might not be economically feasible, though, and it might not produce the best results. Therefore, the capacitors should be placed in the ideal location.

There are two additional types of reactive power support: static and dynamic. The static reactive compensator is unable to quickly modify the reactive power level while keeping a constant voltage level when it is linked to the system. Voltage variations affect how reactive power is generated. The amount of reactive power generated increases at the higher terminal voltage and decreases as the voltage falls. Capacitors and inductors, respectively, are responsible for producing and consuming static reactive power. They are less dependable and less expensive because they have a limited capacity to produce additional reactive power when the voltage level is low or the demand for reactive power is high. On the other side, gear that can quickly modify reactive generation without changing voltage produces dynamic reactive power. As a result, this equipment can increase the degree of reactive power generation even when the voltage level drops and stop a system breakdown. Synchronous condensers, static VAR compensators, and generators—all of which are more dependable—can all be used to produce dynamic reactive power.

2.3 Optimum Capacitor Placement

Different placement strategies for the capacitor were looked at. The development of a continuous and differentiable objective function was necessary for several of them. To simplify such a function, a number of assumptions had to be made. For this, considerations about the capacitor's dimensions, cost, kind, quantity, placement, and switching periods were required (Eajal & El-Hawary, 2010). The offered method has a big drawback in that the solutions will differ based on the starting positions.

Additional optimization procedures have been suggested in order to raise the standard of the problem's solution. These methods include dynamic programming (Dura, 1968), the tabu search (H. T. Yang et al., 1995), expert systems (Al-Ammar et al., 2018), and simulated annealing (Mekhamer et al., 2006). The aforementioned methods have some drawbacks despite the fact that they can be used with discrete variables. These techniques' principal limitations are their speed and the fact that they employ unpredictable, hard-to-predict control parameters.

The widely used optimization method known as the genetic algorithm (GA) will be applied in this thesis (Rojas et al., 2008). The GA is a local search technique used to find approximate solution to the optimization and search problems (Delkhooni et al., 2017). A solution with desirable qualities is carefully selected at that point and carried through the following iterational sequence, mimicking the process of natural evolution together with mutation and crossover. GA is effective when there is limited information about the problem and, like some other optimization techniques, uses probabilistic transition rules. Even though the method is time-consuming in contrast to the same other ways, the ETAP program will be used, which includes the feature to adjust precision to speed ratio. Within the specified time, the optimization will be carried out as exactly as feasible.

In a study (Levitin et al., 2000), it was determined where the capacitor should be placed in the distribution system to maximize capacitor performance for users with different load patterns. The benefits of capacitor placement were evaluated in terms of energy savings using energy computed from the pattern of the feeder curves of the various types of consumers. This resulted in a large reduction in the system loss and a significant release of reactive power loads.

A study that looked at the ideal location for the capacitor and used a sequential linear programming method was described. Branch and Bound, two genetic algorithm techniques, a mixed integer linear programming problem (MILP), and the Branch and Bound strategy were all required for each iteration. The analysis of the Italian network came to the conclusion that, for smaller test cases, the Branch and Bound approach outperforms genetic algorithms since the latter method produced results with a greater number of simplex iterations, which required more computation time. The newly proposed hybrid method uses the initial population generated by the branch and bound strategy as the input for the genetic algorithm as a result.

The INPS system modeling was done in ETAP. In a case study, the load flow of the INPS was investigated. Based on the line capacity, conductor type, and length of the line, the transmission line parameters taken into account in the analysis. The basis for the generator data was the power's design capacity and power factor. All of the loads were transferred to the side with the higher voltage in order to keep the study straightforward (Ghimire & Paudyal, 2019). Nevertheless, the study was carried out regardless of the system peak because it was assumed that each generation was working to its maximum potential. This study's load flow will be carried out while taking the load and generation during the month of Bhadra into consideration.

The study made use of three different kinds of loads: constant power, constant current, and constant impedance. It showed that the load flow solution for the constant power load required less iterations to reach convergence than the other models (Indulkar & Ramalingam, 2008). For the load model in this study, an ETAP constant power load will be used, in which the power consumption remains constant despite variations in terminal voltage.

Numerous articles employ ETAP and highlight its value for analysis. The load flow of multiple connected 132 kV grid substations in Pakistan was examined in a study, together with short circuit and system reliability analysis (Nisar et al., 2015). Similar to this, a paper stresses the value of investigating load flow to fully grasp power flow in the utility system. In order to emphasize the significance of these elements in problem-solving, the authors also looked at the recommended diameters for protection and detection relays. The Ghazaouet 220/63/30 kV substation, which comprises 15 load regions, 8 power transformers, 83 circuit breakers, 7 high voltage lines, 32 isolators, 33 current transformers, and 33 current transformers, was the subject of the study. It is located in Algeria's West Tlemcen Wilaya. It made sure that voltage drop was the primary cause of loss and that the ideal capacitor size and placement were employed to address the problem (Zeggai & Benhamida, 2019).

Other studies describe the ideal capacitor configuration for ETAP's OCP module. The study was successfully completed through the use of the ETAP software and simulations for the electrical model of a 1240 MW combined cycle power plant, including load flow analysis (LFA), voltage stability, and short circuit analysis (SCA). The authors evaluated the impact of voltage instability on the power grid on the system buses of the power plant. The Newton-Raphson technique was used to find the terminal buses that are running below, and the functions of voltage restrictions were taken into account when adjusting their voltages. For the voltage increase, tap changers that can run at full load are also used, as well as reactive power correction. The most suitable (optimal) position for the placement and number of the capacitor banks was obtained by providing the sizes using the OCP module of ETAP. The SCA results are also contrasted with the actual case values of the substation short circuit current. All power system assessments came to the conclusion that the ETAP results were satisfactory (Ullah et al., 2017).

In a similar vein, another research investigated the Kaduna 132/33 kV station and carried out a power flow analysis to determine its operating status under normal circumstances. ETAP was utilized to model and perform LFA using the Single Line Diagram (SLD) and real case data obtained from the substation. The system network's current loss was compensated by placing the capacitor bank using the OCP module. Based on the OCP results, eight capacitor banks were inserted in each of the eight candidate buses. According to the results, the bus voltages were increased from 90.244% & 94.716% to 96.847 & 99.11%, which led to a 22% decrease in the active component of loss (Airoboman et al., 2019). Similar to that, this study will investigate the voltage and loss conditions both before and after the capacitor is installed, and it will then carry out a financial analysis based on the energy savings.

2.4 Financial Analysis

The cost of installing the best-sized capacitor in the best locations will be the capital outlay, and the return will be determined by the amount of energy that is saved as a result of the capacitor's installation. With an energy cost of Rs. 10 per kWh, the project lifetime will be set at 20 years (Poudel & Kumar Mishra, 2020). As a result, the analysis of the financial indicators, including NPV, IRR, BCR, and discounted payback period, will be used to determine the study's financial viability.

CHAPTER THREE: METHODOLOGY

This chapter presents an insight on how the research work was carried out to answer the research question: What will be the effect of placement of capacitor in the distribution line regarding voltage profile and system loss. There are lots of ways for placing the capacitor regarding size and location in the system. IEEE-33 bus radial distribution system and 11 kV existing utility feeder has been taken under consideration for study. Both distribution systems were modeled by using Electric Transient and Analysis Program (ETAP) tool. After modeling the system using the data obtained, the load flow of the system must be determined for the best capacitor location. The installation of the capacitor in accordance with NEA standards and the optimal scenario were technologically and economically compared. The load flow of the existing and the system with capacitors will be compared for the technical analysis. Financial analysis must be done to see whether the study is financially feasible in order to determine its viability. The proposed methodology is shown in Figure 3.1, and some of the key steps are detailed here.

3.1 Research Framework

The study was carried out by following the research framework as shown in Figure 3.1. The research methodology consists of issue identification and research question, analytical model development, scenario analysis and conclusion and recommendations.

3.2 Issue Identification and Research Question

An extensive literature review was carried out on the issue related to the placement of capacitor in the distribution feeder, especially focusing in the context of our country. Regulation issued by Nepal Electricity Authority for the placement of capacitor regarding the private consumers was selected for further study. With the increasing demand of load and consumption pattern, need of reactive power management in transmission and distribution level increasing day by day. The regulation launched by NEA for private consumers to install capacitor bank is quite good for system voltage and loss but is difficult to implement in all level. So, there needs some other better alternatives for capacitor bank installation which will cover all the reactive power requirement in the system. Optimum placement of capacitor might cover all the issues related to the reactive power management regarding light loads to the large loads in the system. Detailed study in the ways of installing capacitors in the distribution system will help policy makers of the concern sector and different stakeholders to understand, develop and implement such policies and regulations in most effective manner.

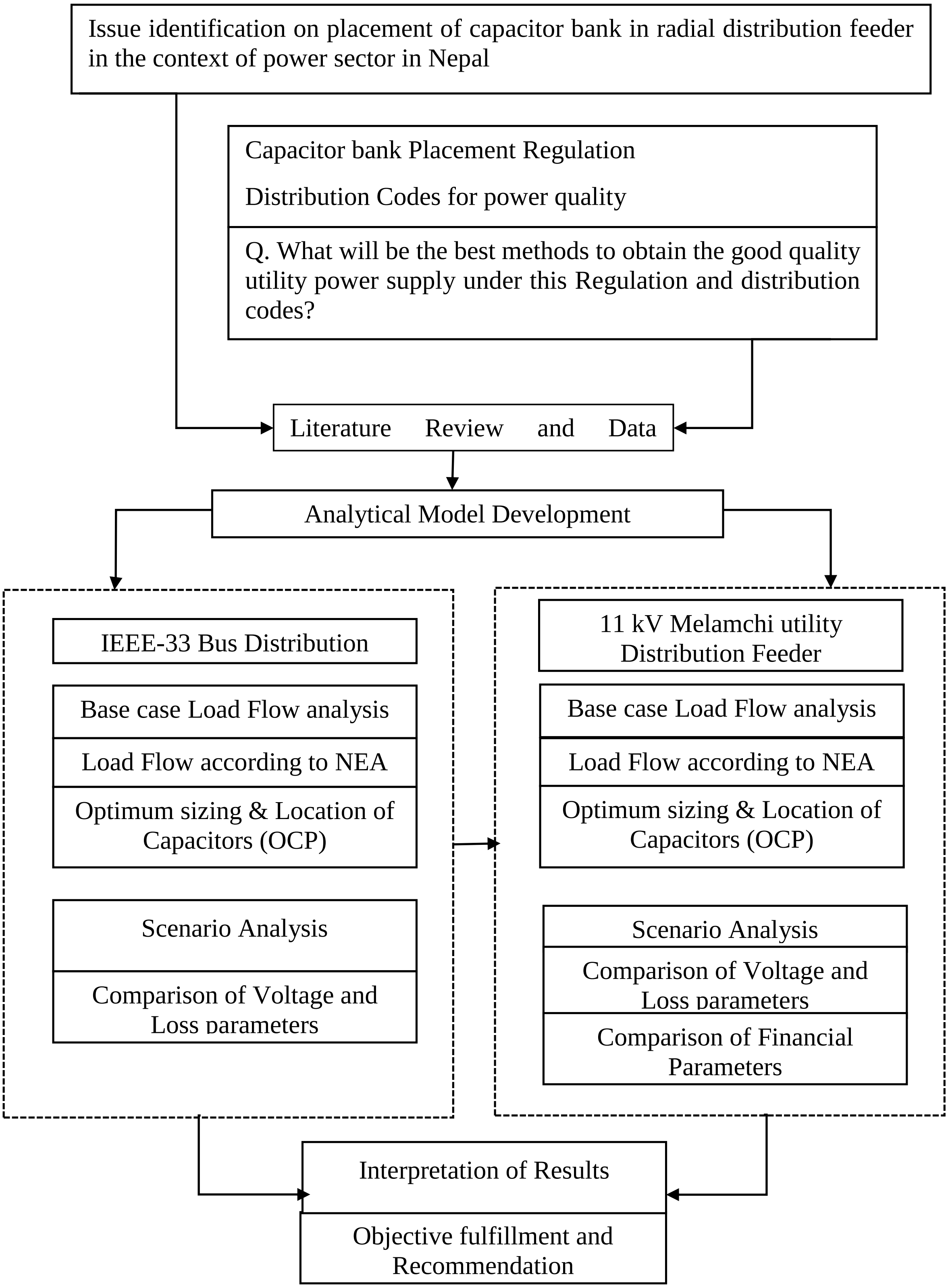

Figure 3.1: Research framework of the study

Based on this, the following research questions were formulated for making further policies and regulation to reactive power management:

a) What would be the change in distribution line parameters like voltage, loss, power factor after installation of capacitors according to NEA?
b) What would be the improvement in distribution line parameter with optimum capacitor placement in overall distribution network?
c) Which scheme of capacitor bank installation covers all the loads connected to the system?
d) Which scheme would be more viable technically and economically?

3.3 Literature Review and Data Collection

After performing lots of reviews on the issues related to the capacitor bank placement in the distribution system nationally and globally we have started data collection. The data required for the study is collected from diverse sources. The log-sheet records of the Melamchi substation are utilized to gather feeder data concerning the peak load. Advanced Metering Infrastructure (AMI) and Time of Day (TOD) data are employed to obtain private load information. The load data for the utility distribution transformers is derived from routine phase current measurements conducted by Melamchi DC. Furthermore, the Single Line Diagram (SLD) and GIS map are utilized to retrieve network data.

3.4 System Modelling

The IEEE standard bus and Melamchi feeder is simulated using ETAP 16.0 software. In the process of modeling the feeder, a constant kVA load model is employed. The power factor of the utility load is assumed to be 0.9, while for private consumers, it is determined by averaging data records obtained from the Time of Day (TOD) meter. The conductor reference from the IS 398-1976 standard is utilized to calculate the distribution line parameters.

3.5 Load Flow Analysis

The Load Flow Analysis (LFA) module in ETAP offers various methodologies, including Adaptive Newton-Raphson, Newton-Raphson, Gauss-Seidel, and Fast Decoupled Power Flow, among others. Within ETAP, the Load Flow analysis employs the adaptive Newton-Raphson technique. This revised method presents a smaller set of stages for iterations until a potential divergence condition is encountered. In situations

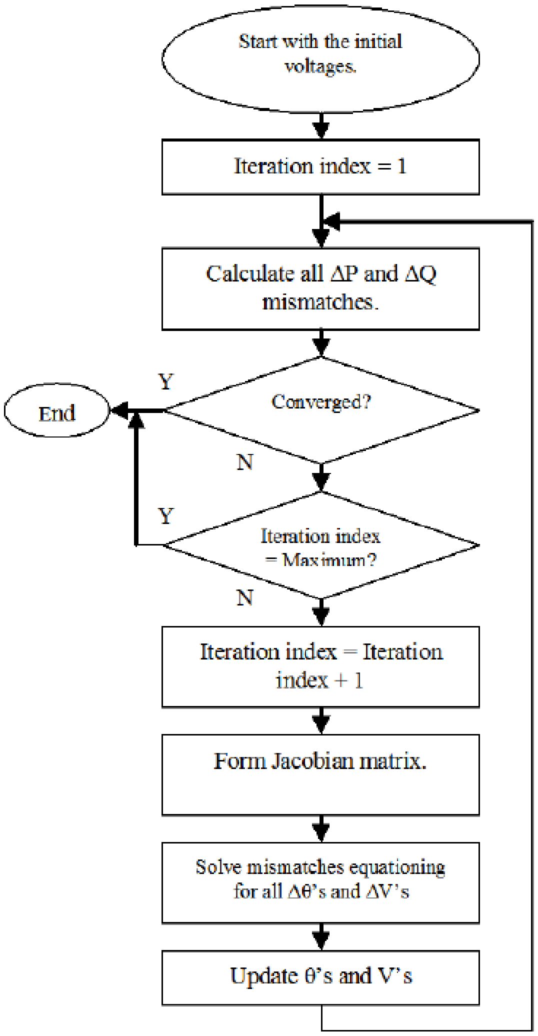

Figure 3.2: Flowchart for Newton-Raphson Load Flow method

where the Newton-Raphson approach may have failed, these incremental value adjustments can aid in finding a load flow solution. Test results indicate that this approach improves convergence for distribution and transmission systems, particularly when significant series capacitance effects (negative series reactance) are present. However, it may face challenges in achieving convergence when the initial guess is not sufficiently close to the actual solution or when the system of equations exhibits high nonlinearity.

The method described above experiences a reduction in speed due to the incorporation of incremental stages in the calculation process. To ensure accuracy, the load flow is set with a precision requirement of 0.0001, and the default number of iterations is set to 99.

3.6 Optimum Capacitor Placement

By utilizing the Optimal Capacitor Placement (OCP) module within ETAP, capacitors can be strategically located in a cost-effective manner, ensuring voltage support and power factor correction. The module features an advanced user interface that provides users with the ability to quickly access and analyze the results, offering flexibility in managing the entire capacitor placement process. The precise calculation methodology automatically determines the optimal location and size of the capacitor banks. Furthermore, a comprehensive report can be generated, detailing the improvement in line branch capacity for power transfer and the energy savings achieved through the capacitor placement over the entire planning period.

The voltage sensitivity index will be evaluated for each of the bus and are sorted based on the values. The optimal placement of capacitor is performed by selecting the top 10% of the bus based in the VSI index. The equation for voltage stability index can be written as:

$$VSI_i = \frac{4Q_i\,(R+X)^2}{X({V_i}^2 + 8RQ_j\,)} \tag{3.1}$$

Where,

$Q_i\,, Q_j\ = the\ apparent\ power\ at\ bus\ i\ (sending\ end), bus\ j\ (receiving\ end)$

$R, X = the\ line\ resistance\ and\ impedance\ between\ bus\ i\ and\ bus\ j$

$V_i\ = Bus\ voltage\ at\ sending\ end$

The candidate bus was chosen based on its higher reactive consumption value and lower voltage level. Input factors such as energy cost per kW, installation expenses, operational costs, maintenance costs, and other relevant considerations were taken into account to determine the optimal size of the capacitor. This careful selection process ensures that the final outcome will yield substantial economic benefits. The objective of the Optimal Capacitor Placement (OCP) approach is to minimize the overall cost of the system, which encompasses the purchase cost of the capacitor, installation expenses, and ongoing operational costs. The operational costs further encompass the annual maintenance fees associated with the installed equipment.

The OCP uses the Genetic Altogothm (GA) for the optimization process. Genetic Algorithms (GAs) offer several advantages over other optimization algorithms in certain scenarios. Here are some of the key advantages:

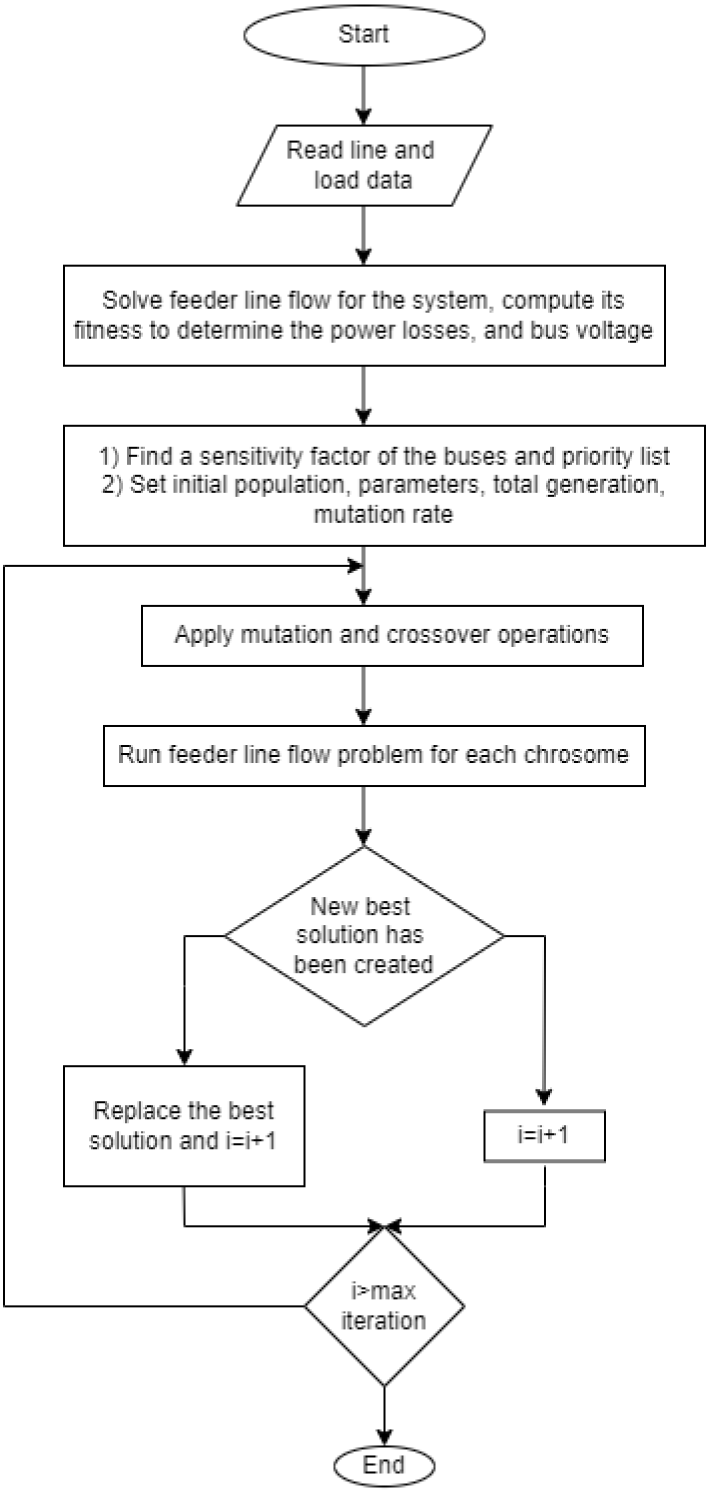

Figure 3.3: Methodology for genetic algorithm (GA)

- Global optimization: Genetic Algorithms are designed to search for solutions across the entire search space, making them well-suited for global optimization problems. They can effectively handle multi-modal and non-differentiable objective functions where traditional gradient-based optimization methods might struggle.

- Exploration and Exploitation: GAs strike a good balance between exploration (diversity) and exploitation (intensification). They maintain a diverse population of solutions while also focusing on promising regions of the search space, increasing the likelihood of finding the global optimum.
- Robustness: Genetic Algorithms can handle noisy and stochastic objective functions since they are based on a population of solutions rather than relying on a single point estimate. This robustness allows them to work well in real-world applications with uncertain or noisy data.
- Handling constraints: GAs can naturally handle constrained optimization problems by incorporating constraints into the fitness evaluation or by using specialized techniques like penalty functions or repair operators.
- Versatility: Genetic Algorithms are versatile and can be adapted to various problem domains and optimization objectives, such as continuous, discrete, combinatorial, and mixed-variable problems.
- Simplicity of implementation: GAs have a relatively straightforward implementation compared to some complex optimization algorithms, making them more accessible to users who might not have an in-depth understanding of optimization techniques.

