VOLTAGE QUALITY MANAGEMENT USING MINIMAL NUMBER OF TRANSFORMERS IN CUET DISTRIBUTION NETWORK

By

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Declaration

I hereby declare that the work contained in this thesis has not been previously submitted to meet the requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is cited.

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Dedication

To my loving Parent, Teachers

and

To my infinitely supportive, amazing wife.

List of Publications

Conference

- Publication 1: Md. Kamrul Hasan, Nur Mohammad "An Outlook over Electrical Energy Generation and Mixing Policies of Bangladesh to Achieve Sustainable Energy Targets Vision 2041", *International Conference on Electrical, Computer and Communication Engineering (ECCE 2019)*, Cox's Bazar, Bangladesh, February, 2019,
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Approval by the Supervisor

This is to certify that Md. Kamrul Hasan has carried out this work under my supervision, and that he has fulfilled relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so that he is qualified to submit the following thesis in application for the degree of MASTER of SCIENCE in Electrical and Electronic Engineering.

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Abstract

Voltage quality management is one of the crucial aspects of power system operation and management. The voltage profile improvement is a pivotal parts of quality management of distribution system which is affected by various factors, including load power factor, the transformer kVA rating and placement etc. The voltage levels at the load end may fall below acceptable limits, causing operational issues and potential damage to connected equipment. Traditional approaches to voltage quality management involve the use of multiple transformers strategically placed throughout the distribution network to regulate voltage levels and mitigate power quality disturbances. However, the installation, operation and maintenance costs associated with a large number of transformers can be significant. The objective is to optimize the placement and operation of transformers to effectively regulate voltage levels while minimizing the overall system loss and operational costs. Here, several cases with particular scenarios are considered to achieve the objective without sacrificing the voltage profile. But to supply proper current to the load, some assumptions has needed to consider including total load demand, low voltage cable model modification and load power factor variation. The study proposes an approach that aims to achieve voltage profile improvement using a minimal number of transformers in CUET distribution network. The approach allows for flexibility in adapting to changing load conditions and network configurations in the near future. An optimized proposed model has been developed with at least 25 three-phase transformers of different rating needs to supply power instead of existing 52 number of three phase-transformer bank. Also, the voltage profile has improved and the system loss has reduced by 56.8%. By doing a tentative cost analysis, almost 48%-50% cost has been reduced for the proposed model. Moreover, some scenarios have been simulated to show the sustainability of proposed model with horizontal load extension in the future. By minimizing the number of transformers and total system loss, power system operators can optimize the use of resources while ensuring reliable and high-quality power supply to consumers. The study highlights the importance of considering both technical and economic factors in voltage quality management strategies.

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Nomenclature

Symbols

%X	Percent of Reactance
%Z	Percent of Impedance
3P	Three Phase
cosϴ	Power factor
I	Current
kV	Kilo Volt
kVAR	Kilo Volt Ampere Reactive
P	Power
R	Resistance
V	Voltage

Acronyms and Abbreviations

AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
BPDB	Bangladesh Power Development Board
BREB-	Bangladesh Rural Electrification board
CUET	Chittagong University of Engineering and Technology
DMS	Distribution Management System
DSS	Distribution System Simulator
GMR	Geometric mean Radius
HT	High Tension
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
LT	Low Tension
LTC	Load Tap Changing Transformer
LV	Low Voltage
P&D	Procurement and Development
PU	Per Unit
PF	Power factor
PMU	Phasor Measurement Units
SCADA	Supervisory Control and Data Acquisition)
SPC	Spun Pre-stressed Concrete

Chapter 1: Introduction

This chapter summaries the background in section 1.1 and context in section 1.2 of research carried out. The sole research purposes and objectives have been delineated in section 1.3 and section 1.4 gives the scopes and significance of this research. At the end, section 1.5 contains an outline of the remaining thesis chapters.

1.1 BACKGROUND

Electricity is a form of energy that has become an essential part of modern life. Electricity is used to power homes, businesses, and industries. It provides the energy needed to run appliances, computers, and other equipment that we rely on every day. Its importance can be seen in many aspects of our daily lives, from the light bulbs that light up our homes to the devices we use to communicate and connect with others.

Electricity is generated in power plants through various methods, including fossil fuels, nuclear energy, hydropower, wind power, and solar power. Once generated, the electricity is transmitted through a power grid to distribution centres. It is then distributed to homes and businesses. An electrical network needs to convey power from substation to the power consumer.

In modern power grids, such networks are operated through specifically designed distribution management systems (DMSs). DMS actively control the network by getting accurate knowledge of the network state [1].

During transmission of electric power over long distances from power plants to consumers, power loss occurs. Several factors like resistance, impedance etc. are responsible for electric power loss in the network.

In order to minimize power loss, utility provider use various techniques such as improving the efficiency of transformers and other electrical equipment, reducing the length of power lines and using high-voltage direct current (HVDC) transmission lines. Additionally, smart grid technologies are being developed to improve the efficiency and reliability of the distribution network, including advanced metering infrastructure (AMI) and demand response systems.

Another effective policy to reduce power losses of the distribution network is feeder reconfiguration. In this way, the configuration of network is changed in order to achieve minimum losses with fulfilling electricity demand of consumers [2]. In developing countries, un-planned growth of load demand is causing the distribution system to operate its maximum operating limits and overloading the distribution system. This cause of voltage instability and a big loss in the distribution system. Voltage instability makes the system unstable and can cause system failures. Voltage instability is defined by variation in voltage magnitude to dangerously low values. The voltage profile along the bus at various loading points is one of the main concerns of the system engineer [2].

The advance in the power systems technologies has brought numerous technical studies of distributed generation and economic studies of distributed electricity pricing [3]. Both of them require a large number of case scenarios. Nonetheless, this can be computationally burdensome, or even unfeasible, due to the grid extension and complexity.

There are plenty of numerical solutions and dedicated simulators designed to speed up power grid simulations. Some of those solutions are Real-Time Simulators. They are limited for small dimension systems. Therefore, a distribution system satisfying all the above-mentioned concerns can be modelled in simulator by applying some reduction techniques.

1.2 CONTEXT

Chittagong University of Engineering and Technology (CUET) is one of the leading public universities of Bangladesh, situated at Raozan, just alongside the Chittagong – Kaptai road. This campus is an area of around 193 acres. There are multiple buildings for academic and administrative purposes and residential buildings for students, teachers, and staff here on campus. Previously, a 33kV incoming line from the Modhunaghat grid substation connected to a 2MVA transformer of the CUET sub-station and stepped down to 11kV. This 11kV again stepped down to 415V by two individual transformers, each of them is a 500 kVA rating. From the CUET sub-station, whole CUET area get the electric power.

One of the biggest problems was the voltage drop in the cable going from the substation to the residential area. As we know that, fall in voltage occurs as the feeder length increase from sending end to receiving end [1]. Sometimes this voltage drop was so acute that the line voltage dropped down below the permissible limit. As a result, lighting loads of the residential area did not respond properly during peak hours.

A BREB substation named "Raozan-3 CUET" has been established at the CUET premises in 2018. CUET authority gives 3 acres of land area for the substation with an interest that, BREB re-construct the distribution network of CUET to remove the voltage drop problem. BREB has started to reconstruct the power system distribution network. A 33kV incoming line has connected to the BREB substation and stepped down to 11kV. BREB implanted 153 spun pre-stressed concrete (SPC) poles throughout the CUET premises for the high voltage overhead line (11kV) and 6 SPC poles for the low voltage overhead line. In front of each load centre such as academic building, administrative building or residential building, BREB has implanted a three-phase transformer bank by connecting three single-phase transformers or a three-phase transformer for the step-down purpose form high voltage (11 kV). Then the secondary of the transformer directly connected to the energy meter by an LT cable. In this study, the major focus has given to reduce the number of transformers as well as the total loss related to the transformer and other parameters.

1.3 PURPOSES AND OBJECTIVES

Distribution systems are in the proximity of consumers, so, it demands to study loss in terms of cost-benefit perspective. Each transformer has core loss, copper loss and other miscellaneous losses. Among them core loss is almost fixed for transformer. Moreover, each transformer needs maintenance and inspection at a regular interval. Although costs related to maintenance are totally from the utility provider (PDB, BREB, PBS), but big number of transformers' operation and maintenance is highly expensive.

Therefore, the objectives of this research work were-

- To analyse the existing bus-feeder model of CUET and the redundancy of the transformer.
- To develop a model of utility distribution feeder to improve the power quality.
- To investigate whether the proposed model can sustain with the horizontal load extension.

1.4 SIGNIFICANCE, SCOPE AND DEFINITIONS

The main cause of power loss in the distribution feeder is for transmission and distribution losses. Transmission loss occur as electricity is transmitted over long distances. The distribution loss happens for network parameters including resistance and impedance of power lines, transformers, switches, and other electrical equipment. Moreover, sometimes losses occur due to poor design of the distribution network. These losses can be reduced by improving the efficiency of the network. Efficiency can be increased by upgrading transformers and other electrical equipment, improving system design and reducing the length of power lines.

By doing this research work, transformers have kept to minimum number as well as the total system loss while keeping the voltage profile within the standard limit.

At first, in this thesis, analysis has been done for the voltage flow with system loss of the existing system and try to explore whether it is a good design or poor design. Then optimization of the number of transformers has been done to get same or better voltage profile. This research finds the significance on the proper selection of low voltage conductors in a distribution network.

1.5 THESIS OUTLINE

This dissertation consists of the following four chapters, including the introductory chapter mentioned above. With brief chapter description, rest of the chapters are arranged as follows. Chapter 2 examines the pertinent studies and current voltage profile improvement methods to identify the research issue. Chapter 3 explains the methodological aids working behind optimized model. Chapter 4 describes the simulation procedures of different cases and the obtained results. Chapter 5 summarizes the key outcomes, deficiencies and future research aspects.

Chapter 2: Literature Review

This chapter begins with a background of distribution system (section 2.1) and reviews literature on the research done so far. Section 2.2 discuss about the significance of voltage levels. Causes of voltage drop in section 2.3 where different reasons behind the voltage drop has been discussed. After that, in section 2.4 importance of power factor for the distribution system has been discussed briefly. Section 2.6 highlights the implications from the literature and develops the conceptual framework for the study.

2.1 HISTORICAL BACKGROUND

Author in the paper [2] proposes algorithms for minimizing economic losses within a distribution feeder. This paper involves in optimizing the placement of equipment (e.g., transformers) or determining the best operational settings. The selection of an optimum conductor likely involves a comprehensive analysis of conductor properties, cost-effectiveness and their impact on voltage profile and losses. This analysis might incorporate both technical and economic factors. Voltage profile improvement could involve the development of control strategies or adjustments to the distribution network's configuration. The paper discuss how voltage profile optimization contributes to the reliability and quality of power supply. The contribution of this paper likely lies in its potential to offer practical solutions for optimizing distribution feeders in terms of economic losses, conductor selection, and voltage profile improvement.

The contribution of the authors in paper[3] lies in potential to offer practical and efficient solutions for improving voltage profiles in distribution networks.

By integrating line reconfiguration and distribution transformer placement strategies, the research may provide valuable insights into optimizing network operation, reducing losses, and enhancing the quality of power supply to consumers. An improved voltage profile ensures that consumers receive consistent and high-quality electrical service while also contributing to energy conservation and cost reduction for utility companies.

Another research [4] provides practical insights into the analysis and selection of distribution transformers for reducing losses, enhancing the efficiency of electrical distribution systems. The methodologies and strategies presented offer utilities and researchers tools to assess and improve the performance of distribution transformers, aligning with sustainability and economic objectives. The economic and environmental implications of their work underscore the importance of efficient transformer selection and operation for a greener and more cost-effective electrical grid.

2.2 DISTRIBUTION SYSTEM MODELING

Distribution network starts from the distribution substation with several distribution lines. In order to service one or more primary feeds, each substation is built.

2.2.1 Research Done so Far on Distribution System Modeling

There has been a significant amount of effort done in the modeling of distribution systems. Distribution Management Systems (DMS) are specific algorithms and models for distribution networks that have been developed in recent years. The DMS is described in detail in reference [5]. Distribution system characteristics such as radial nature, system dimensions, high R/X ratios and reduced measurements are addressed by DMS.

The ladder approach, the power summation method and the current summation method are frequently employed to find the power flow solutions.

These algorithms are compared and presented by the author in [6]. An experimental design method has utilized in reference [7], to validate the qualitative model of the DMS and evaluate the importance of each component.

Authors in paper [8], present an integrated load model that may be used to time series power flows. In paper [9] a model has developed to accurately represent the transformers' impedance in the system loss. Authors in reference [3] try to improve voltage profile by feeder reconfiguration and placement of transformer in a distribution network. The power flow results of a test system with balanced and decoupled models are compared with unbalanced, multi-phase models in reference [10] to demonstrate major modifications. It can be shown that when the amount of loading rises, the inaccuracy associated with approximating a balanced system grows. For operational purposes like volt/var control and service repair, it is crucial to adopt an unbalanced, multi-phase modeling.

A summary of the modeling of two North American feeders by OpenDSS is provided in reference [11]. This paper's goal was to express the two feeders in the Common Information Model (CIM) format.

2.2.2 Layout and Electrical Components of Distribution System

The primary benefit of radial distribution feeders is that power only travels along a single line from the source to each the consumer. Figure 2.1 depicts the layout of a basic distribution system along with each of its parts. Distribution substations having one or more feeders serve as a typical distribution system. Depending on the economics and requirement, the distribution lines may be overhead or underground. Single-phase or three-phase capacitor banks are employed to supply reactive power assistance to crucial points along the feeder. The primary voltage of the substation transformer typically functions at 12.47 kV and is subsequently decreased to 4.16 kV [12].

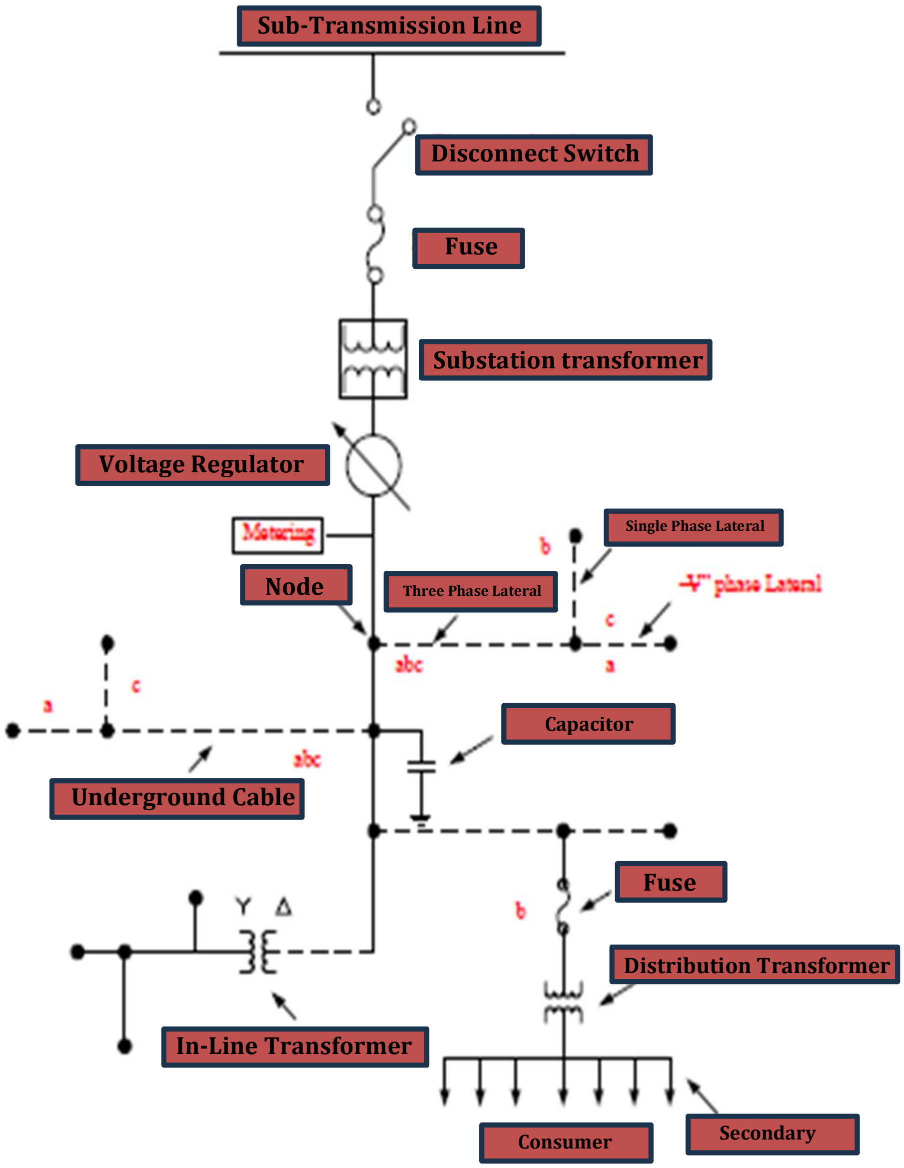


Fig. 2.1 A typical Distribution System

The smaller distribution transformers are known as service transformer, supply power to customers at 120/240V level. The distribution feeder serves various types of loads, including single-phase and poly-phase loads from residential and industrial consumers [13]. The essential characteristics of a distribution system are-

- A distribution substation uses a substation transformer to lower the supply voltage to distribution system level.

- Voltage loss occurs during power flow from the substation to the feeder's load end. This voltage loss is mostly determined by the feeder's loading circumstances. In order to maintain the voltage at all nodes within ANSI standards, voltage regulators modify the voltage settings.
- For high voltage switching, the system comprises of basic switches and HV circuit breakers. The relay-controlled circuit breakers use for LV switching. Reclosers are used in some instances instead of the relay circuit breaker combo.

Aside from these parameters, each device in a distribution feeder has unique electrical properties that must be identified earlier to the feeder's power circulation analysis. Table 2.1 displays the critical electrical properties of each component.

Table 2.1 Electrical Characteristics of Distribution System Components

Components	Characteristics
Overhead Conductor	Spacing among Phase Height above ground Wire Detailing
Wire Parameter	Geometric mean Radius Cable Diameter Per Km Resistance vale Ampere Rating
Voltage regulator	PT Data CT Data Compensator parameter R and X value
Transformer	kVA and Voltage rating Impedance Settings (R and X) No-load power loss
Capacitor	Capacity Phasing and Control type ON-OFF Control

2.2.3 Algorithm on Distribution Power flow

The distribution network serves a large number of unequal single-phase loads causing the system unbalanced. The non-equilateral spacing between three-phase line segments adds to the unbalance. A distribution network's lines have higher resistance to reactance (R/X) ratios. As a result, the system becomes ill-conditioned. The transmission system algorithms commonly used for studying power flow and short-circuit conditions are not suitable for radial distribution networks because they lack appropriate convergence properties and are unable to handle the distinct structure of such systems.

Since the system's loads do not remain constant and metering is sensitive to errors, a precise picture of the load is not achievable. In a distribution system, the assumption of constant power demand cannot be applied because the voltages at system buses are not stable. This leads to a non-linear load flow algorithm, requiring iterative methods to solve the system [14]

To analyse the load flow and short circuit scenarios in a distribution system, an iterative method called the forward backward sweep is employed. Accurate representation of the supplying feeder is crucial for conducting precise power flow and short circuit investigations using three-phase models of essential components. However, there are challenges in accurately simulating each feeder. Obtaining all of the relevant data is one of the most challenging challenges. The majority of the required data is contained in feeder maps. Additional information from utility records includes conventional pole layouts, voltage regulator settings, conductors used on each line segment and three-phase transformer connections. Accurate models are required for the impedance estimates of three-phase unbalanced overhead and underground cables.

2.3 SIGNIFICANCE OF VOLTAGE PROFILE IMPROVEMENT

Voltage management refers to the techniques and strategies used to regulate and control the voltage levels within an electrical power system. It involves monitoring, maintaining, and adjusting the voltage to ensure it remains within specified limits. The voltage profile refers to the distribution of voltage magnitudes and phase angles across the network. It is crucial to maintain a stable and optimal voltage profile for the following reasons:

- Reliable Power Supply: A well-maintained voltage profile ensures the reliable delivery of electrical power to consumers. Voltage variations beyond permissible limits can lead to equipment malfunction, system instability, and potential blackouts. By improving the voltage profile, power system operators can minimize voltage fluctuations and enhance the overall reliability of the electrical grid.
- Equipment Performance: Electrical devices and equipment are designed to operate within specific voltage ranges. Deviations from the desired voltage levels can result in poor performance, increased energy consumption, and premature equipment failure. Improving the voltage profile helps to maintain voltage within acceptable limits, thereby maximizing the operational efficiency and lifespan of equipment.
- Power Quality: Voltage profile improvement contributes to better power quality. High-quality power is characterized by stable voltage levels, low harmonics, and minimal transients. An optimized voltage profile reduces voltage sags, swells and fluctuations, resulting in improved power factor, reduced harmonic distortion, and enhanced overall power quality.
- Loss Reduction: Voltage variations affect power losses in electrical networks. Excessive voltages lead to increased resistive losses, while low voltages result in higher reactive power consumption. By improving the

voltage profile, power losses can be minimized, leading to more efficient energy transfer and reduced operating costs.

- Voltage Stability: Maintaining a stable voltage profile is essential for power system stability. Voltage instability can trigger power failures and voltage collapse, which can have severe consequences on the entire grid. Improving the voltage profile enhances the system's ability to maintain stable operation and prevent voltage instability events.

Voltage profile improvement helps to ensure efficient and secure operation of electrical power systems, benefiting both utilities and consumers.

2.4 CAUSES OF VOLTAGE DROP IN DISTRIBUTION LINE

There are several causes of voltage loss or voltage drop in distribution lines. These losses can occur due to various factors, some of them are listed below [15]-

- Resistance of Conductors: The resistance of the conductors used in distribution lines results in a voltage drop. As current flows through the conductors, it encounters resistance, causing a voltage drop according to Ohm's law. The longer the distribution line and the more the current, the higher the voltage drop [16].
- Load Characteristics: The characteristics of the connected loads can contribute to voltage loss. High-power equipment or appliances that draw significant current can create voltage drops along the distribution line. Large industrial motors or air conditioning units, for example, can cause voltage variations due to their high starting currents or intermittent peak loads.
- Conductor Size: Inadequate conductor size for the load being supplied can lead to excessive voltage drop. If the conductor size is too small to handle the current demand, the resistance and subsequent voltage drop increases.

Proper sizing of conductors based on the load requirements is crucial to minimize voltage losses.

- Distance: Voltage drop increases with the length of the distribution line [17]. This is why distribution systems often utilize step-down transformers to transmit power at higher voltages over long distances and reduce the impact of voltage drop.
- Load Imbalance: In three-phase distribution systems, unbalanced loads can result in voltage imbalance and losses. If the loads on the different phases are not evenly distributed, one or more phases may experience higher current flow, leading to increased voltage drop and potential voltage imbalances.
- Power Factor: A low power factor can contribute to voltage losses. Reactive power, which is necessary for inductive loads, can cause an increase in voltage drop. Low power factor loads result in higher reactive power demand, which increases the apparent power flowing through the distribution lines, leading to higher voltage losses.
- System Configuration: The configuration of the distribution system, such as the arrangement of transformers and the number and size of branches, can affect voltage losses [13]. Improperly designed or overloaded distribution systems can experience higher voltage drops due to inadequate transformer capacity or excessive current flow through certain branches.
- Harmonics: Non-linear loads introduce harmonics into the distribution system. These harmonics can distort the current waveform and cause additional losses, including voltage drops.

Minimizing voltage losses in distribution lines is essential for maintaining the quality and reliability of the electrical supply. Proper design, regular maintenance, load management, and utilizing efficient equipment can help mitigate these losses and ensure that voltage levels remain within acceptable limits at the point of consumption.

2.5 IMPORTANCE OF POWER FACTOR IN DISTRIBUTION NETWORK

Power factor is an important parameter in electrical power systems that measures the efficiency of power transmission and utilization. It represents the ratio of real power to the apparent power in an AC circuit. The power factor can range from 0 to 1, with a higher value indicating better power efficiency.

2.5.1 Causes Behind Low Power Factor

Several factors can contribute to a low power factor in an electrical power system. Some of the common causes include [15]:

- Inductive Loads: Inductive loads, such as electric motors, transformers, and solenoids, require reactive power to create and maintain magnetic fields. These loads can introduce lagging power factor, as the current lags behind the voltage waveform. Industrial facilities with heavy motor loads often experience low power factor due to the presence of induction motors.
- Imbalanced Loads: In cases where the load is not evenly distributed among the phases of a three-phase system, the power factor can be affected. If the loads on the different phases have varying power factors, it can lead to an overall lower power factor for the entire system [18].
- Inefficient Power Factor Correction: Incorrect or inadequate power factor correction methods can result in a low power factor. If the power factor correction capacitors are undersized, improperly connected, or not functioning correctly, they may fail to compensate for the reactive power adequately [19].
- Reactive Power Demand: Certain industrial processes, such as arc furnaces and welding equipment, have high reactive power demands. If the electrical

system is not equipped to handle these demands, it can lead to a low power factor.

- Utility Penalties: Some utility companies impose penalties or additional charges on consumers with low power factors. These penalties serve as an incentive for consumers to improve their power factor and reduce the strain on the power grid [17].