Additionally, the price includes the cost of the actual power losses that remain in the system even after the capacitor has been added. The objective function's mathematical representation of this cost is as follows:

Minimization function:

$$\sum_{i=1}^{Nbus} (x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T + C2 \sum_{i=1}^{Nbus} (\, T_l P_L^1) \qquad (3.2)$$

where,

- Nbus= No of bus candidate
- x_i – 0/1,0 means no cap installed at bus i
- C_{0i} – Installation cost
- C_{1i} – per kVAR cost of capacitor bank
- Q_{ci}– Capacitor bank size in kVAR
- B_i – Number of capacitor banks

- C_{2i} – Operating cost of per bank, per year
- T – Planning period (years)
- C_2 – Cost of each kWh loss in NRs. /kWh
- L – Load levels, maximum, average and minimum
- T_l – Time duration, in hours, of load level 1
- P_{Li}– Total system loss at load level l constraints

The main objective for the placement of capacitor is to meet the load flow constraints. Additionally, the magnitudes of all the load (PQ) buses' voltages shall fall within the permitted range of lower and upper values. Additionally, the power factor (pf) of the bus to which the load is attached should be greater than the necessary minimal value and equal to unity at its maximum. The equality constraints are:

$$P_i(V,\delta) - P_{Gi} - P_{Di} = 0 \tag{3.3}$$

$$Q_i(V,\delta) - Q_{Gi} - Q_{Di} = 0 \tag{3.4}$$

The inequality constraints considered for the genetic algorithm is:

$$V_{i_{min}} \leq V_i \leq V_{i_{max}} \tag{3.5}$$

$$Q_{j_{min}} \leq Q_j \leq Q_{j_{max}} \tag{3.6}$$

Where, i is the number of buses and j is the number of the reactive power sources. The voltage considered in this case is: $0.9\,pu \leq V_i \leq 1.1\,pu$ for IEEE-33 bus system and $0.8\,pu \leq V_i \leq 1.05\,pu$ for the Melamchi feeder since the initial

The voltage constraint will be combined while enhancement of the bus voltages. The bus voltages must fall below these limits after the capacitor has been installed.

The OCP module offers details on the number of capacitor banks needed for reactive compensation, which raises the voltage in the designated candidate buses and throughout the system, as well as the best area to deploy them.

3.7 Financial Analysis

To assess the financial elements of the actual application of the study, the Internal Rate of Return (IRR), Benefit to Cost Ratio (BCR), and Discounted Payback Period were also determined. The economic analysis was carried out with a 20-year project lifetime and an inflation rate of 10% annually.

Internal Rate of Returns (IRR): It can be used to estimate the profitability of possible investments because it represents the annual percentage growth that a certain investment is anticipated to achieve. It is the discount rate at which the net present value (NPV) of an investment is equal to zero. In other words, it is the rate at which the sum of the discounted future cash flows of an investment equals the initial investment. A higher IRR means that an investment is expected to generate higher returns. Any project that surpasses the Required Rate of Return (RRR) is deemed acceptable, and for the purposes of case comparison, the scenario with the highest IRR is considered to be the more financially feasible option.

$$0 = NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} - R_0 \tag{3.7}$$

where,

R_t = net cash inflows-outflows during a single period t

R_0 = Total initial investment cost

i = discount rate

t = number of time periods

Benefit Cost Ratio (BCR): It can be expressed in quantitative or monetary terms and offers an inclusive relationship between the project's costs and benefits. The BCR is a measure of the benefits of an investment compared to its costs. It is calculated by dividing the total benefits of the investment by the total costs of the investment. A BCR of 1 means that the benefits of the investment are equal to the costs. A BCR greater than 1 means that the benefits are greater than the costs, while a BCR less than 1 means that the benefits are less than the costs.

$$BCR = \frac{\sum_{t=0}^{n} \frac{R_b}{(1+i)^t}}{\sum_{t=0}^{n} \frac{R_c}{(1+i)^t}} \tag{3.8}$$

where,

R_b = benefit net cash inflows during a single period t

R_c = cost net cash outflows during a single period t

i = discount rate

t = number of time periods

Discounted Payback Period: By discounting future cash flows and taking the time value of money into account, it provides a quantitative estimate of how long it will take for a project to become financially viable after incurring the first expense. The sooner the project generates the money needed to pay off its initial investment, the lower the value of the time should be. It will be more appropriate to pursue the project with the lower discounted payback time value.

3.8 Interpretation of Result

Interpretation of results are done on the fulfilling the objectives of this study. Conclusions and recommendations are given after analysis and interpretation of the results in Chapter 5.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 IEEE 33 Bus Radial Distribution System

The analysis is first performed with the IEEE-33 bus radial distribution system. The load flow analysis of the system was performed first followed by the placement of the capacitors as per both: NEA's regulations and optimal locations.

4.1.1 Base Case Scenario

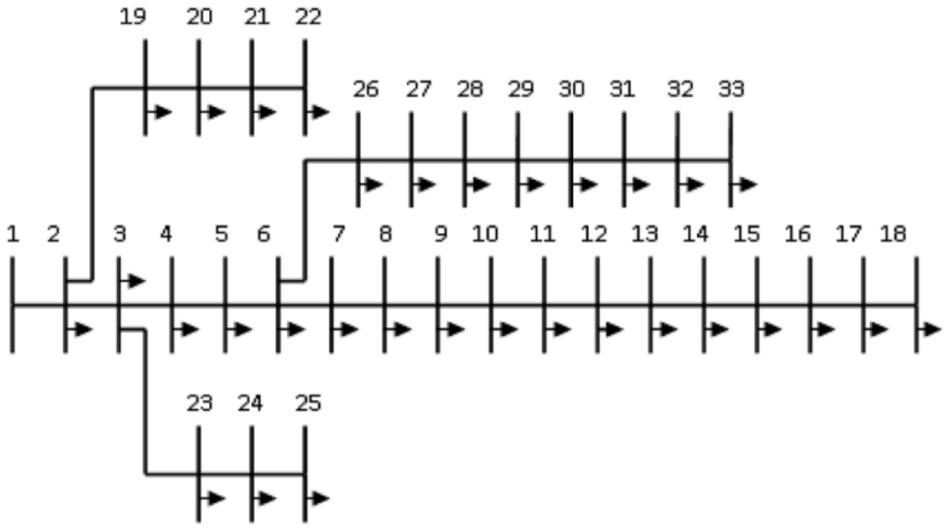

Figure 4.1: Model of the standard IEEE 33 bus radial distribution system

The load flow analysis of the IEEE-33 bus radial distribution system is performed with the adaptive Newton-Raphson method. From the results voltage profile in Figure 4.2, it can be determined that the voltage of the buses obtained after the load flow using adaptive Newton Raphson method is identical to the standard results.

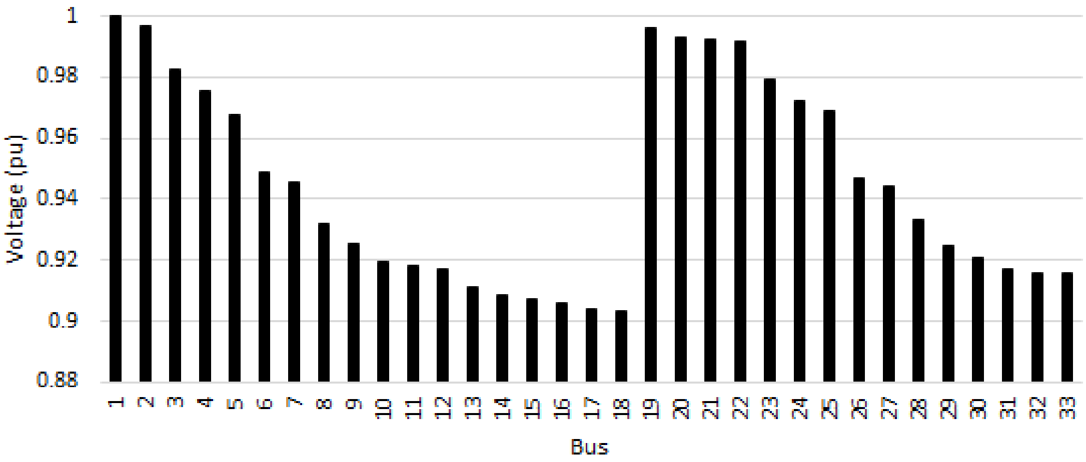

Figure 4.2: Voltage profile at each bus of IEEE-33 bus system

From the Figure 4.2, it was evident that the minimum voltage is observed at Bus18 with value 0.903pu. The system loss is 212.93kW active and 144.35kvar reactive loss. Similarly, the active loss of branches is shown in Figure 4.3. More than 40 kW losses in the branch 2 and 5 contribute to over 44% of the loss of the overall IEEE-33 Bus radial distribution system.

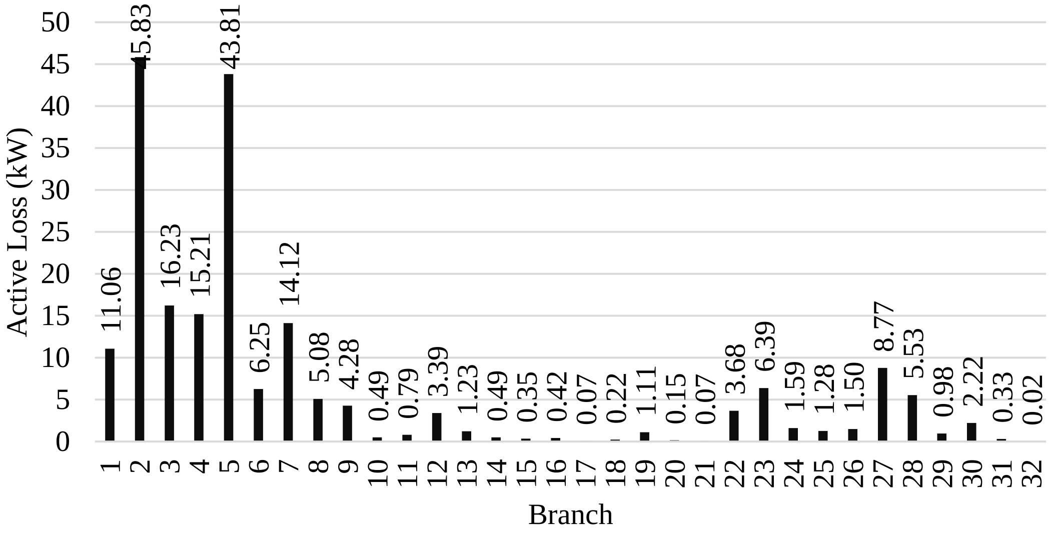

Figure 4.3: Real power loss in the branches of IEEE-33 bus system

4.1.2 Optimal Capacitor Placement

With the ETAP software, the optimal placement and location of the capacitor was determined. The Voltage Sensitivity Index for the bus was determined. The VSI values are shown in the Table 4.1. The values for voltage, resistance, inductance, reactive power flow were all calculated in p.u. terms.

Table 4.1: VSI calculation for OCP

Bus	VSI
Bus2	0.02501
Bus3	0.117336
Bus4	0.07005
Bus5	0.070053
Bus6	0.129508
Bus7	0.015615
Bus8	0.081407
Bus9	0.038453
Bus10	0.036794
Bus11	0.008582
Bus12	0.01446

Bus	VSI
Bus13	0.036509
Bus14	0.011442
Bus15	0.006537
Bus16	0.007473
Bus17	0.00966
Bus18	0.003643
Bus19	0.00266
Bus20	0.01823
Bus21	0.003355
Bus22	0.002942
Bus3	0.02222
Bus24	0.038016
Bus25	0.019281
Bus26	0.024493
Bus27	0.03328
Bus30	0.053046
Bus29	0.08
Bus28	0.104803
Bus31	0.024259
Bus32	0.005233
Bus33	0.001717

The 12 bus with higher VSI values are selected as the candidate bus based on which the optimal location of the capacitor placement was determined.

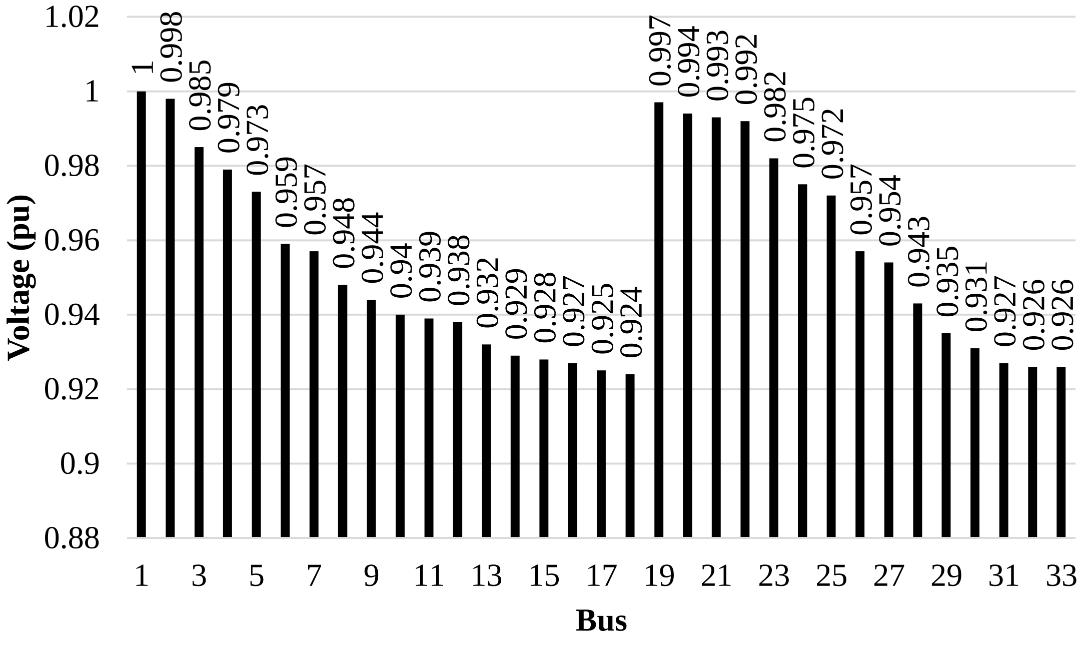

Figure 4.4: Bus Voltages with OCP

The results show that for the 11kV system, a total of 1650kvar is to be installed. The optimal locations are at Bus3, Bus6 and Bus10 with sizes 580kvar, 550kvar and 520kvar respectively. With this, the voltage at the 18th bus would improve to 0.924pu and overall active and reactive loss decreases to 154.43kW and reactive loss to 104.91kvar.

4.1.3 Capacitor Placement as per NEA's Guidelines

For the capacitor placement as per NEA's regulation guideline, the capacitors are placed at each of the 32 Bus beyond Bus1. A total of 1363kvar are required at these locations. The result shows that the overall system voltage improves and the loss decreases. The minimum voltage at Bus18 improves to 0.921pu with the active loss decreasing to 163.28kW and 112.24kvar respectively.

However, not all the bus as considered in the IEEE bus system may be private in the real case scenario. So, the analysis considering that the even buses are private transformers and the odd are NEA's transformers is considered and the technical parameters of the systems was evaluated. The 30% of the kVA rating was considered for the private transformers. In doing so, the bus voltage of the Bus 18 improves to 0.915pu as shown in Figure 4.5.The active and reactive loss are 171kW and 116kVAR resepectively.

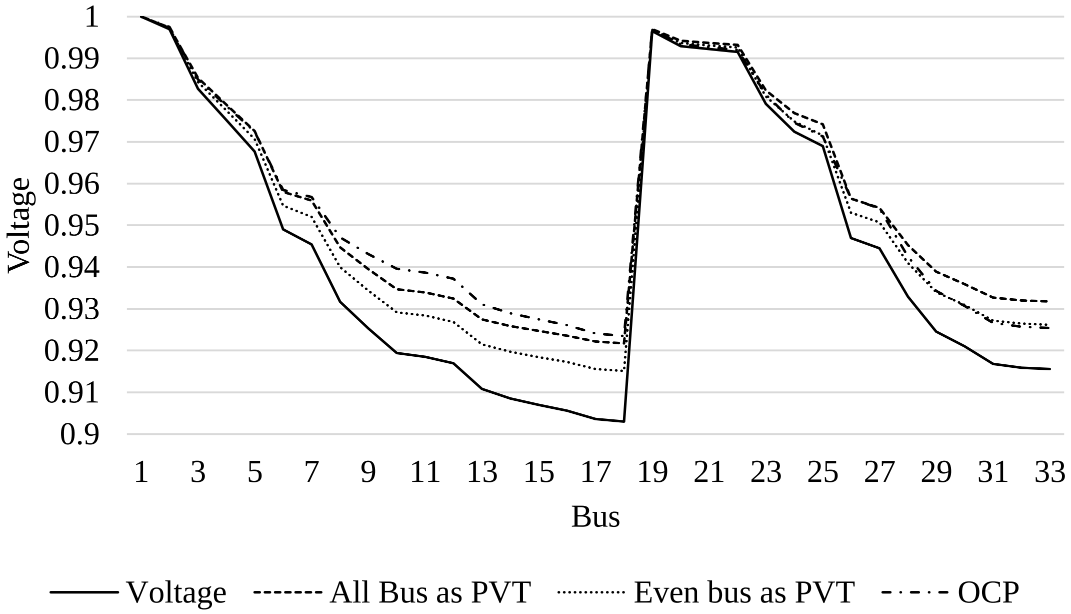

Figure 4.5: Bus Voltages of the IEEE-33 bus at various scenarios

The comparison of the system loss for the different scenarios are presented in Fig. 4.6.

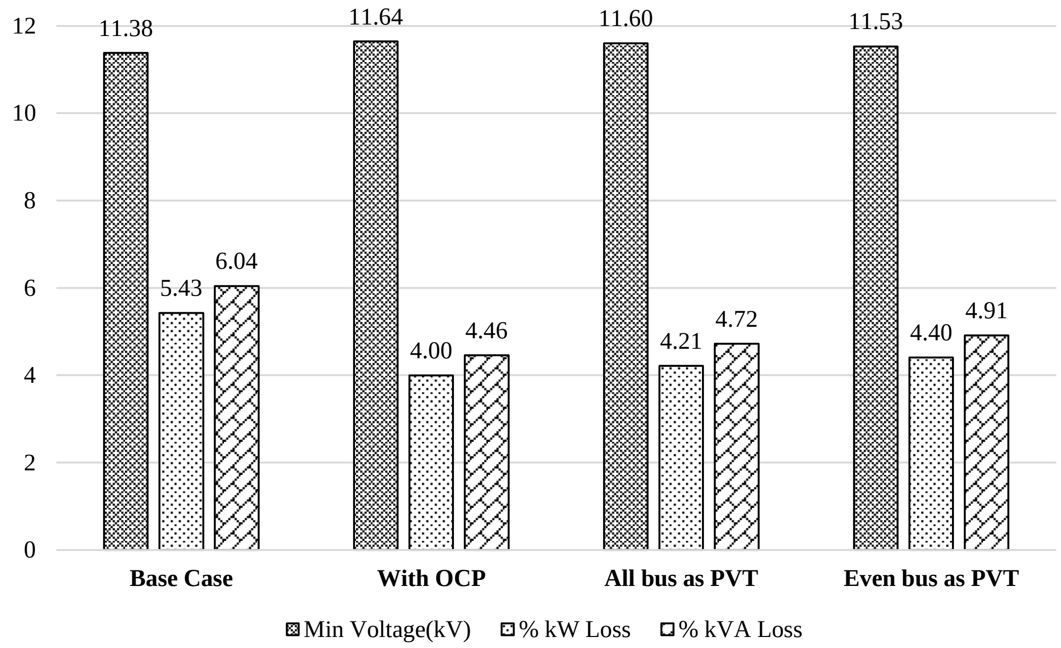

Figure 4.6: Min. votage and % loss comparison for test bus system

4.2 Utility Distribution Feeder

The similar simulation is also carried out in case of the distribution Feeder of NEA. The feeder has peak load demand of 2.97MVA with the total length of 88km composed of Dog, Rabbit and Weasel conductors. There are altogether 99 transformers with 81 of them belonging to the utility consumers and remaining 18 owned by the private consumers. The major of those private consumers are crushers near the Indrawati river.

The analysis was performed for the base case and with the placement of the capacitor at the optimal location and as per NEA's guidelines.

4.2.1 Base Case Scenario

The nodal voltages of the Melamchi feeder are shown in Figure 4.7. The result shows that the bus voltages along the feeder drops up to 0.732pu at Bhirkharka in the peak load case. The cause for such drop in the voltage is due to the higher line loading and longer radial length. The loss of the overall system in the peak is evaluated to be 439kW and 302kvar active and reactive loss respectively. Therefore, the loss is 14.79% at the peak conditions considered. The major loss occurring line sections of Melamchi feeder are presented in Fig. 4.8.

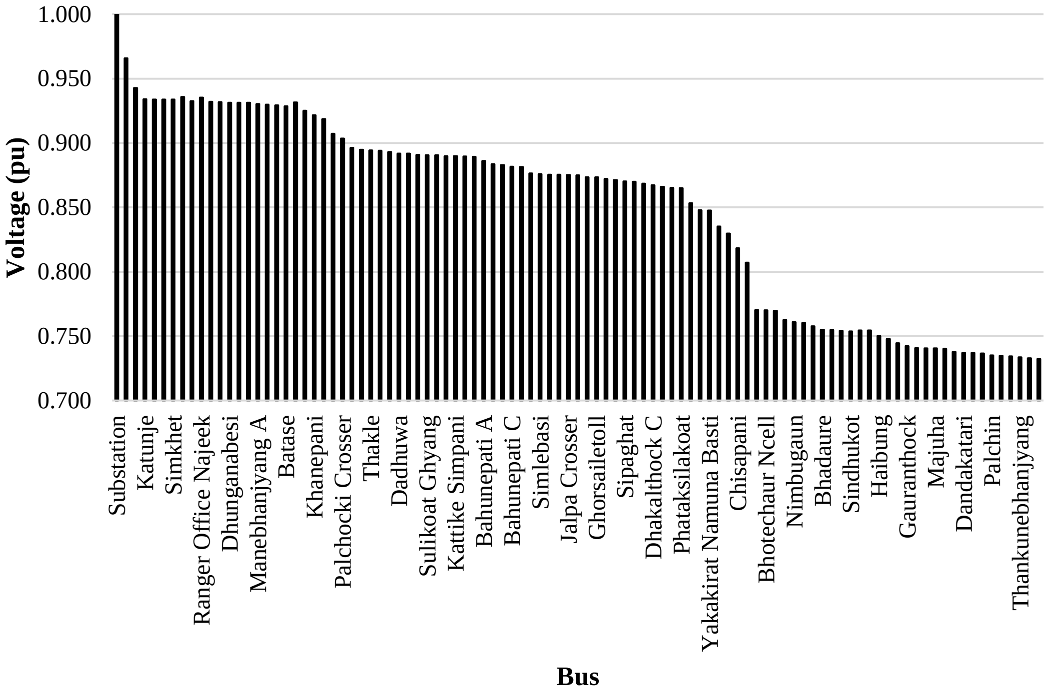

Figure 4.7: Bus voltages for Melamchi feeder

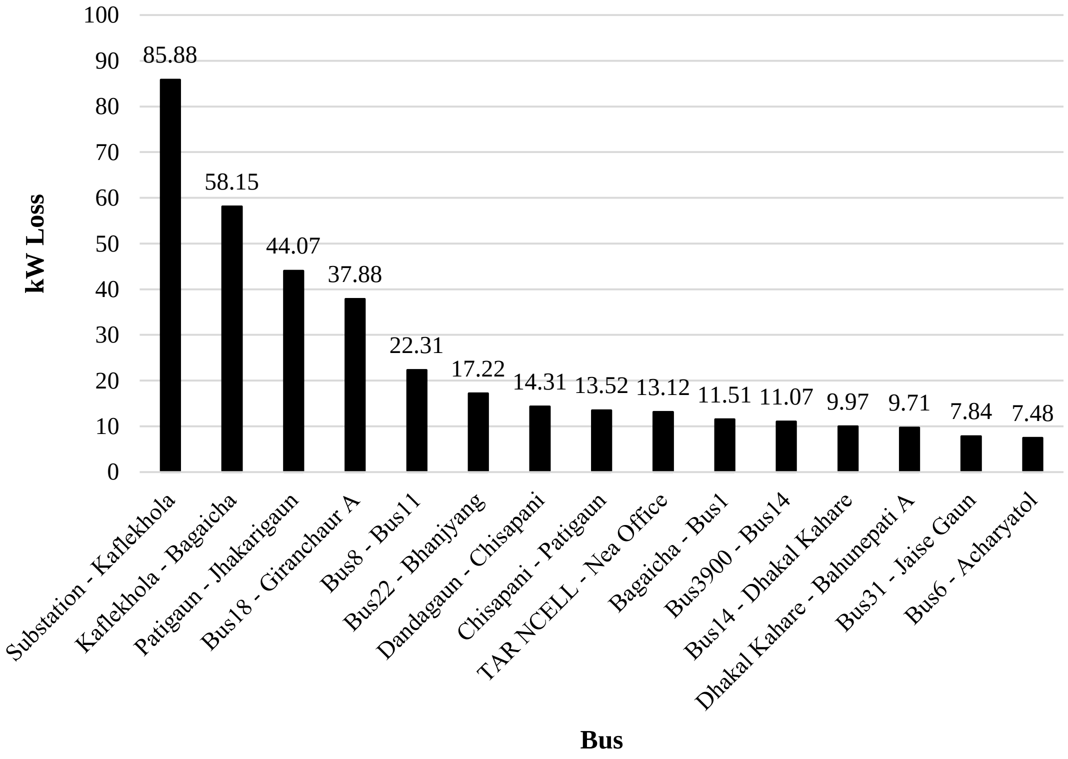

Figure 4.8: Major loss occuring line sections in Melamchi feeder

4.2.2 Optimal Capacitor Placement

The optimal placement of the capacitors was determined. The VSI for each of the bus was determined and based on which, the candidate buses were selected.

Table 4.2: VSI values for the buses of Melamchi feeder

From Bus	To Bus	R	X	Q_i	Q_j	V	VSI
Substation1	Kaflekhola	0.064	0.064	0.176	0.168	0.966	0.178
Bus1	Indrawati Scholl Aghadi	0.042	0.042	0.170	0.164	0.936	0.123
Bus38	Bus39	0.010	0.010	0.161	0.159	0.737	0.046
Bus39	Bus40	0.002	0.002	0.137	0.137	0.735	0.010
Bus40	Patibhangyang	0.050	0.050	0.021	0.021	0.734	0.030
Bus39	Dandakatari	0.050	0.025	0.005	0.005	0.737	0.008
Palchin	Basaree	0.010	0.005	0.001	0.001	0.735	0.000
Piple	Banskharka	0.015	0.007	0.003	0.003	0.737	0.002
Banskharka	Okahranechaur	0.020	0.020	0.016	0.016	0.737	0.009
Patibhangyang	Thankunebhanjyang	0.005	0.005	0.139	0.139	0.734	0.020
Thankunebhanjyang	Chipling	0.025	0.025	0.015	0.015	0.733	0.011
Chipling	Bhirkharka	0.083	0.025	0.056	0.056	0.732	0.183
Simkhet	Nepane	0.007	0.007	0.013	0.013	0.933	0.002
Bus37	Dandathock	0.002	0.002	0.137	0.137	0.741	0.010
Dandathock	Bokrang	0.058	0.017	0.008	0.008	0.741	0.019
Bokrang	Majuha	0.033	0.010	0.054	0.053	0.741	0.071
Majuha	Dahapokhari	0.058	0.017	0.007	0.007	0.740	0.016
Bus40	Palchin	0.033	0.010	0.004	0.004	0.735	0.006
Bus18	Bus20	0.008	0.002	0.000	0.000	0.876	0.000
Bus20	Simlebasi	0.074	0.022	0.052	0.051	0.876	0.109
Simlebasi	Bus23	0.050	0.015	0.004	0.004	0.876	0.006
Bus23	Bus24	0.017	0.005	0.003	0.003	0.875	0.001
Bus22	Bhanjyang	0.157	0.047	0.002	0.002	0.835	0.008
Bus24	Bus25	0.015	0.015	0.005	0.005	0.875	0.002
Bus25	Bus26	0.020	0.020	0.004	0.004	0.874	0.002
Bus26	Bus27	0.091	0.027	0.002	0.002	0.874	0.005
Bus27	Bus28	0.025	0.007	0.002	0.002	0.872	0.001
Bus28	Bus30	0.041	0.012	0.001	0.001	0.871	0.001
Bus30	Sipaghat	0.005	0.005	0.133	0.132	0.870	0.014
Sipaghat	Sipaghat Trt	0.002	0.002	0.133	0.133	0.870	0.007
Bus28	Baharetar	0.005	0.005	0.132	0.132	0.872	0.014
Bus30	Lama Crosser	0.015	0.015	0.130	0.129	0.871	0.040
Bus24	Ghorsaine Toll	0.007	0.007	0.126	0.125	0.875	0.019
Nepane	Bus6	0.005	0.005	0.125	0.124	0.932	0.011
Bus25	Jalpa Crosser	0.099	0.030	0.002	0.002	0.875	0.005
Bus26	Melamchi Phatkaswari	0.030	0.030	0.121	0.119	0.874	0.073

From Bus	To Bus	R	X	Q_i	Q_j	V	VSI
Bus20	Ganga Indrawati Crosser	0.008	0.002	0.002	0.002	0.876	0.000
Bus23	Dotelgaun	0.074	0.022	0.050	0.050	0.875	0.105
Dotelgaun	Dhunganthock	0.017	0.005	0.000	0.000	0.875	0.000
Bus27	Ghorsailetoll	0.010	0.010	0.119	0.118	0.873	0.024
Sipaghat Trt	Danuargaun	0.015	0.015	0.117	0.116	0.869	0.036
Danuargaun	Dhakalthock C	0.041	0.012	0.010	0.010	0.867	0.013
Indrawati Scholl Aghadi	Bus4	0.256	0.077	0.048	0.047	0.936	0.284
Dhakalthock C	Padherachaur	0.041	0.012	0.010	0.010	0.866	0.012
Padherachaur	Thanti	0.058	0.017	0.003	0.003	0.865	0.005
Thanti	Phataksilakoat	0.099	0.030	0.002	0.002	0.865	0.005
Bahunepati Hospital	Bus16	0.083	0.025	0.001	0.001	0.883	0.003
Bus16	Bahunepati B	0.008	0.002	0.047	0.047	0.883	0.011
Bus6	Acharyatol	0.116	0.035	0.007	0.007	0.931	0.021
Bhanjyang	Dandagaun	0.058	0.017	0.007	0.007	0.830	0.013
Acharyatol	Manebhanjyang A	0.074	0.022	0.005	0.006	0.930	0.011
Manebhanjyang A	Bus9	0.017	0.005	0.005	0.005	0.930	0.002
Bus9	Manebhanjyang	0.008	0.002	0.001	0.001	0.930	0.000
Kaflekhola	Bagaicha	0.008	0.002	0.000	0.000	0.943	0.000
Dandagaun	Chisapani	0.008	0.002	0.005	0.005	0.818	0.001
Bus9	Bus12	0.091	0.027	0.004	0.004	0.929	0.009
Bus12	Upallogaun	0.033	0.010	0.003	0.003	0.929	0.002
Bus12	Batase	0.066	0.020	0.001	0.001	0.929	0.002
Bus6	Bus7	0.025	0.007	0.001	0.001	0.932	0.001
Bus7	Talamarang	0.058	0.017	0.000	0.000	0.932	0.000
Talamarang	Dhunganabesi	0.017	0.017	0.106	0.105	0.931	0.033
Dhunganabesi	Urlenibesi	0.015	0.015	0.105	0.104	0.931	0.028
Bus7	Terse	0.007	0.007	0.101	0.100	0.932	0.014
Bagaicha	Bus1	0.002	0.002	0.099	0.098	0.938	0.004
Ranger Office Najeek	Bus2	0.010	0.010	0.097	0.096	0.934	0.017
Bus2	Buspark	0.033	0.010	0.001	0.001	0.933	0.001
Buspark	TAR NCELL	0.140	0.042	0.065	0.064	0.932	0.219
TAR NCELL	Nea Office	0.008	0.002	0.000	0.000	0.925	0.000
Nea Office	Khanepani	0.050	0.015	0.005	0.005	0.922	0.006
Khanepani	Bus8	0.033	0.010	0.061	0.061	0.919	0.053
Bus8	Chalisegaun	0.017	0.005	0.004	0.004	0.919	0.002
Bus8	Bus11	0.025	0.007	0.002	0.003	0.907	0.002
Bus11	Rice Mill	0.008	0.002	0.000	0.000	0.907	0.000
Chisapani	Patigaun	0.033	0.010	0.042	0.042	0.807	0.047
Bus4	Ranger Office Najeek	0.074	0.022	0.016	0.016	0.935	0.030
Bus3900	Palchocki Crosser	0.041	0.012	0.013	0.013	0.904	0.015
Bus11	Bus3900	0.083	0.025	0.002	0.002	0.904	0.004

From Bus	**To Bus**	**R**	**X**	**Q_i**	**Q_j**	**V**	**VSI**
Bus3900	Bus14	0.107	0.032	0.010	0.010	0.898	0.029
Bus14	Dhakalthock A	0.099	0.030	0.009	0.009	0.896	0.025
Patigaun	Jhakarigaun	0.025	0.007	0.001	0.001	0.770	0.001
Dhakalthock A	Bus4100	0.058	0.017	0.004	0.004	0.895	0.006
Bus4100	Pipalchaur	0.074	0.022	0.002	0.002	0.895	0.005
Pipalchaur	Thakle	0.008	0.002	0.005	0.005	0.894	0.001
Thakle	Bansbari	0.140	0.042	0.026	0.026	0.894	0.100
Jhakarigaun	Bus29	0.066	0.020	0.020	0.020	0.770	0.050
Bus1	Bus3	0.041	0.012	0.020	0.020	0.935	0.021
Bus4100	Dhakalthock B	0.058	0.017	0.019	0.019	0.893	0.030
Dhakalthock B	Dadhuwa	0.008	0.002	0.002	0.002	0.892	0.000
Dadhuwa	Sulikoat Ghyang B	0.041	0.012	0.016	0.016	0.891	0.019
Sulikoat Ghyang B	Bus19	0.017	0.005	0.015	0.015	0.891	0.007
Bus19	Sulikoat Ghyang A	0.074	0.022	0.011	0.011	0.891	0.023
Bus19	Sulikoat Ghyang	0.083	0.025	0.003	0.003	0.891	0.008
Bus29	Bus32	0.066	0.020	0.007	0.007	0.770	0.018
Bus19	Bus21	0.091	0.027	0.006	0.006	0.890	0.015
Bus21	Sindhukoat A	0.083	0.025	0.004	0.004	0.890	0.010
Sindhukoat A	Sindhukoat	0.025	0.007	0.002	0.002	0.889	0.001
Bus3	Katunje	0.074	0.022	0.001	0.001	0.934	0.001
Bus21	Dhusinechaur	0.149	0.045	0.002	0.002	0.890	0.008
Dhusinechaur	Kattike Simpani	0.157	0.047	0.001	0.001	0.890	0.005
Bus14	Dhakal Kahare	0.058	0.017	0.003	0.003	0.892	0.006
Dhakal Kahare	Bahunepati A	0.116	0.035	0.002	0.002	0.886	0.007
Bahunepati A	Bahunepati Hospital	0.149	0.045	0.001	0.001	0.884	0.004
Bus16	Bus17	0.041	0.012	0.004	0.004	0.882	0.005
Bus17	Bus18	0.050	0.015	0.002	0.002	0.878	0.003
Bus17	Koiralatar	0.008	0.002	0.001	0.001	0.882	0.000
Bus18	Giranchaur A	0.025	0.007	0.001	0.001	0.853	0.001
Katunje	aarukharka	0.074	0.022	0.001	0.001	0.934	0.003
Bus17	Bahunepati C	0.017	0.017	0.031	0.031	0.882	0.011
Bus32	Bhotechaur Bazar	0.005	0.005	0.027	0.027	0.770	0.004
Giranchaur A	Bus22	0.002	0.002	0.026	0.026	0.848	0.001
Bus22	Giranchaur	0.005	0.005	0.024	0.024	0.848	0.003
Giranchaur	Yakakirat Namuna Basti	0.002	0.002	0.022	0.022	0.848	0.001
Bus32	Bhotechaur Ncell	0.022	0.022	0.022	0.022	0.770	0.013
Bus29	Bus31	0.002	0.002	0.018	0.017	0.766	0.001
Bus31	Khalde	0.025	0.025	0.016	0.016	0.763	0.011
Katunje	Katunje tama Gaun	0.022	0.022	0.015	0.015	0.934	0.006
Khalde	Nimbugaun	0.035	0.035	0.011	0.011	0.761	0.011
Nimbugaun	Tallo Joshigaun	0.002	0.002	0.009	0.009	0.760	0.001
Nimbugaun	Suyalchhap	0.058	0.017	0.001	0.001	0.758	0.002
Suyalchhap	Bhadaure	0.008	0.002	0.004	0.004	0.755	0.001

From Bus	To Bus	R	X	Q_i	Q_j	V	VSI
Bus36	Dhakalgaun Damaitol	0.041	0.012	0.002	0.002	0.755	0.004
Bus36	Sindhukot Healthpost	0.008	0.002	0.000	0.000	0.754	0.000
Sindhukot Healthpost	Sindhukot	0.008	0.002	0.004	0.004	0.754	0.001
Bhadaure	Bus36	0.002	0.002	0.004	0.004	0.755	0.000
Bus3	Simkhet	0.050	0.015	0.002	0.002	0.934	0.002
Bus31	Jaise Gaun	0.025	0.007	0.000	0.000	0.755	0.000
Jaise Gaun	Haibung	0.025	0.007	0.002	0.002	0.750	0.002
Haibung	Gurungaun	0.074	0.022	0.009	0.009	0.748	0.026
Gurungaun	Haibu 5	0.066	0.020	0.007	0.007	0.745	0.018
Jaise Gaun	Everest Tea State	0.091	0.027	0.006	0.006	0.755	0.020
Haibu 5	Gauranthock	0.074	0.022	0.004	0.004	0.742	0.011
Gauranthock	Bus37	0.058	0.017	0.002	0.002	0.741	0.004
Bus37	Bus38	0.002	0.002	0.101	0.100	0.739	0.007
Bus38	Piple	0.008	0.002	0.002	0.002	0.738	0.001

As per the results the 1,230kvar, 475kvar and 175kvar are to be placed at the locations: Koiralatar, Gurunggaun and Melamchi Phatkeswori respectively. Since the voltage at the minimum location is much lower than the standard voltage, the voltage limit is set to the range of 0.8pu and 1.05 pu with the placement of the capacitor.

The minimum voltage at Bhirkharka increases to 0.817pu with the placement of the capacitor. Moreover, the overall system active and reactive loss decreases to 286kW and 186kvar respectively, i.e., 10.16%. There is an increment on the voltage profile of overall bus with the optimal placement of the capacitor. The voltage loss and overall loss in the capacitor connected bus/section is illustrated in Annex C.

4.2.3 Capacitor Placement as per NEA's Guidelines

Considering the regulations of the NEA, the voltage profile as shown in Figure 4.9 was obtained. The system minimum voltage at Bhirkharka increases to 0.774pu. Also, the active and reactive loss from the existing system drops down to 349kW and 222kvar respectively i.e., to 12.3%.

Also, the Figure 4.10 presents the comparison of the loss in the major loss occurring sections with the placement of the capacitors and the base case scenario. The results indicate that in all the major sections, the loss is lower with the optimal placement of the capacitor than with the installation as per the NEA's guidelines by the private consumers.

So, in case of the Melamchi feeder the result shows that with the optimal capacitor placement, the system voltage has improved with lower value of the system loss as compared to that with NEA regulations. Technically, in terms of the overall system loss, the optimal location of capacitor is better as compared to the placement of capacitor with NEA's guideline. This needs to be confirmed from the financial analysis too.

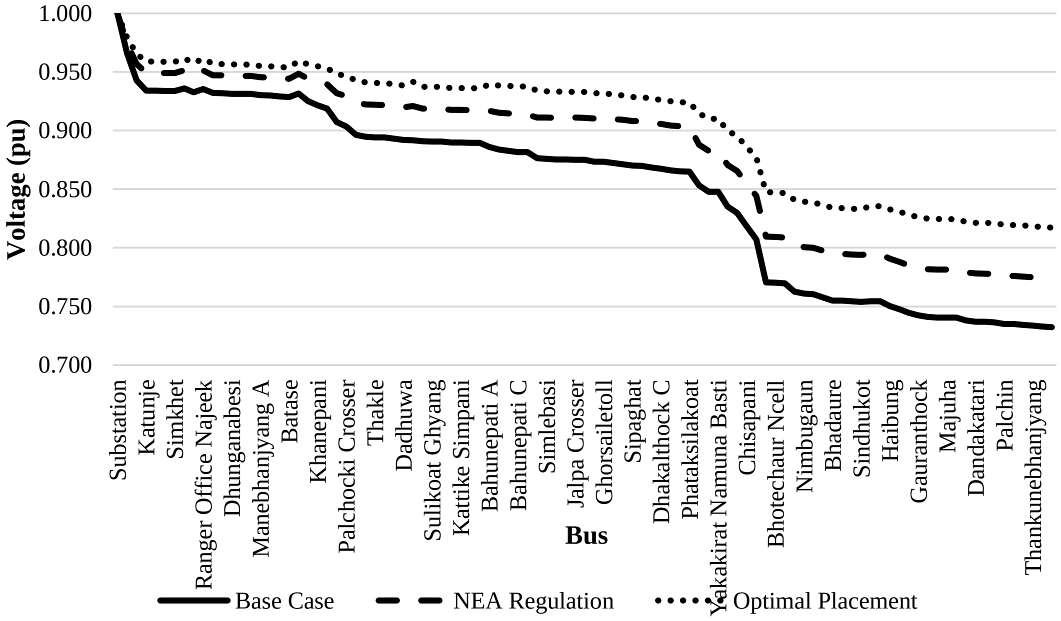

Figure 4.9: Comparison of bus voltages for Melamchi feeder in different cases

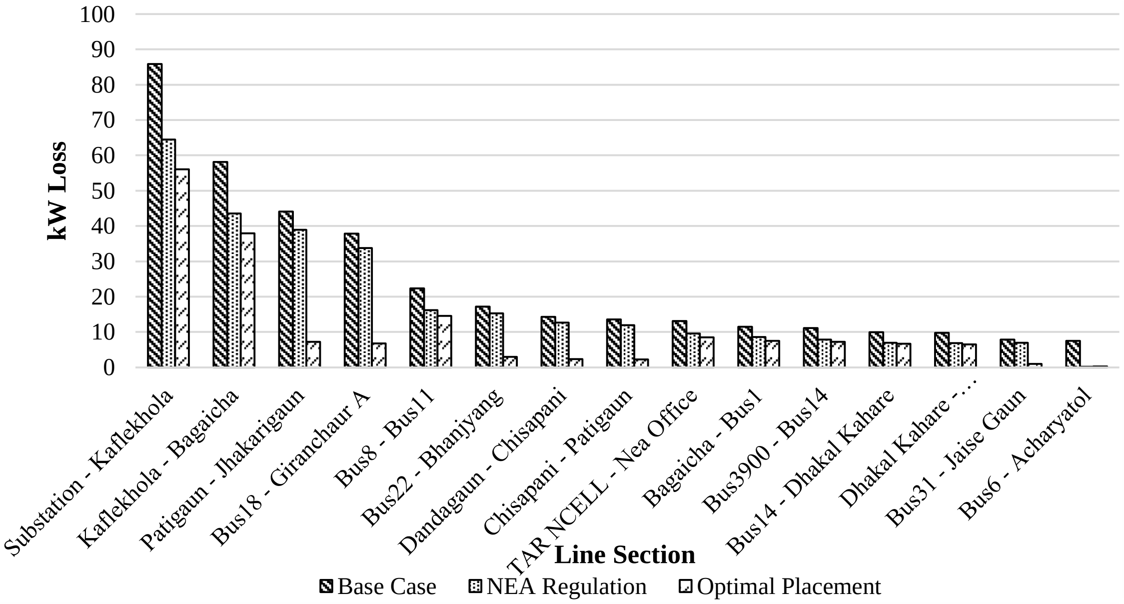

Figure 4.10: Loss of the major loss coccuring line sections with/without the placement of capacitor in Melamchi feeder

Also, the overall power factor of the system from the incomer perspective is improved with the placement of capacitor. From the Figure 4.11, it can be seen that the power factor at the incomer side of the feeder is highest for the system with the optimal placement of the capacitor. The power factor at base case 0.849 gets improved to 0.968 and 0.998 with the placement of capacitor according to NEA regulation and optimum scenario respectively.