It is important to identify the specific causes of low power factor in a particular system to implement effective power factor correction measures. Conducting power quality assessments, load studies, and utilizing power factor correction equipment can help address low power factor issues and improve the overall efficiency of the power system [19].

2.5.2 Effects of Low Power Factor in Distribution System

The power factor has several effects on power systems:

- Transmission Losses: A low power factor can result in increased transmission losses. When the power factor is less than 1, the current waveform lags behind the voltage waveform, causing an increase in reactive power. Reactive power does not perform useful work but still flows in the transmission lines, leading to additional losses.
- Voltage Drop: A low power factor can cause voltage drop issues in the power system. When there is a significant reactive power component, it causes additional current flow in the system, leading to voltage drops along the transmission lines. This can result in reduced voltage levels at the load end, affecting the performance of electrical equipment.
- Increased Current: A low power factor requires higher current to deliver the same amount of real power. This can also necessitate the use of larger conductors and equipment to handle the higher currents.

- Transformer Overloading: Transformers are designed to handle a certain level of real power and reactive power [20]. When the power factor is low, the reactive power component increases, which can overload transformers. This overloading can lead to increased losses, reduced efficiency, and potential damage to the transformer.

To mitigate the negative effects of a low power factor, power factor correction techniques are employed.

2.5.3 Ways to Improve Power Factor of the System

Improving the power factor techniques involve the use of power factor correction capacitors or synchronous condensers to supply the required reactive power locally, reducing the burden on the power system. It allows for better utilization of electrical infrastructure, reduces strain on the power grid, and enables the system to accommodate more load without requiring significant upgrades. Improving power factor involves reducing the reactive power component and increasing the displacement power factor of the electrical system. Here are some methods to improve power factor:

- Power Factor Correction Capacitors: Installing power factor correction capacitors is the most common method to improve power factor. These capacitors supply reactive power locally, offsetting the reactive power demand of inductive loads [21]. The capacitors are connected in parallel to the load and can be fixed or automatically controlled based on the load conditions.
- Load Balancing: Balancing the load among the phases in a three-phase system helps improve power factor. By evenly distributing the load, the reactive power demand can be more evenly distributed, resulting in a higher power factor.
- Upgrading Inductive Loads: Energy-efficient motors and transformers are designed to operate with better power factors. Upgrading or replacing

inefficient or oversized equipment with more efficient models can significantly improve power factor.

- Minimizing Harmonics: Non-linear loads that introduce harmonics can distort the current waveform and lower the power factor. Using filters, harmonic mitigating devices or employing power electronic equipment with active front-end converters can help reduce harmonics and improve power factor.
- Correcting Power Factor at the Source: Power factor correction at the source, such as at the main distribution board, can provide overall improvement. This approach involves installing power factor correction capacitors at the main power supply point to compensate for the reactive power demand of the entire facility.
- Proper Sizing and Configuration: Ensuring that power factor correction capacitors are correctly sized and properly connected is crucial. Conducting a power factor analysis or consulting with a qualified electrical engineer can help determine the appropriate capacitor size and configuration for effective power factor correction.

It's important to note that power factor correction should be carried out in consultation with qualified professionals, such as electrical engineers or power system experts, to ensure proper design and implementation according to the specific requirements of the system

2.6 TRANSFORMER PLACEMENT IN DISTRIBUTION NETWORK

Transformer placement refers to the strategic positioning of electrical transformers in an electrical power distribution system. Transformers are essential devices used to step-up or step-down voltage levels for efficient transmission and distribution of electricity [22]. The placement of transformers in a power distribution system is crucial for maintaining an optimal and reliable electrical supply.

2.6.1 Factors Related to Transformer Placement

Several factors are taken into consideration when determining transformer placement, including:

- Load Centres: Transformers are typically placed near load centres, which are areas with high electricity demand. Placing transformers closer to the loads reduces transmission and distribution losses, improves voltage regulation, and ensures a more stable power supply to consumers.
- Voltage Drop: Transformers should properly be positioned to minimize voltage drop in the distribution network. By placing transformers at suitable locations, voltage levels can be maintained within acceptable limits, ensuring consistent power supply to consumers.
- System Configuration: The configuration of the distribution system, such as radial or looped, influences transformer placement. In a radial system, transformers are usually placed at the end of each feeder, while in a looped system, transformers can be strategically positioned at multiple locations to enhance system reliability and flexibility.
- Fault Tolerance: Transformer placement is also considered with regards to fault tolerance. By locating transformers at different suitable points in the network, the impact of a fault or failure can be minimized, allowing for quick restoration of power and reducing downtime.
- Future Expansion: Transformers may be positioned with future expansion in mind. Anticipated growth in load demand or the addition of new substations or industrial areas can influence the placement of transformers to accommodate future requirements.
- Environmental Factors: Environmental considerations, such as accessibility, safety, noise levels, and aesthetic concerns, may also influence transformer placement decisions. Transformers are typically located in well-ventilated

areas, away from residential or sensitive areas to minimize noise and potential hazards.

Transformer placement is typically determined through engineering studies, load flow analysis, and modelling of the power distribution system. Power utilities and electrical engineers use advanced tools and techniques to optimize transformer placement, considering various technical, operational, and economic factors to ensure efficient and reliable power delivery to consumers.

2.6.2 Bank of Three Single Phase Transformer or Single Three-Phase Transformer?

A single three-phase transformer is mostly used for economic reasons. However, this does not exclude the usage of a bank of three single-phase transformers. A single three-phase transformer may be extremely large and thus difficult to carry from the Transformer manufacturer to the site. As a result, a bank of three single phase transformers is used in this scenario.

The advantages and disadvantages of bank of 3 single phase transformer [23] are listed below-

1. It is more expensive due to the need for three single-phase transformers. Three single-phase transformers necessitate additional iron for the core, oil, and accessories.
2. In this situation, a star or delta connection on the HV side necessitates the use of six distinct HV Bushings to bring out the HV terminals of three single phase transformers. Installation requires more space.
3. It provides better erection and installation flexibility. The cost of spare inventory is lower.

4. As a spare, only one single phase transformer is required, which is less expensive. This is less efficient due to losses in the three units. The losses are more due to use of more iron core.
5. Because of the losses in the three components, this is less efficient. Because of the increased use of iron core, the losses are greater.

The advantages and disadvantages of single three phase transformer are given below:

1. It is also simple to replace a single unit.
2. It is quite cost effective due to the use of a smaller iron core, a smaller tank volume, and hence a smaller volume of Transformer Oil.
3. Because the delta / star connection is made inside the transformer tank, only three or four HV bushings are required.
4. Installation takes up less area.
5. Because it is a single item, there is no flexibility in erection and installation.
6. When compared to a single unit of single-phase transformer, the cost of a single three-phase transformer as a spare is rather expensive.
7. Repairing and replacing it is quite difficult.
8. It is more efficient and has lower losses due to the reduced need for iron core.

2.7 SUMMARY AND IMPLICATIONS

It has been reflected from the literature review that, volage drop in a distribution network depends on various issues which has to monitor properly. Also, there are many methods to reduce the voltage loss. Proper cable selection is one of the important issues which must be selected carefully according to the system configuration and load current. Another parameter needs to monitor whether the recommended transformer's rating is enough for the load or the transformer could be overloaded or underloaded.

The primary goal of this research is voltage management in case of improving the voltage profile. This also increase system stability and reduce costs.

To improve the voltage profile and also to reduce the system loss, some questions has been raised and analysis has been done to find the answers.

1. Does the total loss of the existing system permissible?
2. Does the voltage profile of the system in the permissible range?
3. Do the transformers of the system run overload, normal load, or underload? Is there any redundant possibility?

All the question's answer has been found after the simulation. Also, by analysing the answer, decision has been made to select the equipment which are responsible for the system loss. Again, decision has been made about how they could replace with the suitable one for the improvement of the overall system.

Chapter 3: Research Methodology

This chapter of the thesis illustrates the design and methodology of this research. The chapter has organized into several sections. First of all, 3.1 gives an overview of the existing distribution model of CUET and 3.2 Gives the model of a proposed optimized model of the distribution network. Section 3.3 describes the optimization methodology for selecting the components that have been used in the model. After that, section 3.4 outlines the tool that has been adopted to find the optimized model.

3.1 OVERVIEW OF EXISTING DISTRIBUTION MODEL OF CUET

A single-line diagram of the existing CUET distribution network has been given in Figure 3.1 and the Table 3.1 lists some general information about the network.

Table 3.1. Existing Feeder Description of CUET distribution network

No.	Description	Unit
1	Number of Three-phase transformers	10
2	Number of Single-phase transformers	117
3	Number of Three Phase section	4
4	Number of HT poles	153
5	Number of LT poles	06

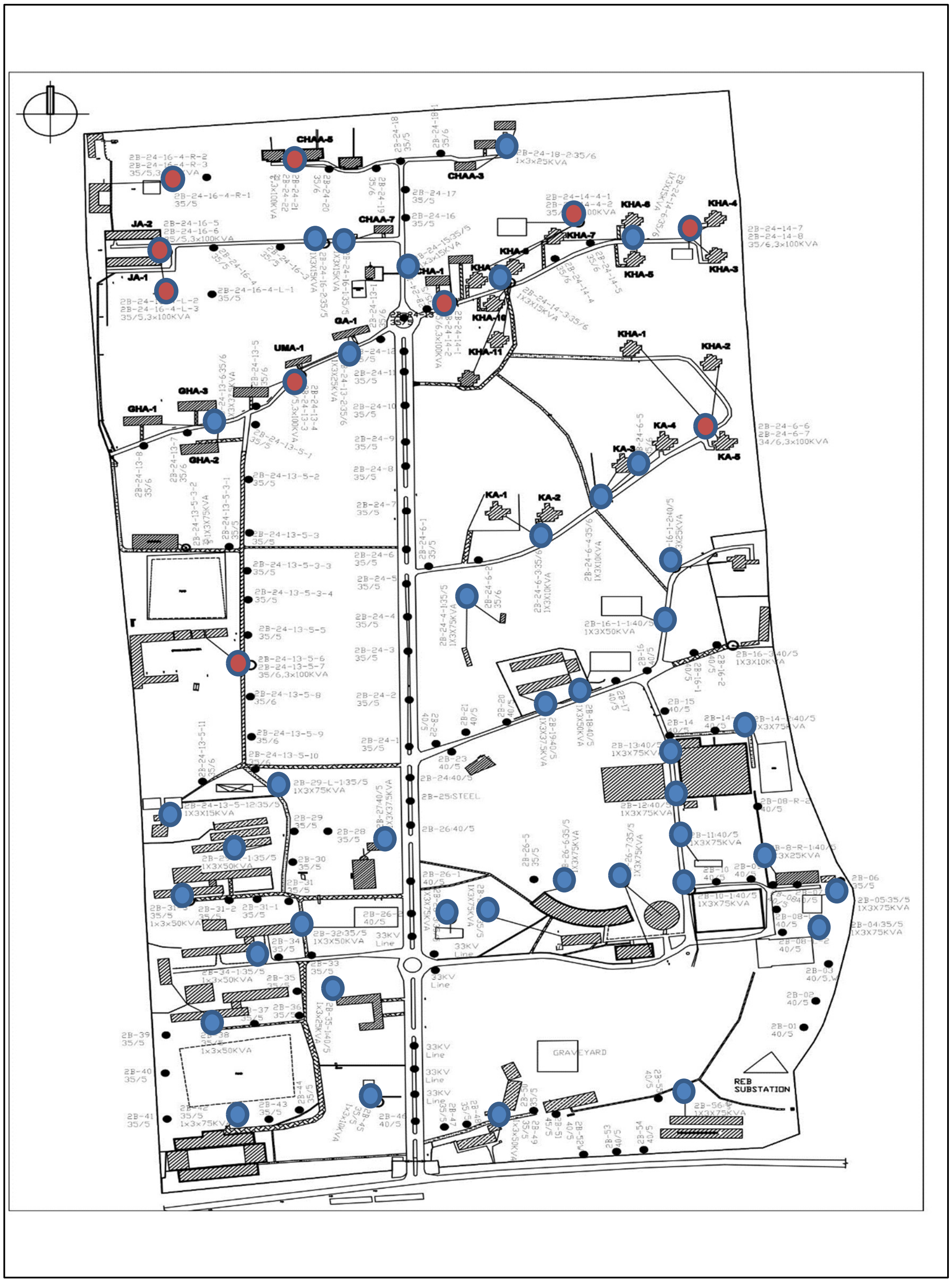


Fig. 3.1 Single Line Diagram of CUET Distribution Network

All the information in Table 3.1 has been extracted from the REB. In Figure 3.1, the red colour circle represents the single three-phase transformers and blue colour circle represents three-phase bank of transformers position. There are 10 three-phase transformers of 100kVA rating and 41 three-phase transformer banks formed by joining three single-phase transformers having different KVA ratings (10 kVA to 75 kVA) and configurations. So, each three-phase bank is from 30kVA to 225kVA. Table 3. represents the placement of the transformers in the existing distribution model. Table 3.3 gives information about the transformer's rating and percentage of impedance (%Z).

Table 3.2 List of Transformer Placement and Rating use in the Existing Network

Sl. no	Placement of Transformer	Transformer Rating (kVA)
1	Auditorium	3*75
2	Academic Building 5 (Arch & URP)	3*75
3	Engineering Section	3*25
4	Academic Building 1 (CE)	3*75
5	New Library	3*50
6	Academic Building 2 (EEE & ME)	3*75
7	Mechanical Work Shop	3*75
8	Academic Building 3 (CSE)	3*75
9	Ladies New Hall	3*50
10	VC Residence	3*25
11	Answer Camp	3*10
12	Samsen Nahar Hall	3*50
13	Sufia Kamal Hall	3*37.5
14	Garage and Pump	3*75
15	Bangalow Ka1 and Ka2	3*10
16	Bangalow Ka3 and Ka4	3*10
17	Bangalow Ka5, Kha1 and Kha 2	3P100
18	Professor Building 2 & Bachelor Ladies Teacher	3*25
19	Uma 1, Gha 4 (3-storied building for teachers)	3P100
20	Gha 1,2&3 (3-storied building for teachers)	3*37.5
21	Teacher dormitory	3*75
22	CUET School and College	3P100
23	CUET School and College dormitory	3*15
24	3 storied 2 building for the officer(cha 1,2)	3P100
25	Bangalow Kha10, 11 &12	3*15
26	Professor Building-1, Kha 8 & 9	3P100
27	Bangalow Kha 5, 6 & 7	3*15
28	New Professor Building-1, Kha 3 & 4	3P100
29	Residential Mosque and 4 Storied building for the officer (cha 3)	3*15

30	1-storied building for stuff(chaa7)	3*15
31	Car workshop	3*15
32	Three 3 storied buildings for Staff (Ja 1&2)	3P100
33	One 5 storied, Two 3 Storied and one 1 Storied building for stuff	3P100
34	Dormitory for Stuff	3P100
35	Two 3 storied buildings for Staff (Chaa 1&2)	3*25
36	One 5 storied building and three 3-storied buildings (Chaa 3, Chaa 4, and Chaa 5)	3P100
37	Administrative building 1	3*75
38	West and East Gallery	3*25
39	Pre-Engineering Building	3*75
40	Administrative building 2	3*75
41	Central Mosque	3*37.5
42	Sheik Rasel Hall	3*75
43	QK Hall extension	3*50
44	QK Hall	3*50
45	TSC	3*50
46	Tarek Huda Hall	3*50
47	Canteen	3*25
48	Shah hall	3*50
49	Bangabandhu Hall	3*75
50	Medical center	3*10
51	Sonali bank, Hall extension and Police quarter	3*50
52	Academic Building 4 (PME)	3*75

In the table "3*75" represents a transformer bank formed by joining three single-phase transformers of 75 kVA and "3P100" represents a single three-phase transformer of 100 kVA.

Table 3.3 Transformer Configuration use in the Existing Network

Sl.	Transformer KVA Ratings	Phase	%Impedance (%Z)
1	10	1	2.5
2	15	1	2.5
3	25	1	2.6
4	37.5	1	2.67
5	50	1	3
6	75	1	3
7	100	3	3

Characteristics of the cable model used in the network have been given in Table 3.4. AWG model D-3(4/0) type cable has been used for high voltage phase line, model D-2(1/0) type has been used for high voltage neutral line and D-11 model type cable has been used for low voltage line (from transformer to load energy meter).

Table 3.4. Cable Model Information used in the Existing System [24]

Model	Diameter of the conductor (mm)	Resistance /KM (Ω)	Current Rating (A)
D-3(4/0)	14.30	0.9527	340
D-2(1/0)	10.11	0.55177	230
D-11	5.04	2.15	70

3.2 PROPOSED OPTIMIZED MODEL OF CUET DISTRIBUTION NETWORK

Modification has been done in the low voltage side of the distribution network as we are concerned about the reduction of the number of transformers while keeping the voltage profile almost as same as the previous network.

To implement the idea, the selected area needs to divide into a few zones and each zone should have some buildings and a three-phase transformer. A single-line diagram of the tentative zone model is represented in Figure 3.2. Power delivers to the load from the transformer through the LT cable. Here, during modeling, the voltage profile must be maintained at a level as if no low voltage problem arises during peak hours. At first, simplification has been done in the case of reduction of the number of transformers and after optimizing the number of transformers focus has been kept on the cable model.

In the existing system, the transformer is situated at the load center and a three-phase transformer is used for each load so it needs a small length of low-voltage cable. But in a simplified system, a three-phase transformer can supply power to more load.

3.3 OPTIMIZATION METHODOLOGY

A bus feeder in combination with various types of devices such as transmission lines, transformers, voltage regulators, induction machines, capacitor banks, and a mixture of distributed and spot loads results in a significantly complete system where numerous options can be examined [25]. Single-phase transformer capacities range from 10kVA to 75kVA and three-phase ranges from 100kVA to 250 kVA for pole mounted substation. The LV network provides for the connecting of single-phase or three-phase loads, with single-phase being preferred over three-phase. As a result, even if the feeder model is balanced, LV networks are simply unbalanced [26].

For meaningful distribution system analysis, correct information about the feeder parameter is necessary. Obtaining all of the relevant data is one of the most challenging challenges. However, these parameters are not known accurately in many cases (especially in developing countries) [27].

Generally, distribution feeder parameters are obtained by using these three approaches as follows:

1) Theoretical calculation method: Empirical equations can be used to compute the impedance and admittance of distribution feeders based on grounding state, line height, line arrangement, and other physical distribution feeder properties. Three-phase power systems were assumed to be balanced in the theoretical calculation [28].

2) Parameter measurement method: Feeder parameters can be measured using specific devices under operation or blackout of distribution feeders.

3) Parameter estimation method: Essentially, the feeder's component estimate method is based on measurement data from the feeder's two terminals. The feeder equivalent model can be used to determine the link between feeder parameters and data measured at the two terminals of a feeder. PMUs, SCADA, fault recorders, and other measurement devices can provide these measurements [28].

Network reduction is a method of lowering system complexity and associated time by deleting buses and lines from a circuit to reduce the number of variables that must be solved [29]. The majority of the required data is contained in feeder maps. Additional information from the utility's stored records includes standard pole layouts, individual conductors used on each line segment, three-phase transformer connections and voltage regulator settings.

Power losses in distribution networks are among the most critical performance indicators for the economic operations of electricity distribution businesses. As a result, the distribution system should be carefully planned to guarantee that it operates within allowed boundaries.

There are several reasons to occur system loss in a distribution network. The main causes (technical terms) are listed below [30]-

- Length of 11kV feeder line
- Overloaded/ under-loaded Distribution Transformer
- Length of Low-tension line
- Pole size
- Loose connection
- Not connected to an appropriate grounding
- Not properly wiring the transformer
- The wrong size of LT cable.

The losses due to the technical terms mentioned above, maybe reduce by proper planning and modeling of a distribution network. The losses may be reduced by minimizing the length of the 11kV line as low as possible. Also, the size of the cable used in the line should be according to the transformer rating and current flow. Moreover, the length of the LT line should be minimized by proper load distribution.

3.3.1 Number of Transformer Optimization

The transformer is one of the costliest and most important pieces of equipment in any power system [31]. As it is a costlier device, the decision should make carefully to install a transformer in any location because it should not be running overloaded or underloaded. Normally during installation, the transformer rating keeps a fixed percent more than the load demand of that zone, thinking about the future extension of demand. The distribution transformer parameters are not sensitive to the played-in voltages, it is important to represent the distribution transformer parameters accurately in the considered feeder and load model [32].

The most important is the selection of transformer rating. During selection kVA rating, voltage rating, impedance setting and no-load power loss must be considered. The formula for calculating the transformer's kVA is straightforward [33]. The first is that, I only need the load's current and voltage needs. Then, using equations 3.1 and 3.2, multiply them and divide the result by 1000 to express it in kVA.

The formula for a single-phase transformer is:

$$kVA = \frac{Load\ voltage \times Load\ Current}{1000} \tag{3.1}$$

And for a three-phase transformer:

$$kVA = \frac{Load\ voltage \times Load\ Current \times \sqrt{3}}{1000} \tag{3.2}$$

Another method to find the kVA capacity, I need to prepare the load list which is fed to the transformer, along with their active (kW) and reactive (kVAR) power requirements. Then need to identify the type of transformer based on cooling. After that, I need to keep some spare capacity for overcoming the overloading. Now by adding the kW requirements for loads from the load list and the spare kWs and kVARs, the total kW and kVAR have been obtained, and the total load kVA has been found using equation 3.3 below.

$$kVA = \sqrt{((kW)^2 + (kVAR)^2)} \tag{3.3}$$

Assuming all loads to be operating at their maximum capacity, the voltage drop at the farthest bus should be </=5% [4]. If this criterion did not mate, I increased the rated kVA and again sew the voltage drop.

If the kVA satiates all the above-mentioned criteria, only then consider it as the selected kVA.

Only four types of three-phase distribution transformers have been used for the optimized model. Three-phase transformer ratings and other parameters are given in Table 3.5.

Table 3.5 Configuration of Transformers Used in the Optimized Model

Transformer KVA Ratings	Phase	%Impedance (%Z)	Reactance Ratio XHL (%)
100	3	4	4
150	3	4	5.7
200	3	4	4.5
250	3	4	4.2

The percentage of impedance has given in the nameplate of the transformer provided by the manufacturer directly. Sometimes manufacturers provide information about impedance voltage, then %Z can be calculated by equation 3.4 given below.

$$\%Z = \frac{Impedance\ Voltage}{Rated\ Voltage} \times 100 \quad (3.4)$$

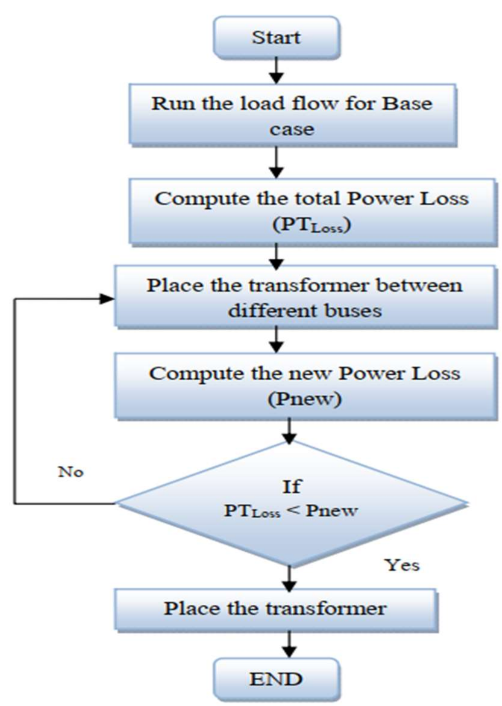


Fig. 3.2 Flow Chart for uses for Finding the Placement of Distribution Transformer [3].

To find the suitable location for the transformer where the total system loss has been reduced is found by the algorithm given in the above Figure 3.2.

Table 3.6 gives the transformer information placement for the transformer in the modified system.