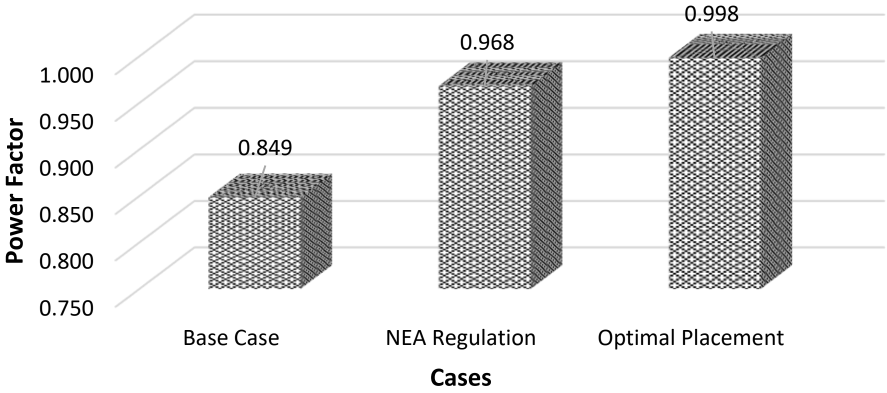

Figure 4.11: Power factor of the system at feeder incomer

The comparison of the voltage and loss of the system is shown in Fig. 4.12.

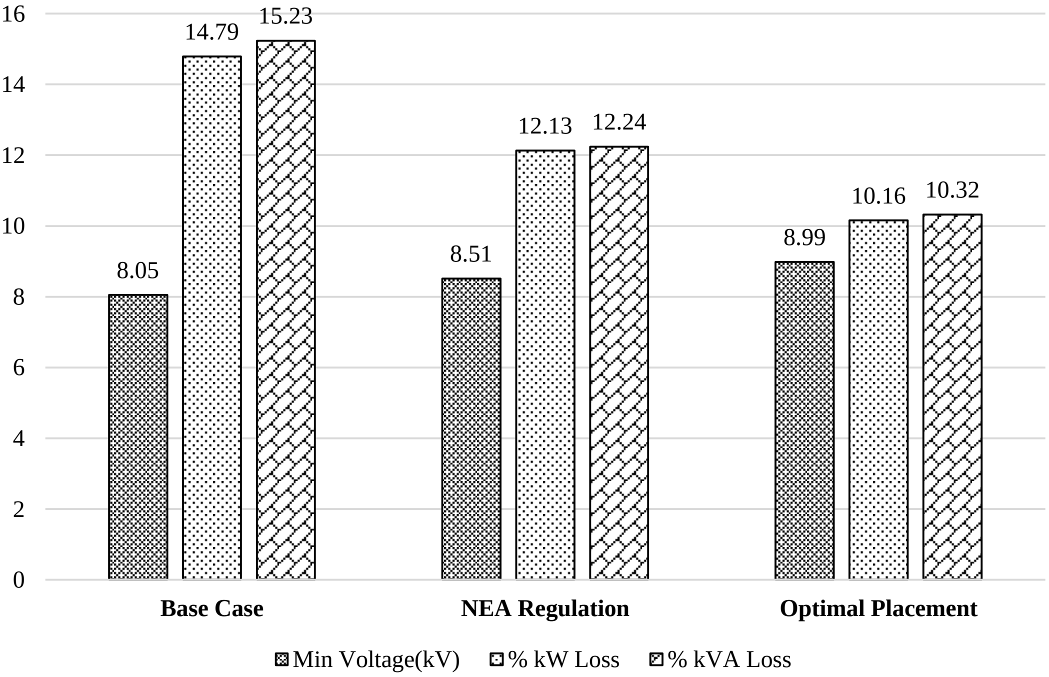

Figure 4.12: Min. votage and % loss comparison for Melamchi feeder

This needs to be confirmed from the financial analysis too.

4.3 Financial Analysis

The financial analysis for the study was carried out considering the annual interest rate of 10% p.a. and operation and maintenance cost 5% per annum of the initial investment cost.

Table 4.3 Summary of the financial analysis

S. N.	**Parameters**	**NEA's Capacitor Placement**	**Optimal Capacitor Placement**
1.	Capital Investment (NRs.)	4,445,400.00	6,764,000.00
2.	Annual cost Savings (NRs.)	1,639,872.00	2,787,782.40
3.	O & M Cost (NRs.)	222,270.00	338,200.00

The financial analysis was performed with the comparison of the placement of capacitors per NEA's regulations and with optimal placement and sizing. The BCR is evaluated to be 2.20 and 2.46. Higher value to BCR represents that the benefit is higher in terms of the cost associated. In comparison, this benefit is higher for the optimal placement of the capacitor.

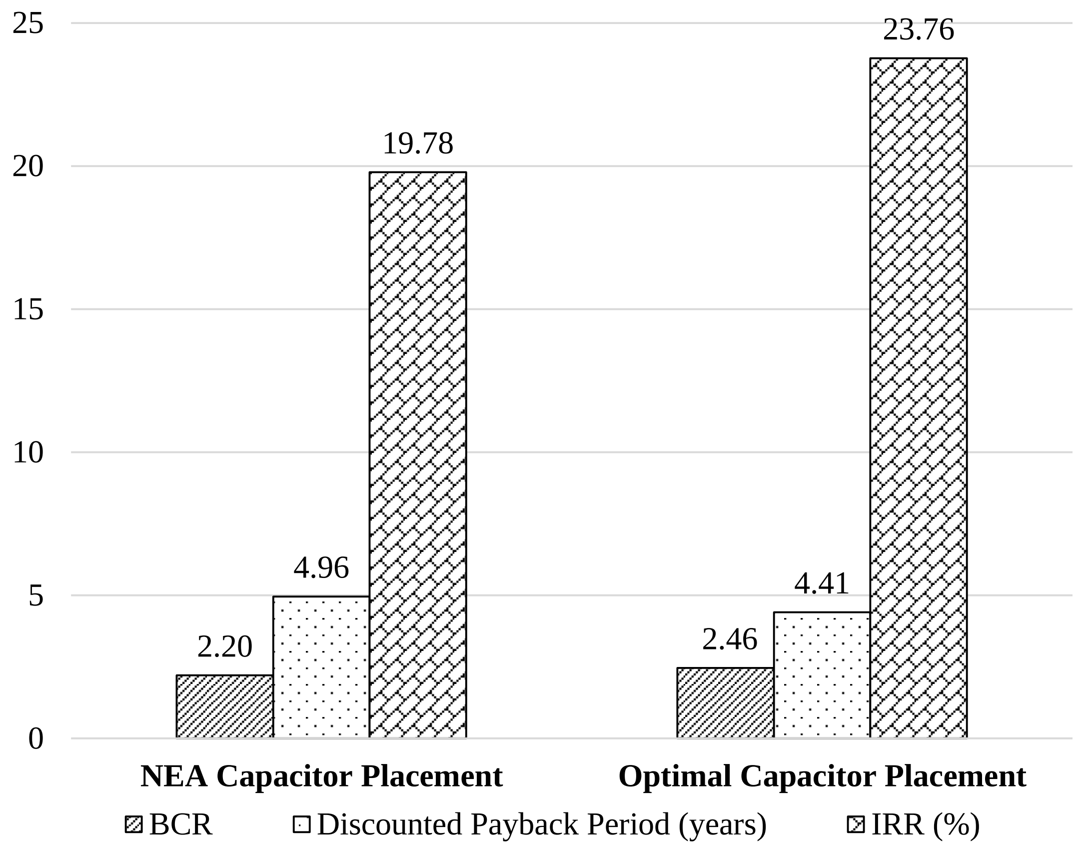

Figure 4.13: Comparison of the financial indicators for both cases

In addition, the IRR and payback period for the placement of the capacitor as per the regulation and optimal locations were evaluated to be 19.78% & 4.96 years and 23.76% & 4.41 years respectively as shown in Figure 4.13.

A higher IRR indicates a more financially attractive investment. In this case, the IRR for the optimal placement of the capacitor (23.76%) is lower than the IRR for the placement according to the NEA's regulation (19.78%). This suggests that the investment in the optimal placement of the capacitor is more profitable from a financial perspective.

A shorter payback period indicates that the investment will recover its initial cost more quickly. The payback period for the optimal placement of the capacitor (4.41 years) is shorter than the payback period for the placement according to the NEA's regulation (4.96 years). This implies that the investment in the optimal placement takes short period to recoup its initial cost compared to following the NEA's regulation. The detail calculation of the financial analysis is presented in Annex E.

Therefore, from the financial analysis, it can be inferred the optimal placement of capacitor is more financially justifiable as compared to the NEA's regulation for capacitor placement.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The various conclusions and recommendations have been obtained from study.

5.1 Conclusions

Following conclusions have been drawn from study:

- The voltage improvement and reduction in the overall loss can be achieved with the placement of the capacitor banks. In case of the IEEE-33 bus system, the voltage profile with optimal placement was better 0.924pu as compared to the case with NEA regulation which is 0.921pu. However, the overall system loss is lower for the optimal placement of the capacitor. With active loss being 163.28kW and 154.43kW respectively with the capacitor placed as per NEA's guidelines and optimal scenario respectively. So, voltage can be better for the utility feeder dominated with the private consumers.
- The analysis of the utility distribution feeder indicates that both the reduction of loss and the improvement of the voltage profile is better with the optimal placement of the capacitor as compared to the installation as per the NEA's guidelines. The existing loss of 14.79% has dropped to 10.16% and 12.30% for the optimal scenario and NEA's guidelines of installation respectively.
- From the financial analysis for the comparison of the two cases, it was evaluated that the IRR, BCR & discounted payback periods are 19.78%, 2.20 & 4.96 years and 23.76%, 2.46 & 4.41years for the placement with NEA's guidelines and optimization respectively. This majorly indicates that the optimal placement of the capacitor is a bit more cost effective than the other case.
- From both the technical and financial perspective, the capacitor placement in the distribution feeder at the optimal locations was determined more suitable than the installation at the private consumer's point as per the NEA's guidelines. So, the private consumers can aid the system voltage and mitigate loss with the collaborative evaluation of the optimal location and sizing of the capacitor in the utility's distribution feeder.

5.2 Recommendations

Following recommendations have been made from the study:

- Extension of the study can be performed with the detail analysis of the size of the capacitor that can be assigned to the distribution feeder depending upon the consumer category with determination of size which will be more beneficial than the NEA's regulations.

- To ensure optimal planning, plans and study can be established for the placement of the capacitor while taking into account load forecasts for the next few years.
- A thorough investigation can be conducted into the effects of capacitor switching on transient characteristics, taking into account changes in system loss and the seasonal peak.

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ANNEX A: INPUT SYSTEM DATA

Table A.1: Load data of Melamchi feeder

S.N.	Place	Load Type	Active Load (kW)	Apparent Load (kVA)
1	aarukharka	NEA	14.964	16.813
2	Acharyatol	NEA	18.490	23.112
3	Bagaicha	NEA	113.513	138.431
4	Baharetar	NEA	16.169	17.965
5	Bahunepati A	NEA	61.918	73.712
6	Bahunepati B	NEA	28.036	33.376
7	Bahunepati C	Private	3.104	3.735
8	Bansbari	NEA	16.340	19.687
9	Banskharka	NEA	17.281	19.417
10	Basaree	NEA	13.672	15.191
11	Batase	NEA	30.613	34.397
12	Bhadaure	NEA	74.984	86.189
13	Bhanjyang	NEA	47.672	53.564
14	Bhirkharka	NEA	18.056	20.518
15	Bhotechaur Bazar	NEA	67.078	81.803
16	Bhotechaur Ncell	Private	3.106	3.825
17	Bokrang	NEA	14.276	15.862
18	Buspark	NEA	7.246	8.051
19	Chalisegaun	NEA	26.829	31.563
20	Chipling	NEA	17.799	21.189
21	Chisapani	NEA	18.145	22.401
22	Dadhuwa	NEA	25.974	28.860
23	Dahapokhari	NEA	12.558	14.270
24	Dandagaun	NEA	26.659	30.642
25	Dandakatari	NEA	26.489	31.163
26	Dandathock	NEA	32.509	40.135
27	Danuargaun	NEA	31.990	39.494
28	Dhakal Kahare	Private	3.104	3.875
29	Dhakalgaun Damaitol	NEA	13.416	16.563
30	Dhakalthock A	NEA	13.762	15.291
31	Dhakalthock B	Private	3.104	3.605
32	Dhakalthock C	NEA	13.673	16.473
33	Dhunganabesi	NEA	2.993	3.645
34	Dhunganthock	Private	3.106	3.825
35	Dhusinechaur	NEA	14.013	16.883
36	Dotelgaun	NEA	18.056	22.291
37	Everest Tea State	Private	29.833	35.098

S.N.	**Place**	**Load Type**	**Active Load (kW)**	**Apparent Load (kVA)**
38	Ganga Indrawati Crosser	Private	76.804	85.338
39	Gauranthock	NEA	18.574	22.651
40	Ghorsailetoll	NEA	37.152	42.218
41	Ghorsaine Toll	NEA	35.082	42.268
42	Giranchaur	NEA	26.489	31.914
43	Giranchaur A	NEA	60.195	70.818
44	Gurungaun	NEA	23.562	27.398
45	Haibu 5	NEA	40.087	45.553
46	Haibung	NEA	3.927	4.897
47	Indrawati Scholl Aghadi	NEA	34.572	38.413
48	Jaise Gaun	NEA	63.634	74.863
49	Jalpa Crosser	Private	5.170	5.868
50	Jhakarigaun	NEA	14.099	16.022
51	Kaflekhola	NEA	14.189	16.693
52	Kattike Simpani	NEA	2.945	3.305
53	Katunje	NEA	15.393	18.325
54	Katunje tama Gaun	NEA	56.410	64.839
55	Khalde	NEA	30.442	38.052
56	Khanepani	Private	6.580	7.651
57	Koiralatar	NEA	16.257	18.686
58	Lama Crosser	Private	53.480	65.220
59	Majuha	NEA	13.502	15.171
60	Manebhanjyang	Private	3.105	3.565
61	Manebhanjyang A	NEA	35.945	42.288
62	Melamchi Phatkaswari	Private	75.803	87.130
63	Nea Office	NEA	63.634	74.863
64	Nepane	NEA	32.336	38.042
65	Nimbugaun	NEA	25.454	30.302
66	Okahranechaur	NEA	17.198	19.998
67	Padherachaur	NEA	29.411	36.310
68	Palchin	NEA	14.875	16.903
69	Palchocki Crosser	Private	0.551	0.621
70	Patibhangyang	NEA	17.111	19.897
71	Patigaun	NEA	14.359	17.094
72	Phataksilakoat	NEA	32.165	36.140
73	Pipalchaur	NEA	18.488	21.009
74	Piple	NEA	22.187	27.057
75	Ranger Office Najeek	NEA	71.548	83.195
76	Rice Mill	Private	29.833	35.098

S.N.	Place	Load Type	Active Load (kW)	Apparent Load (kVA)
77	Simkhet	NEA	18.576	21.600
78	Simlebasi	NEA	15.825	19.537
79	Sindhukoat	NEA	15.395	19.006
80	Sindhukoat A	NEA	25.796	29.651
81	Sindhukot	NEA	34.052	41.027
82	Sindhukot Healthpost	NEA	30.093	34.197
83	Sipaghat	NEA	27.691	34.187
84	Sipaghat Trt	Private	1.802	2.253
85	Sulikoat Ghyang	Private	3.106	3.645
86	Sulikoat Ghyang A	NEA	14.619	16.613
87	Sulikoat Ghyang B	NEA	17.801	20.228
88	Suyalchhap	NEA	14.964	16.813
89	Talamarang	NEA	32.844	39.054
90	Tallo Joshigaun	NEA	38.357	42.619
91	TAR NCELL	Private	3.104	3.875
92	Terse	NEA	19.008	21.600
93	Thakle	NEA	13.239	14.710
94	Thankunebhanjyang	NEA	17.456	21.820
95	Thanti	NEA	26.661	33.326
96	Upallogaun	NEA	40.743	49.088
97	Urlenibesi	NEA	27.689	32.575
98	Yakakirat Namuna Basti	NEA	37.152	44.762

Table A.2: Line Data of Melamchi Feeder

S.N.	From	To	R	X
1	Substation	Kaflekhola	0.711	0.883
2	Bus1	Indrawati Scholl Aghadi	0.055	0.068
3	Bus38	Bus39	0.861	0.290
4	Bus39	Bus40	1.163	0.392
5	Bus40	Patibhangyang	1.068	0.360
6	Bus39	Dandakatari	0.309	0.104
7	Palchin	Basaree	0.927	0.312
8	Piple	Banskharka	1.854	0.625
9	Banskharka	Okahranechaur	1.957	0.660
10	Patibhangyang	Thankunebhanjyang	0.721	0.243
11	Thankunebhanjyang	Chipling	1.442	0.486
12	Chipling	Bhirkharka	1.854	0.625
13	Simkhet	Nepane	0.273	0.340
14	Bus37	Dandathock	0.515	0.174
15	Dandathock	Bokrang	0.618	0.208

S.N.	From	To	R	X
16	Bokrang	Majuha	0.103	0.035
17	Majuha	Dahapokhari	0.309	0.104
18	Bus40	Palchin	0.927	0.312
19	Bus18	Bus20	0.191	0.238
20	Bus20	Simlebasi	0.055	0.068
21	Simlebasi	Bus23	0.027	0.034
22	Bus23	Bus24	0.055	0.068
23	Bus22	Bhanjyang	0.987	0.333
24	Bus24	Bus25	0.008	0.011
25	Bus25	Bus26	0.236	0.294
26	Bus26	Bus27	0.007	0.009
27	Bus27	Bus28	0.260	0.323
28	Bus28	Bus30	0.246	0.306
29	Bus30	Sipaghat	0.383	0.476
30	Sipaghat	Sipaghat Trt	0.027	0.034
31	Bus28	Baharetar	0.721	0.243
32	Bus30	Lama Crosser	0.039	0.013
33	Bus24	Ghorsaine Toll	0.515	0.174
34	Nepane	Bus6	0.082	0.102
35	Bus25	Jalpa Crosser	0.103	0.035
36	Bus26	Melamchi Phatkaswari	0.103	0.035
37	Bus20	Ganga Indrawati Crosser	0.013	0.016
38	Bus23	Dotelgaun	0.618	0.208
39	Dotelgaun	Dhunganthock	0.309	0.104
40	Bus27	Ghorsailetoll	0.309	0.104
41	Sipaghat Trt	Danuargaun	0.927	0.312
42	Danuargaun	Dhakalthock C	0.824	0.278
43	Indrawati Scholl Aghadi	Bus4	0.008	0.010
44	Dhakalthock C	Padherachaur	1.133	0.382
45	Padherachaur	Thanti	0.927	0.312
46	Thanti	Phataksilakoat	0.721	0.243
47	Bahunepati Hospital	Bus16	0.027	0.034
48	Bus16	Bahunepati B	0.026	0.009
49	Bus6	Acharyatol	0.721	0.243
50	Bhanjyang	Dandagaun	0.412	0.139
51	Acharyatol	Manebhanjyang A	0.721	0.243
52	Manebhanjyang A	Bus9	0.412	0.139
53	Bus9	Manebhanjyang	0.103	0.035
54	Kaflekhola	Bagaicha	0.465	0.578
55	Dandagaun	Chisapani	0.927	0.312
56	Bus9	Bus12	0.618	0.208
57	Bus12	Upallogaun	0.206	0.069
58	Bus12	Batase	1.957	0.660

S.N.	**From**	**To**	**R**	**X**
59	Bus6	Bus7	0.164	0.204
60	Bus7	Talamarang	0.219	0.272
61	Talamarang	Dhunganabesi	1.133	0.382
62	Dhunganabesi	Urlenibesi	0.309	0.104
63	Bus7	Terse	0.515	0.174
64	Bagaicha	Bus1	0.109	0.136
65	Ranger Office Najeek	Bus2	0.055	0.068
66	Bus2	Buspark	0.005	0.007
67	Buspark	TAR NCELL	0.055	0.068
68	TAR NCELL	Nea Office	0.164	0.204
69	Nea Office	Khanepani	0.082	0.102
70	Khanepani	Bus8	0.055	0.068
71	Bus8	Chalisegaun	1.236	0.417
72	Bus8	Bus11	0.328	0.408
73	Bus11	Rice Mill	0.103	0.035
74	Chisapani	Patigaun	0.927	0.312
75	Bus4	Ranger Office Najeek	0.005	0.007
76	Bus3900	Palchocki Crosser	0.206	0.069
77	Bus11	Bus3900	0.109	0.136
78	Bus3900	Bus14	0.164	0.204
79	Bus14	Dhakalthock A	0.515	0.174
80	Patigaun	Jhakarigaun	3.193	1.076
81	Dhakalthock A	Bus4100	0.515	0.174
82	Bus4100	Pipalchaur	0.721	0.243
83	Pipalchaur	Thakle	1.236	0.417
84	Thakle	Bansbari	1.045	0.352
85	Jhakarigaun	Bus29	0.012	0.004
86	Bus1	Bus3	0.547	0.680
87	Bus4100	Dhakalthock B	1.442	0.486
88	Dhakalthock B	Dadhuwa	0.721	0.243
89	Dadhuwa	Sulikoat Ghyang B	0.927	0.312
90	Sulikoat Ghyang B	Bus19	0.206	0.069
91	Bus19	Sulikoat Ghyang A	0.103	0.035
92	Bus19	Sulikoat Ghyang	0.121	0.041
93	Bus29	Bus32	0.103	0.035
94	Bus19	Bus21	1.133	0.382
95	Bus21	Sindhukoat A	0.412	0.139
96	Sindhukoat A	Sindhukoat	0.824	0.278
97	Bus3	Katunje	0.633	0.340
98	Bus21	Dhusinechaur	0.309	0.104
99	Dhusinechaur	Kattike Simpani	0.721	0.243
100	Bus14	Dhakal Kahare	0.191	0.238
101	Dhakal Kahare	Bahunepati A	0.164	0.204