Table 3.6. List of Transformer, Configuration and Location for Optimized Model

Sl. no	Transformer Name	kVA	Load	Placement
1	Taudi	250	Auditorium, Academic Building 5, Engineering Section	Bus 8L3
2	Tce	200	Academic Building 1, New Library Building Old library building	Bus 10_1
3	Teme	200	Academic Building 2 Mechanical Workshop	Bus 13
4	Tcse	150	Academic building 3	Bus 14_2
5	Tladies	250	Answer Camp Samseen Nahar Hall VC Residence	Bus 16
6	Twskhall	150	Sufia kamal Hall Garage and Pump House	Bus 19
7	Tbanglow1	150	Banglow Ka 1 & ka 2 Banglow Ka 3 & ka 4 Banglow Ka 5 Banglow Kha 11 & Kha12	Bus 24_6_4
8	Tga	150	Building Ga 1 Professors Building 2 Residential Mosque Car Wash and Garage	Bus 24_13_1
9	Tgha	200	Building Uma 1 Building Gha 3 & Gha 4 Building Gha 1 & Gha 2	Bus 24_13_6
10	Tdormitory	200	Teachers Dormitory	Bus 24_13_5_3_2
11	Tcuets&c	100	CUET School and College	Bus 24_13_5_3_5
12	Tnpb1	200	New Professors' Building 1 Banglow Kha 3 & Kha 4 Banglow Kha 5 & Kha 6 Banglow Kha 7	Bus 24_14_6
13	Tcha	250	Cha 1 & Cha 2 Cha 3 & Chaa 7 Banglow Kha 8, Kha 9 & Kha 10 Professors' Building 1	Bus 24_14_1

14	Tja	250	Building Ja-1, Ja-2, Ja-3, Ja-4 & Ja-5 Stuff Dormitory	Bus 24_16_5
15	TchaaA	100	Building Chaa-1, Chaa-2 & Chaa-3.	Bus 24_18_2
16	TchaaB	150	Building Chaa-4, Chaa-5 and Chaa-6.	Bus 24_21
17	Tsrhall	200	Central Mosque Sheik Rasel Hall CUET School and College Dormitory	Bus 29L1
18	Tqkhall	150	Q K Hall Extension Q. K Hall	Bus 29R1
19	Ttsc	200	TSC Canteen	Bus 33
20	Tsmshall	200	South Hall North Hall	Bus 34_1
21	Tbbhall	200	Bangabandhu Hall Medical Centre	Bus 42
22	Tsb	150	Sonali Bank Hall Extension Police Station	Bus 50
23	Tpme	200	Academic Building 4	Bus 56
24	Tadmin1	200	Administrative Building 1 Pre-Engineering Building West and East gallery	Bus 26_3
25	Tadmin2	200	Administrative Building 2	Bus 26_5

At least 25 nos. three-phase transformers of different ratings need to support the whole distribution system but more length of low voltage cable has to use to connect from transformer to load point. Fig 3.3 shows the single line diagram of optimized CUET distribution network where the placement of three phase transformer shown in red circle. Table 3.7 represents the number of transformers and cable length comparison for both (proposed and existing) systems.

Table 3.7. Comparison of Existing and Optimized Models

Compare Parameter	Existing System	Modified System
No of three phase Transformer Bank	51	25
Length of HT cable (km)	4.81	3.74
Length of LT cable (km)	1.88	3.51

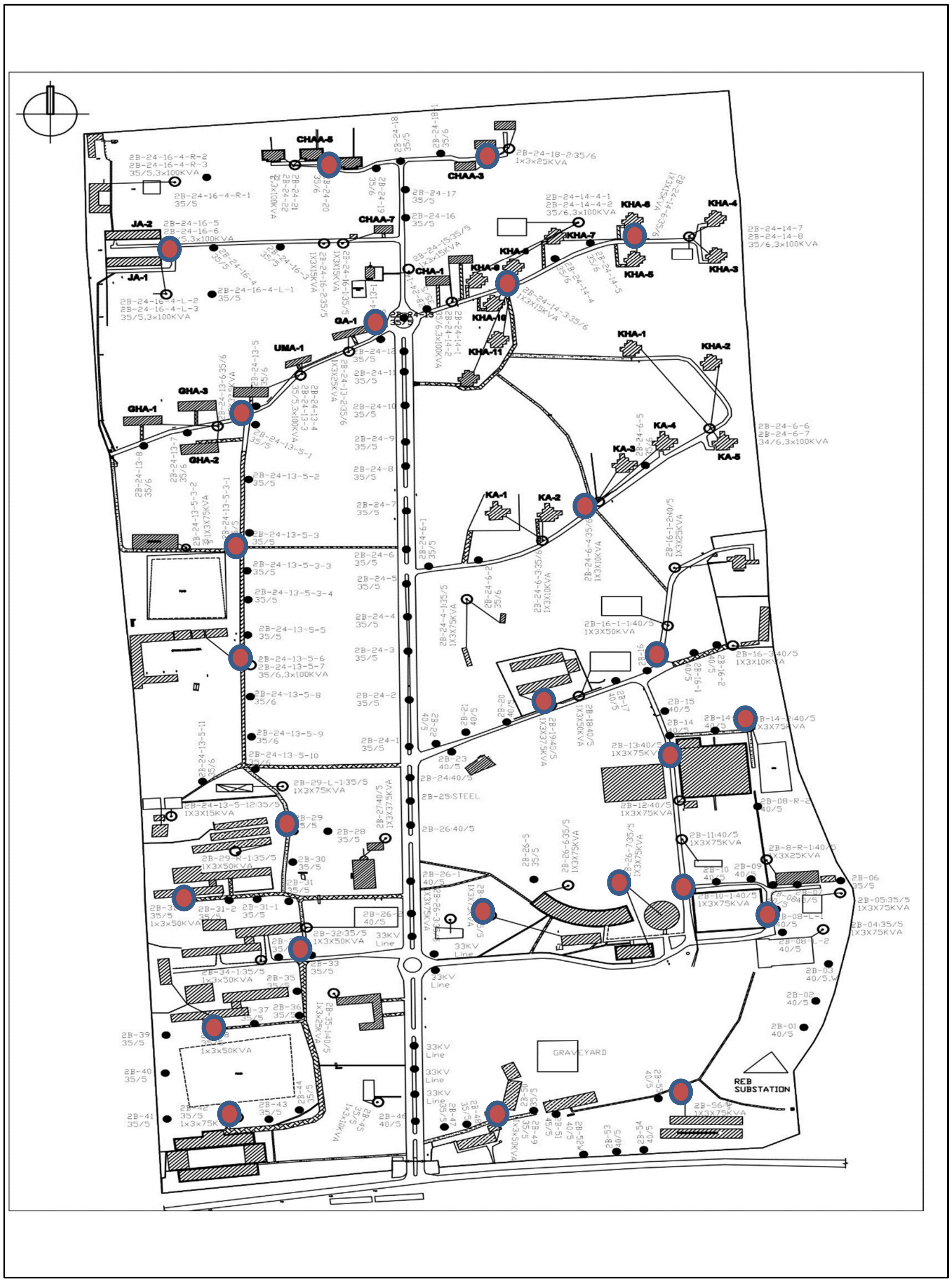


Fig. 3.3 Single Line Diagram of Optimized CUET Distribution Network

Some future load has been predicted for the future load extension and as a vision of the university for the year 2035. This load has been added to the optimized model and simulated to analysis whether the optimized distribution system could sustain the extended load or other steps have to take. Table. 3.8 has given the information about the predicted load which has been collected from the Planning and Development (P&D) section of the university.

Table 3.8 List of Horizontal Load Extension of CUET by the Year 2035

Sl. no	**Name of the Building**	**Load Prediction (kW)**
1	Professor Quarter (10 Storied Building)	64.5
2	Studio Apartment (10 Storied Building)	80
3	Stuff Quarter (5 Storied building)	30
4	Medical Center (3 Storied Building)	15
5	Residential Hall Male Student (5 Storied Building)	64.5
6	Residential Hall-1 Female Student (5 Storied Building)	64.5
7	Residential Hall Post-Graduate Student (5 Storied Building)	50
8	Residential Hall-2 Female Student (5 Storied Building)	64.5
9	New Teachers' Dormitory (3 Storied Building)	30
10	New Auditorium	30
11	New Residential Area Mosque	15
12	Pro-VC Bangalow	10
13	Guest House (3 Storied Building)	21
14	Community Center	21
15	Staff Dormitory (3 storied Building)	30

3.3.2 Cable Model Selection

An ideal conductor has the lowest cost, the least power loss, the largest thermal capacity, and the best voltage profile overall buses. Accurate models are needed for three-phase unbalanced overhead lines' impedance estimates. Depending on load requirements, consumer loads may be connected to the distribution system through feeders, distributors, or service mains. In general, one of the largest causes of distribution system loss is the conductor. So, it is crucial to choose a conductor that is economical and ideal. Due to larger currents and lower voltages, the distribution system loses more power than a transmission system with a higher voltage. Rural distribution networks are typically radial in design, with a single direction of power flow. The resistance is determined after reading a conductor data table, based on the type of conductor used in the feeder [27] and the reactance of the feeder is calculated from the knowledge of the geometric configuration of the conductors in the feeder. During cable modeling parameters like geometric mean radius (GMR), wire diameter, resistance and current capacity needs to be considered.

The present distribution feeder has been simulated numerous times in OpenDSS for various line conductors as part of this study. The voltage magnitude at each bus, active power loss, ampere flow in each line section, etc.) are measured as part of the feeder's load flow analysis, and the findings are compared. Based on these comparisons, the feeder's best conductors, which have a better voltage profile, fewer losses, lower costs, and generate more income, have been chosen for the various line sections. Three different cable model performances have been seen in this optimized system for the low-voltage line, but the high-voltage cable model has been left unchanged from the current network. Characteristics of that type of cable have been given in Table 3.9.

Table 3.9. Cable Types and Parameter used in the Optimized Model [24], [34]

Model	**Diameter of the conductor (mm)**	**Resistance /KM (Ω)**	**Current Rating (A)**
WASP	13.2	0.28	260
ANT	9.3	0.55	172
D-11	5.04	2.15	70

3.3.3 Load Demand

Spot loads and dispersed loads both include the assumption that loads are evenly distributed over a line section. Single-phase or three-phase loads are also possible. Single-phase loads can be connected line-to-ground, whereas three-phase loads can be connected in a wye connection or a delta connection. Residential loads are made up of an assortment of electrical appliances from different houses, some of which exhibit linear behavior and others that exhibit nonlinear features [20].

A constant kW and kVAR (PQ), constant impedance (Z), or constant current (I) model can be applied to all loads. The codes that use typically to characterize the various loads are listed in Table 3.10.

Table 3.10. List of Load Model Codes and Description [35]

Model No.	**Load Model Codes**	**Code Connection Model**
Model 1	Y-PQ	Wye Constant kW and kVAR
Model 2	Y-I	Wye Constant Current
Model 3	Y-Z	Wye Constant Impedance
Model 4	D-PQ	Delta Constant kW and kVAR
Model 5	D-I	Delta Constant Current
Model 6	D-Z	Delta Constant Impedance

An exact representation of the load is not achievable. The loads on the distribution system are not consistent and the metering is prone to error. In a thorough modeling analysis for a utility distribution feeder, some of these modeling difficulties have to be taken into account. The units of measurement for all load information are kW and kVAR or kW and power factor per phase. The conversion of kW and kVAR for constant current and constant impedance loads should be done assuming rated voltage (1.0 per unit). Phases 1, 2, and 3 of wye-connected loads are connected as a-g, b-g, and c-g, respectively, while phases a, b, and c of delta-connected loads are connected as a-b, b-c, and c-a, respectively.

Equipment generally use for household application can be assigned to-

1) Brown goods

Brown products are electronic consumer goods that are relatively light. They are classified as either office/communication or entertainment equipment. There is no fixed limit between these appliances, and their interaction is shifting as this sector innovates rapidly.

- Office/communications equipment, such as a PC, LCD, printer, scanner, phone, router and so on.
- Electronics for entertainment: TV, CD/DVD player, hi-fi system, video gaming console, projector and so on.

2) White goods

Major appliances and whiteware are other terms for white goods. They are large domestic equipment that performs typical housekeeping activities like cooking, food preservation, and cleaning.

- Kitchen appliances such as a stove, refrigerator, freezer, dishwasher, microwave and so on.
- Laundry appliances: washing machine, dryer, drying cabinet and so forth.
- Air conditioner, water heater and so on.

3) Small Appliances

In comparison to brown and white goods, small appliances are portable or semi-portable.

- Kitchen appliances such as a kettle, toaster, blender, waffle maker, juicer, coffee machine and so on.
- Household appliances such as a fan, iron, sewing machine, vacuum cleaner, clock and so on.
- Electronic devices, such as cell phones, digital (video) cameras, radios, mp3 players, digital photo frames, netbooks, e-book readers and so on.
- Personal care items such as a hair dryer, curling iron, shaver, electric toothbrush and so on.

To calculate the residential or academic load firstly need to sum and calculate all the wattage rating of all lighting branch circuits, permanent appliances and also plug-in outlet circuits.

$$kW = \frac{W\ of\ all\ lighting\ load + \quad of\ all\ permanent\ appliance + W\ of\ Plug\ in\ outlet\ circuit}{1000} \qquad (3.5)$$

Another approach may be used to determine the total load of a building by exploring the ampere rating of the circuit breaker going from the energy meter to the building. After that multiply the ampere with the supply voltage and power factor, as the formula for calculating power is given below-

$$P = V \times I \times cos\theta \qquad (3.6)$$

In most of the case power rating of buildings like student halls, academic buildings and administrative buildings has been calculated by the second approach as the load calculation for these types of buildings is almost difficult due to continuous changes in load demand. By selecting the ampere rating of the circuit breaker maximum probable load has been taken into account for the simulation.

The load demand for the residential building is almost fixed which can be achieved from the load curve of that building. These load data were collected from the Engineering Section of the university and given in the following Table 3.11.

Table 3.11. Existing Load Name, Location and Demand

Sl. No	Load Name	Load Location	Load Demand (kW)
1	New Load.2baudi	Bus1=Laudi	64.5
2	New Load.2burp	Bus1=Lurp	64.5
3	New Load.2bengr	Bus1=Lengr	30
4	New Load.2b.ce	Bus1=Lce	64.5
5	New Load.2bnlib	Bus1=Lnlib	45
6	New Load.2b.eme	Bus1=Leme	64.5
7	New Load.2b.wshop	Bus1=Lwshop	64.5
8	New Load.2bcse	Bus1=Lcse	80
9	New Load.2bwnhall	Bus1=Lwnhall	64.5
10	New Load.2bvcres	Bus1=Lvcres	21
11	New Load.2banswer	Bus1=Lanswer	15
12	New Load.2bwsnhall	Bus1=Lwsnhall	64.5
13	New Load.2bwskhall	Bus1=Lwskhall	45
14	New Load.2bg&p	Bus1=Lg&p	64.5
15	New Load.2bka1	Bus1=Lka1.1	4
16	New Load.2bka2	Bus1=Lka2.2	4
17	New Load.2bka3	Bus1=Lka3.1	4
18	New Load.2bka4	Bus1=Lka4.2	4
19	New Load.2bka5	Bus1=Lka5.1	4
20	New Load.2bkha1	Bus1=Lkha1.2	4
21	New Load.2bkha2	Bus1=Lkha2.3	4
22	New Load.2bga1	Bus1=Lga1	9
23	New Load.2bpb2	Bus1=Lpb2	24
24	New Load.2buma1	Bus1=Luma1	9
25	New Load.2bgha4	Bus1=Lgha4	18
26	New Load.2bgha3	Bus1=Lgha3	18
27	New Load.2bgha2	Bus1=Lgha2	18
28	New Load.2bgha1	Bus1=Lgha1	18
29	New Load.2btd	Bus1=Ltd	80
30	New Load.2bcuets&c	Bus1=Lcuets&c	45
31	New Load.2bstd	Bus1=Lstd	15
32	New Load.2bcha1	Bus1=Lcha1	18
33	New Load.2bcha2	Bus1=Lcha2	18
34	New Load.2bkha10	Bus1=Lkha10.1	4
35	New Load.2bkha11	Bus1=Lkha11.2	4
36	New Load.2bkha12	Bus1=Lkha12.3	4
37	New Load.2bpb1	Bus1=Lpb1	24
38	New Load.2bkha8	Bus1=Lkha8.3	4
39	New Load.2bkha9	Bus1=Lkha9.2	4

40	New Load.2bkha7	Bus1=Lkha7.1	4
41	New Load.2bkha6	Bus1=Lkha6.2	4
42	New Load.2bkha5	Bus1=Lkha5.3	4
43	New Load.2bkha4	Bus1=Lkha4.1	4
44	New Load.2bkha3	Bus1=Lkha3.2	4
45	New Load.2bnpb1	Bus1=Lnpb1	24
46	New Load.2bmoq	Bus1=Lmoq	15
47	New Load.2bcha3	Bus1=Lcha3	24
48	New Load.2bchaa7	Bus1=Lchaa7.1	4
49	New Load.2bcws	Bus1=Lcws.1	4
50	New Load.2bja1	Bus1=Lja1	18
51	New Load.2bja2	Bus1=Lja2	18
52	New Load.2bja3	Bus1=Lja3	18
53	New Load.2bja4	Bus1=Lja4	18
54	New Load.2bsd	Bus1=Lsd	24
55	New Load.2bja5	Bus1=Lja5	24
56	New Load.2bchaa1	Bus1=Lchaa1	18
57	New Load.2bchaa2	Bus1=Lchaa2	18
58	New Load.2bchaa3	Bus1=Lchaa3	18
59	New Load.2bchaa4	Bus1=Lchaa4	18
60	New Load.2bchaa5	Bus1=Lchaa5	18
61	New Load.2bchaa6	Bus1=Lchaa6	24
62	New Load.2bab1	Bus1=Lab1	64.5
63	New Load.2bwg&eg	Bus1=Lwg&eg	9
64	New Load.2bpeb	Bus1=Lpeb	45
65	New Load.2bab2	Bus1=Lab2	45
66	New Load.2bolib	Bus1=Lolib	15
67	New Load.2b.cmoq	Bus1=Lcmoq	15
68	New Load.2b.srhall	Bus1=Lsrhall	64.5
69	New Load.2b.qkhex	Bus1=Lqkhex	15
70	New Load.2b.qkhall	Bus1=Lqkhall	40
71	New Load.2b.tsc	Bus1=Ltsc	64.5
72	New Load.2b.sthhall	Bus1=Lsthhall	40
73	New Load.2b.canteen	Bus1=Lcanteen	9
74	New Load.2b.smshall	Bus1=Lsmshall	40
75	New Load.2b.bbhall	Bus1=Lbbhall	80
76	New Load.2bmc	Bus1=Lmc	15
77	New Load.2bsbA	Bus1=Lsb.1	6
78	New Load.2bsbB	Bus1=Lpc.2	6
79	New Load.2bsbC	Bus1=Lsms&bb.3	20
80	New Load.2bpme	Bus1=Lpme	64.5

3.3.4 Overhead Line Modelling

The distance between the conductors and the conductor-to-ground distance would fluctuate as a result of the conductor's sag. The self and mutual reactance of a three-phase line would change with these changes in distances, even for a specific grounding condition, as shown by the equations of self and mutual reactance [27]. During the line modeling, there should be kept spacing among the phases, also need to know the wire data. Overhead lines must maintain a specific distance from the ground. In this system all the SPC pole is almost 40 feet in height, so they must be digging 6 feet deep in the ground.

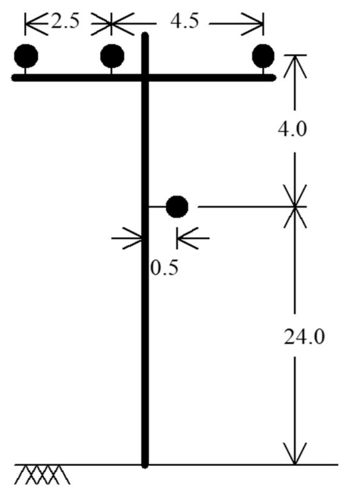


Fig. 3.4. Line Spacing for Phase Conductor and Neutral Conductor [30]

Figure 3.4 shows the line spacing for three phase four wire system which has been considered in this research.

3.4 SIMULATION SOFTWARE-OPENDSS

A thorough electrical system simulation tool for electric utility distribution systems is the Open Distribution System Simulator (OpenDSS or just DSS). The Electric Power Research Institute created the open-source software known as OpenDSS [36]. A standalone executable platform and an in-process COM server DLL that can be used to drive OpenDSS from a variety of other platforms are the two available implementations of the technology.

Users can create scripts and see solutions using the executable version's simple User Interface on the DSS solution engine. A text-programming standalone user interface serves as the basic user interface and is adequate for the majority of the analysis. All common steady-state analyses for electricity distribution systems can be supported by OpenDSS. The most significant benefit of OpenDSS is that it permits analysis with time series power flow and distributed generation integration. By adding user-developed DLLs to the solution engine, OpenDSS can be enhanced to accommodate new requirements.

3.4.1 OpenDSS Architecture

Figure 3.5 depicts the OpenDSS engine's architecture. The distribution system simulation is managed by a DSS executive in the primary simulation engine. Five object classes make up the various distribution components, including-

- Power Delivery elements
- Power Conversion elements
- Controls
- Meters
- General

The construction of the bus lists and the adjustment of the primitive Z and Y matrices for each component of the circuit are handled by the Open DSS executive structure, which was built in Delphi.

The DSS executive also manages the execution of the control elements and the meter elements, which are used to collect results. The system Y matrix is created by feeding the sparse matrix solver the Y primitive matrices. The voltages are first estimated using a no-load power flow solution. Cutting off the shunt elements while preserving the series power delivery elements, is accomplished.

This is done to ensure that the relationship between the phase angles and voltage magnitudes is correct.

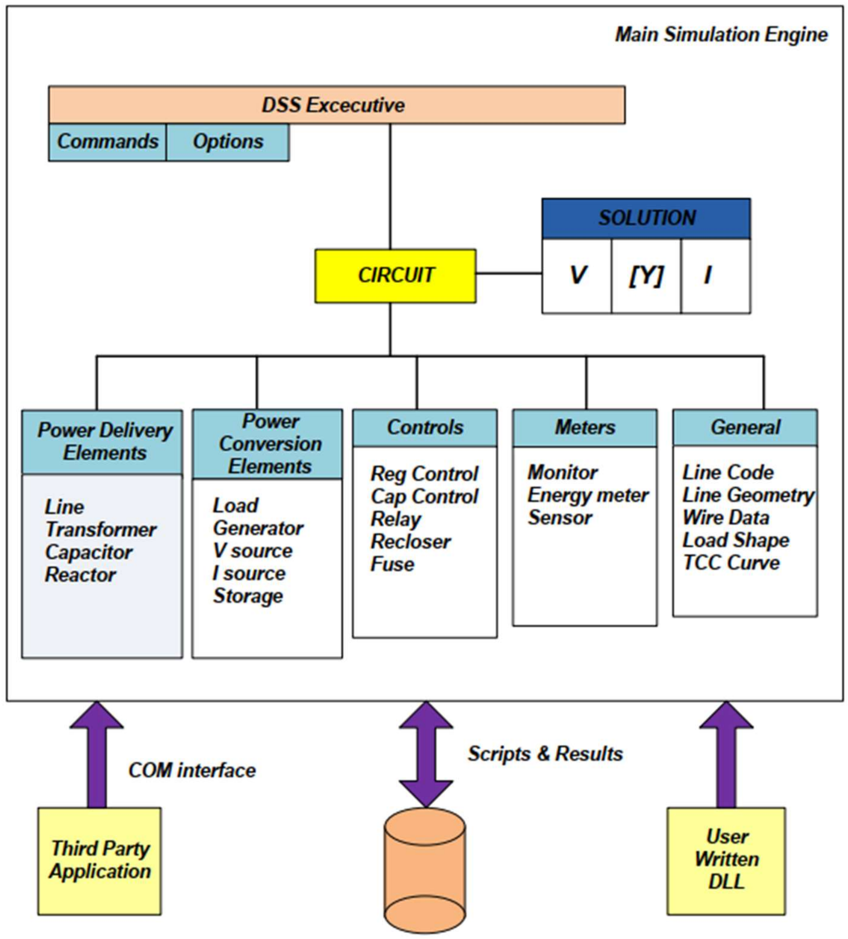


Fig. 3.5 OpenDss Architecture [37]

The current injections from each of the power conversion components are collected, and they are then added to the line vector to begin the iteration cycle. Iteratively solve the sparse collection of matrices until the voltages converge to the required tolerance. For the majority of distribution systems with sufficient capacity to fulfill the demand, it is discovered that this straightforward iterative solution converges well. When running yearly or daily simulations, the current time step's solution serves as the starting point for the subsequent time step's solution [38].

Unless there is a significant change in the load, the solution usually converges in two iterations. If control actions are required after a converged solution, control iterations are carried out.

Since the power flow problem is the most commonly solved using the program, OpenDSS is not a power flow program. It derives from general-purpose harmonic analysis tools, giving it some unique and powerful capabilities. Originally, the application was intended to do harmonics analysis as part of distribution planning for distributed generating. OpenDSS is intended to execute a distribution power flow for small to medium-sized feeders when the bulk power system is the primary energy source. The circuit model could be a multi-phased or positive sequence.

The power flow can be executed in numerous solution modes such as the Single snapshot mode, Daily mode, Duty Cycle mode and Monte Carlo mode. The time duration can be any arbitrary period and commonly, for planning purposes it can be a 24-hour day, a month or a year.

There are two essential power stream arrangement types given by OpenDSS, in particular the iterative and direct power flow arrangements. Loads and distributed generators are regarded as injection sources in the iterative power flow mode. For the iterative power flow mode, two power flow calculations are right now utilized to be specific, normal current injection mode and Newton current injection mode. While the Newton mode is more durable for circuits that are challenging to solve, the normal mode is typically faster. The normal mode is a straightforward iterative method with a fixed point that works well for almost all distribution systems. Due to its speed, it is the preferred method for annual simulations. In the direct solution mode, the system admittance matrix is directly solved without iterating after the loads and generators are included as admittances.

With non-linear load models, power flow calculations typically use an iterative solution, whereas, with linear load models, fault studies use a direct solution. As depicted in Figure 3.5, the losses, voltages, flow, and other data for the system, each component and a few designated areas are accessible following the completion of the power flow. For each time moment, losses are accounted for as kW losses and energy meter models are utilized to coordinate the control throughout a period span. OpenDSS is used to carry out a three-phase unbalanced distribution power flow for the AEP feeder in this thesis.