S.N.	From	To	R	X
102	Bahunepati A	Bahunepati Hospital	0.082	0.102
103	Bus16	Bus17	0.027	0.034
104	Bus17	Bus18	0.109	0.136
105	Bus17	Koiralatar	0.412	0.139
106	Bus18	Giranchaur A	1.751	0.590
107	Katunje	aarukharka	0.128	0.069
108	Bus17	Bahunepati C	0.103	0.035
109	Bus32	Bhotechaur Bazar	0.618	0.208
110	Giranchaur A	Bus22	0.412	0.139
111	Bus22	Giranchaur	0.206	0.069
112	Giranchaur	Yakakirat Namuna Basti	0.309	0.104
113	Bus32	Bhotechaur Ncell	0.103	0.035
114	Bus29	Bus31	0.412	0.139
115	Bus31	Khalde	0.927	0.312
116	Katunje	Katunje tama Gaun	0.192	0.103
117	Khalde	Nimbugaun	0.515	0.174
118	Nimbugaun	Tallo Joshigaun	0.999	0.337
119	Nimbugaun	Suyalchhap	1.339	0.451
120	Suyalchhap	Bhadaure	1.236	0.417
121	Bus36	Dhakalgaun Damaitol	0.309	0.104
122	Bus36	Sindhukot Healthpost	0.721	0.243
123	Sindhukot Healthpost	Sindhukot	0.927	0.312
124	Bhadaure	Bus36	0.033	0.011
125	Bus3	Simkhet	0.219	0.272
126	Bus31	Jaise Gaun	1.751	0.590
127	Jaise Gaun	Haibung	0.824	0.278
128	Haibung	Gurungaun	0.515	0.174
129	Gurungaun	Haibu 5	0.721	0.243
130	Jaise Gaun	Everest Tea State	0.103	0.035
131	Haibu 5	Gauranthock	0.515	0.174
132	Gauranthock	Bus37	0.206	0.069
133	Bus37	Bus38	0.927	0.312
134	Bus38	Piple	1.051	0.354

ANNEX B: ETAP MODEL

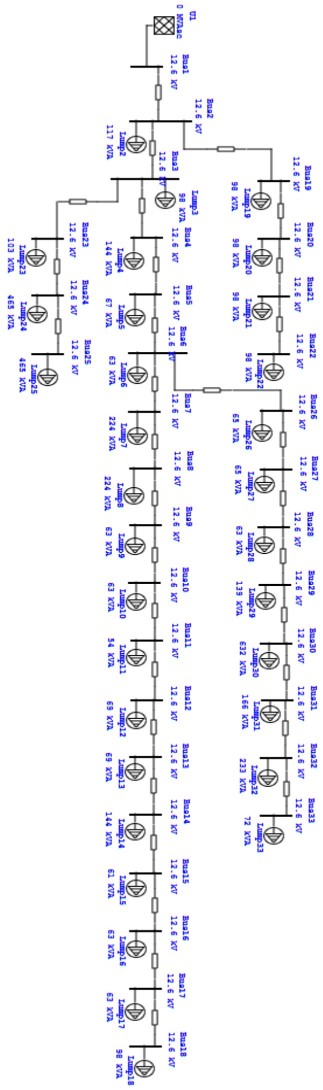


Figure B.1: ETAP simulation model of the IEEE-33 bus radial distribution feeder

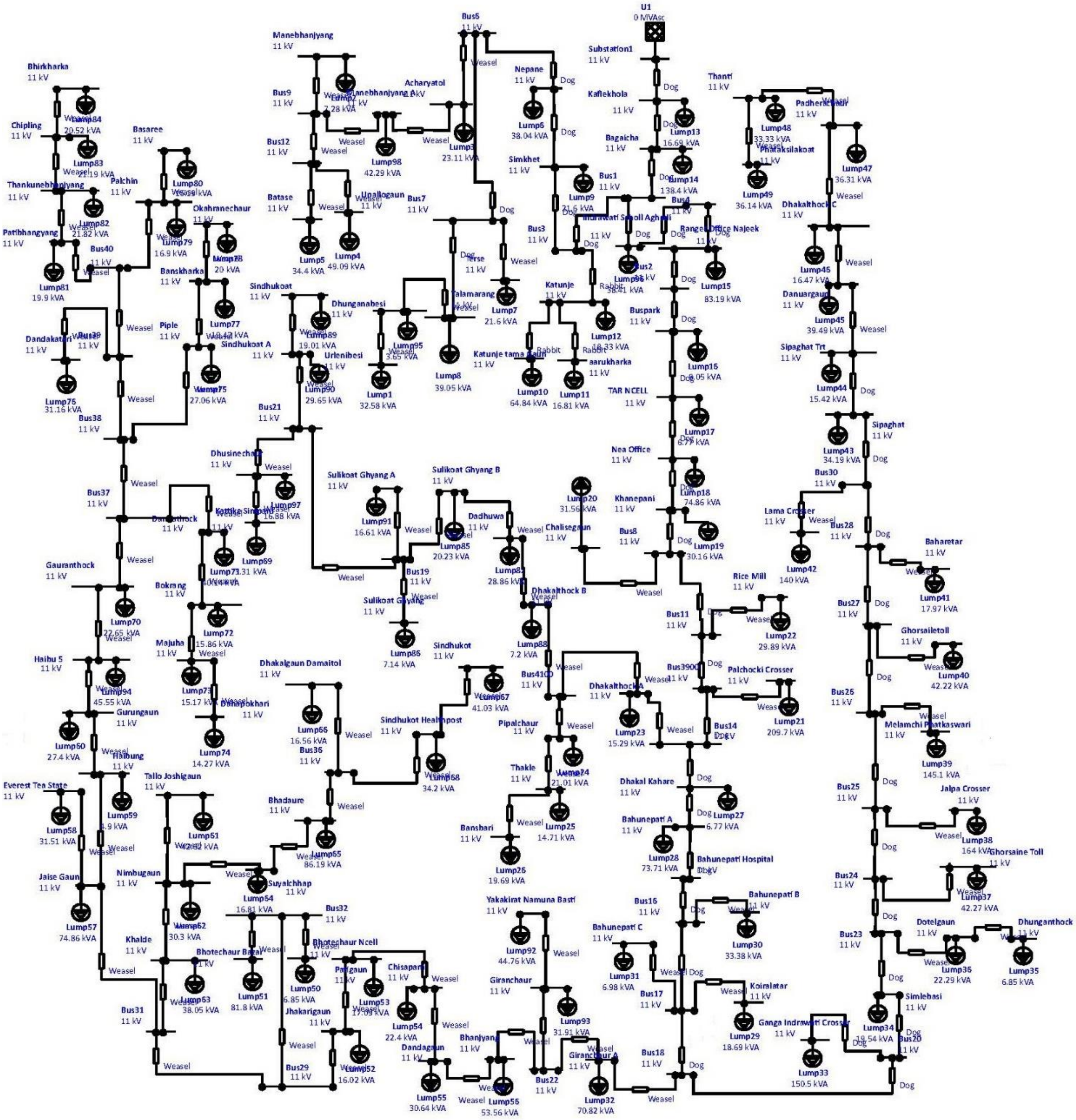
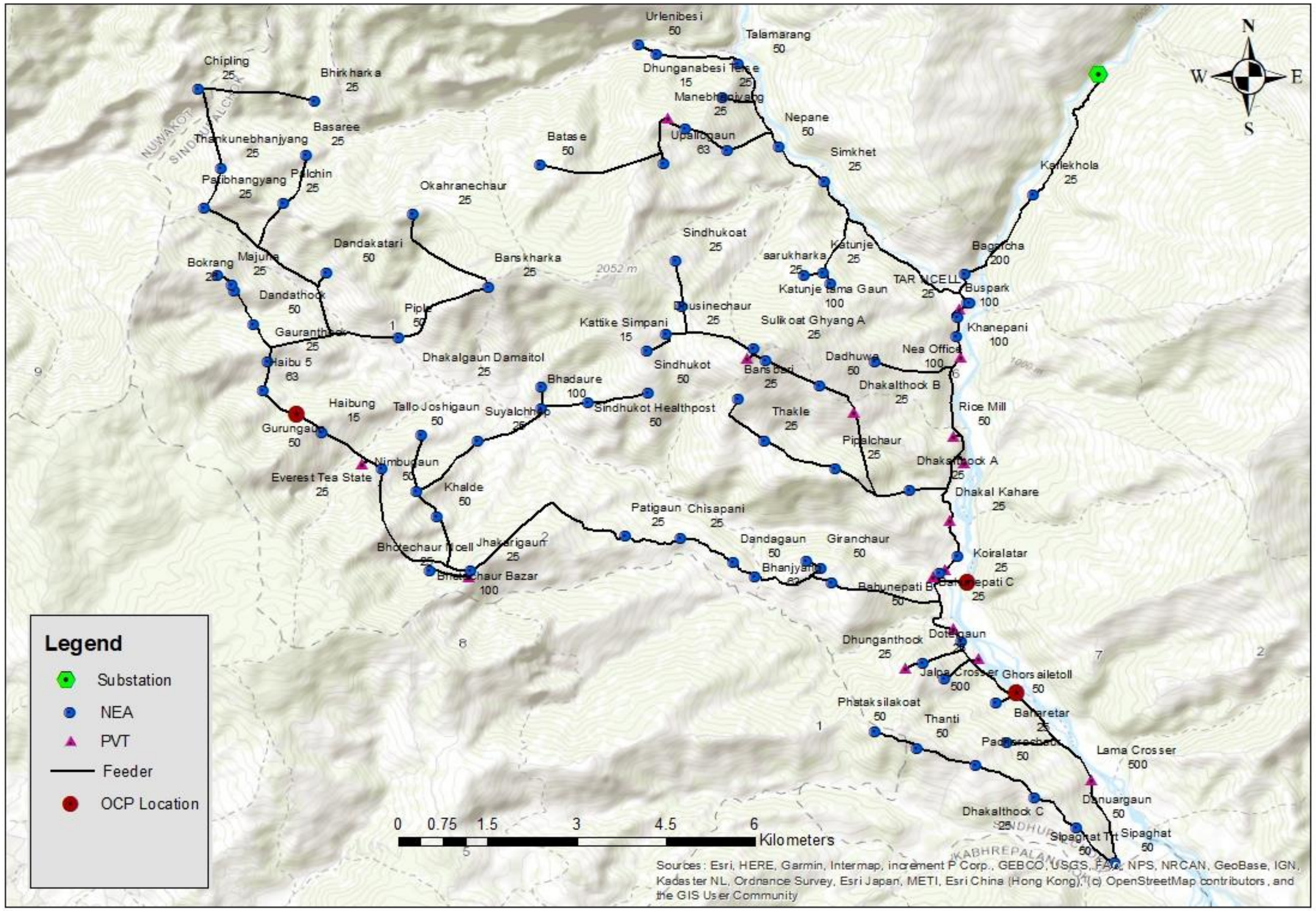


Figure B.2. ETAP simulation model of the Melamchi Feeder

ANNEX C: RESULTS OF MELAMCHI FEEDER



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure C.1: GIS map of Melamchi feeder with NEA & PVT transformers and OCP capacitor placement locations

Table C.1: Bus voltages for existing Melamchi feeder

S.N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
1	Substation	1.000	11.000	183.60
2	Kaflekhola	0.966	10.625	8.554
3	Bagaicha	0.943	10.371	182.7
4	Katunje	0.934	10.274	1.081
5	aarukharka	0.934	10.273	123.6
6	Katunje tama Gaun	0.934	10.272	1.984
7	Simkhet	0.934	10.271	0.222
8	Indrawati Scholl Aghadi	0.936	10.294	119.2
9	Nepane	0.933	10.259	1.156
10	Ranger Office Najeek	0.935	10.288	2.792
11	Terse	0.932	10.252	1.085
12	Talamarang	0.932	10.250	1.944
13	Dhunganabesi	0.931	10.245	12.35
14	Urlenibesi	0.931	10.244	71.57
15	Acharyatol	0.931	10.243	1.47
16	Manebhanjyang A	0.930	10.232	5.579
17	Manebhanjyang	0.930	10.228	0.26
18	Upallogaun	0.929	10.221	3.207
19	Batase	0.929	10.215	175
20	TAR NCELL	0.932	10.248	145.3
21	Nea Office	0.925	10.175	22.9
22	Khanepani	0.922	10.137	150
23	Chalisegaun	0.919	10.105	13.97
24	Rice Mill	0.907	9.979	5.429
25	Palchocki Crosser	0.904	9.939	140
26	Dhakalthock A	0.896	9.860	4.883
27	Pipalchaur	0.895	9.843	138.2
28	Thakle	0.894	9.837	4.689
29	Bansbari	0.894	9.835	136.2
30	Dhakalthock B	0.893	9.823	119.2
31	Dadhuwa	0.892	9.811	117.2
32	Dhakal Kahare	0.892	9.810	115.9
33	Sulikoat Ghyang B	0.891	9.799	5.215
34	Sulikoat Ghyang	0.891	9.797	35.31
35	Sulikoat Ghyang A	0.891	9.797	4.035
36	Dhusinechaur	0.890	9.787	76.29
37	Kattike Simpani	0.890	9.787	29.06
38	Sindhukoat A	0.890	9.786	27.51
39	Sindhukoat	0.889	9.783	24.98

S.N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
40	Bahunepati A	0.886	9.747	24.64
41	Bahunepati Hospital	0.884	9.721	19.41
42	Bahunepati B	0.883	9.711	16.9
43	Bahunepati C	0.882	9.698	62.68
44	Koiralatar	0.882	9.697	15.84
45	Ganga Indrawati Crosser	0.876	9.640	56.87
46	Simlebasi	0.876	9.635	5.834
47	Dotelgaun	0.875	9.629	6.361
48	Dhunganthock	0.875	9.629	21.1
49	Jalpa Crosser	0.875	9.626	15.08
50	Ghorsaine Toll	0.875	9.625	10.4
51	Melamchi Phatkaswari	0.874	9.609	8.193
52	Ghorsailetoll	0.873	9.607	136.2
53	Baharetar	0.872	9.594	11.5
54	Lama Crosser	0.871	9.584	145.3
55	Sipaghat	0.870	9.571	1.804
56	Sipaghat Trt	0.870	9.570	2.971
57	Danuargaun	0.869	9.554	66.28
58	Dhakalthock C	0.867	9.540	8.09
59	Padherachaur	0.866	9.526	1.011
60	Thanti	0.865	9.518	68.21
61	Phataksilakoat	0.865	9.515	2.219
62	Giranchaur A	0.853	9.385	6.027
63	Giranchaur	0.848	9.326	9.742
64	Yakakirat Namuna Basti	0.848	9.325	123.8
65	Bhanjyang	0.835	9.187	1.152
66	Dandagaun	0.830	9.127	12.39
67	Chisapani	0.818	9.000	8.295
68	Patigaun	0.807	8.878	7.366
69	Jhakarigaun	0.770	8.474	2.038
70	Bhotechaur Ncell	0.770	8.471	0.229
71	Bhotechaur Bazar	0.770	8.466	1.183
72	Khalde	0.763	8.390	1.563
73	Nimbugaun	0.761	8.370	2.441
74	Tallo Joshigaun	0.760	8.363	5.111
75	Suyalchhap	0.758	8.335	22.69
76	Bhadaure	0.755	8.305	2.537
77	Dhakalgaun Damaitol	0.755	8.304	2.536
78	Sindhukot Healthpost	0.754	8.297	4.745
79	Sindhukot	0.754	8.292	80.64
80	Jaise Gaun	0.755	8.300	27.81

S.N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
81	Everest Tea State	0.755	8.300	25.9
82	Haibung	0.750	8.253	28.15
83	Gurungaun	0.748	8.225	152.1
84	Haibu 5	0.745	8.190	35.79
85	Gauranthock	0.742	8.166	0.352
86	Dandathock	0.741	8.150	63.77
87	Bokrang	0.741	8.146	183.6
88	Majuha	0.741	8.146	0.195
89	Dahapokhari	0.740	8.144	5.612
90	Piple	0.738	8.117	3.644
91	Dandakatari	0.737	8.107	21.1
92	Banskharka	0.737	8.107	140.4
93	Okahranechaur	0.737	8.102	1.113
94	Palchin	0.735	8.086	3.929
95	Basaree	0.735	8.084	2.085
96	Patibhangyang	0.734	8.077	0.201
97	Thankunebhanjyang	0.734	8.071	7.265
98	Chipling	0.733	8.062	5.235
99	Bhirkharka	0.732	8.056	144.7

Table C.2: Branch results for existing Melamchi feeder

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
1	Substation - Kaflekhola	183.6	85.88	86.86	65.11%
2	Kaflekhola - Bagaicha	182.7	58.15	58.84	64.79%
3	Bagaicha - Bus1	175	44.07	11.64	62.06%
4	Bus4 - Ranger Office Najeek	150	37.88	0.452	53.19%
5	Bus1 - Bus3	22.9	22.31	0.372	8.12%
6	Bus3 - Katunje	5.612	17.22	0.312	3.02%
7	Katunje - aarukharka	0.945	14.31	0.0715	0.51%
8	Katunje - Katunje tama Gaun	3.644	13.52	0.0996	1.96%
9	Bus3 - Simkhet	17.31	13.12	0.0329	6.14%
10	Bus1 - Indrawati Scholl Aghadi	152.1	11.51	4.63	53.94%
11	Simkhet - Nepane	16.11	11.07	0.0793	5.71%
12	Bus22 - Bhanjyang	71.57	9.97	4.84	52.63%
13	Nepane - Bus6	13.97	9.71	0.0392	4.95%
14	Indrawati Scholl Aghadi - Bus4	150	7.84	0.632	53.19%
15	Bus6 - Acharyatol	8.554	7.48	0.191	6.29%
16	Bhanjyang - Dandagaun	68.21	7.01	1.96	50.15%
17	Acharyatol - Manebhanjyang A	7.265	6.99	0.216	5.34%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
18	Manebhanjyang A - Bus9	4.883	6.88	0.124	3.59%
19	Bus9 - Manebhanjyang	0.201	5.22	0.0238	0.15%
20	Dandagaun - Chisapani	66.28	4.82	3.99	48.74%
21	Bus9 - Bus12	4.689	4.59	0.193	3.45%
22	Bus12 - Upallogaun	2.773	4.34	0.0643	2.04%
23	Bus12 - Batase	1.944	4.08	0.63	1.43%
24	Bus6 - Bus7	5.429	3.47	0.188	1.93%
25	Bus7 - Talamarang	4.226	3.45	0.246	1.50%
26	Talamarang - Dhunganabesi	2.038	2.26	0.361	1.50%
27	Dhunganabesi - Urlenibesi	1.836	2.01	0.103	1.35%
28	Bus7 - Terse	1.216	1.56	0.162	0.89%
29	Ranger Office Najeek - Bus2	145.3	1.39	3.5	51.52%
30	Bus2 - Buspark	145.3	1.37	0.424	51.52%
31	Buspark - TAR NCELL	144.9	1.36	3.47	51.38%
32	TAR NCELL - Nea Office	144.7	1.05	13.2	51.31%
33	Nea Office - Khanepani	140.4	0.913	6.92	49.79%
34	Khanepani - Bus8	140	0.898	4.85	49.65%
35	Bus8 - Chalisegaun	1.804	0.81	0.399	1.33%
36	Bus8 - Bus11	138.2	0.742	22.43	49.01%
37	Bus11 - Rice Mill	2.031	0.653	0.0308	1.49%
38	Chisapani - Patigaun	64.86	0.628	3.77	47.69%
39	Bus3900 - Palchocki Crosser	0.036	0.617	0.0501	0.03%
40	Bus11 - Bus3900	136.2	0.523	7.04	48.30%
41	Bus3900 - Bus14	136.2	0.448	11.13	48.30%
42	Bus14 - Dhakalthock A	12.39	0.421	0.0878	9.11%
43	Patigaun - Jhakarigaun	63.77	0.386	12.31	46.89%
44	Dhakalthock A - Bus4100	11.5	0.343	0.0978	8.46%
45	Bus4100 - Pipalchaur	3.226	0.317	0.227	2.37%
46	Pipalchaur - Thakle	2.005	0.294	0.375	1.47%
47	Thakle - Bansbari	1.156	0.29	0.322	0.85%
48	Jhakarigaun - Bus29	62.68	0.27	0.0463	46.09%
49	Bus4100 - Dhakalthock B	8.295	0.266	0.352	6.10%
50	Dhakalthock B - Dadhuwa	8.09	0.249	0.18	5.95%
51	Dadhuwa - Sulikoat Ghyang B	6.404	0.247	0.249	4.71%
52	Sulikoat Ghyang B - Bus19	5.215	0.233	0.062	3.83%
53	Bus19 - Sulikoat Ghyang A	0.979	0.23	0.0271	0.72%
54	Bus19 - Sulikoat Ghyang	0.215	0.222	0.037	0.16%
55	Bus29 - Bus32	5.834	0.203	0.0153	4.29%
56	Bus19 - Bus21	4.035	0.181	0.332	2.97%
57	Bus21 - Sindhukoat A	2.859	0.166	0.138	2.10%
58	Sindhukoat A - Sindhukoat	1.122	0.165	0.245	0.83%
59	Bus21 - Dhusinechaur	1.183	0.161	0.0896	0.87%
60	Dhusinechaur - Kattike Simpani	0.195	0.158	0.206	0.14%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
61	Bus14 - Dhakal Kahare	123.8	0.156	9.99	43.90%
62	Dhakal Kahare - Bahunepati A	123.6	0.138	9.73	43.83%
63	Bahunepati A - Bahunepati Hospital	119.2	0.13	4.08	42.27%
64	Bus16 - Bus17	117.2	0.128	2.01	41.56%
65	Bus17 - Bus18	115.9	0.109	5.22	41.10%
66	Bus17 - Koiralatar	1.113	0.0788	0.136	0.82%
67	Bus18 - Giranchaur A	80.64	0.0662	10.74	59.29%
68	Bus17 - Bahunepati C	0.222	0.0653	0.0329	0.16%
69	Bus32 - Bhotechaur Bazar	5.579	0.0636	0.119	4.10%
70	Giranchaur A - Bus22	76.29	0.0632	2.11	56.10%
71	Bus22 - Giranchaur	4.745	0.0579	0.0561	3.49%
72	Giranchaur - Yakakirat Namuna Basti	2.771	0.0565	0.0697	2.04%
73	Bus32 - Bhotechaur Ncell	0.26	0.0519	0.0132	0.19%
74	Bus29 - Bus31	56.87	0.0515	1.2	41.82%
75	Bus31 - Khalde	21.1	0.0479	0.201	15.51%
76	Khalde - Nimbugaun	18.51	0.0462	0.0679	13.61%
77	Nimbugaun - Tallo Joshigaun	2.942	0.0423	0.215	2.16%
78	Nimbugaun - Suyalchhap	13.5	0.0324	0.0509	9.93%
79	Suyalchhap - Bhadaure	12.35	0.0294	0.0801	9.08%
80	Bus36 - Dhakalgaun Damaitol	1.152	0.0268	0.075	0.85%
81	Bus36 - Sindhukot Healthpost	5.222	0.0267	0.138	3.84%
82	Sindhukot Healthpost - Sindhukot	2.856	0.0244	0.204	2.10%
83	Bhadaure - Bus36	6.361	0.0225	0.0059	4.68%
84	Bus31 - Jaise Gaun	35.79	0.0205	1.92	26.32%
85	Jaise Gaun - Haibung	28.15	0.0193	0.487	20.70%
86	Haibung - Gurungaun	27.81	0.0174	0.293	20.45%
87	Gurungaun - Haibu 5	25.9	0.0168	0.315	19.04%
88	Jaise Gaun - Everest Tea State	2.441	0.0167	0.0192	1.79%
89	Haibu 5 - Gauranthock	22.69	0.0156	0.157	16.68%
90	Gauranthock - Bus37	21.1	0.0153	0.0603	15.51%
91	Bus37 - Bus38	15.08	0.0136	0.017	11.09%
92	Bus38 - Piple	4.696	0.0133	0.198	3.45%
93	Bus38 - Bus39	10.4	0.0133	0.0875	7.65%
94	Bus39 - Bus40	8.193	0.0132	0.165	6.02%
95	Bus40 - Patibhangyang	5.929	0.0129	0.185	4.36%
96	Bus39 - Dandakatari	2.219	0.0118	0.0609	1.63%
97	Palchin - Basaree	1.085	0.0112	0.192	0.80%
98	Piple - Banskharka	2.792	0.0098	0.367	2.05%
99	Banskharka - Okahranechaur	1.425	0.0091	0.402	1.05%
100	Patibhangyang - Thankunebhanjyang	4.514	0.0083	0.141	3.32%
101	Thankunebhanjyang - Chipling	2.971	0.0067	0.281	2.18%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
102	Chipling - Bhirkharka	1.47	0.0064	0.374	1.08%
103	Bus37 - Dandathock	6.027	0.0062	0.0823	4.43%
104	Dandathock - Bokrang	3.207	0.0054	0.13	2.36%
105	Bokrang - Majuha	2.085	0.0052	0.0233	1.53%
106	Majuha - Dahapokhari	1.011	0.005	0.0585	0.74%
107	Bus40 - Palchin	2.285	0.005	0.18	1.68%
108	Bus18 - Bus20	35.31	0.0047	0.708	12.52%
109	Bus20 - Simlebasi	30.23	0.0045	0.153	10.72%
110	Simlebasi - Bus23	29.06	0.0037	0.0716	10.30%
111	Bus23 - Bus24	27.51	0.0035	0.0978	9.76%
112	Bus24 - Bus25	24.98	0.0034	0.0102	8.86%
113	Bus25 - Bus26	24.64	0.0029	0.271	8.74%
114	Bus26 - Bus27	19.41	0.0024	0.0021	6.88%
115	Bus27 - Bus28	16.9	0.0021	0.0125	5.99%
116	Bus28 - Bus30	15.84	0.0019	0.0443	5.62%
117	Bus30 - Sipaghat	11.93	0.0018	0.225	4.23%
118	Sipaghat - Sipaghat Trt	9.869	0.0017	0.0105	3.50%
119	Bus28 - Baharetar	1.081	0.0015	0.215	0.79%
120	Bus30 - Lama Crosser	3.929	0.0014	0.0109	2.89%
121	Bus24 - Ghorsaine Toll	2.536	0.0014	0.149	1.86%
122	Bus25 - Jalpa Crosser	0.352	0.0012	0.0354	0.26%
123	Bus26 - Melamchi Phatkaswari	5.235	0.001	0.0177	3.85%
124	Bus20 - Ganga Indrawati Crosser	5.111	0.0004	0.0129	1.81%
125	Bus23 - Dotelgaun	1.563	0.0003	0.191	1.15%
126	Dotelgaun - Dhunganthock	0.229	0.0003	0.0856	0.17%
127	Bus27 - Ghorsailetoll	2.537	0.0001	0.0848	1.87%
128	Sipaghat Trt - Danuargaun	9.742	0.0001	0.176	7.16%
129	Danuargaun - Dhakalthock C	7.366	0.0001	0.207	5.42%
130	Dhakalthock C - Padherachaur	6.38	0	0.281	4.69%
131	Padherachaur - Thanti	4.192	0	0.258	3.08%
132	Thanti - Phataksilakoat	2.193	0	0.206	1.61%
133	Bahunepati Hospital - Bus16	119.2	0	1.39	42.27%
134	Bus16 - Bahunepati B	1.984	0	0.0077	1.46%

Table C.3: Bus voltages in descending order for Melamchi feeder with capacitor as per NEA’s regulations

S. N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
1	Substation	1.000	11.000	159
2	Kaflekhola	0.974	10.715	159
3	Bagaicha	0.957	10.523	158.2
4	Katunje	0.949	10.441	5.522

S. N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
5	aarukharka	0.949	10.440	0.93
6	Katunje tama Gaun	0.949	10.439	3.586
7	Simkhet	0.949	10.438	16.79
8	Indrawati Scholl Aghadi	0.952	10.467	130.2
9	Nepane	0.948	10.426	15.61
10	Ranger Office Najeek	0.951	10.463	128.2
11	Terse	0.947	10.419	1.197
12	Talamarang	0.947	10.418	4.158
13	Dhunganabesi	0.947	10.414	2.005
14	Urlenibesi	0.947	10.413	1.806
15	Acharyatol	0.947	10.412	8.18
16	Manebhanjyang A	0.946	10.401	6.92
17	Manebhanjyang	0.945	10.397	0.404
18	Upallogaun	0.945	10.391	2.728
19	Batase	0.944	10.384	1.912
20	TAR NCELL	0.949	10.435	123.6
21	Nea Office	0.944	10.385	123.4
22	Khanepani	0.942	10.358	119.8
23	Chalisegaun	0.940	10.335	1.763
24	Rice Mill	0.932	10.251	1.683
25	Palchocki Crosser	0.929	10.223	11.84
26	Dhakalthock A	0.924	10.163	11.58
27	Pipalchaur	0.922	10.146	3.128
28	Thakle	0.922	10.141	1.944
29	Bansbari	0.922	10.139	1.121
30	Dhakalthock B	0.921	10.128	7.774
31	Dadhuwa	0.920	10.117	7.62
32	Dhakal Kahare	0.921	10.130	103.7
33	Sulikoat Ghyang B	0.919	10.105	5.981
34	Sulikoat Ghyang	0.919	10.104	0.408
35	Sulikoat Ghyang A	0.918	10.102	0.949
36	Dhusinechaur	0.918	10.094	1.147
37	Kattike Simpani	0.918	10.094	0.189
38	Sindhukoat A	0.917	10.091	2.772
39	Sindhukoat	0.917	10.090	1.088
40	Bahunepati A	0.917	10.086	103.5
41	Bahunepati Hospital	0.915	10.067	99.65
42	Bahunepati B	0.915	10.061	1.915
43	Bahunepati C	0.914	10.051	0.401
44	Koiralatar	0.914	10.050	1.073
45	Ganga Indrawati Crosser	0.911	10.023	8.671

S. N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
46	Simlebasi	0.911	10.022	28.89
47	Dotelgaun	0.911	10.020	1.433
48	Dhunganthock	0.911	10.020	0.394
49	Jalpa Crosser	0.911	10.021	9.447
50	Ghorsaine Toll	0.911	10.019	2.436
51	Melamchi Phatkaswari	0.910	10.014	8.364
52	Ghorsailetoll	0.910	10.013	2.434
53	Baharetar	0.910	10.007	1.037
54	Lama Crosser	0.909	10.002	8.079
55	Sipaghat	0.908	9.990	10.91
56	Sipaghat Trt	0.908	9.990	9.404
57	Danuargaun	0.907	9.974	9.326
58	Dhakalthock C	0.906	9.962	7.051
59	Padherachaur	0.904	9.947	6.108
60	Thanti	0.904	9.941	4.014
61	Phataksilakoat	0.903	9.937	2.1
62	Giranchaur A	0.888	9.766	76.13
63	Giranchaur	0.883	9.709	4.557
64	Yakakirat Namuna Basti	0.883	9.708	2.662
65	Bhanjyang	0.871	9.578	67.42
66	Dandagaun	0.866	9.521	64.19
67	Chisapani	0.855	9.402	62.34
68	Patigaun	0.844	9.286	60.99
69	Jhakarigaun	0.810	8.906	59.95
70	Bhotechaur Ncell	0.809	8.903	0.444
71	Bhotechaur Bazar	0.809	8.897	5.308
72	Khalde	0.802	8.825	20.04
73	Nimbugaun	0.801	8.807	17.58
74	Tallo Joshigaun	0.800	8.800	2.796
75	Suyalchhap	0.798	8.773	12.82
76	Bhadaure	0.795	8.745	11.73
77	Dhakalgaun Damaitol	0.795	8.744	1.094
78	Sindhukot Healthpost	0.794	8.737	4.958
79	Sindhukot	0.794	8.733	2.712
80	Jaise Gaun	0.795	8.741	33.64
81	Everest Tea State	0.795	8.741	2.081
82	Haibung	0.791	8.697	26.66
83	Gurungaun	0.788	8.669	26.34
84	Haibu 5	0.785	8.636	24.52
85	Gauranthock	0.783	8.614	21.48
86	Dandathock	0.782	8.599	5.712

S. N.	Bus	Voltage (pu)	Voltage (kV)	Current (A)
87	Bokrang	0.781	8.594	3.04
88	Majuha	0.781	8.594	1.976
89	Dahapokhari	0.781	8.593	0.959
90	Piple	0.779	8.568	4.445
91	Dandakatari	0.778	8.559	2.102
92	Banskharka	0.778	8.558	2.644
93	Okahranechaur	0.778	8.553	1.35
94	Palchin	0.776	8.538	2.163
95	Basaree	0.776	8.536	1.027
96	Patibhangyang	0.776	8.531	5.611
97	Thankunebhanjyang	0.775	8.524	4.271
98	Chipling	0.774	8.516	2.812
99	Bhirkharka	0.774	8.511	1.392

Table C.4: Branch Loss for Melamchi feeder with capacitor as per NEA’s regulations

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
1	Substation - Kaflekhola	159	64.450	64.930	56.38%
2	Kaflekhola - Bagaicha	158.20	43.590	43.940	56.10%
3	Bagaicha - Bus1	151.20	8.590	8.650	53.62%
4	Bus4 - Ranger Office Najeek	128.20	0.327	0.328	45.46%
5	Bus1 - Bus3	22.30	0.999	0.293	7.91%
6	Bus3 - Katunje	5.52	0.063	0.324	2.97%
7	Katunje - aarukharka	0.93	0.000	0.074	0.50%
8	Katunje - Katunje tama Gaun	3.59	0.008	0.103	1.93%
9	Bus3 - Simkhet	16.79	0.216	0.056	5.95%
10	Bus1 - Indrawati Scholl Aghadi	130.20	3.360	3.370	46.17%
11	Simkhet - Nepane	15.61	0.232	0.106	5.54%
12	Bus22 - Bhanjyang	67.42	15.280	4.240	49.57%
13	Nepane - Bus6	13.51	0.048	0.046	4.79%
14	Indrawati Scholl Aghadi - Bus4	128.20	0.458	0.459	45.46%
15	Bus6 - Acharyatol	8.18	0.166	0.204	6.01%
16	Bhanjyang - Dandagaun	64.19	6.190	1.710	47.20%
17	Acharyatol - Manebhanjyang A	6.92	0.125	0.229	5.09%
18	Manebhanjyang A - Bus9	4.59	0.029	0.130	3.37%
19	Bus9 - Manebhanjyang	0.41	0.000	0.025	0.30%
20	Dandagaun - Chisapani	62.34	12.660	3.480	45.84%
21	Bus9 - Bus12	4.61	0.045	0.200	3.39%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
22	Bus12 - Upallogaun	2.73	0.005	0.067	2.01%
23	Bus12 - Batase	1.91	0.024	0.651	1.41%
24	Bus6 - Bus7	5.34	0.017	0.195	1.89%
25	Bus7 - Talamarang	4.16	0.013	0.255	1.47%
26	Talamarang - Dhunganabesi	2.01	0.015	0.373	1.47%
27	Dhunganabesi - Urlenibesi	1.81	0.003	0.106	1.33%
28	Bus7 - Terse	1.20	0.002	0.168	0.88%
29	Ranger Office Najeek - Bus2	123.90	2.530	2.520	43.94%
30	Bus2 - Buspark	123.90	0.306	0.306	43.94%
31	Buspark - TAR NCELL	123.50	2.510	2.510	43.79%
32	TAR NCELL - Nea Office	123.40	9.540	9.540	43.76%
33	Nea Office - Khanepani	119.60	4.990	4.980	42.41%
34	Khanepani - Bus8	119.50	3.510	3.510	42.38%
35	Bus8 - Chalisegaun	1.76	0.013	0.418	1.30%
36	Bus8 - Bus11	117.90	16.220	16.190	41.81%
37	Bus11 - Rice Mill	1.68	0.001	0.033	1.24%
38	Chisapani - Patigaun	60.99	11.960	3.280	44.85%
39	Bus3900 - Palchocki Crosser	11.85	0.076	0.031	8.71%
40	Bus11 - Bus3900	116.20	5.100	5.080	41.21%
41	Bus3900 - Bus14	114.90	7.880	7.860	40.74%
42	Bus14 - Dhakalthock A	11.58	0.257	0.110	8.51%
43	Patigaun - Jhakarigaun	59.95	38.940	10.710	44.08%
44	Dhakalthock A - Bus4100	10.72	0.216	0.118	7.88%
45	Bus4100 - Pipalchaur	3.13	0.025	0.242	2.30%
46	Pipalchaur - Thakle	1.94	0.016	0.399	1.43%
47	Thakle - Bansbari	1.12	0.004	0.343	0.82%
48	Jhakarigaun - Bus29	58.91	0.146	0.040	43.32%
49	Bus4100 - Dhakalthock B	7.62	0.290	0.397	5.60%
50	Dhakalthock B - Dadhuwa	7.62	0.147	0.200	5.60%
51	Dadhuwa - Sulikoat Ghyang B	5.98	0.114	0.272	4.40%
52	Sulikoat Ghyang B - Bus19	4.83	0.018	0.067	3.55%
53	Bus19 - Sulikoat Ghyang A	0.95	0.000	0.029	0.70%
54	Bus19 - Sulikoat Ghyang	0.41	0.000	0.039	0.30%
55	Bus29 - Bus32	5.26	0.007	0.018	3.87%
56	Bus19 - Bus21	3.91	0.059	0.355	2.88%
57	Bus21 - Sindhukoat A	2.77	0.012	0.147	2.04%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
58	Sindhukoat A - Sindhukoat	1.09	0.003	0.260	0.80%
59	Bus21 - Dhusinechaur	1.15	0.001	0.095	0.84%
60	Dhusinechaur - Kattike Simpani	0.19	0.000	0.219	0.14%
61	Bus14 - Dhakal Kahare	103.60	6.990	6.930	36.74%
62	Dhakal Kahare - Bahunepati A	103.50	6.810	6.760	36.70%
63	Bahunepati A - Bahunepati Hospital	99.65	2.850	2.820	35.34%
64	Bus16 - Bus17	97.90	1.400	1.390	34.72%
65	Bus17 - Bus18	96.78	3.640	3.590	34.32%
66	Bus17 - Koiralatar	1.07	0.002	0.146	0.79%
67	Bus18 - Giranchaur A	76.13	33.760	9.480	55.98%
68	Bus17 - Bahunepati C	0.40	0.000	0.035	0.30%
69	Bus32 - Bhotechaur Bazar	5.31	0.058	0.135	3.90%
70	Giranchaur A - Bus22	71.95	6.650	1.860	52.90%
71	Bus22 - Giranchaur	4.56	0.016	0.062	3.35%
72	Giranchaur - Yakakirat Namuna Basti	2.66	0.006	0.076	1.96%
73	Bus32 - Bhotechaur Ncell	0.45	0.000	0.015	0.33%
74	Bus29 - Bus31	53.66	3.860	1.050	39.46%
75	Bus31 - Khalde	20.04	1.230	0.140	14.74%
76	Khalde - Nimbugaun	17.58	0.589	0.036	12.93%
77	Nimbugaun - Tallo Joshigaun	2.80	0.027	0.240	2.06%
78	Nimbugaun - Suyalchhap	12.82	0.730	0.106	9.43%
79	Suyalchhap - Bhadaure	11.73	0.556	0.127	8.63%
80	Bus36 - Dhakalgaun Damaitol	1.09	0.001	0.083	0.80%
81	Bus36 - Sindhukot Healthpost	4.96	0.060	0.157	3.65%
82	Sindhukot Healthpost - Sindhukot	2.71	0.024	0.228	1.99%
83	Bhadaure - Bus36	6.04	0.004	0.007	4.44%
84	Bus31 - Jaise Gaun	33.64	6.920	1.610	24.74%
85	Jaise Gaun - Haibung	26.66	2.030	0.398	19.60%
86	Haibung - Gurungaun	26.34	1.220	0.238	19.37%
87	Gurungaun - Haibu 5	24.52	1.400	0.251	18.03%
88	Jaise Gaun - Everest Tea State	2.08	0.001	0.022	1.53%
89	Haibu 5 - Gauranthock	21.48	0.805	0.117	15.79%
90	Gauranthock - Bus37	19.97	0.346	0.042	14.68%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
91	Bus37 - Bus38	14.27	0.665	0.029	10.49%
92	Bus38 - Piple	4.45	0.071	0.226	3.27%
93	Bus38 - Bus39	9.84	0.284	0.118	7.24%
94	Bus39 - Bus40	7.75	0.238	0.202	5.70%
95	Bus40 - Patibhangyang	5.61	0.114	0.215	4.13%
96	Bus39 - Dandakatari	2.10	0.005	0.068	1.55%
97	Palchin - Basaree	1.03	0.003	0.214	0.76%
98	Piple - Banskharka	2.64	0.043	0.412	1.94%
99	Banskharka - Okahranechaur	1.35	0.012	0.449	0.99%
100	Patibhangyang - Thankunebhanjyang	4.27	0.047	0.160	3.14%
101	Thankunebhanjyang - Chipling	2.81	0.038	0.317	2.07%
102	Chipling - Bhirkharka	1.39	0.012	0.418	1.02%
103	Bus37 - Dandathock	5.71	0.052	0.095	4.20%
104	Dandathock - Bokrang	3.04	0.020	0.146	2.24%
105	Bokrang - Majuha	1.98	0.002	0.026	1.45%
106	Majuha - Dahapokhari	0.96	0.001	0.065	0.71%
107	Bus40 - Palchin	2.16	0.014	0.202	1.59%
108	Bus18 - Bus20	36.42	0.971	0.750	12.91%
109	Bus20 - Simlebasi	28.55	0.198	0.122	10.12%
110	Simlebasi - Bus23	28.12	0.102	0.061	9.97%
111	Bus23 - Bus24	27.33	0.156	0.090	9.69%
112	Bus24 - Bus25	26.54	0.022	0.012	9.41%
113	Bus25 - Bus26	21.43	0.395	0.118	7.60%
114	Bus26 - Bus27	15.65	0.006	0.002	5.55%
115	Bus27 - Bus28	13.60	0.175	0.135	4.82%
116	Bus28 - Bus30	12.74	0.151	0.153	4.52%
117	Bus30 - Sipaghat	10.91	0.169	0.298	3.87%
118	Sipaghat - Sipaghat Trt	8.95	0.004	0.013	3.17%
119	Bus28 - Baharetar	1.04	0.003	0.234	0.76%
120	Bus30 - Lama Crosser	8.08	0.009	0.010	5.94%
121	Bus24 - Ghorsaine Toll	2.44	0.010	0.162	1.79%
122	Bus25 - Jalpa Crosser	9.45	0.036	0.028	6.95%
123	Bus26 - Melamchi Phatkaswari	8.37	0.016	0.017	6.15%
124	Bus20 - Ganga Indrawati Crosser	8.67	0.003	0.012	3.07%
125	Bus23 - Dotelgaun	1.28	0.004	0.207	0.94%
126	Dotelgaun - Dhunganthock	0.40	0.000	0.093	0.29%

S. N.	Line Section	Amp Flow	kW Loss	kVAR Loss	% Loading
127	Bus27 - Ghorsailetoll	2.43	0.006	0.093	1.79%
128	Sipaghat Trt - Danuargaun	9.33	0.266	0.207	6.86%
129	Danuargaun - Dhakalthock C	7.05	0.148	0.234	5.18%
130	Dhakalthock C - Padherachaur	6.11	0.143	0.314	4.49%
131	Padherachaur - Thanti	4.01	0.052	0.284	2.95%
132	Thanti - Phataksilakoat	2.10	0.011	0.225	1.54%
133	Bahunepati Hospital - Bus16	99.65	0.970	0.959	35.34%
134	Bus16 - Bahunepati B	1.92	0.000	0.008	1.41%

Table C.5: Bus Voltage for Melamchi feeder with capacitor optimally selected

S.N.	Bus	Voltage (pu)	Voltage (kV)
1	Substation	1	11
2	Kaflekhola	0.9793	10.7723
3	Bagaicha	0.9655	10.6205
4	Katunje	0.9588	10.5468
5	aarukharka	0.9588	10.5468
6	Katunje tama Gaun	0.9587	10.5457
7	Simkhet	0.9585	10.5435
8	Indrawati Scholl Aghadi	0.9616	10.5776
9	Nepane	0.9575	10.5325
10	Ranger Office Najeek	0.9613	10.5743
11	Terse	0.9569	10.5259
12	Talamarang	0.9567	10.5237
13	Dhunganabesi	0.9564	10.5204
14	Urlenibesi	0.9563	10.5193
15	Acharyatol	0.9561	10.5171
16	Manebhanjyang A	0.9551	10.5061
17	Manebhanjyang	0.9548	10.5028
18	Upallogaun	0.9542	10.4962
19	Batase	0.9536	10.4896
20	TAR NCELL	0.9595	10.5545
21	Nea Office	0.9563	10.5193
22	Khanepani	0.9547	10.5017
23	Chalisegaun	0.9531	10.4841
24	Rice Mill	0.9481	10.4291
25	Palchocki Crosser	0.9465	10.4115
26	Dhakalthock A	0.9427	10.3697
27	Pipalchaur	0.9411	10.3521