The power flow can be carried out in a variety of solution modes, including Single, snapshot, Daily, Duty Cycle, and Monte Carlo. The length of time can be anything, but for planning purposes, it is typically a 24-hour day, a month, or an entire year.

3.4.2 Simulation Methodology

The X and Y coordinates, which correspond to the actual physical location of every system component, serve as the starting point for the OpenDSS utility feeder model's geographical location.

The overhead line objects require detailed modeling in OpenDSS. The above line models have three parts, to be specific the wire information, the line math and the line definition. The wire information characterizes the actual transmitter information used to process the impedances for the line. The transformer object has two or more windings, and each winding has its own set of parameters.

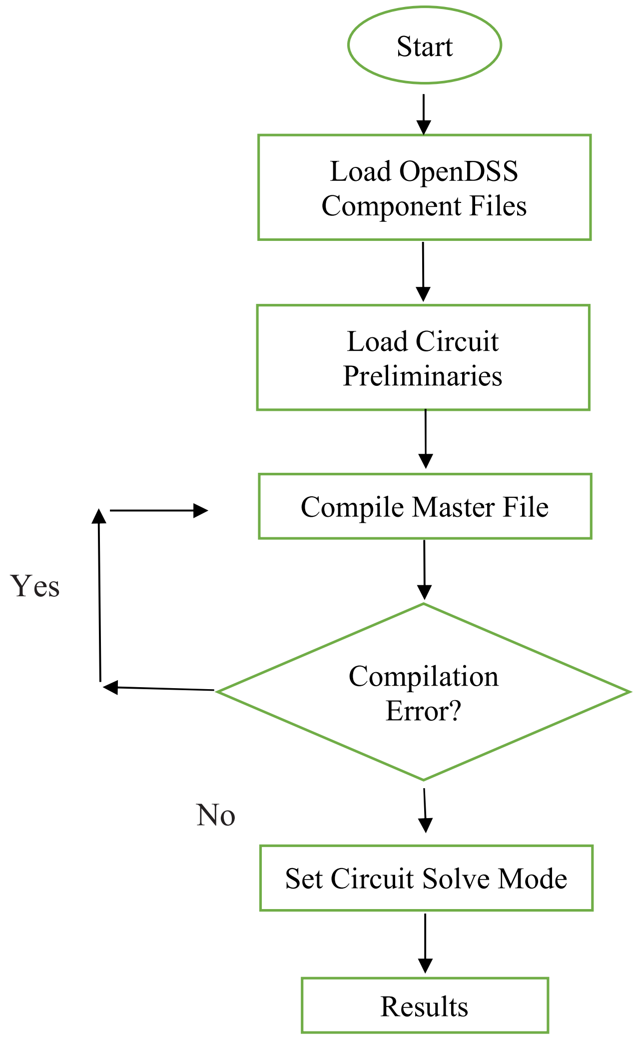


Fig. 3.6 OpenDss Code for Line Code Definition

Fig. 3.6 shows the flow chart for the operating model in OpenDSS. A detailed one-on-one parameter mapping needs to model every component in OpenDSS.

After giving all the component information the master file can compile which can coordinate all the component files and give the simulation output.

3.4.3 Power Delivery Component

Lines and transformers are the most common multi-phased power delivery elements, transporting energy from one location to another.

3.4.3.1 *Line Object:*

Most multi-phase, two-port lines or cables are represented by the Line element. The line impedance at a base frequency can be defined directly in a Line object definition, or it can be imported from a LineCode object. Both of these impedance definitions are very similar, with the exception that the LineCode object may execute Kron reduction. All previous definitions are ignored if the geometry attribute is provided. Each time the frequency changes, the DSS computes the impedance matrices from the provided geometry. The following Table 3.12 describes the parameters that have to use to model the transmission and distribution line object.

Table 3.12. List of Parameters Used to Define Line Object [35]

Sl no.	Name of the Parameter	Description
1	Bus1	Name of the bus for terminal 1.
2	Bus2	Name of the bus for terminal 2.
3	Line-code	Name of an existing Line-code object containing impedance definitions
4	Length	Length multiplier to be applied to the impedance data.
5	Phases	No. of phases. Default = 3

3.4.3.2 *Transformer Object:*

The transformer is implemented as a multi-terminal power delivery element. The following Table 3.13 describes the parameters that have to use to define the transformer object.

Table 3.13. List of Parameters Used to Define Transformer Object [35]

Sl no.	Name of the parameter	Description
1	Phases	The number of phases. Default is 3
2	Wdg	An integer representing the winding that has become the active winding for subsequent data.

3	Bus	Definition for the connection of the winding
4	Conn	Connection of the winding.
5	kV	Rated voltage of the winding, kV.
6	kVA	Base kVA rating of the winding
7	Tap	Per unit tap on which the winding is set
8	%R	Percent resistance of the winding on the rated kVA base.
9	XHL	Percent reactance high-to-low (winding 1 to winding 2)

3.4.4 Power Conversion Component

Power conversion elements are responsible for transferring electrical energy from one form to another. These parts can also temporarily store energy. Loads and generators are the most frequently used components in power conversion.

The load is the fundamental power conversion component of all power flow and voltage drop analyses. The following Table 3.14 describes the parameters that have to use to define the load component.

Table 3.14. List of Parameters Used to Define Load Component[35]

Sl no.	Name of the parameter	Description
1	Bus1	Name of bus to which the load is connected
2	Phases	No. of phases this load
3	kV	Base voltage for load.
4	kW	Nominal active power, kW, for the load
5	PF	Nominal Power Factor for load.
6	Model	Integer defining how the load varies with voltage
7	Conn	{wye | y | LN} for Wye (Line-Neutral) connection; {delta | LL} for Delta (Line-Line) connection. Default = wye.
8	kVAR	Base kvar

3.4.5 General Object Properties

General Objects are objects common to all circuits in the OpenDSS.

3.4.5.1 Line Code:

LineCode objects are general library objects that contain impedance characteristics for lines and cables. The impedance of a line is described by its series impedance matrix and nodal capacitive admittance matrix [39]. The following Table 3.15 describes the parameters that have to use to define the Line Code.

Table 3.15. List of Parameters Used to Define Line Code [35]

Sl no.	Name of the parameter	Description
1	Nphases	Number of phases. Default = 3.
2	Units	{mi | km | kft | m | ft | in | cm} Length units.
3	Rmatrix	Series resistance matrix, ohms per unit length.
4	Xmatrix	Series reactance matrix, ohms per unit length
5	Cmatrix	Shunt nodal capacitance matrix, nanofarads per unit length.
6	BaseFreq	Base Frequency at which the impedance values are specified. Default = 60.0 Hz.
7	Normamps	Normal ampacity, amps.

3.4.5.2 Line Geometry:

Line Geometry is the class of objects used to specify the position of the conductors, the type of conductors and the Kron reduction settings. The following Table 3.16 describes the parameters that have used to define the line geometry.

Table 3.16. List of Parameters Used to Define Line Geometry [35]

Sl no.	Name of the parameter	Description
1	Nconds	The number of conductors in this geometry. Default is 3
2	Nphases	The number of phases. Default =3
3	Cond	Set this to the number of the conductor wish to define. Default is 1.
4	Wire	Code for a WireData-class object
5	X	x coordinate.
6	H	Height of conductor above the earth
7	Units	Units for x and h: {mi|kft|km|m|Ft|in|cm } Initial default is "ft", but defaults to the last unit defined.
8	Normamps	Normal ampacity, amperes for the line.

Chapter 4: Simulation and Result Analysis

Chapter 4 illustrates the results from several case studies to observe the performance of our proposed distribution system. The main strategy is to analyze the existing system and then try to improve or keep the same voltage profile while reducing the number of transformers. If the number of transformers reduces, the power loss of the system reduces automatically. In this chapter, ten different scenarios from 5 different cases have been discussed. Section 4.1 explores the existing distribution system. Section 4.2 undertakes the re-configuration of the existing system without changing the configuration or location of any transformer. Re-configuration has been done by changing the cable configuration. Section 4.3 analyses the impact of changing the number, ratting and placement of transformers and also the cable configuration to find the optimized model. Finally, section 4.4 discusses the impact of horizontal load extension in the future and the sustainability of the optimized model with the extended load demand. The following Table 4.1 represents the constructed cases with their short descriptions.

Table 4.1. List of Cases and Scenarios Considered in this Research

Cases	**Features**	**Scenarios**
Case#1	Existing CUET Distribution Network	Scenario-1: Analysis by varying load power factor
Case#2	Simulation to Find Minimal Number of Transformers by changing ratings and placement of Transformer.	Scenario-1: Analysis by varying number of transformers.
		Scenario-2: Analysis by varying load power factor with the minimal number of transformers.

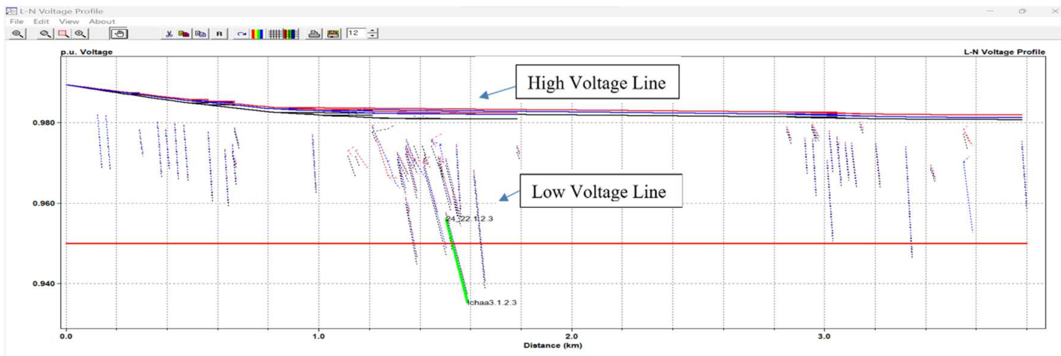
Case#3	Simulation to Find the Right LT Cable Type	Scenario 1: Analysis by varying load power factor to optimized model using LT cable model WASP.
		Scenario-2: Analysis by varying load power factor to optimized model using LT cable model ANT.
Case#4	Re-design of Existing CUET Distribution Network by Changing Low Voltage Cable Type.	Scenario-1: Analysis by varying load power factor to existing model using LT cable model ANT.
		Scenario 2: Analysis by varying load power factor to existing model using LT cable model WASP.
Case#5	Horizontal Load Extension to Optimized Model.	Scenario-1: Horizontal Load Extension Model Using D-11 Cable Type.
		Scenario-2: Horizontal Load Extension Model Using WASP Cable Type.
		Scenario-3: Horizontal Load Extension Model Using ANT Cable Type.

4.1 CASE# 1: EXISTING CUET DISTRIBUTION NETWORK

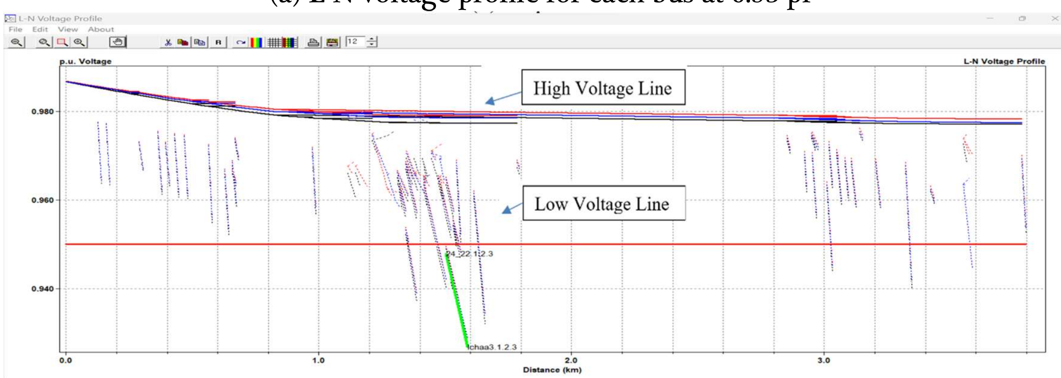
The existing CUET distribution network has been designed with 52 different kVA ratings of three transformer banks. Here, D-11 model type cable has been used as the low voltage cable which has a very little current carrying capacity compared to other types of cable and D-2 and D-3 model types of cable used for the phase and neutral connection of HVAC line. All the parameters (cable configuration, transformer configuration, load point) related to the system has been defined before in section 3.1 and section 3.3.

4.1.1 Scenario-1: Analysis by Varying Load Power Factor Value

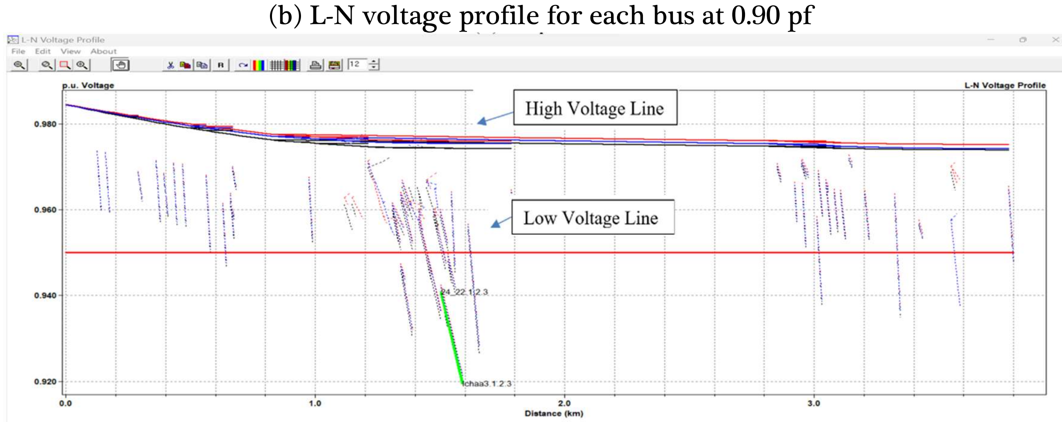
Figure 4.1 represents the output window of changes per unit voltage for both high voltage line and low voltage line with distance. The Solid line represents the per unit voltage for the high voltage line and the dotted line represents the per unit voltage for the low voltage line.



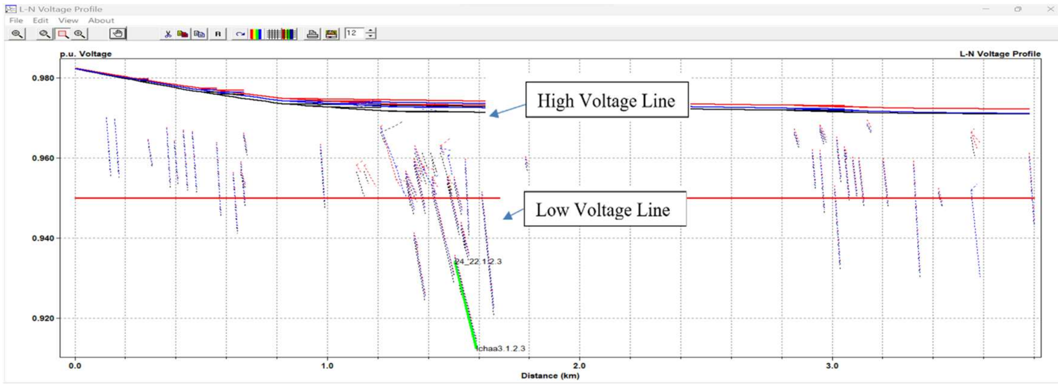
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf



(c) L-N voltage profile for each bus at 0.85 pf

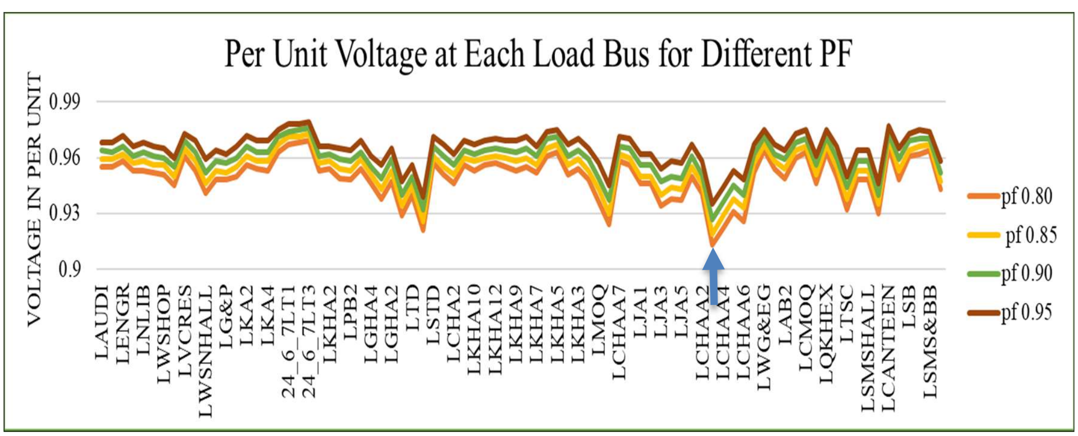


(d) L-N voltage profile for each bus at 0.80 pf

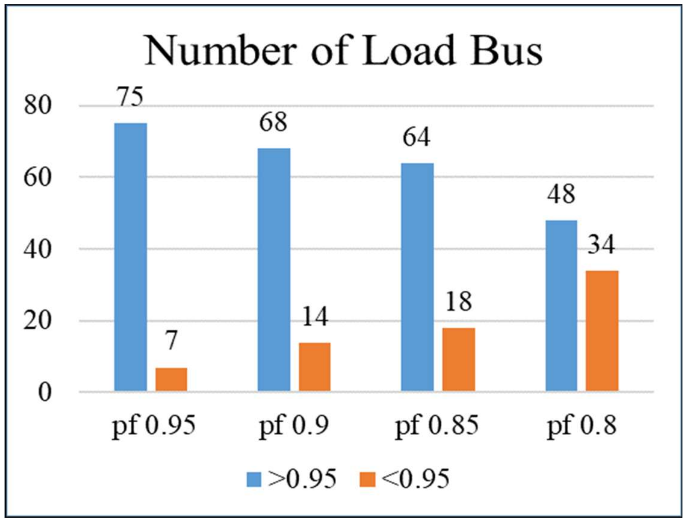
Fig. 4.1. Per Unit (p.u) voltage profile window from simulator for existing model at different load pf.

From the figure, it can easily be understood that the more distance from the source, the lower the value of voltage. It can also be seen in Figure 4.1(a), Figure 4.1(b), Figure 4.1(c) and Figure 4.1(d) for the variation of load power factor (pf) for 0.95, 0.90, 0.85 and 0.80 respectively. At pf 0.80 much more load point is under per unit (p.u.) voltage baseline than 0.95 load power factor.

Per unit voltage for high voltage line is almost between 0.99 to 0.97 p.u. voltage. The lowest per unit value is found at the bus “LCHAA3” as it is situated at the highest distance from the source transformer.



(a)



(b)

Fig. 4.2. (a) L-N p.u. voltage at different load bus at different load power factor for existing model (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.2 (a) represents a graph for the numeric value of per unit voltage at each load bus. The graph shows a clear change in p.u. voltages with load and power factor. The lowest value is found 0.913 at 0.80 pf at load bus "LCHAA3" indicated by an arrow. Again Figure 4.2 (b) represents the number of load bus different power factor and it is seen that 68 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

The following graph at Figure 4.3 represents active and reactive power loss in each three-phase transformer bank of the existing model. The more power factor decreases the more loss increases as the real power decreases. It is clear that most of the transformer's active power loss is below 1kW and the highest power loss is found 1.78kW and 4.89kVAR at 0.80 power factor for transformer bank "TR36" indicated by an arrow.

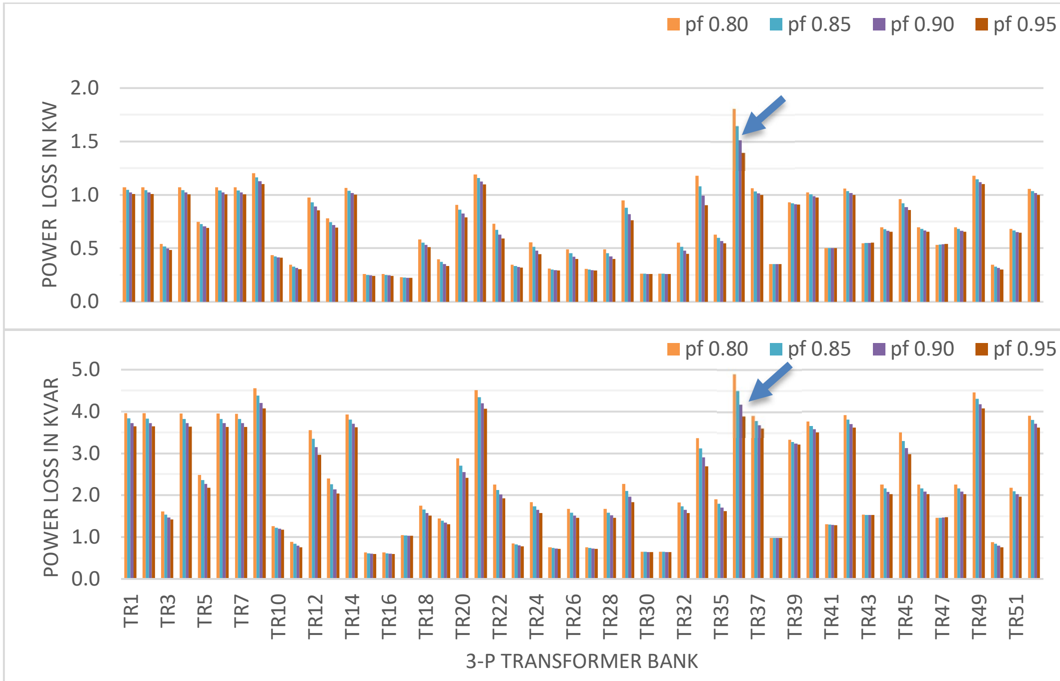


Fig. 4.3. Active and re-active power loss at different transformer for different power factor.

The following case#1 scenario-1 contains four individual simulations as here considered four different load power factor to analyse the power flow and system loss. The summary of that individual simulation file has been given in Table 4.2.

Table 4.2. Summary of Case#1 Scenario-1

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power (MW)	2.085	2.087	2.087	2.013
Reactive Power (MVAR)	0.82	1.14	1.42	1.63
Active Loss (MW)	0.078 (3.78%)	0.0854 (4.09%)	.0929 (4.45%)	0.098 (4.86%)
Reactive Loss (MVAR)	0.162	0.173	0.185	0.192

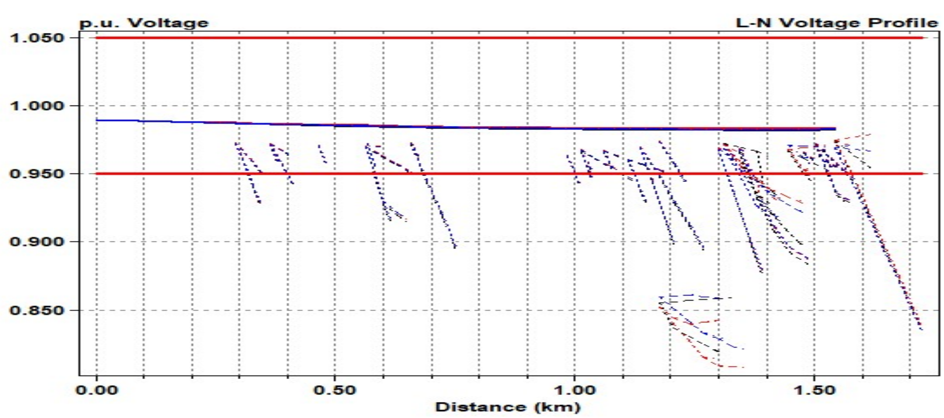
Here, from the table data, it is clear that power loss for both active and reactive power have been increased with power factor decrement.

4.2 CASE# 2: SIMULATION TO FIND MINIMAL NUMBER OF TRANSFORMER

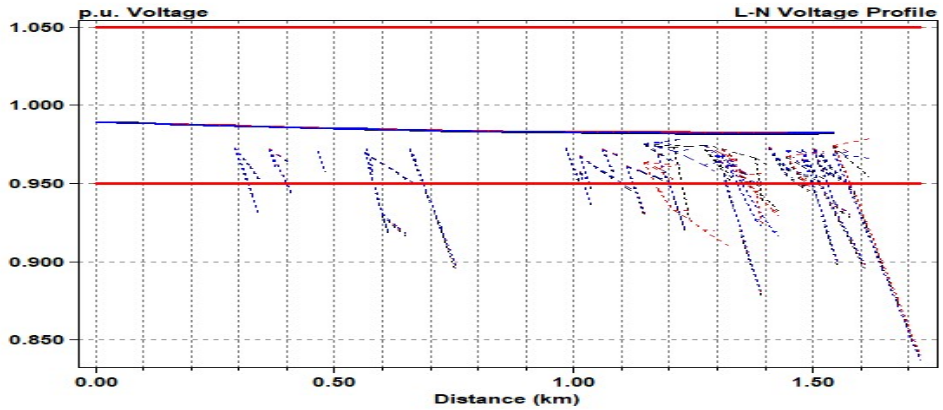
Three-phase transformers of different ratting have been used in the simulation. In the first scenario, several transformers have changed to a minimum number and tried to find the best output in terms of voltage profile improvement and loss reduction. In the second scenario, considering the best one having a minimal number of transformers and has tried to explore the performance in case of load pf variation. A single line diagram of this proposed network has given in Figure 3.3 and data related to this model has given in section 3.2 and section 3.3.