S.N.	Bus	Voltage (pu)	Voltage (kV)
28	Thakle	0.9407	10.3477
29	Bansbari	0.9405	10.3455
30	Dhakalthock B	0.9395	10.3345
31	Dadhuwa	0.9384	10.3224
32	Dhakal Kahare	0.9416	10.3576
33	Sulikoat Ghyang B	0.9374	10.3114
34	Sulikoat Ghyang	0.9372	10.3092
35	Sulikoat Ghyang A	0.9372	10.3092
36	Dhusinechaur	0.9363	10.2993
37	Kattike Simpani	0.9363	10.2993
38	Sindhukoat A	0.9362	10.2982
39	Sindhukoat	0.936	10.296
40	Bahunepati A	0.9394	10.3334
41	Bahunepati Hospital	0.9385	10.3235
42	Bahunepati B	0.9382	10.3202
43	Bahunepati C	0.9377	10.3147
44	Koiralatar	0.9377	10.3147
45	Ganga Indrawati Crosser	0.9339	10.2729
46	Simlebasi	0.9335	10.2685
47	Dotelgaun	0.9332	10.2652
48	Dhunganthock	0.9332	10.2652
49	Jalpa Crosser	0.933	10.263
50	Ghorsaine Toll	0.9328	10.2608
51	Melamchi Phatkaswari	0.9319	10.2509
52	Ghorsailetoll	0.9318	10.2498
53	Baharetar	0.9307	10.2377
54	Lama Crosser	0.9298	10.2278
55	Sipaghat	0.9286	10.2146
56	Sipaghat Trt	0.9286	10.2146
57	Danuargaun	0.9271	10.1981
58	Dhakalthock C	0.9261	10.1871
59	Padherachaur	0.9249	10.1739
60	Thanti	0.9242	10.1662
61	Phataksilakoat	0.9239	10.1629
62	Giranchaur A	0.9146	10.0606
63	Giranchaur	0.9101	10.0111
64	Yakakirat Namuna Basti	0.91	10.01
65	Bhanjyang	0.8998	9.8978
66	Dandagaun	0.8953	9.8483
67	Chisapani	0.886	9.746
68	Patigaun	0.8771	9.6481

S.N.	Bus	Voltage (pu)	Voltage (kV)
69	Jhakarigaun	0.8475	9.3225
70	Bhotechaur Ncell	0.8473	9.3203
71	Bhotechaur Bazar	0.8467	9.3137
72	Khalde	0.841	9.251
73	Nimbugaun	0.8393	9.2323
74	Tallo Joshigaun	0.8388	9.2268
75	Suyalchhap	0.8364	9.2004
76	Bhadaure	0.834	9.174
77	Dhakalgaun Damaitol	0.8339	9.1729
78	Sindhukot Healthpost	0.8334	9.1674
79	Sindhukot	0.8329	9.1619
80	Jaise Gaun	0.8356	9.1916
81	Everest Tea State	0.8356	9.1916
82	Haibung	0.8327	9.1597
83	Gurungaun	0.8309	9.1399
84	Haibu 5	0.8281	9.1091
85	Gauranthock	0.8262	9.0882
86	Dandathock	0.8249	9.0739
87	Bokrang	0.8245	9.0695
88	Majuha	0.8245	9.0695
89	Dahapokhari	0.8244	9.0684
90	Piple	0.8222	9.0442
91	Dandakatari	0.8214	9.0354
92	Banskharka	0.8213	9.0343
93	Okahranechaur	0.8209	9.0299
94	Palchin	0.8196	9.0156
95	Basaree	0.8195	9.0145
96	Patibhangyang	0.819	9.009
97	Thankunebhanjyang	0.8184	9.0024
98	Chipling	0.8177	8.9947
99	Bhirkharka	0.8173	8.9903

Table C.6: Branch Loss for Melamchi feeder with capacitor optimally selected

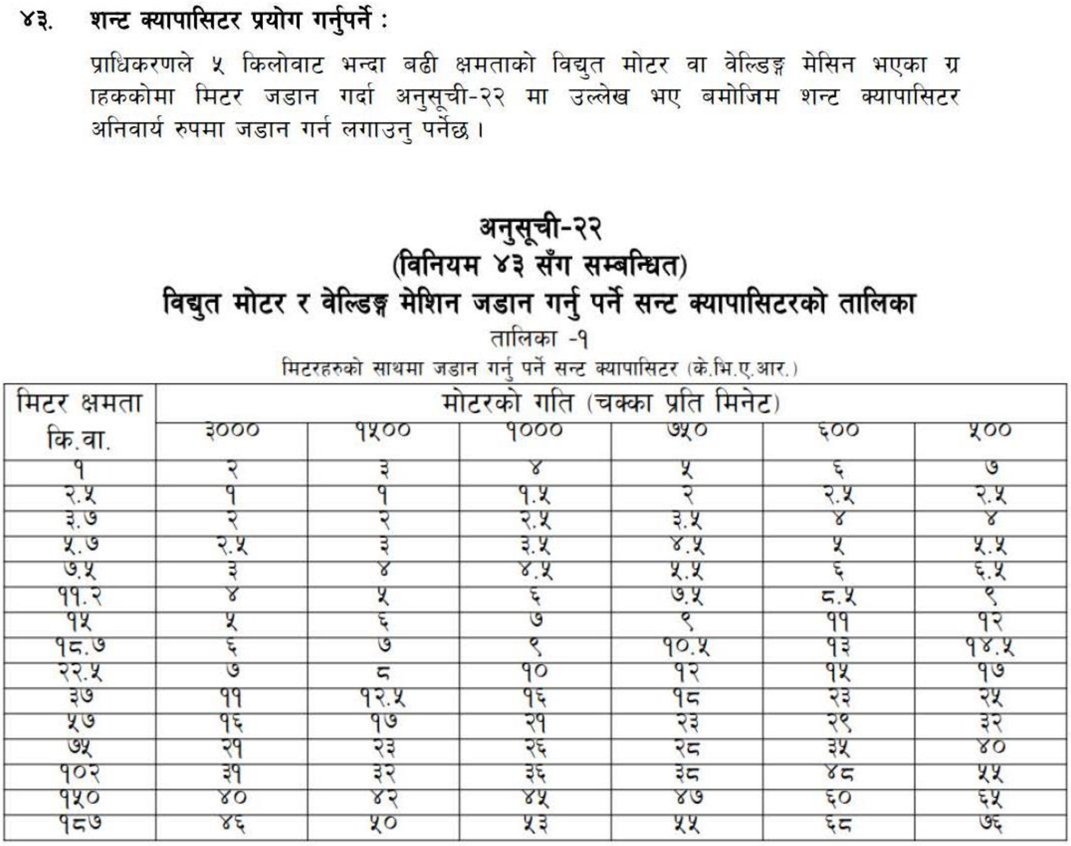
S. N.	Line Section	Amp Flow	kW Losses	kvar Losses	% Loading
1	Substation - Kaflekhola	148	55.81	56.09	52.48%
2	Kaflekhola - Bagaicha	147.2	37.76	37.96	52.20%
3	Bagaicha - Bus1	141	7.47	7.5	50.00%
4	Bus4 - Ranger Office Najeek	120.8	0.291	0.29	42.84%
5	Bus1 - Bus3	22.3	0.999	0.279	7.91%
6	Bus3 - Katunje	5.466	0.062	0.332	2.94%
7	Katunje - aarukharka	0.92	0.0004	0.0754	0.49%

S. N.	Line Section	Amp Flow	kW Losses	kvar Losses	% Loading
8	Katunje - Katunje tama Gaun	3.55	0.0079	0.105	1.91%
9	Bus3 - Simkhet	16.86	0.218	0.0596	5.98%
10	Bus1 - Indrawati Scholl Aghadi	122.6	2.98	2.98	43.48%
11	Simkhet - Nepane	15.68	0.234	0.11	5.56%
12	Bus22 - Bhanjyang	57.08	10.96	2.94	41.97%
13	Nepane - Bus6	13.6	0.0488	0.0469	4.82%
14	Indrawati Scholl Aghadi - Bus4	120.8	0.407	0.406	42.84%
15	Bus6 - Acharyatol	8.328	0.172	0.207	6.12%
16	Bhanjyang - Dandagaun	54.06	4.39	1.17	39.75%
17	Acharyatol - Manebhanjyang A	7.073	0.131	0.233	5.20%
18	Manebhanjyang A - Bus9	4.754	0.0308	0.132	3.50%
19	Bus9 - Manebhanjyang	0.196	0	0.0251	0.14%
20	Dandagaun - Chisapani	52.35	8.93	2.36	38.49%
21	Bus9 - Bus12	4.565	0.0438	0.205	3.36%
22	Bus12 - Upallogaun	2.7	0.0049	0.0679	1.99%
23	Bus12 - Batase	1.893	0.0231	0.665	1.39%
24	Bus6 - Bus7	5.286	0.0165	0.2	1.87%
25	Bus7 - Talamarang	4.116	0.0126	0.261	1.46%
26	Talamarang - Dhunganabesi	1.985	0.0145	0.381	1.46%
27	Dhunganabesi - Urlenibesi	1.788	0.0034	0.108	1.31%
28	Bus7 - Terse	1.185	0.0023	0.171	0.87%
29	Ranger Office Najeek - Bus2	117.3	2.26	2.25	41.60%
30	Bus2 - Buspark	117.3	0.274	0.273	41.60%
31	Buspark - TAR NCELL	116.9	2.25	2.24	41.45%
32	TAR NCELL - Nea Office	116.7	8.54	8.51	41.38%
33	Nea Office - Khanepani	113.6	4.5	4.48	40.28%
34	Khanepani - Bus8	113.3	3.16	3.14	40.18%
35	Bus8 - Chalisegaun	1.738	0.0126	0.43	1.28%
36	Bus8 - Bus11	112	14.66	14.57	39.72%
37	Bus11 - Rice Mill	1.943	0.0013	0.0337	1.43%
38	Chisapani - Patigaun	51.15	8.41	2.21	37.61%
39	Bus3900 - Palchocki Crosser	0.034	0	0.055	0.03%
40	Bus11 - Bus3900	110.6	4.62	4.59	39.22%
41	Bus3900 - Bus14	110.6	7.3	7.26	39.22%
42	Bus14 - Dhakalthock A	11.77	0.265	0.115	8.65%
43	Patigaun - Jhakarigaun	50.21	27.32	7.19	36.92%
44	Dhakalthock A - Bus4100	10.92	0.224	0.123	8.03%
45	Bus4100 - Pipalchaur	3.065	0.0242	0.253	2.25%
46	Pipalchaur - Thakle	1.905	0.0151	0.416	1.40%
47	Thakle - Bansbari	1.099	0.0043	0.357	0.81%
48	Jhakarigaun - Bus29	49.27	0.102	0.0269	36.23%
49	Bus4100 - Dhakalthock B	7.878	0.31	0.411	5.79%
50	Dhakalthock B - Dadhuwa	7.683	0.149	0.209	5.65%
51	Dadhuwa - Sulikoat Ghyang B	6.082	0.117	0.283	4.47%
52	Sulikoat Ghyang B - Bus19	4.952	0.0185	0.0699	3.64%
53	Bus19 - Sulikoat Ghyang A	0.93	0.0003	0.0301	0.68%

S. N.	Line Section	Amp Flow	kW Losses	kvar Losses	% Loading
54	Bus19 - Sulikoat Ghyang	0.204	0	0.041	0.15%
55	Bus29 - Bus32	5.301	0.0075	0.0195	3.90%
56	Bus19 - Bus21	3.832	0.0569	0.371	2.82%
57	Bus21 - Sindhukoat A	2.716	0.0116	0.154	2.00%
58	Sindhukoat A - Sindhukoat	1.066	0.0031	0.271	0.78%
59	Bus21 - Dhusinechaur	1.124	0.0013	0.0993	0.83%
60	Dhusinechaur - Kattike Simpani	0.185	0.0001	0.228	0.14%
61	Bus14 - Dhakal Kahare	102.1	6.78	6.7	36.21%
62	Dhakal Kahare - Bahunepati A	101.9	6.6	6.53	36.13%
63	Bahunepati A - Bahunepati Hospital	99.35	2.83	2.8	35.23%
64	Bus16 - Bus17	98.23	1.41	1.39	34.83%
65	Bus17 - Bus18	94.63	3.48	3.42	33.56%
66	Bus17 - Koiralatar	1.046	0.0017	0.154	0.77%
67	Bus18 - Giranchaur A	65.12	24.71	6.76	47.88%
68	Bus17 - Bahunepati C	0.209	0	0.0372	0.15%
69	Bus32 - Bhotechaur Bazar	5.071	0.0526	0.151	3.73%
70	Giranchaur A - Bus22	61.23	4.82	1.31	45.02%
71	Bus22 - Giranchaur	4.42	0.0146	0.0661	3.25%
72	Giranchaur - Yakakirat Namuna Basti	2.582	0.0058	0.0809	1.90%
73	Bus32 - Bhotechaur Ncell	0.237	0	0.016	0.17%
74	Bus29 - Bus31	44.51	2.66	0.679	32.73%
75	Bus31 - Khalde	19.11	1.12	0.0845	14.05%
76	Khalde - Nimbugaun	16.75	0.535	0.0058	12.32%
77	Nimbugaun - Tallo Joshigaun	2.667	0.0241	0.265	1.96%
78	Nimbugaun - Suyalchhap	12.22	0.663	0.158	8.99%
79	Suyalchhap - Bhadaure	11.18	0.505	0.171	8.22%
80	Bus36 - Dhakalgaun Damaitol	1.042	0.0013	0.0917	0.77%
81	Bus36 - Sindhukot Healthpost	4.725	0.0542	0.176	3.47%
82	Sindhukot Healthpost - Sindhukot	2.585	0.0218	0.252	1.90%
83	Bhadaure - Bus36	5.755	0.0037	0.0078	4.23%
84	Bus31 - Jaise Gaun	28.01	4.8	0.935	20.60%
85	Jaise Gaun - Haibung	23.19	1.53	0.23	17.05%
86	Haibung - Gurungaun	23.02	0.936	0.139	16.93%
87	Gurungaun - Haibu 5	23.22	1.25	0.19	17.07%
88	Jaise Gaun - Everest Tea State	2.205	0.0015	0.0238	1.62%
89	Haibu 5 - Gauranthock	20.34	0.721	0.0784	14.96%
90	Gauranthock - Bus37	18.9	0.31	0.0247	13.90%
91	Bus37 - Bus38	13.5	0.595	0.0754	9.93%
92	Bus38 - Piple	4.208	0.0633	0.257	3.09%
93	Bus38 - Bus39	9.313	0.254	0.15	6.85%
94	Bus39 - Bus40	7.335	0.213	0.24	5.39%
95	Bus40 - Patibhangyang	5.309	0.102	0.247	3.90%
96	Bus39 - Dandakatari	1.991	0.004	0.0763	1.46%
97	Palchin - Basaree	0.973	0.003	0.239	0.72%

S. N.	Line Section	Amp Flow	kW Losses	kvar Losses	% Loading
98	Piple - Banskharka	2.503	0.0385	0.462	1.84%
99	Banskharka - Okahranechaur	1.279	0.0106	0.501	0.94%
100	Patibhangyang - Thankunebhanjyang	4.041	0.0416	0.182	2.97%
101	Thankunebhanjyang - Chipling	2.66	0.0339	0.356	1.96%
102	Chipling - Bhirkharka	1.318	0.0106	0.467	0.97%
103	Bus37 - Dandathock	5.412	0.0466	0.109	3.98%
104	Dandathock - Bokrang	2.88	0.0181	0.164	2.12%
105	Bokrang - Majuha	1.872	0.0013	0.0292	1.38%
106	Majuha - Dahapokhari	0.908	0.0008	0.0727	0.67%
107	Bus40 - Palchin	2.048	0.0126	0.226	1.51%
108	Bus18 - Bus20	29.53	0.639	0.397	10.47%
109	Bus20 - Simlebasi	24.8	0.15	0.0681	8.79%
110	Simlebasi - Bus23	23.78	0.0727	0.0295	8.43%
111	Bus23 - Bus24	22.42	0.105	0.0346	7.95%
112	Bus24 - Bus25	20.21	0.0126	0.0021	7.17%
113	Bus25 - Bus26	19.9	0.341	0.0491	7.06%
114	Bus26 - Bus27	18.17	0.0086	0.0003	6.44%
115	Bus27 - Bus28	15.82	0.237	0.0867	5.61%
116	Bus28 - Bus30	14.83	0.204	0.113	5.26%
117	Bus30 - Sipaghat	11.17	0.177	0.311	3.96%
118	Sipaghat - Sipaghat Trt	9.236	0.0044	0.0134	3.28%
119	Bus28 - Baharetar	1.013	0.0025	0.245	0.74%
120	Bus30 - Lama Crosser	3.682	0.0018	0.0126	2.71%
121	Bus24 - Ghorsaine Toll	2.378	0.0099	0.17	1.75%
122	Bus25 - Jalpa Crosser	0.33	0	0.0403	0.24%
123	Bus26 - Melamchi Phatkaswari	7.48	0.0126	0.0184	5.50%
124	Bus20 - Ganga Indrawati Crosser	4.796	0.0011	0.0149	1.70%
125	Bus23 - Dotelgaun	1.466	0.0047	0.217	1.08%
126	Dotelgaun - Dhunganthock	0.215	0	0.0972	0.16%
127	Bus27 - Ghorsailetoll	2.378	0.0057	0.097	1.75%
128	Sipaghat Trt - Danuargaun	9.118	0.254	0.224	6.70%
129	Danuargaun - Dhakalthock C	6.893	0.141	0.249	5.07%
130	Dhakalthock C - Padherachaur	5.971	0.136	0.333	4.39%
131	Padherachaur - Thanti	3.924	0.0495	0.298	2.89%
132	Thanti - Phataksilakoat	2.053	0.0104	0.236	1.51%
133	Bahunepati Hospital - Bus16	99.35	0.964	0.952	35.23%
134	Bus16 - Bahunepati B	1.867	0.0003	0.0087	1.37%

ANNEX D: NEA REGULATION 2078



४३. शन्ट क्यापासिटर प्रयोग गर्नुपर्ने :

प्राधिकरणले ५ किलोवाट भन्दा बढी क्षमताको विद्युत मोटर वा वेल्डिङ्ग मेसिन भएका ग्राहककोमा मिटर जडान गर्दा अनुसूची-२२ मा उल्लेख भए बमोजिम शन्ट क्यापासिटर अनिवार्य रुपमा जडान गर्न लगाउनु पर्नेछ ।

अनुसूची-२२

(विनियम ४३ सँग सम्बन्धित)

विद्युत मोटर र वेल्डिङ्ग मेशिन जडान गर्नु पर्ने सन्ट क्यापासिटरको तालिका

तालिका -१

मिटरहरुको साथमा जडान गर्नु पर्ने सन्ट क्यापासिटर (के.भि.ए.आर.)

मिटर क्षमता कि.वा.	मोटरको गति (चक्का प्रति मिनेट)					
	३०००	१५००	१०००	७५०	६००	५००
१	२	३	४	५	६	७
२.५	१	१	१.५	२	२.५	२.५
३.७	२	२	२.५	३.५	४	४
५.७	२.५	३	३.५	४.५	५	५.५
७.५	३	४	४.५	५.५	६	६.५
११.२	४	५	६	७.५	८.५	९
१५	५	६	७	९	११	१२
१८.७	६	७	९	१०.५	१३	१४.५
२२.५	७	८	१०	१२	१५	१७
३७	११	१२.५	१६	१८	२३	२५
५७	१६	१७	२१	२३	२९	३२
७५	२१	२३	२६	२८	३५	४०
१०२	३१	३२	३६	३८	४८	५५
१५०	४०	४२	४५	४७	६०	६५
१८७	४६	५०	५३	५५	६८	७६

[Source: NEA]

ANNEX E: FINANCIAL ANALYSIS RESULTS

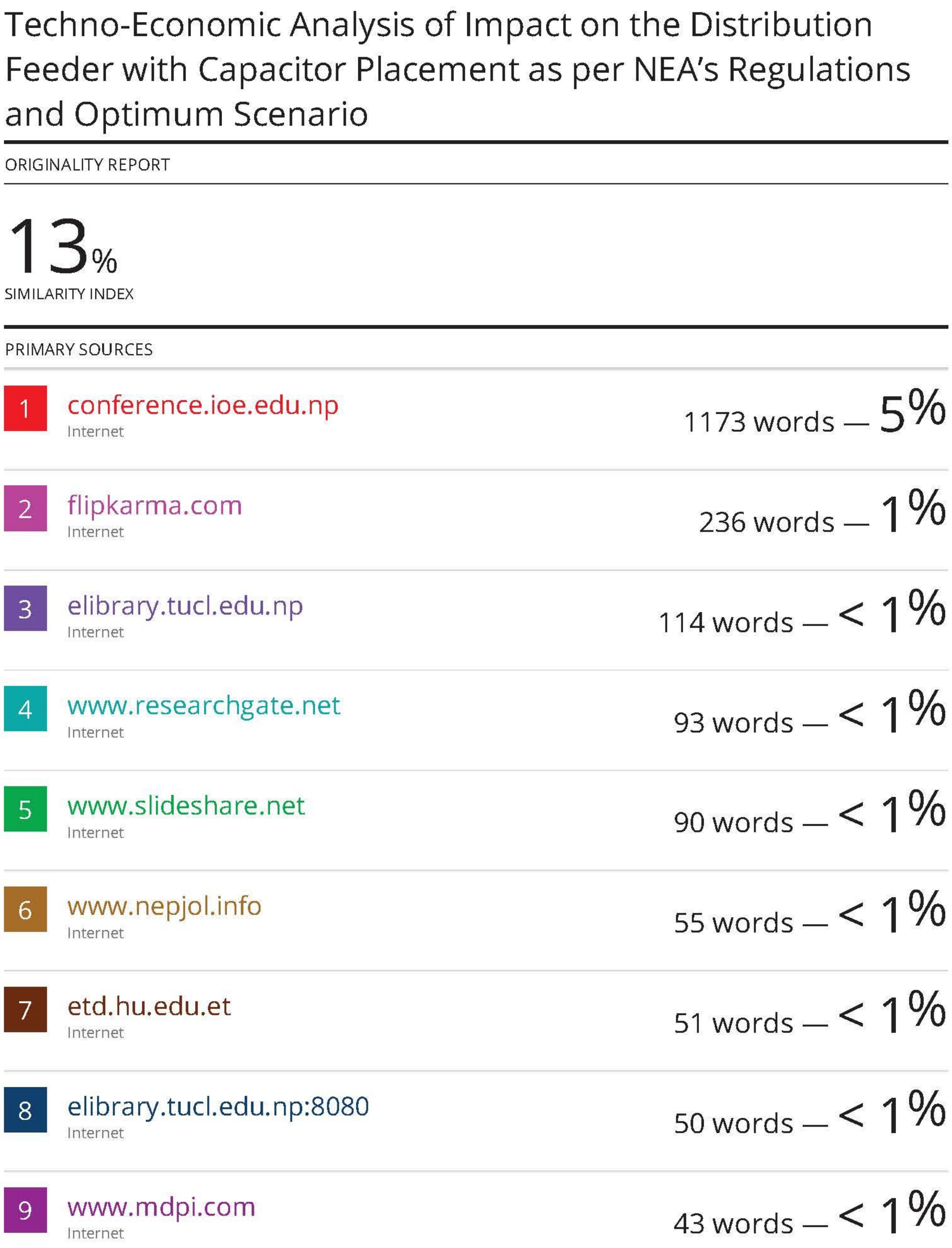
Table E.1: Financial analysis results for capacitor placement with NEA guidelines

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Discount Factor	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	4,445,400	-	4,445,400	-	(4,445,400)	1.00	4,445,400	-	(4,445,400)	(4,445,400)
1	-	222,270	222,270	1,639,872	1,417,602	0.91	202,064	1,490,793	1,288,729	(3,156,671)
2	-	222,270	222,270	1,639,872	1,417,602	0.83	183,694	1,355,266	1,171,572	(1,985,099)
3	-	222,270	222,270	1,639,872	1,417,602	0.75	166,995	1,232,060	1,065,065	(920,034)
4	-	222,270	222,270	1,639,872	1,417,602	0.68	151,813	1,120,055	968,241	48,208
5	-	222,270	222,270	1,639,872	1,417,602	0.62	138,012	1,018,231	880,219	928,427
6	-	222,270	222,270	1,639,872	1,417,602	0.56	125,466	925,665	800,199	1,728,626
7	-	222,270	222,270	1,639,872	1,417,602	0.51	114,060	841,514	727,454	2,456,080
8	-	222,270	222,270	1,639,872	1,417,602	0.47	103,691	765,012	661,322	3,117,402
9	-	222,270	222,270	1,639,872	1,417,602	0.42	94,264	695,466	601,202	3,718,604
10	-	222,270	222,270	1,639,872	1,417,602	0.39	85,695	632,242	546,547	4,265,151
11	-	222,270	222,270	1,639,872	1,417,602	0.35	77,904	574,765	496,861	4,762,011
12	-	222,270	222,270	1,639,872	1,417,602	0.32	70,822	522,514	451,692	5,213,703
13	-	222,270	222,270	1,639,872	1,417,602	0.29	64,384	475,013	410,629	5,624,332
14	-	222,270	222,270	1,639,872	1,417,602	0.26	58,531	431,830	373,299	5,997,631
15	-	222,270	222,270	1,639,872	1,417,602	0.24	53,210	392,572	339,363	6,336,994
16	-	222,270	222,270	1,639,872	1,417,602	0.22	48,372	356,884	308,511	6,645,505
17	-	222,270	222,270	1,639,872	1,417,602	0.20	43,975	324,440	280,465	6,925,970
18	-	222,270	222,270	1,639,872	1,417,602	0.18	39,977	294,945	254,968	7,180,938
19	-	222,270	222,270	1,639,872	1,417,602	0.16	36,343	268,132	231,789	7,412,727
20	-	222,270	222,270	1,639,872	1,417,602	0.15	33,039	243,757	210,718	7,623,445
	Total						**6,337,710**	**13,961,155**	**7,623,445**	**4.96**

Table E.2: Financial analysis results for optimal capacitor placement

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Discount Factor	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	6,764,000	-	6,764,000	-	(6,764,000)	1.00	6,764,000	-	(6,764,000)	(6,764,000)
1	-	338,200	338,200	2,787,782	2,449,582	0.91	307,455	2,534,348	2,226,893	(4,537,107)
2	-	338,200	338,200	2,787,782	2,449,582	0.83	279,504	2,303,952	2,024,448	(2,512,659)
3	-	338,200	338,200	2,787,782	2,449,582	0.75	254,095	2,094,502	1,840,408	(672,251)
4	-	338,200	338,200	2,787,782	2,449,582	0.68	230,995	1,904,093	1,673,098	1,000,847
5	-	338,200	338,200	2,787,782	2,449,582	0.62	209,996	1,730,994	1,520,998	2,521,845
6	-	338,200	338,200	2,787,782	2,449,582	0.56	190,905	1,573,630	1,382,725	3,904,570
7	-	338,200	338,200	2,787,782	2,449,582	0.51	173,550	1,430,573	1,257,023	5,161,593
8	-	338,200	338,200	2,787,782	2,449,582	0.47	157,773	1,300,521	1,142,748	6,304,341
9	-	338,200	338,200	2,787,782	2,449,582	0.42	143,430	1,182,292	1,038,862	7,343,203
10	-	338,200	338,200	2,787,782	2,449,582	0.39	130,391	1,074,811	944,420	8,287,623
11	-	338,200	338,200	2,787,782	2,449,582	0.35	118,537	977,101	858,564	9,146,187
12	-	338,200	338,200	2,787,782	2,449,582	0.32	107,761	888,273	780,512	9,926,700
13	-	338,200	338,200	2,787,782	2,449,582	0.29	97,964	807,521	709,557	10,636,256
14	-	338,200	338,200	2,787,782	2,449,582	0.26	89,059	734,110	645,052	11,281,308
15	-	338,200	338,200	2,787,782	2,449,582	0.24	80,962	667,373	586,411	11,867,718
16	-	338,200	338,200	2,787,782	2,449,582	0.22	73,602	606,703	533,101	12,400,819
17	-	338,200	338,200	2,787,782	2,449,582	0.20	66,911	551,548	484,637	12,885,456
18	-	338,200	338,200	2,787,782	2,449,582	0.18	60,828	501,407	440,579	13,326,035
19	-	338,200	338,200	2,787,782	2,449,582	0.16	55,298	455,825	400,526	13,726,561
20	-	338,200	338,200	2,787,782	2,449,582	0.15	50,271	414,386	364,115	14,090,676
	Total						**9,643,287**	**23,733,963**	**14,090,676**	**4.41**

ANNEX F: ORIGINALITY REPORT



Techno-Economic Analysis of Impact on the Distribution Feeder with Capacitor Placement as per NEA's Regulations and Optimum Scenario

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ANNEX G: PUBLICATION

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Techno-economic analysis of impact on the distribution feeder with capacitor placement as per NEA's regulations and optimum scenario

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Abstract

With the aim of distribution loss reduction, Nepal Electricity Authority has brought regulation to install the capacitor with size equivalent to approx. 30% of the load demand. This paper compares the techno-economical impact of the placement of the capacitor as per NEA's regulations and the other case for the optimal placement and sizing with the cost minimization function of genetic algorithm. Melamchi feeder taken into account, the base case minimum voltage and loss was obtained as 0.704pu and 17.67% respectively. The minimum voltage with the capacitor placement as per NEA's regulation and Optimal capacitor placement (OCP) are 0.75pu and 0.802pu with loss 15.13% and 10.37% respectively. Moreover, IRR are 18.02% and 24.30% respectively. The techno-economical results indicates that the optimal placement of the capacitor is the better alternative than the placement mentioned by NEA's regulations

Keywords

OCP, genetic algorithm, NEA's regulation with capacitor

1. Introduction

The distribution system, being near to the consumers is often prioritized in case of quality power supply. The components of the qualitative power supply include the regulation of the system voltage along with the loss minimization. Also, the system has an huge investment to benefit cost as compared to the transmission and distribution systems. So, the further investments need to be made considering the technical improvements and financial aspects associated with it.

Along the various methods of the enhancement of the distribution system, the addition of capacitor is an effective method. In general case, the distribution feeders need to carry the reactive load to the end consumer. This power requirement cause increase in the current at the line sections of feeder which in turn increases the system loss and cause voltage drop.

In context of Nepal, Nepal Electricity Authority (NEA) is the major utility distributor.The voltage at the distribution feeders (11kV) are stepped-down to the required level (0.23/0.4kV) through the utility and privately owned distribution transformers. The private consumers get supply from either of these transformers and contributes in over 55% of the energy consumption [1, 2]. Acknowledging the importance of the reactive power management in the distribution system, NEA has recently issued a regulation stating that the private consumers should install the capacitor with size 30% of the load demand.

In this paper, the technical impacts of this regulation is analyzed and is compared with the scenario of optimal capacitor placement . The technical impacts of system voltage and loss has been analysed. Also, a comparison is made based on the financial analysis, about the suitability of the the installation.

The optimal capacitor size and placement in radial distribution systems have been carried out in the article [3] taking into account the parameters: capacitor cost, voltage, angle, and load variations. When completing the load flow with the inequality constraints of the aforementioned parameters, the system loss minimization was taken into account. The findings show where the capacitors should be placed specifically to minimize energy system losses. The papers [4–12] presents various optimization techniques including generic algorithm and particle swarm optimization for the reduction of the distribution system loss.

Another study [13] used the Electrical Transient Analyzer Program's (ETAP) optimum capacitor module to accomplish the best capacitor placement for the IEEE 118 bus system. The selection of optimal size and location of the capacitor has been performed with objective function of minimization of cost of annual loss and annualized investment cost.The load flow equations are the equality constraints; and voltage deviation and reactive power constraint as the inequality constraints.

In this study a distribution feeder: Melamchi feeder is simulated in the ETAP software and the optimal placement and sizing of the capacitor is carried out with the genetic algorithm.

2. Materials and Methods

The methods and techniques followed in the course of the study are presented in this section.

2.1 System Modeling

The 11kV Melamchi feeder has been modeled in ETAP software. The voltage at the feeder source, i.e. substation is considered as 1pu. The line parameters are considered for the network from the ACSR standard data sheet. For the load , the current measured by the Melamchi DC for the NEA transformers is considered. The load for the private transformers are taken from the private transformer's TOD billing data. The overall load is then scaled for the time of feeder peak.

2.2 NEA's Capacitor placement

As per the regulation of NEA, the capacitor banks needs to be installed by the private consumers above 5kVA load demand with size equivalent to 30% of the demand. As mentioned, these private consumers get supply from both utility transformers or their own private transformers(for large consumers). In case of the private consumers with their own transformer, the capacitor of the size 30% of the load demand of the consumer is placed. While in the case of the NEA transformers, there can be a large number of private consumers with up to 5kVA load demand is present. So, the size of capacitor is obtained from the summation of the load demands connected to the specific utility's transformer.

2.3 Optimal Capacitor sizing and placement

Figure1 is a presentation of the genetic algorithm's objective function together with its accompanying equality and inequality constraints:

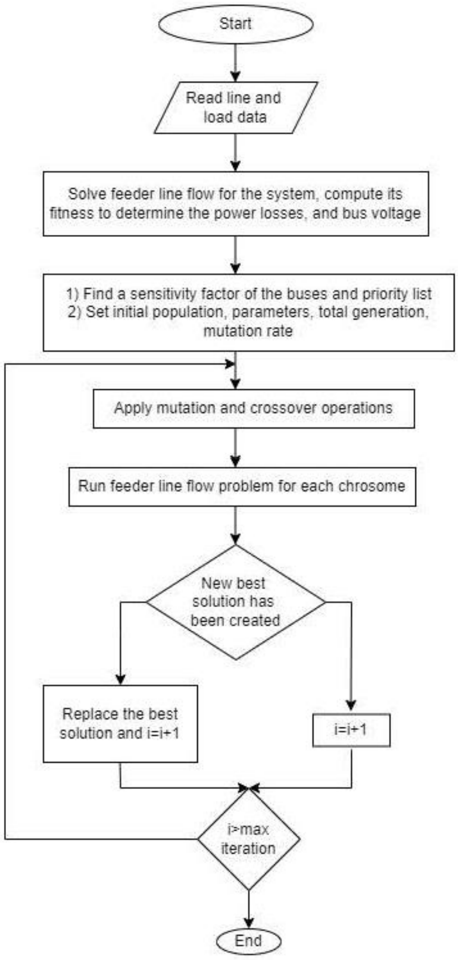

Figure 1: GA Methodology

Objective Function: The system's cost can be expressed mathematically as follows:
Minimization function=

$$\sum_{i=1}^{Nbus}(x_1C_{0i}+Q_{ci}C_{1i}+B_iC_{2i}T+C_2\sum_{i=1}^{Nbus}(T_1P_L^1)) \quad (1)$$

where,

$Nbus$ Candidate bus number
x_i 0/1,1 means the capacitor installed at bus i

C_{0i} Initial investment cost for installation
C_{li} cost of cap bank per kVAR
Q_{ci} Size of cap bank in kVAR
B_i No. of cap banks
C_{2i} Operation cost of bank per year per bank,
T Project period (years)
C_2 Cost of kWh loss in \$/kWh
L Load levels: maximum, average and minimum
T_1 Time duration (hr) of load level 1
P_{Li} Loss at load level l Constraints

The equality constraints are:

$$\begin{aligned} P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \\ Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \end{aligned} \tag{2}$$

The inequality constraints considered for the genetic algorithm is:

$$\begin{aligned} V_{i_{min}} \leq V_i \leq V_{i_{max}} \\ Q_{j_{min}} \leq Q_j \leq Q_{j_{max}} \end{aligned} \tag{3}$$

Where, i is the no. of buses and j is the no.of the source of reactive power. The flowchart for for the methodology of GA is shown in Figure 1. The iteration is performed with mutation and crossover of each individuals with the convergence in the minimization of the objective function.

3. Results and Discussion

3.1 IEEE-33 bus radial distribution system

The IEEE-33 bus radial bus system is simulated and the voltage and the loss status of the system is determined. From the Figure 2, it was evident that the minimum voltage is observed at Bus18 with value 0.903pu. The system loss is 212.93kW active and 144.35kvar reactive loss.

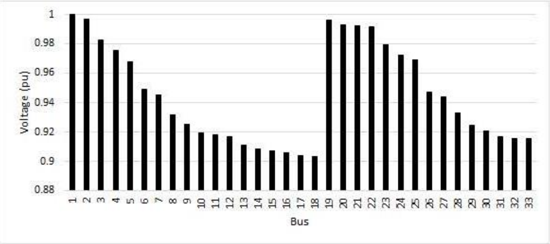

Figure 2: Voltage profile of 33kV bus

With the ETAP software, the optimal placement and location of the capacitor was determined. The results shows that for the 33kV system, a total of 1650kvar is to be installed. The optimal location are at Bus3, Bus6 and Bus10 with sizes 580kvar, 550kvar and 520kvar respectively. With this the voltage at the 18th bus would improve to 0.927pu and overall active and reactive loss decreases to 163.28kW and 112.24kvar respectively.

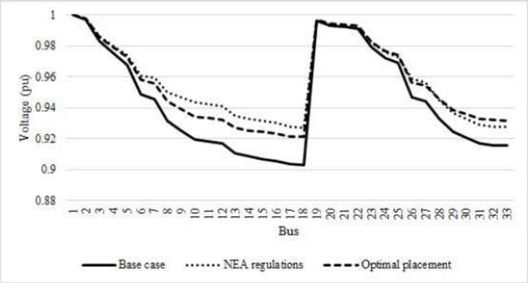

Figure 3: Comparison of voltage profile for 33kV bus

For the capacitor placement as per NEA's regulation guideline, the capacitors are placed at each of the 32 bus beyond Bus1. A total of 1363kvar are required at these locations. The results shows that the overall system voltage improves and the loss decreases. The minimum voltage at Bus18 improves to 0.921pu with the active loss decreasing to 154.43kW and reactive loss to 104.91kvar.

The voltage profile of the system for the original case, with optimal capacitor placement and capacitor placement as per NEA's guidelines is shown in Figure3.

3.2 Utility Feeder

The similar siumulation is also carried out in case of the distribution Feeder of NEA. The feeder has peak load demand of 2.97MVA with the total length of 88km composed of Dog, Rabbit and Weasel conductors. There are altogether 99 transformers with 81 of them belonging to the utility consumers and remaining 18 owned by the private consumers. The major of those private consumers are crushers near the Indrawati river.

The nodal voltages of the Melamchi feeder are shown in Figure 4. The results shows that the bus voltages along the feeder drops up to 0.704pu at Bhirkharka in the peak load case. The cause for such drop in the voltage is due to the higher line loading and longer radial length. The loss of the overall system in the peak is evaluated to be 542kW and 344kvar active and reactive loss respectively. So, the loss is 17.67% at the peak conditions considered.

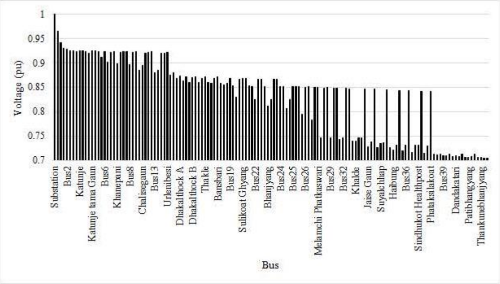

Figure 4: Bus voltages for Melamchi feeder

The optimal placement of the capacitors are determined. As per the results the 1,230kvar, 475kVAR and 175kvar are to be placed at the locations: Koiralatar, Gurunggaun and Yakikrit namuna basti respectively. The minimum voltage at Bhirkharka increases to 0.802pu with the placement of the capacitor. Moreover, the overall system active and reactive loss decreases to 292kW and 263kvar respectively, i.e. 10.37% as shown in Figure 5.

Considering the regulations of the NEA, the voltage profile as shown in Figure 5 was obained. The system minium voltage at Bhirkharka increases to 0.75pu. Also, the active and reactive loss from the existing system drops down to 449.9kW and 102.78kvar respectively i.e. to 15.13%.

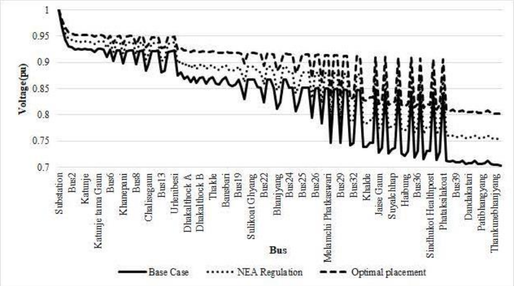

Figure 5: Comparison of bus voltages for Melamchi feeder in different cases

So, in case of the Melamchi feeder the result shows that with the optimal capacitor placement, the system voltage has improved with lower value of the system loss as compared to that with NEA regulations. Also for the 33-bus radial system the loss is lower with the placement of optimal sized capacitor at the optimal locations. So, technically, the optimal location of capacitor is better as compared to the placement of capacitor with NEA's guideline. This needs to be confirmed from the financial analysis too.

3.3 Financial Analysis

The financial analysis was performed with the comparison of the placement of capacitor as per NEA's regulations and with optimal placement and sizing. The IRR and payback period for the placement of the capacitor as per the regulation and optimal locations were evaluated to be 18.02% & 5.27years and 24.30% & 4.34years respectively. So, from the financial analysis, it can be inferred the optimal placement of capacitor is more financially justifiable as compared to the NEA's regulation for capacitor placement.

4. Conclusion

From the results, it can be concluded that the system yields the better results with the placement of the capacitor at the optimal location and with optimal size than the regulations of the NEA. The size of the capacitor determined from the optimal capacitor placement are: 1,230kvar, 475kVAR and 175kvar at Koiralatar, Gurunggaun and Yakikrit namuna basti respectively. The system voltage and loss initially at 0.704pu & 17.67% at peak changes to 0.75pu & 15.13% and 0.802pu & 10.37% for the system with the NEA's placement of capacitor and optimal sizing & placement of capacitor respectively. The financial analysis indicates that the optimal placement is more beneficial financially than the other case with IRR 24.30% over 18.02% respectively.

The future recommendations for the extension of the project can be performed with the detail analysis of the size of the capacitor that can be assigned to the distribution feeder depending upon the consumer category with the size which will be more beneficial than the NEA's regulations.

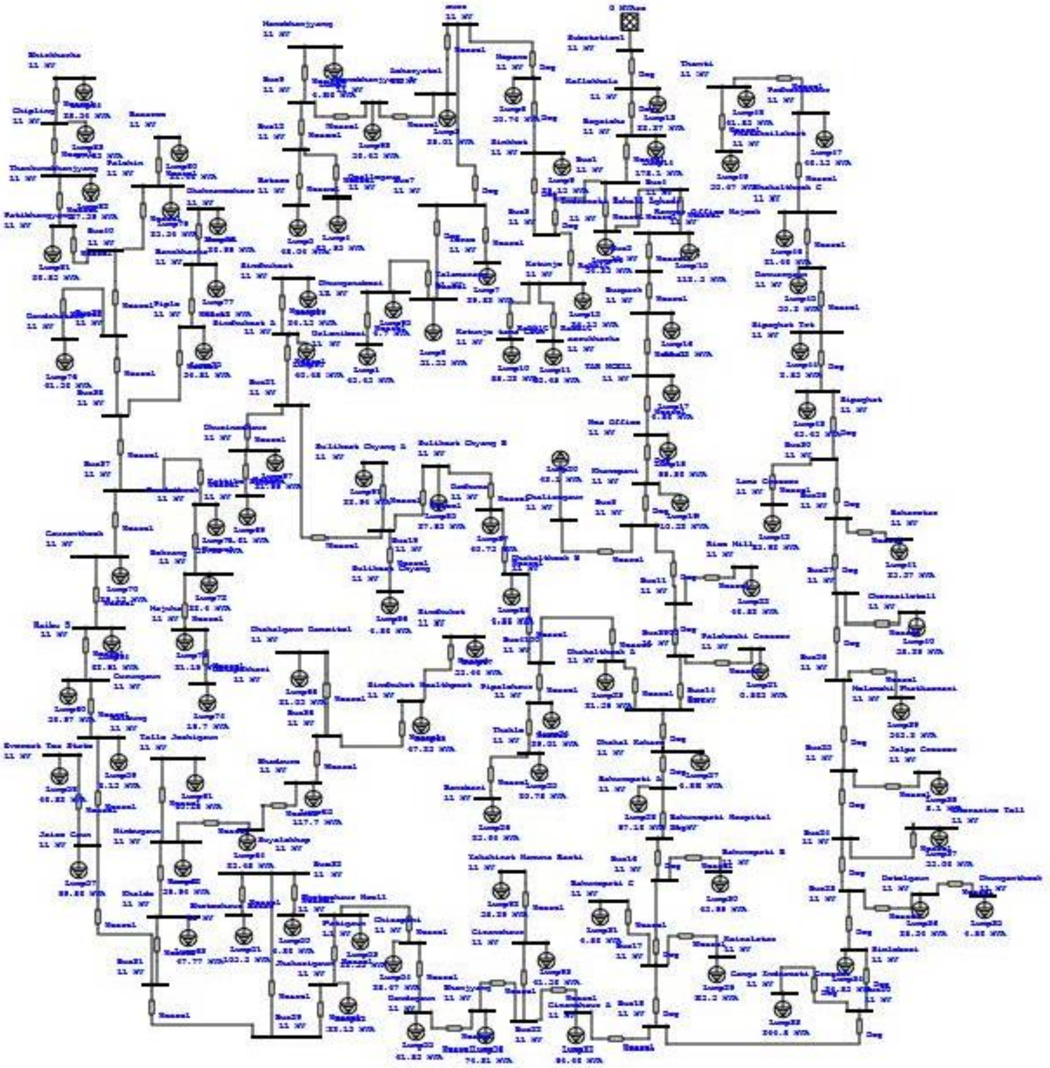

Figure 6: SLD of Melamchi Feeder

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