4.2.1 Scenario-1: Analysis by Varying Number of Transformer

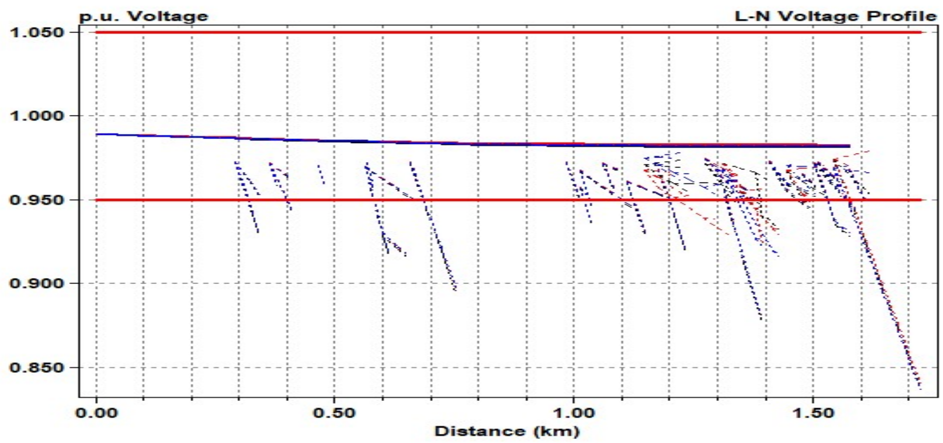
The distribution network has been divided into some regions and give one transformer to supply the necessary power. At first, 22 transformers are placed in the whole network and analysed whether it is enough to supply power with a good voltage profile or not. If it is not enough, another region has been created and re-distributed the whole load demand. Again, analysis has been done to justify the voltage profile. Scenario-1 represents the simulation models with 22-27 transformers. The results after the simulation are presented in Figure 4.5. The following Figure 4.5 represents the per unit voltage profile of each simulation model having 22-27 transformers.



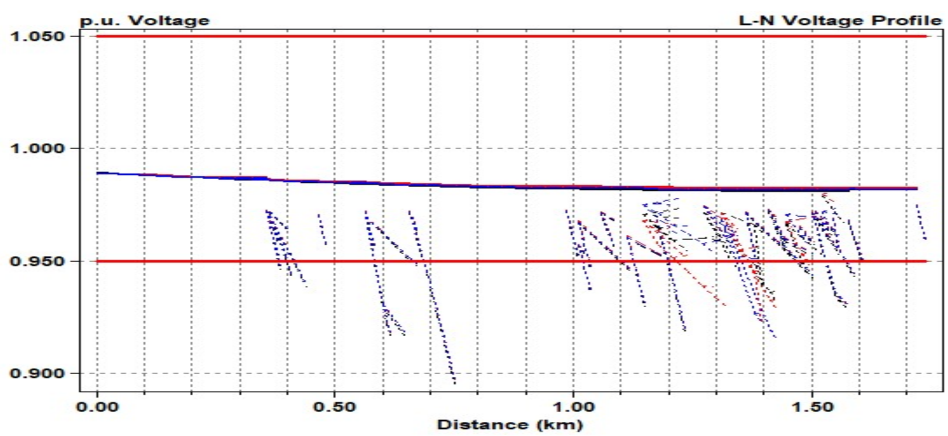
(a) L-N voltage profile for Optimized Model-1 (22 transformers)



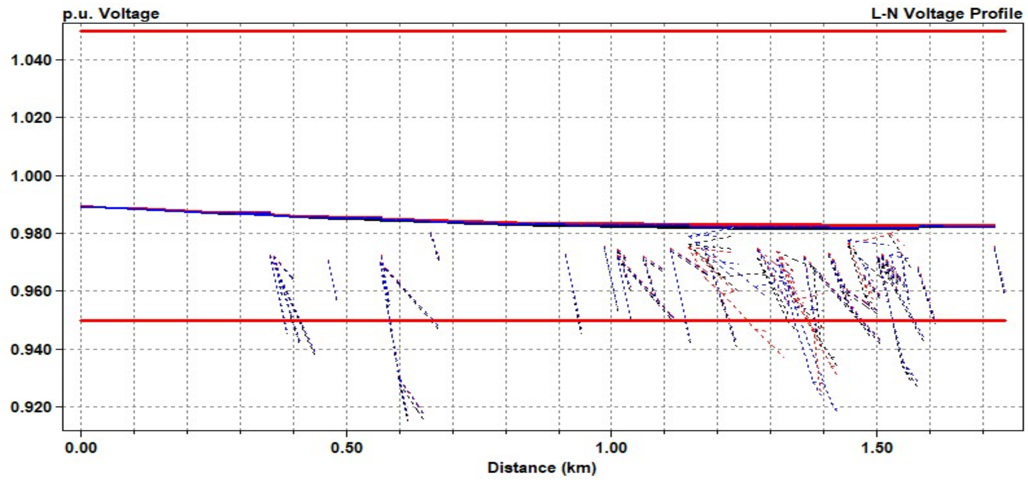
(b) L-N voltage profile for Optimized Model-2 (23 transformers)



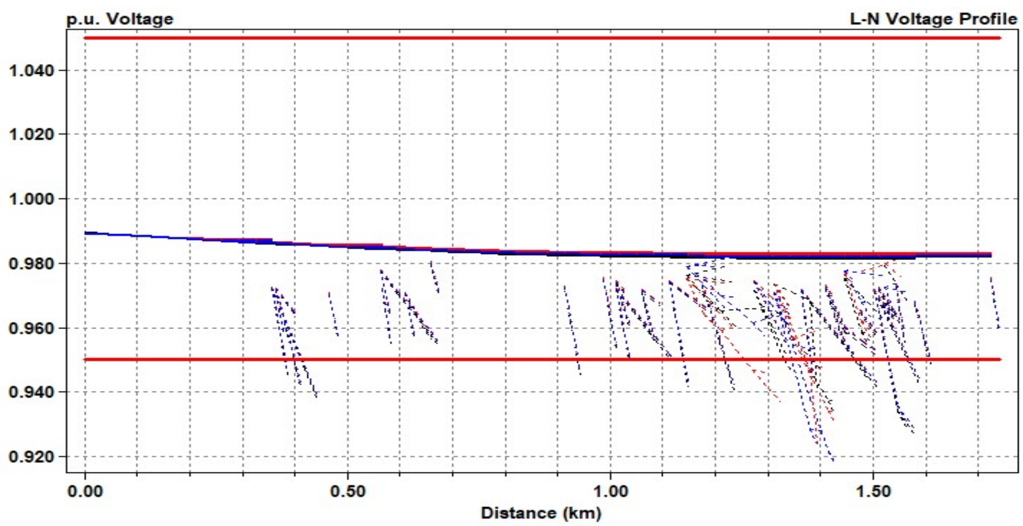
(c) L-N voltage profile for Optimized Model-3 (24 transformers)



(d) L-N voltage profile for Optimized Model-4 (25 transformers)



(e) L-N voltage profile for Optimized Model-5 (26 transformers)



(f) L-N voltage profile for Optimized Model-6 (27 transformers)

Fig. 4.4. Per Unit (p.u) voltage profile window from simulator finding a minimal number of transformer model.

Among all, Figure 4.4(f) represents the line to neutral voltage profile for optimized model-6 having 27 transformers. This result shows a good profile than other models. It is also reflected in Figure 4.5. But here Model-4 has been considered the summary of each simulation gives in Table 4.3.

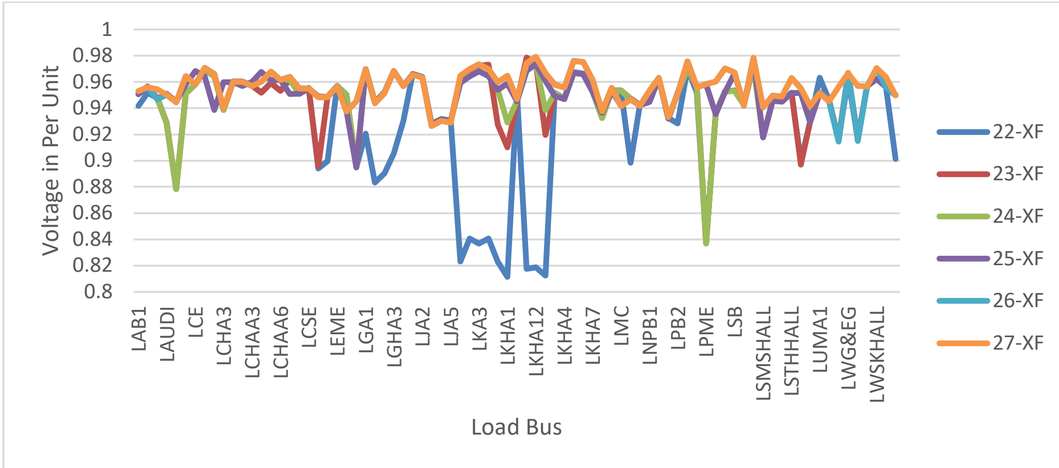


Fig. 4.5. L-N P.U. Voltage at Different Load Bus by Varying Number of Transformer.

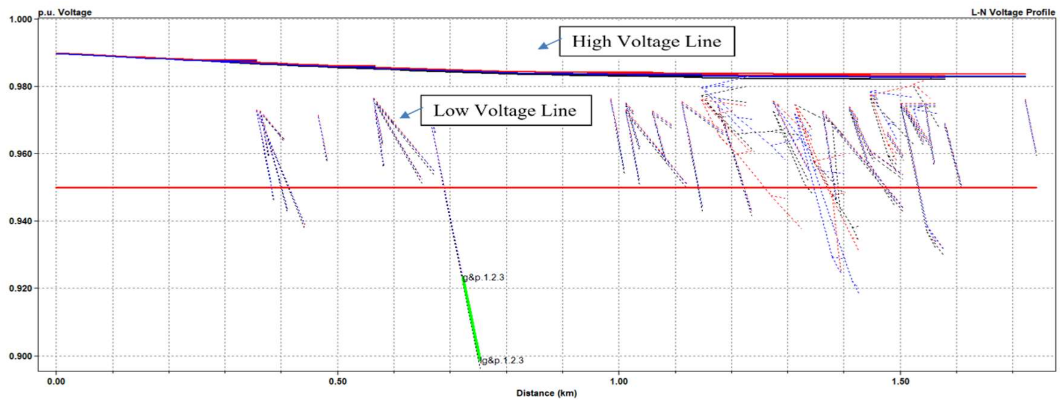
Table 4.3 data reflects the line loss, transformer loss and total loss of the system for the optimized model-1 to model-4 having 22-27 transformers in the network. Although minimum loss has been found for model-6, designed with 27 transformers but later model -4 has been taken for consideration as it has the loss in the permissible limit and almost all the load bus point is above the permissible per unit voltage level.

Table 4.3. Summary of Case#2 Scenario-1

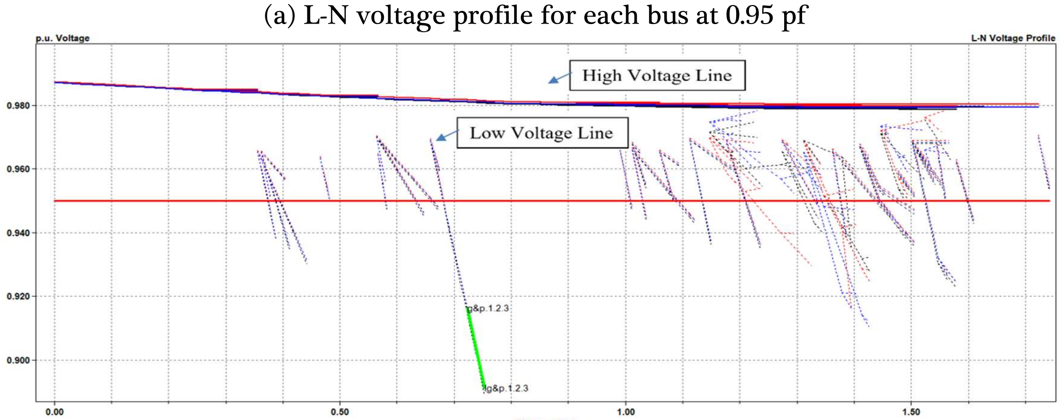
Optimized Model	Number of Transformer	Line Loss (kW)	Transformer Loss (kW)	Total Loss (%)
Model-1	22	85.5	24.3	5.46
Model-2	23	86.1	24.5	5.44
Model-3	24	75.0	24.8	4.78
Model-4	25	62.4	25.0	4.14
Model-5	26	57.2	20.7	3.75
Model-6	27	53.6	20.3	3.54

4.2.2 Scenario-2: Analysis by Varying Load Power Factor with Minimal Number of Transformers.

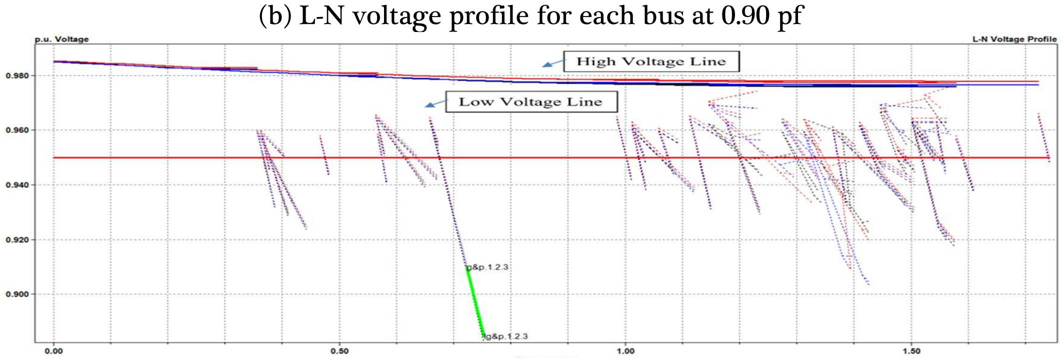
After optimizing the number of transformers, the placement of the transformer has been optimized. The methodology behind the optimum placement selection describes in Figure 3.2 of section 3.3.1. Now, the optimized model is analysed by varying load power factor. Figure 4.6 shows the p.u. L-N voltage profile of re-modeled simulation.



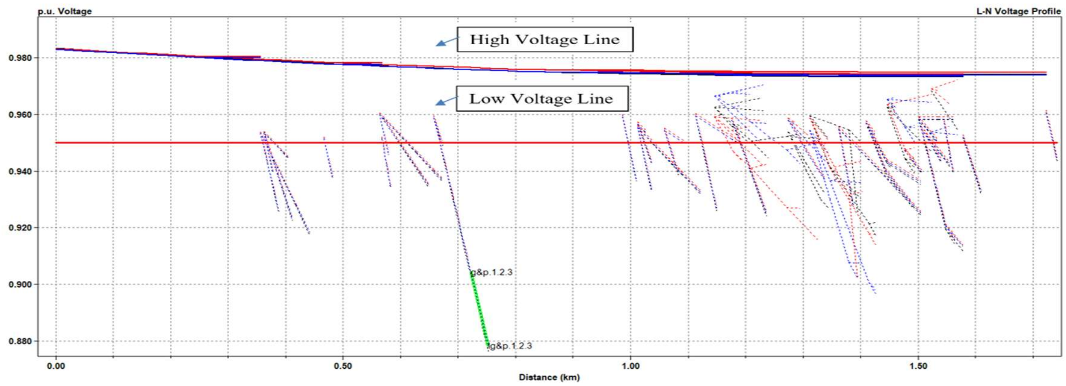
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf



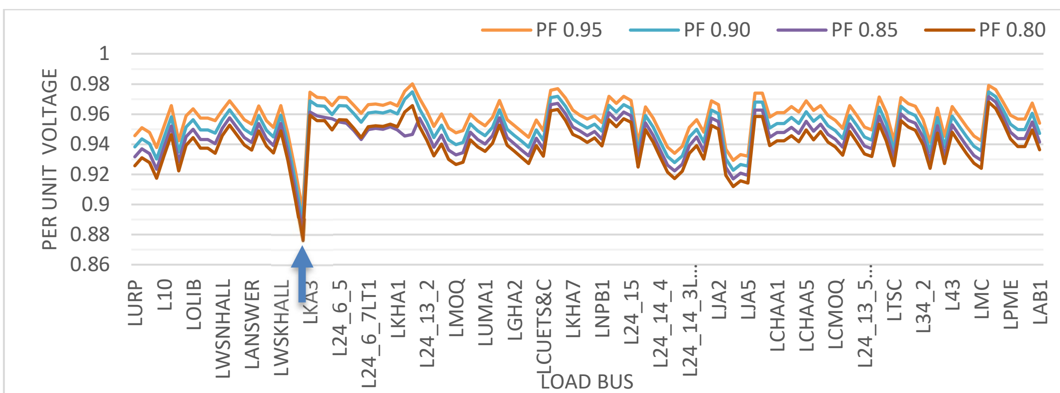
(c) L-N voltage profile for each bus at 0.85 pf



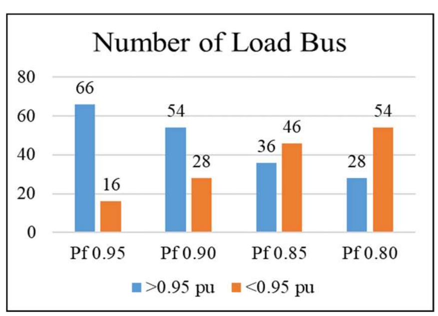
(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.6. Per Unit (P.U.) L-N Voltage Profile for Each Bus at Different Pf for Optimized Model using D-11 LT Cable.

From the above figure, it is clearly understood that, p.u. voltage for both HT and LT line is performing good at 0.95 power factor (pf) than the other pf value. At pf 0.80 p.u. voltage at most of the bus is below 5% of the rated value. It is also reflected in Figure 4.7.



(a)



(b)

Fig. 4.7. (a) Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model D-11 for Optimized Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.7(a) represents the graphical analysis and comparison of p.u. voltage at each bus. The lowest value 0.875 has been found at bus "LG&P". Again Figure 4.7(b) represents the number of load bus at different power factor. It is seen that total 54 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

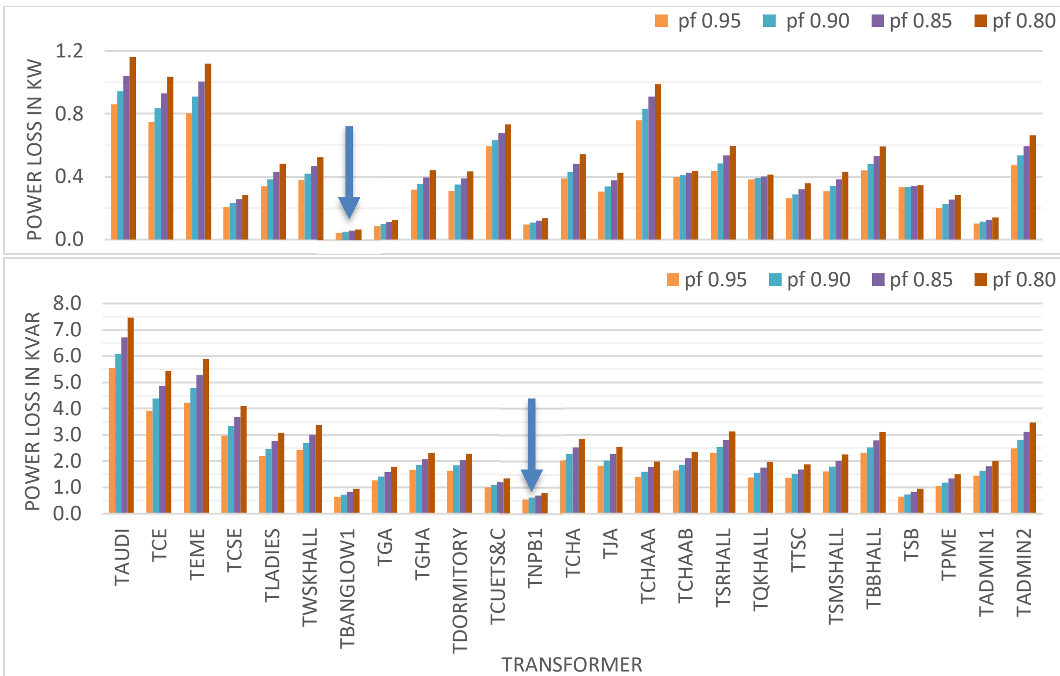


Fig. 4.8. Active and Re-active Power Loss of Transformers at Different P.F. for Optimized Model using D-11 LT Cable.

The active and reactive power loss in the transformer shows in Figure 4.8. Maximum losses for both active and reactive power are found at "TAUDI" transformer and minimum active and reactive losses are found at "TBANGLOW1" and "TNPB1" transformer respectively.

The summary of the simulation by using the D-11 model cable for case#2 scenario#2 (C2S2) has been given in Table 4.4. The Table focus on load power demand and power loss. Power loss is much more than the existing system for each pf variation because the length of LT cable has increased. Due to the per km resistance properties of the D-11 model, the loss has also been increased.

Table 4.4 Summary of CASE#2, Scenario-2

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.065	2.06	2.05	2.04
Reactive Power Flow (MVAR)	0.76	1.08	1.35	1.60
Active Power Loss (MW)	0.76 (3.69%)	0.08 (4.10%)	.0929 (4.56%)	0.10 (5.10%)
Reactive Power Loss (MVAR)	0.11	0.12	0.13	0.15

A comparison of different loss parameters has shown in Figure 4.9 between the case#1 scenario#1 and case#2 scenario#2.

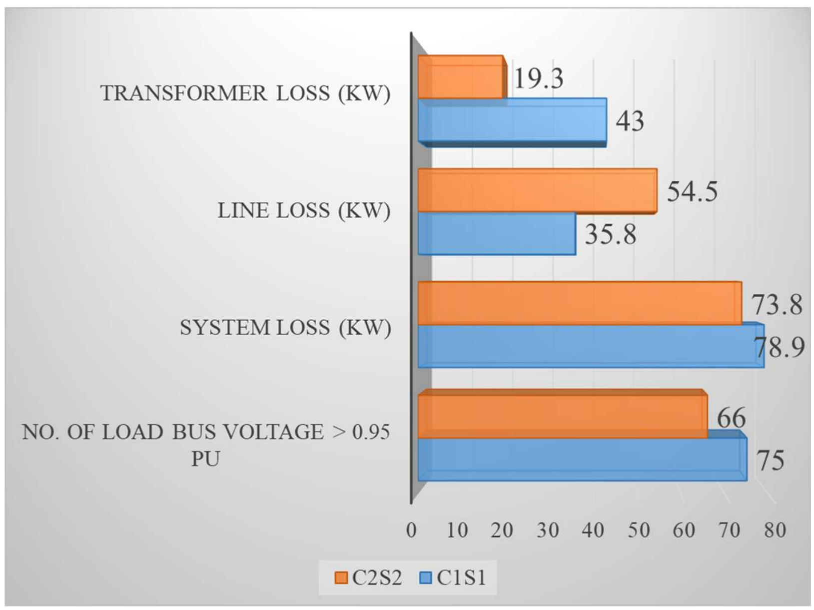


Fig. 4.9. Comparison of Different Parameters between C1S1 and C2S2

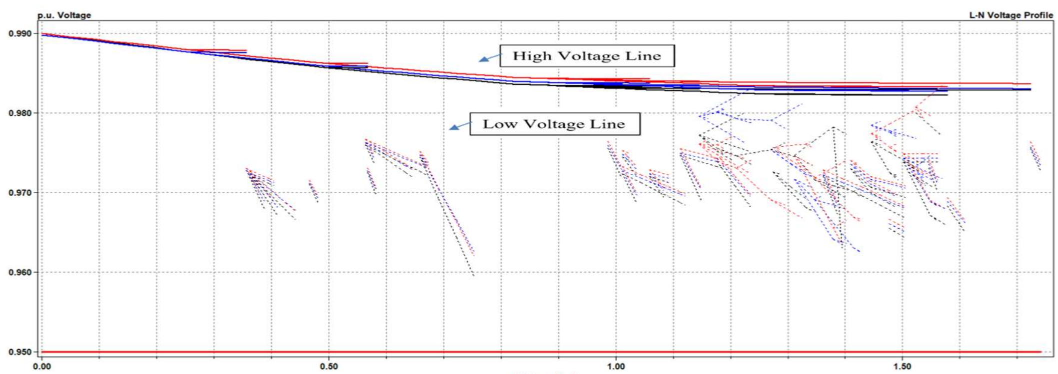
From the figure it is clearly seen that, case#2 scenario#2 (25 transformers) has shown a better result than case#1 scenario#1 (existing system with 52 transformers).

4.3 CASE# 3: SIMULATION TO FIND THE RIGHT LT CABLE TYPE

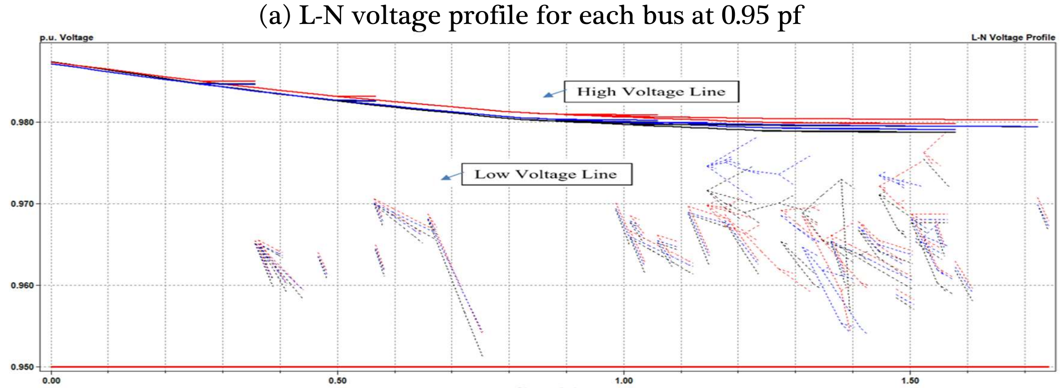
Optimization has been done by reducing the number of transformers in Case#2. As the length of the LT cable has been increased to the existing model, the loss due to the line has also been increased. In this case, simulation has been done for the optimized model developed in Case#2 scenario-2 with two different LT cable types and the results are shown below for analysis.

4.3.1 Scenario-1: Analysis by Varying Load Power Factor to Optimized Model using LT Cable Type "WASP"

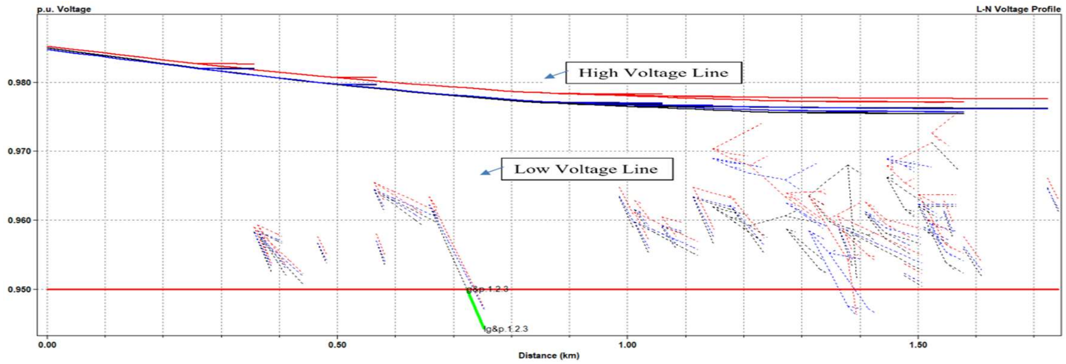
The optimized distribution network has been designed and simulated with LT cable type "WASP" and analyzed by varying load power factor. Figure 4.10 shows the p.u. L-N voltage profile of simulation.



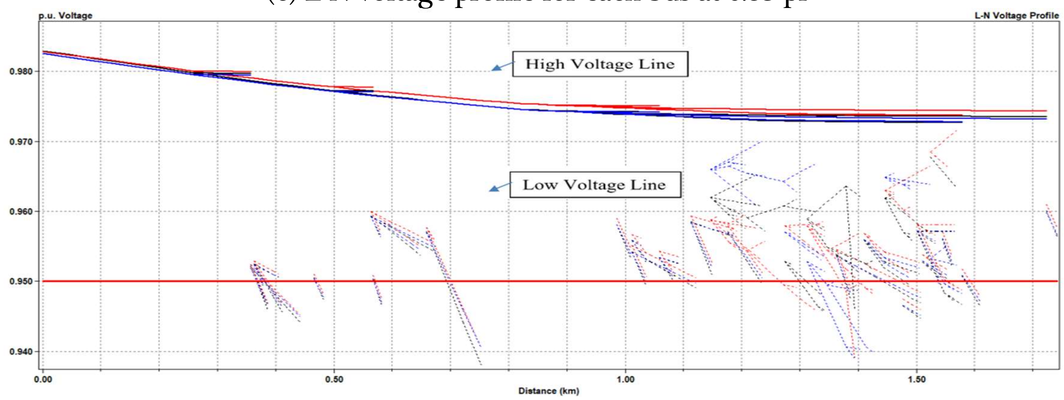
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf



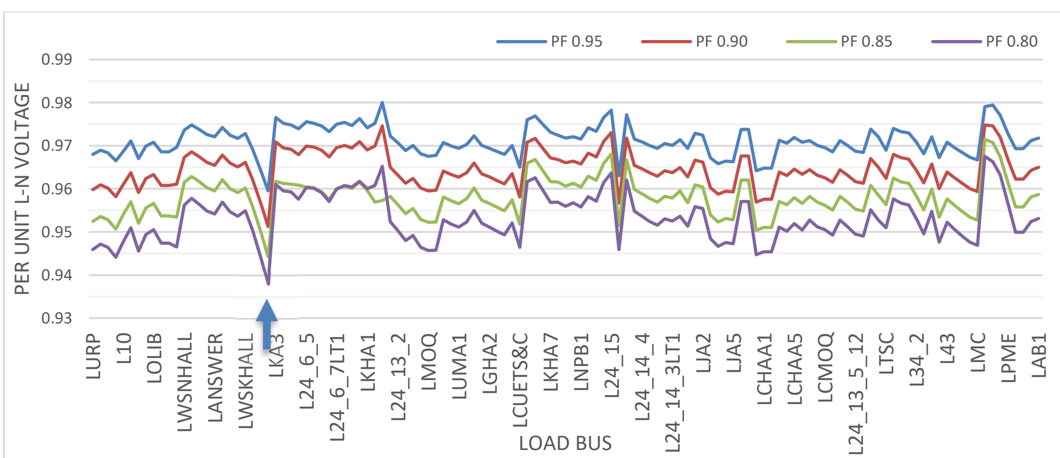
(c) L-N voltage profile for each bus at 0.85 pf



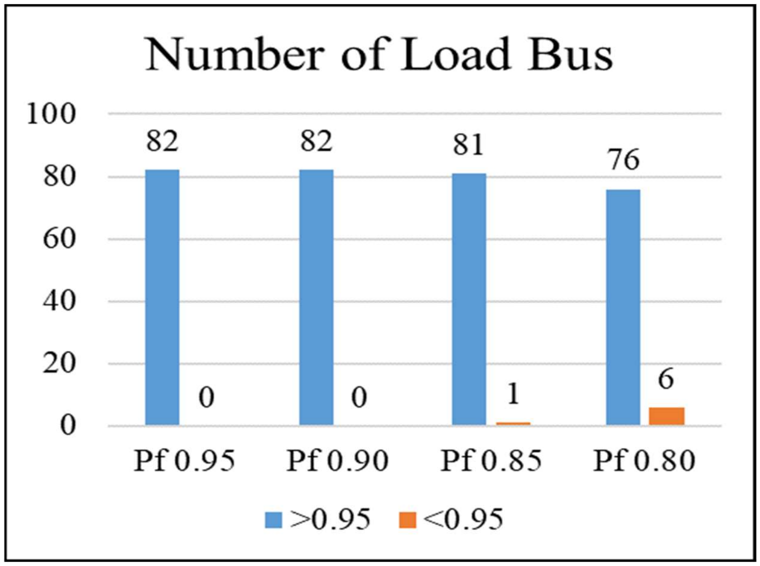
(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.10. Per Unit (P.U.) L-N Voltage Profile for Each Bus at Different Pf for Optimized Model using WASP LT Cable.

At pf 0.95 and 0.90, the per unit L-N voltage at each bus is between 0.98-0.95. But at pf 0.85 and 0.80 a small number of bus voltage is below 0.95 baseline.



(a)



(b)

Fig. 4.11. (a) Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model WASP for Optimized Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.11(a) gives the comparison of p.u. voltage for each power factor. The lowest voltage is 0.960 p.u. at pf 0.95 and 0.938 p.u. at 0.80 pf which is found at "LG&P" bus and indicated by an arrow. Again Figure 4.11(b) represents the number of load bus at different power factor. It is seen that total 82 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

The active and reactive power loss in the transformer shows in Fig.4.12. Maximum loss for both active and reactive power is found at "TAUDI" transformer and minimum loss for active power and reactive power is found at "TBANGLOW1" transformer and "TNPB1" transformer location respectively.

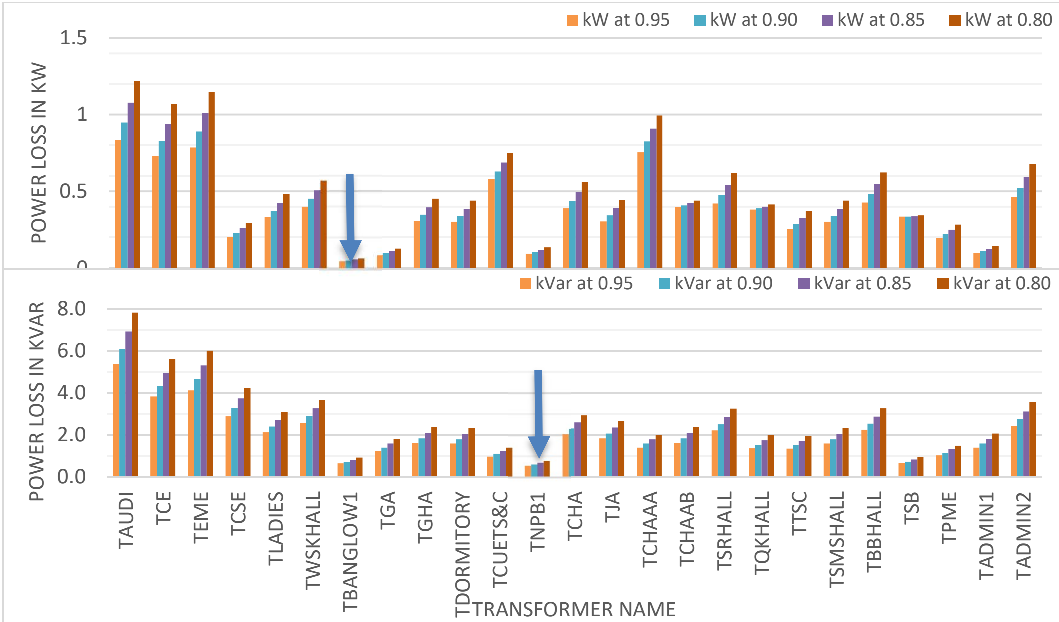


Fig. 4.12. Active and Re-active Power Loss of Transformers at Different P.F. for Optimized Model using WASP LT Cable.

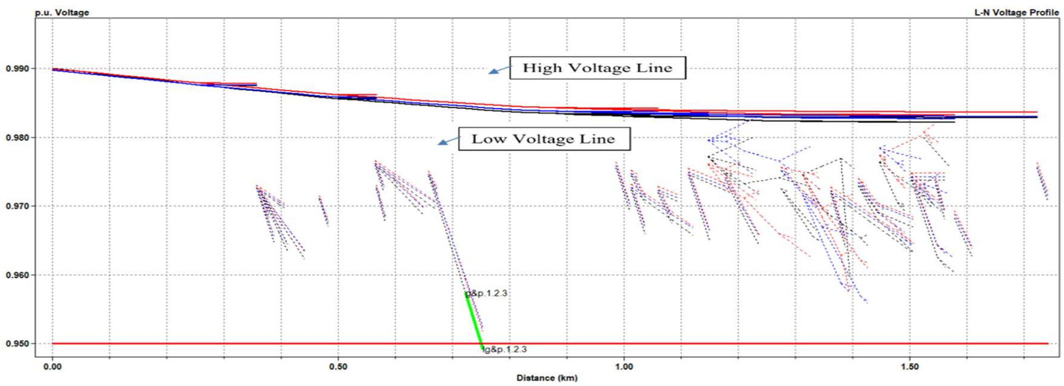
The summary of the simulation by using the WASP model cable for case#3 Scenario#1 has been given in Table 4.5. The Table focus on load power demand and power loss. Power loss has been found much less than the existing system for each pf variation.

Table 4.5 Summary of Case#3, Scenario-1(WASP)

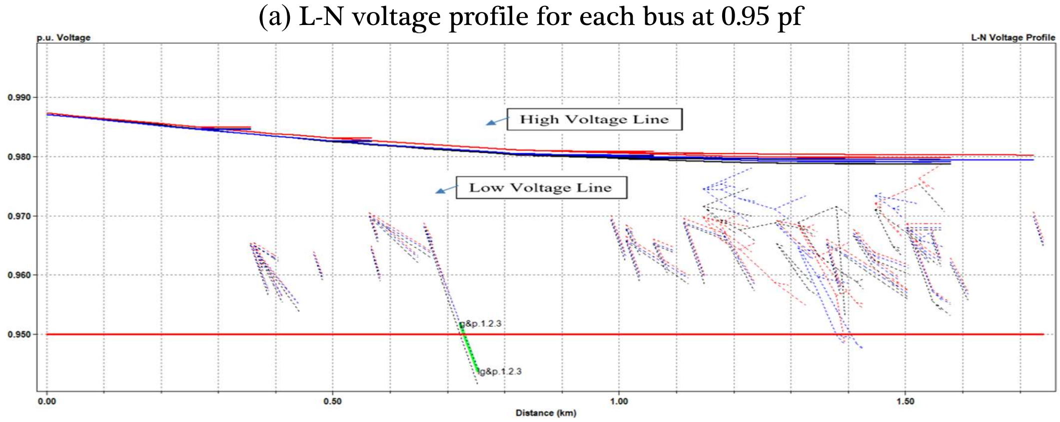
Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.04	2.05	2.05	2.05
Reactive Power Flow (MVAR)	0.76	1.08	1.37	1.65
Active Power Loss (MW)	0.034 (1.67%)	0.038 (1.88%)	0.043 (2.11%)	0.049 (2.40%)
Reactive Power Loss (MVAR)	0.10	0.115	0.130	0.148

4.3.2 Scenario-2: Analysis by Varying Load Power Factor using LT Cable Model ANT

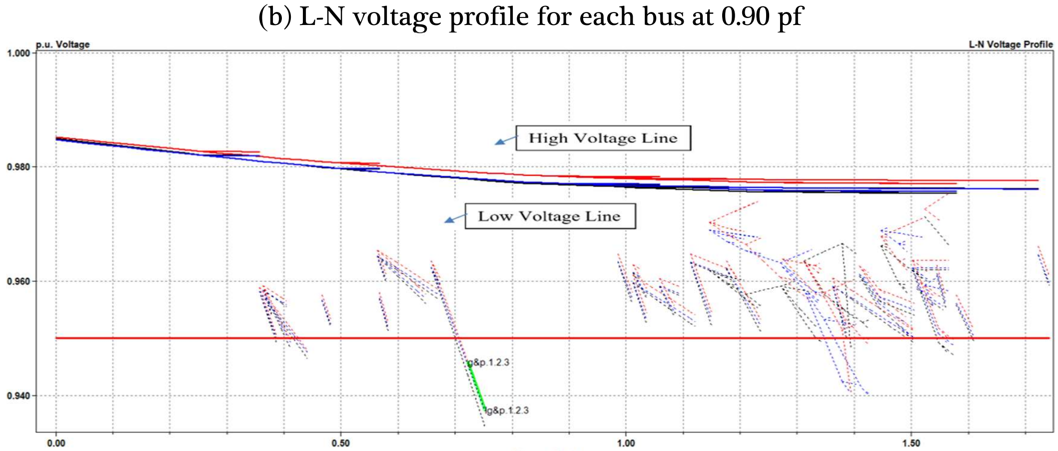
In Scenario 3, the distribution network has been designed and simulated with LT cable model ANT and analyzed by varying load power factor. Figure 4.13 shows the p.u. L-N voltage profile of re-modeled simulation.



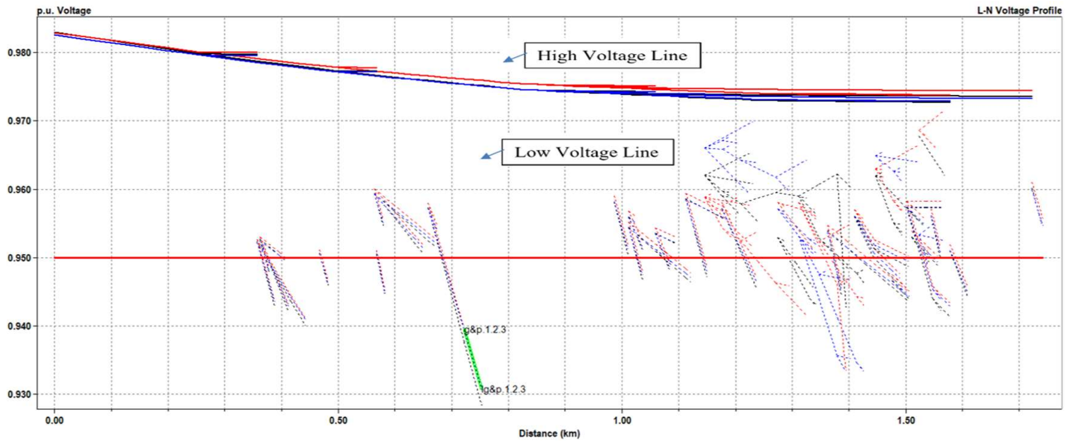
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf



(c) L-N voltage profile for each bus at 0.85 pf

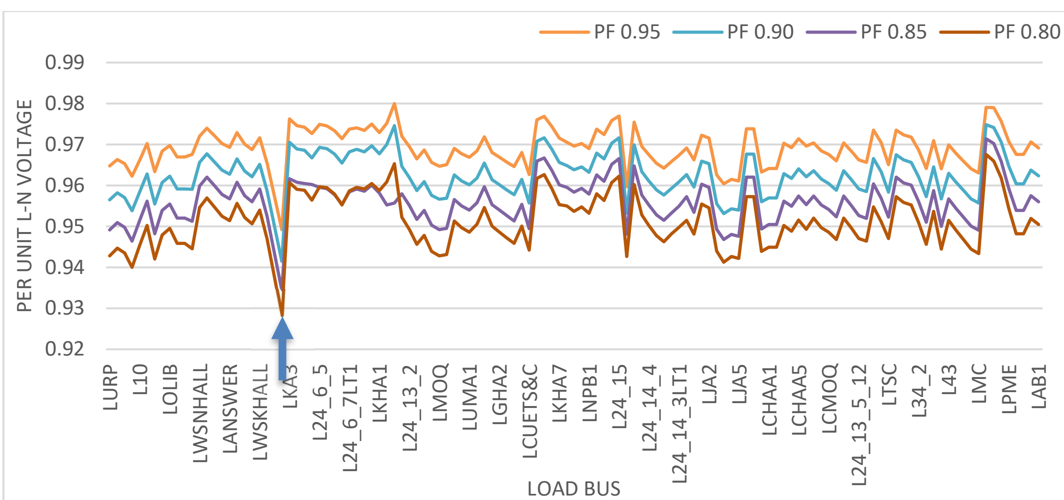


(d) L-N voltage profile for each bus at 0.80 pf

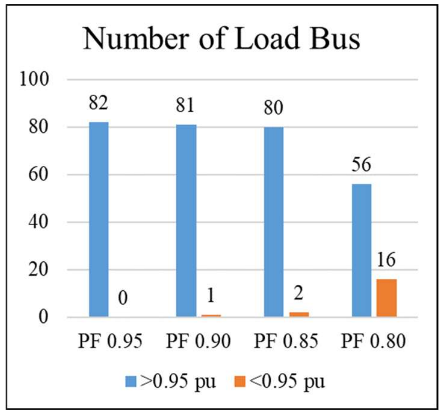
Fig. 4.13. Per Unit (P.U.) L-N Voltage Profile for Each Bus at Different Pf for Optimized Model using ANT LT Cable.

At pf 0.95, the per unit L-N voltage at each bus is in 0.95 p.u. But at other power factors (pf 0.90, pf 0.85 and pf 0.80) a small number of bus p.u. voltage is below 0.95 baselines.

. Figure 4.14(a) gives the comparison of p.u. voltage for each power factor. The lowest voltage is 0.949 p.u. at pf 0.95 and 0.928 p.u. at 0.80 pf which is found at "LG&P" bus.



(a)



(b)

Fig. 4.14. (a)Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model ANT for Optimized Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.14(b) represents the number of load bus at different power factor. It is seen that total 81 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

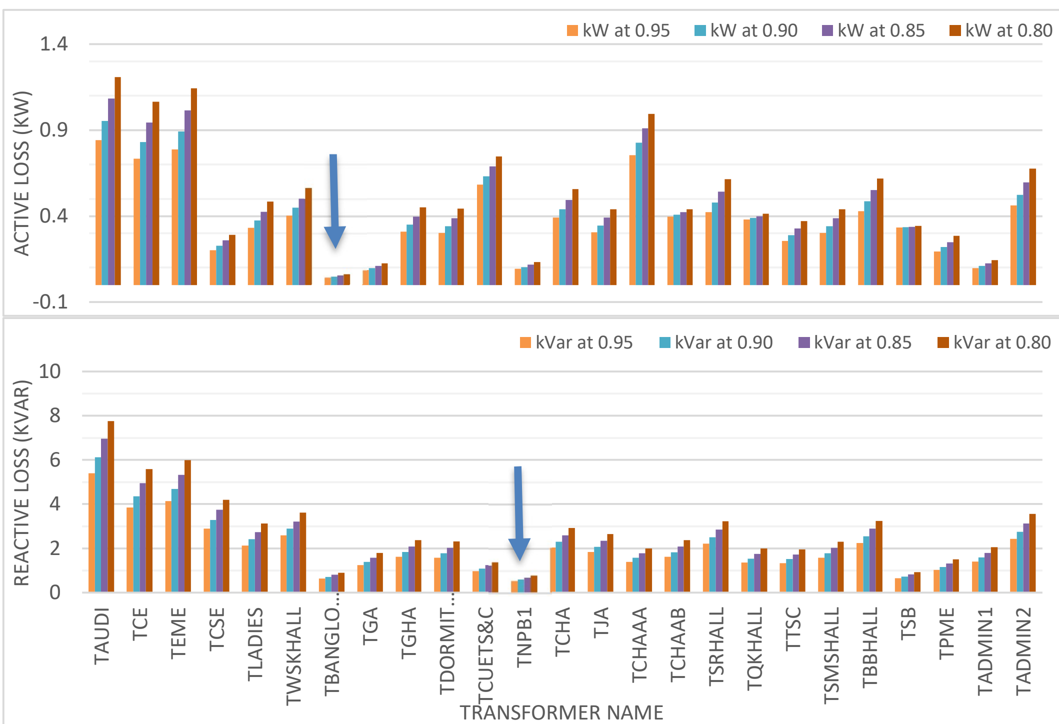


Fig. 4.15. Active and Re-active Power Loss of Transformers at Different P.F. for Optimized Model using ANT LT Cable.

The active and reactive power loss in the transformer shows in Fig.4.15. Maximum loss for both active and reactive power is found at “TAUDI” transformer and minimum loss for active power and reactive power is found at “TBANGLOW1” transformer and “TNPB1” transformer location respectively which is indicated by the blue color arrow.

Table 4.6 Summary of Case#3, Scenario-2 (ANT)

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.05	2.05	2.05	2.04
Reactive Power Flow (MVAR)	0.78	1.09	1.38	1.65
Active Power Loss (MW)	0.042 (2.08%)	0.048 (2.33%)	0.053 (2.62%)	0.060 (2.94%)
Reactive Power Loss (MVAR)	0.11	0.12	0.14	0.16

The summary of the simulation using the ANT model cable for case#3 scenario#2 has been given in Table 4.6. Power loss has been found much less than the existing system but slightly greater than scenario-2 for each pf variation.

4.3.3 Comparison of L-N per unit voltage at different Load Bus of Optimized Case for different Cable Type:

The optimized model has been designed with almost half the number of transformers of the existing system. Although the length of low voltage cable has increased than the existing design it reduces the overall system loss.

The following Figure 4.16 represents the per unit voltage at different power factor for three types of cable models against each bus.

Fig. 4.16. Comparison of L-N p.u. Voltage at Different PF for Different LT Cable Type for Optimized Model.

From the above figure, it is clear that the performance for WASP and ANT cable models is almost the same, but at some point, WASP performs better than ANT cable.

A comparison of different loss parameters has shown in Figure 4.17 among the case#3 scenario#1, case#3 scenario#1 and case#2 scenario#2.

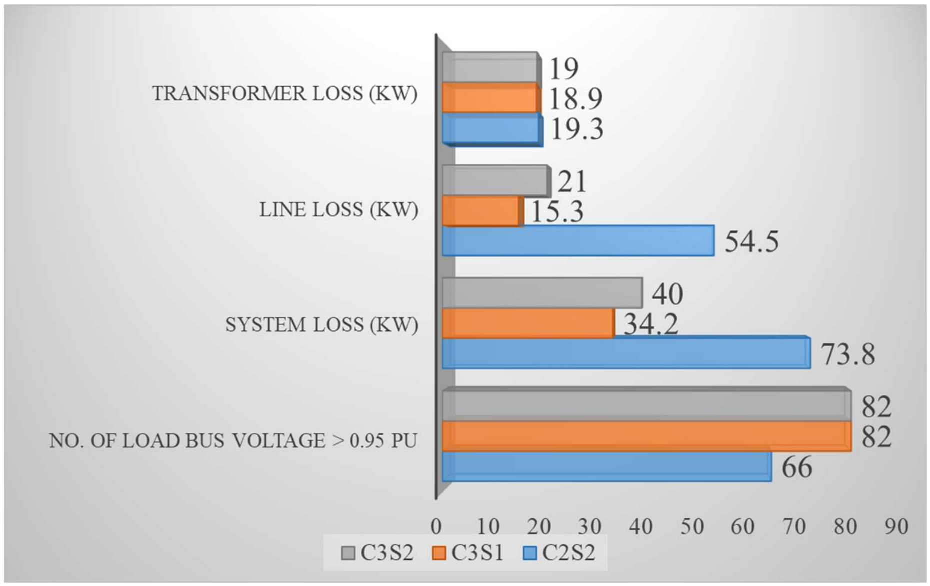


Fig. 4.17. Comparison of Different Parameters among C3S1, C3S2 and C2S2

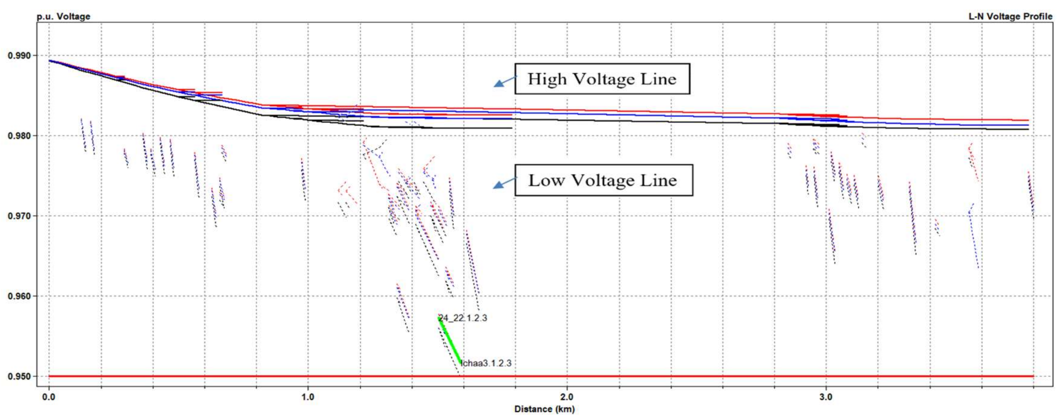
From the analysis it is clearly seen that case#3 scenario#1 (25 transformers, WASP LT cable) has shown a better result than other scenarios.

4.4 CASE# 4: RE-DESIGN OF EXISTING CUET DISTRIBUTION NETWORK BY CHANGING LOW VOLTAGE CABLE TYPE

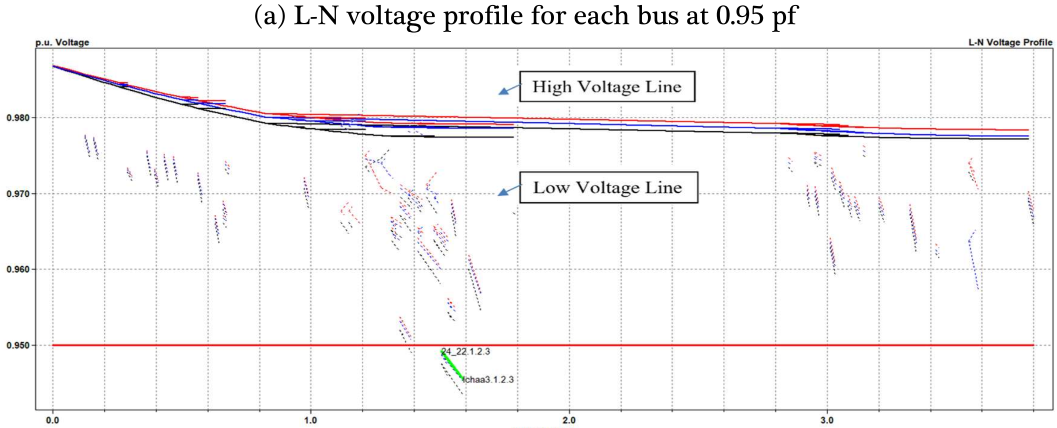
The existing CUET distribution network has been established with the "D-11" LT cable type. Here in the re-configuration case simulation has been done by only changing the LT cable model, other parameters like the number and rating of transformers and length of HT and LT line have been kept the same as the existing model. Parameters related to the cable has defined before in section 3.1 and section 3.3.2.

4.4.1 Scenario-1: Analysis by varying load power factor using LT cable model named "ANT"-

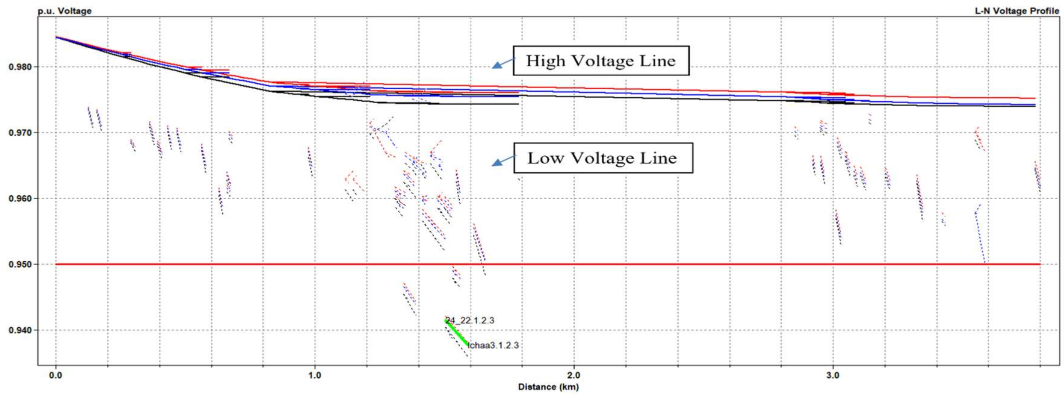
The existing distribution network has been simulated by using the low tensile (LT) cable model "ANT" instead of the existing "D-11" model. Per unit voltage and transformer power loss has been studied at different power factor. Figure 4.18 shows the simulated output of p.u. L-N voltage profile.



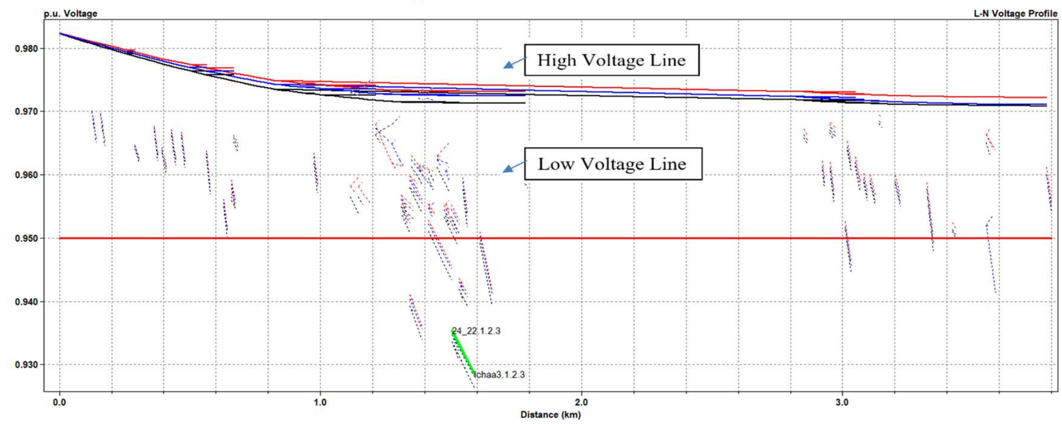
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf

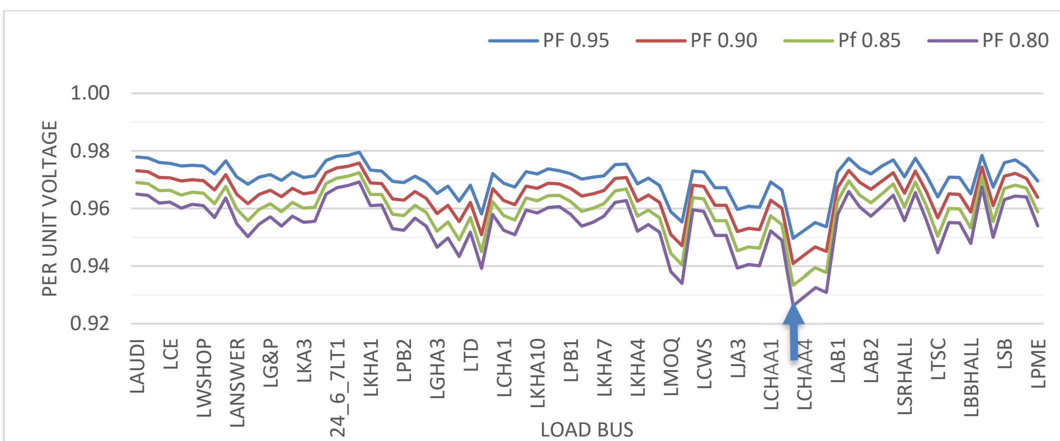


(c) L-N voltage profile for each bus at 0.85 pf

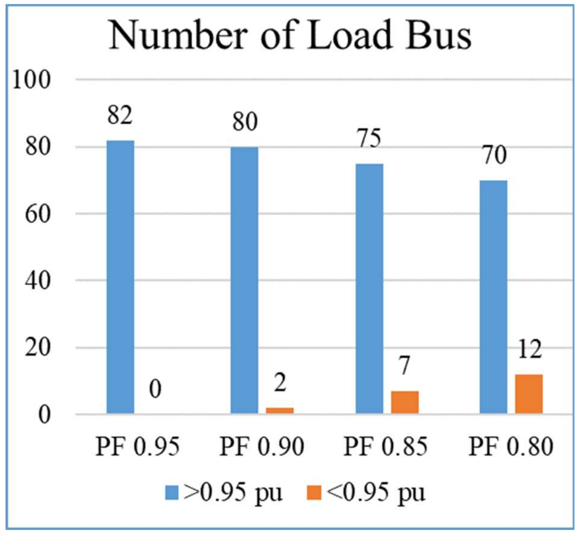


(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.18. Per Unit (p.u) voltage profile window from simulator using "ANT" LT cable model at different load pf.



(a)



(b)

Fig. 4.19. (a)L-N p.u. voltage at different load bus at different load power factor using ANT LT cable model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Using the "ANT" cable model for low voltage lines at different load pf, the line to the neutral voltage at different load bus is shown in the graph of Figure 4.19 (a). The lowest voltage is found at load bus "LCHAA3" which is 0.928 p.u. voltage at 0.80 pf. Figure 4.19(b) represents the number of load bus at different power factor. It is seen that total 80 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

The following graph at Figure 4.20 represents the power loss of each 3-phase transformer bank at different load pf. From the graph of it can easily be found that the highest loss has been found in "TR36" at 0.80 pf for both active and reactive power loss.

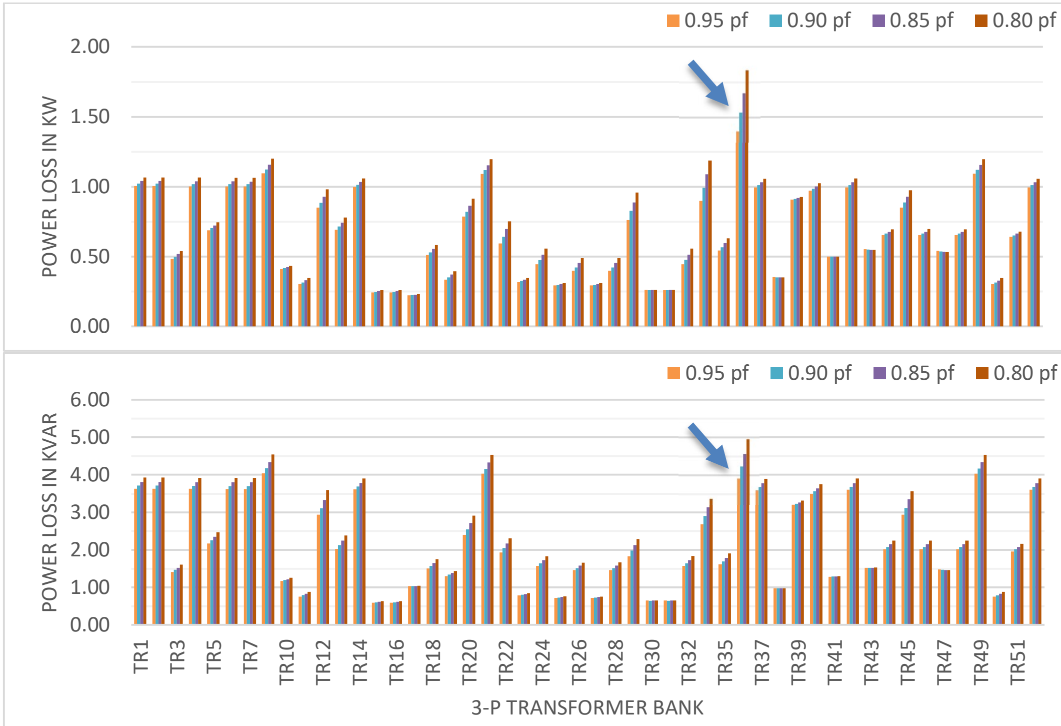


Fig. 4.20. Active and re-active power loss at different transformer for different power factor.

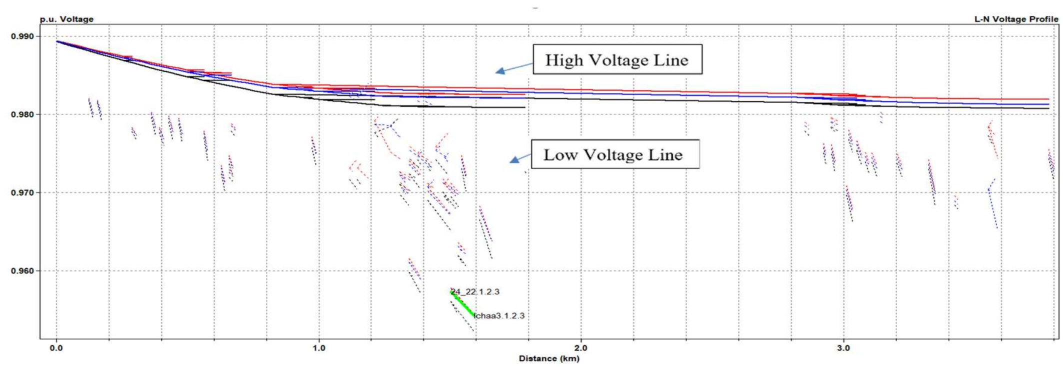
Table 4.7 Summary of CASE#4, Scenario-1

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.06	2.07	2.07	2.07
Reactive Power Flow (MVAR)	0.821	1.14	1.43	1.70
Active Power Loss (MW)	0.059 (2.88%)	0.064 (3.09%)	0.069 (3.33%)	0.075 (3.62%)
Reactive Power Loss (MVAR)	0.160	0.17	0.18	0.20

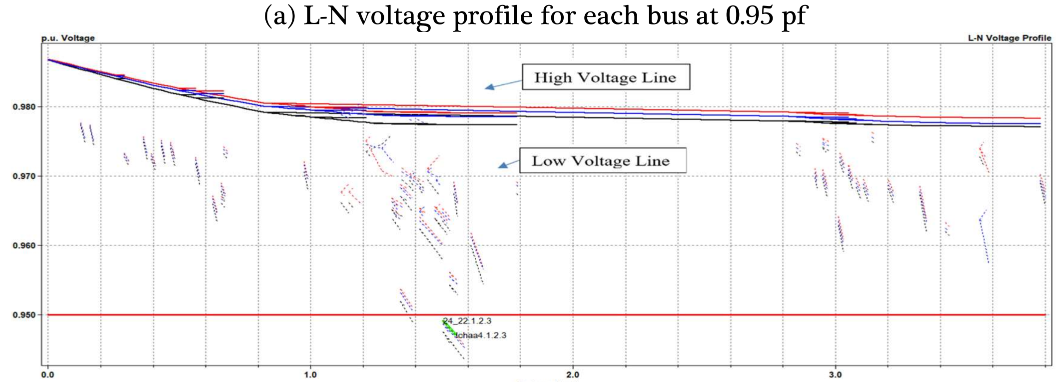
The summary of that individual simulation file has been given in Table 4.7 for Scenario-1. The Table represents load power demand and power loss. Although the power loss has increased with a decrement of pf, it is in the permissible limit and much lower than the existing distribution system which has used the "D-11" cable type.

4.4.2 Scenario-2: Analysis by varying load power factor using LT cable model named "WASP"

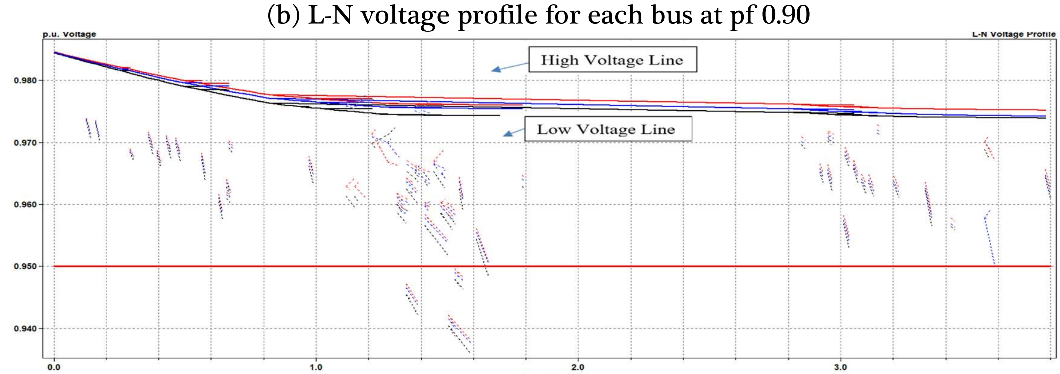
In this scenario, the existing distribution network has been simulated by using LT cable model "WASP" instead of the existing model "D-11". Figure 4.21 represents the changes of per unit voltage profile for both the high tensile (HT) line and low tensile (LT) line with distance.



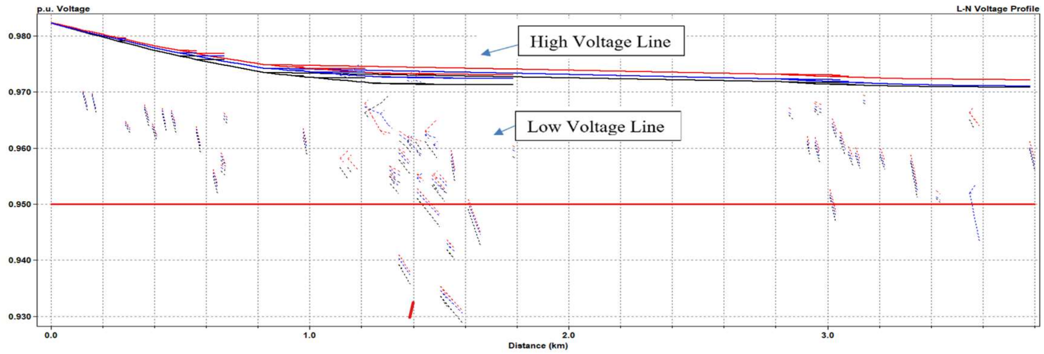
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at pf 0.90

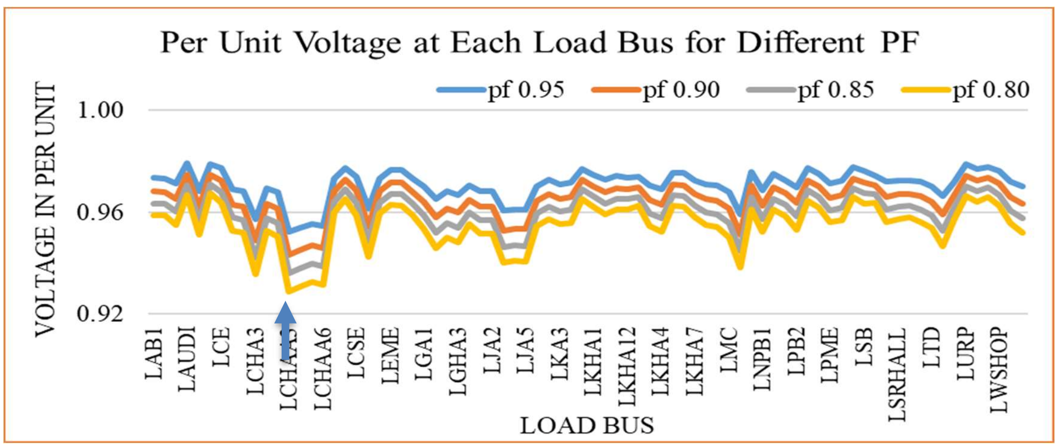


(c) L-N voltage profile for each bus at pf 0.85

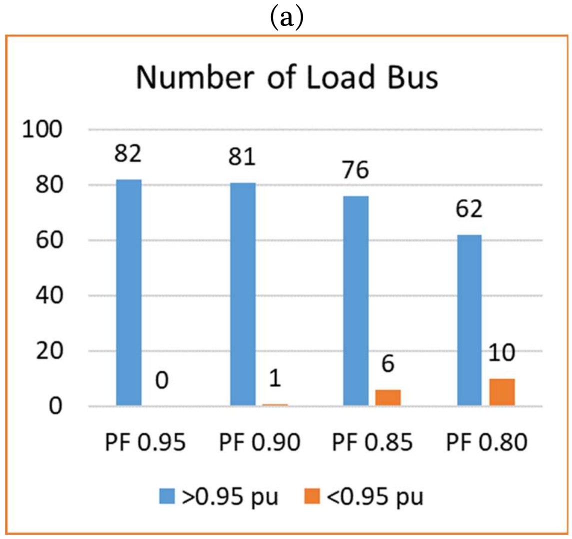


(d) L-N voltage profile for each bus at pf 0.80

Fig. 4.21. Per Unit (p.u) voltage profile window from simulator for re-configuration model using WASP LT cable at different load pf.



(a)



(b)

Fig. 4.22. (a)L-N p.u. voltage at different load bus at different load power factor for Case#2 model using WASP cable model. (b) Number of Load Bus Above and Under 0.95 pf.

Using the WASP cable model for LT line at different load pf, the line to the neutral voltage at different load bus is drawn in the graph of Figure 4.22(a). From the graph, it is clear that the lowest voltage is found at load bus "LCHAA3". Figure 4.22(b) represents the number of load bus at different power factor. It is seen that total 81 load points out of 82 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

The graph at Figure 4.23 represents transformer loss of each 3-phase transformer bank of the existing model at different load pf. Both active power loss and reactive power loss are shown in this graph and the highest power loss is found at "TR36".

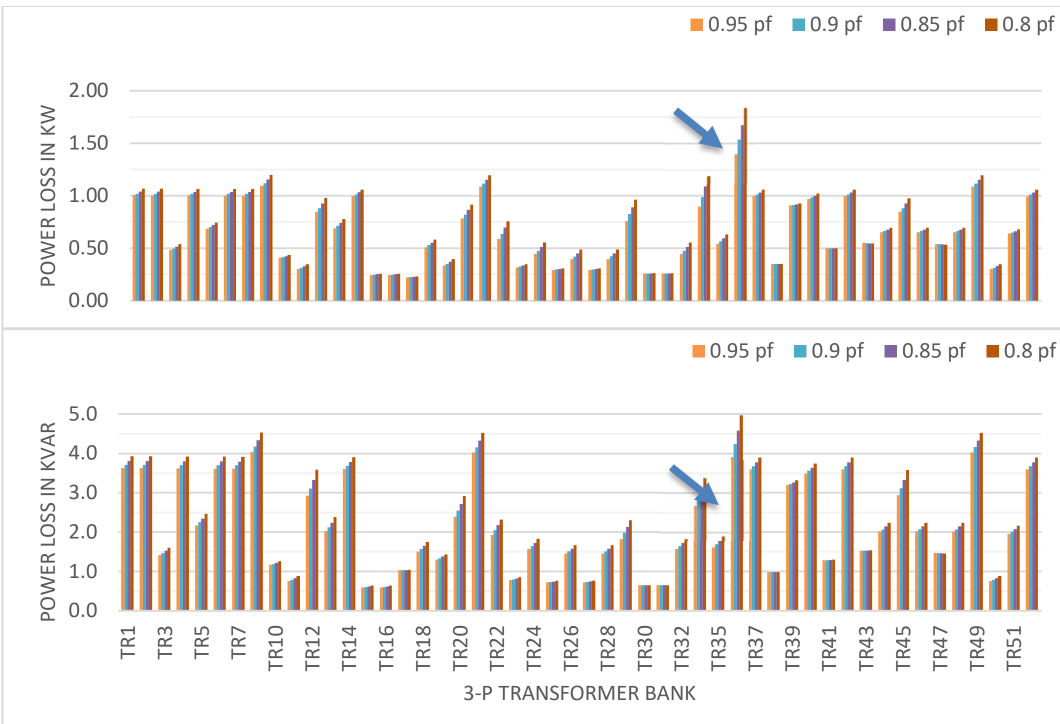


Fig. 4.23. The active and reactive power loss of the transformer bank at different power factor.

The summary of that individual simulation file has been given in Table 4.8 for Scenario-2.

Table 4.8 Summary of CASE#4, Scenario-2

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.07	2.06	2.07	2.07
Reactive Power Flow (MVAR)	0.821	1.14	1.43	1.70
Active Power Loss (MW)	0.563 (2.73%)	0.060 (2.91%)	0.065 (3.14%)	0.071 (3.40%)
Reactive Power Loss (MVAR)	0.160	0.17	0.18	0.19

The power loss has increased with decrement of pf but it is good enough that did not cross the permissible limit. Also, it is clear that modeling with 'WASP' type cable, draws much lower loss than the existing distribution system.

4.4.3 Comparison of L-N Per Unit Voltage at Different Bus of Existing Model for Different Cable Models:

Low voltage cable D-11 has been used in the existing distribution system and another two types of low voltage cable ANT and WASP model has been used in the simulation to explore the difference in per unit voltage profile and other system parameters. Figure 4.24 represents the per unit voltage at different power factor for three types of cable models against each bus.

From the figure, it is clear that at each pf, per unit voltage at each bus for the D-11 cable model is lower than the other two types of cable model (WASP and ANT). If I consider 0.95 pf, it is seen that, at some bus points, per unit voltage for line D-11 is below the per unit baseline, but for using WASP and ANT cable model simulation, no bus voltage is below 0.95 p.u voltage.

Although the performance for WASP and ANT cable model is almost the same, at some point, WASP performs better than ANT cable.

Fig. 4.24. Comparison of L-N Per Unit Voltage at Different PF for Different Cable for Case#4.

A comparison of different loss parameters has shown in Figure 4.25 among the case#1 scenario#1, case#4 scenario#1 and case#4 scenario#2.

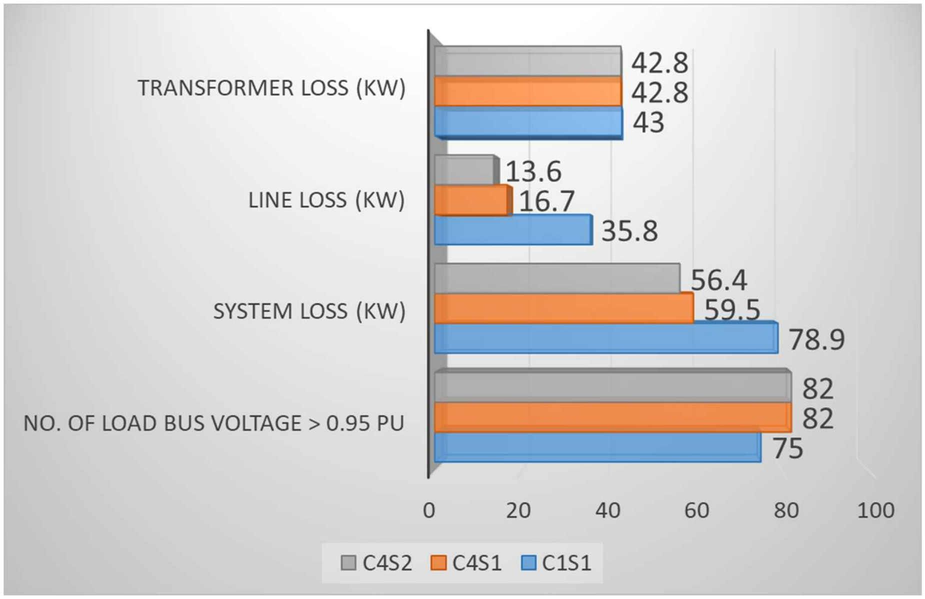


Fig. 4.25. Comparison of Different Parameters among C1S1, C4S1 and C4S2

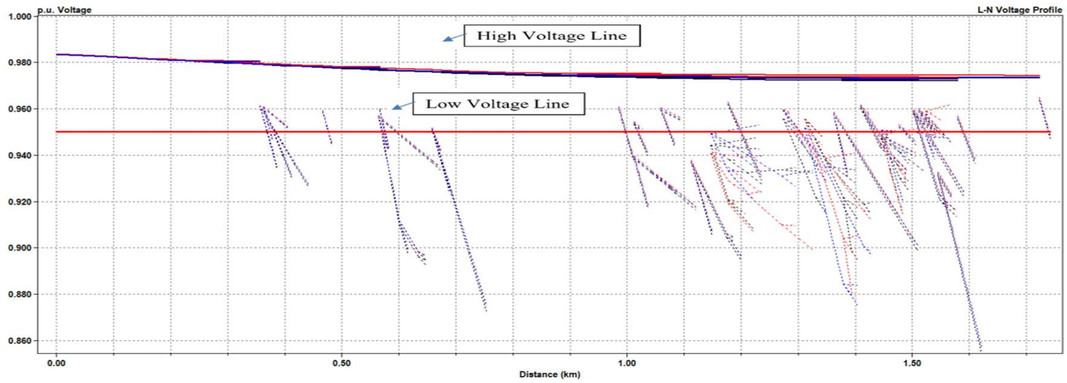
From the analysis it is clearly seen that, case#4 scenario#2 (52 transformers, WASP LT cable) has shown a better result than other scenarios.

4.5 CASE# 5: HORIZONTAL LOAD EXTENSION TO OPTIMIZED MODEL

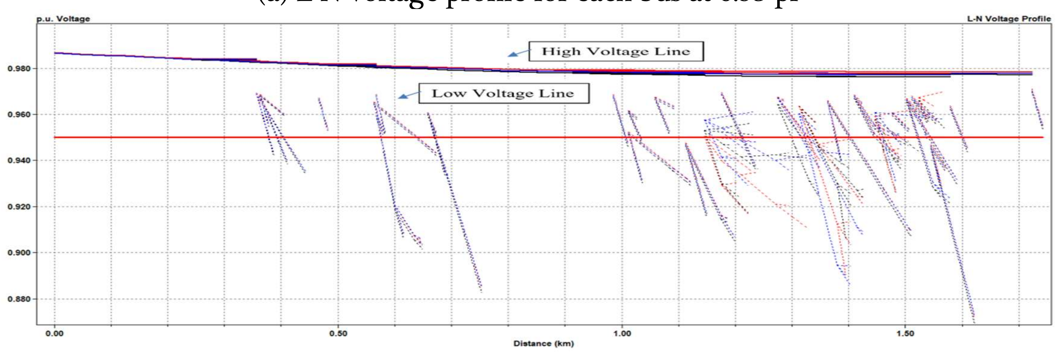
In this case, some horizontal load has been added as an extended demand in the future and simulated to find the sustainability of the optimized network that was designed in case 3. This load prediction is according to the organogram and planning of the university for the vision by the year 2035.

4.5.1 Scenario-1: Horizontal Load Extension Model using D-11 Cable Type

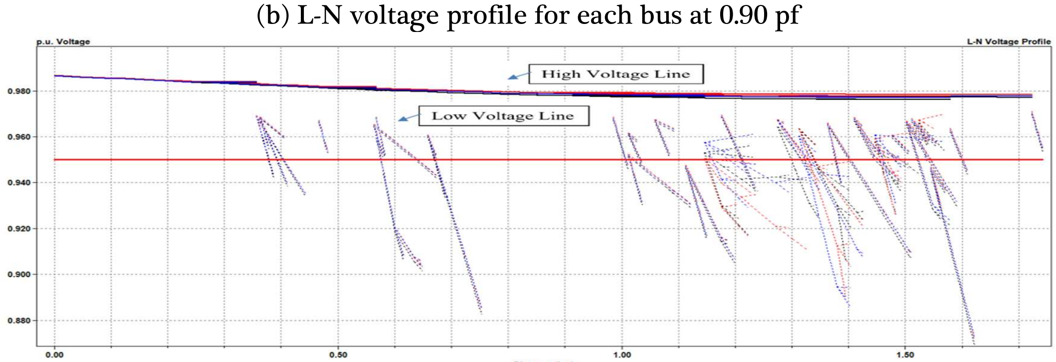
In this scenario, an optimized distribution model with horizontal load extension has been designed and simulated with LT cable D-11 and analyzed by varying load power factor. The following Figure 4.26 shows the p.u. L-N voltage profile of the simulation.



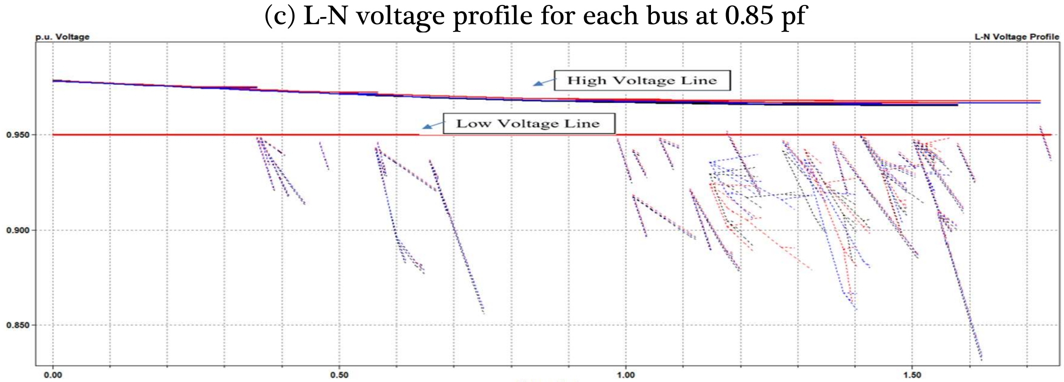
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf



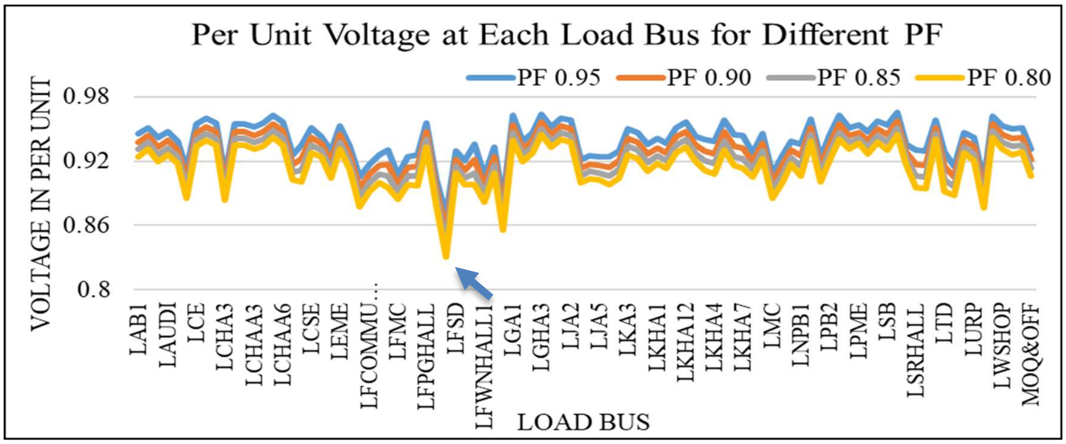
(c) L-N voltage profile for each bus at 0.85 pf



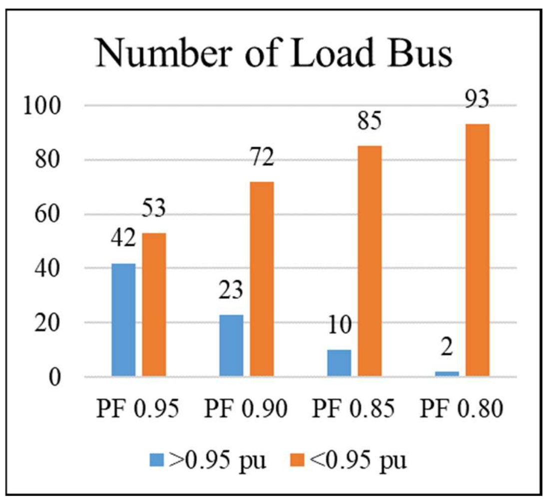
(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.26. Per Unit (P.U) L-N Voltage Profile at Each Bus at Different Pf for Horizontal Load Extension Model using D-11 LT Cable.

In Figure 4.26, per unit voltage almost each bus has found below the permissible regulation because in some region power demand exceeds the transformer's handled capacity due to the addition of the extended load.



(a)



(b)

Fig. 4.27. (a) Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model D-11 for Horizontal Load Extension Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.27(a) gives the comparison of p.u. voltage for each power factor at each bus. The lowest voltage is 0.869 p.u. at pf 0.95 and 0.830 p.u. at 0.80 pf which is found on "LFSA" bus, which is at 10 storied Future Studio Apartment building for the Teachers'. Figure 4.27(b) represents the number of load bus at different power factor. It is seen that total 23 load points out of 95 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

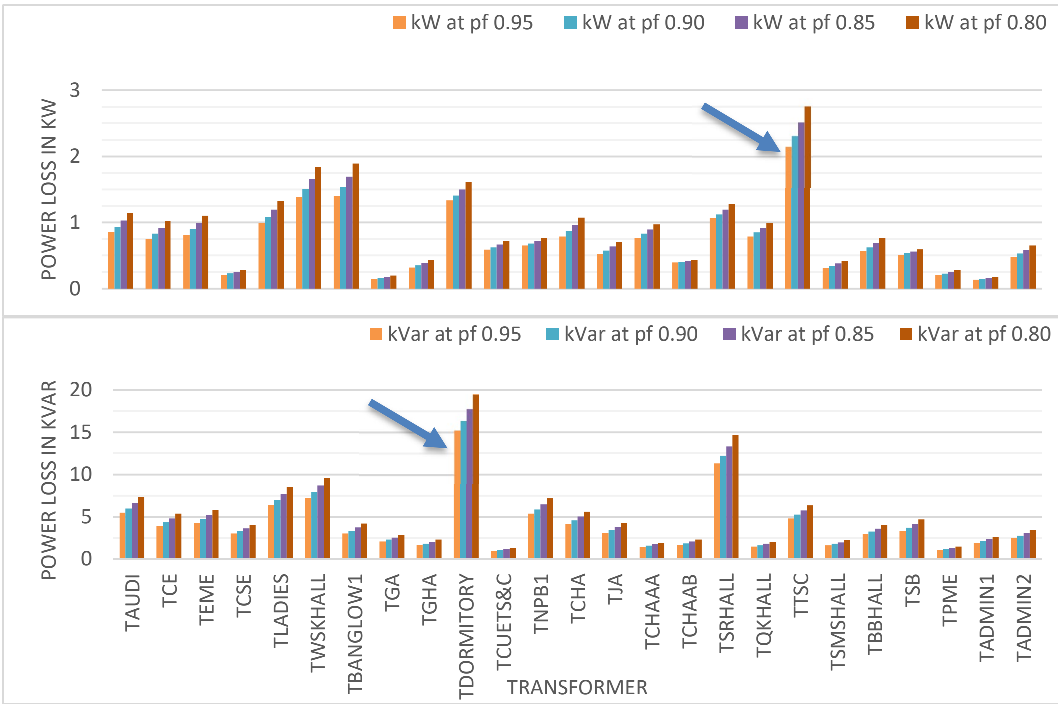


Fig. 4.28. Power Loss of Transformers at Different Power Factor using Cable Model D-11 for Horizontal Load Extension Model.

The active and reactive power loss in the transformer shows in Figure 4.28. Maximum loss for both active and reactive power are found at "TTSC" and "TDORMITORY" transformers respectively. Minimum active and reactive loss are found at "TADMIN1" and "TCUETS&C" transformers respectively.

Table 4.9 Summary of CASE#5, Scenario-1

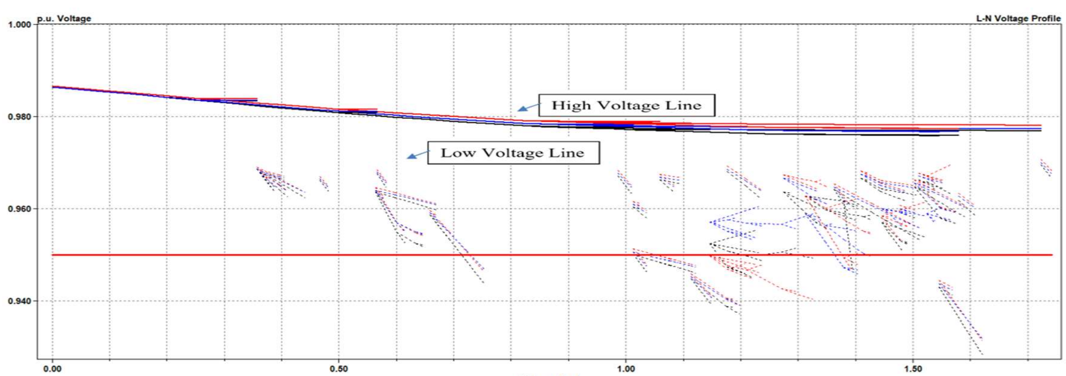
Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.63	2.60	2.58	2.56
Reactive Power Flow (MVAR)	1.01	1.41	1.74	2.05

Active Power Loss (MW)	0.012(4.62%)	0.13(5.11%)	0.146(5.67%)	0.16(6.34%)
Reactive Power Loss (MVAR)	0.19	0.21	0.23	0.26

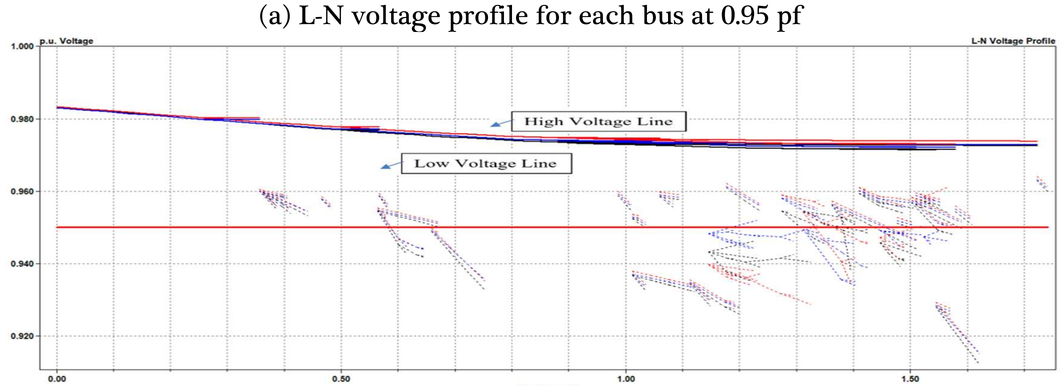
The summary of the simulation using the D-11 model cable for case#4 has been given in Table 4.9. Power loss has increased by increasing the load power factor.

4.5.2 Scenario-2: Horizontal Load Extension Model using WASP Cable Type

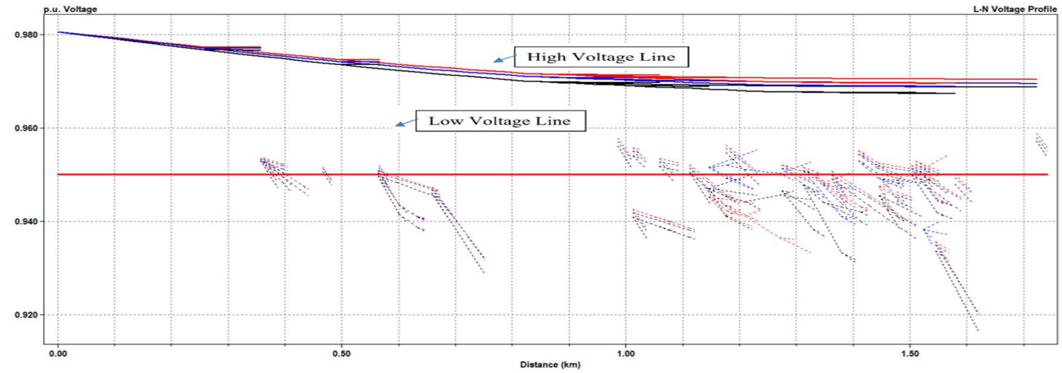
In this scenario, the optimized distribution network with extended future load has been redesigned and re-simulated by using LT cable WASP and analyzed the per unit voltage and power loss varying load power factor. The following Figure 4.29 shows the p.u. L-N voltage profile of the simulation.



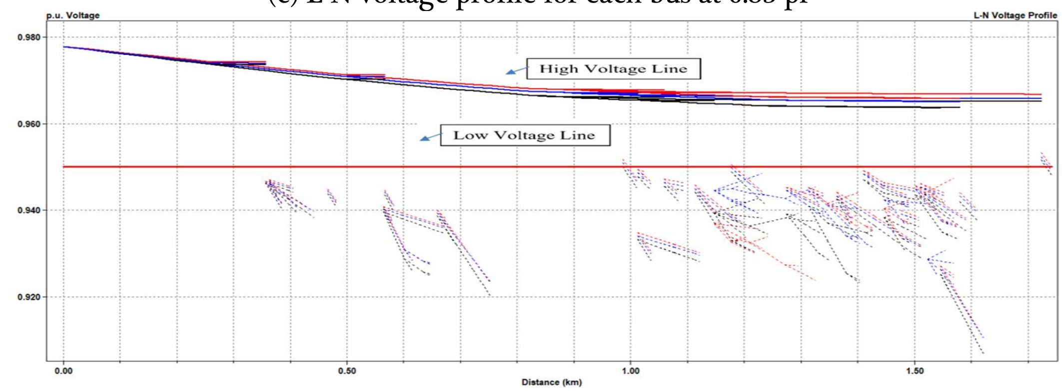
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf

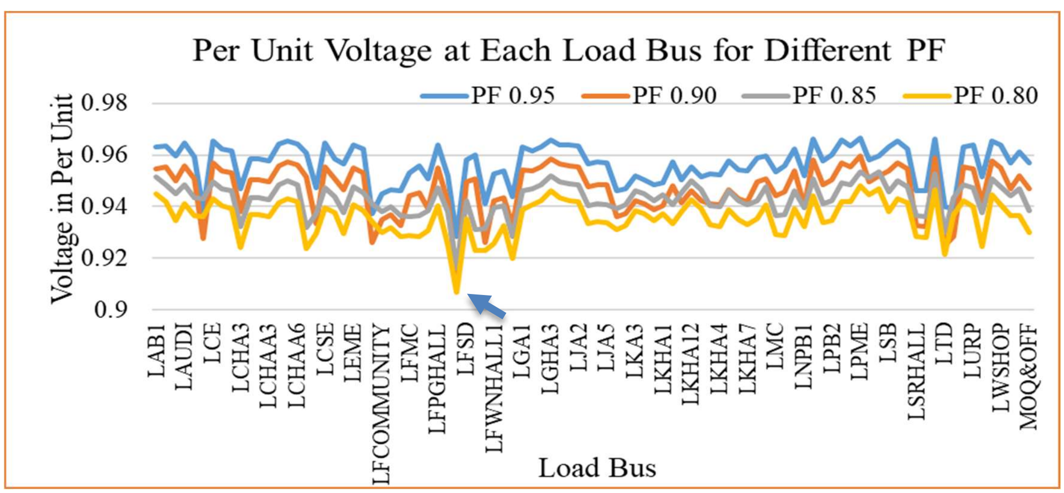


(c) L-N voltage profile for each bus at 0.85 pf

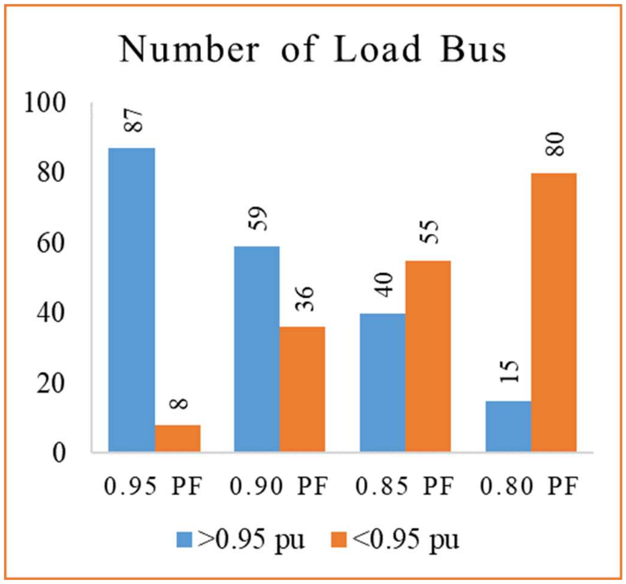


(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.29. Per Unit (P.U) L-N Voltage Profile at Each Bus at Different Pf for Horizontal Load Extension Model using WASP LT Cable.



(a)



(b)

Fig. 4.30. (a)Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model WASP for Horizontal Load Extension Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.30(a) gives the comparison of p.u. voltage for each power factor. The lowest voltage is 0.93 p.u. at pf 0.95 and 0.90 p.u. at 0.80 pf which is found at "LFSA" bus, which is at 10 storied Future Studio Apartment building for the Teachers'. Figure 4.30(b) represents the number of load bus at different power factor. It is seen that total 59 load points out of 95 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

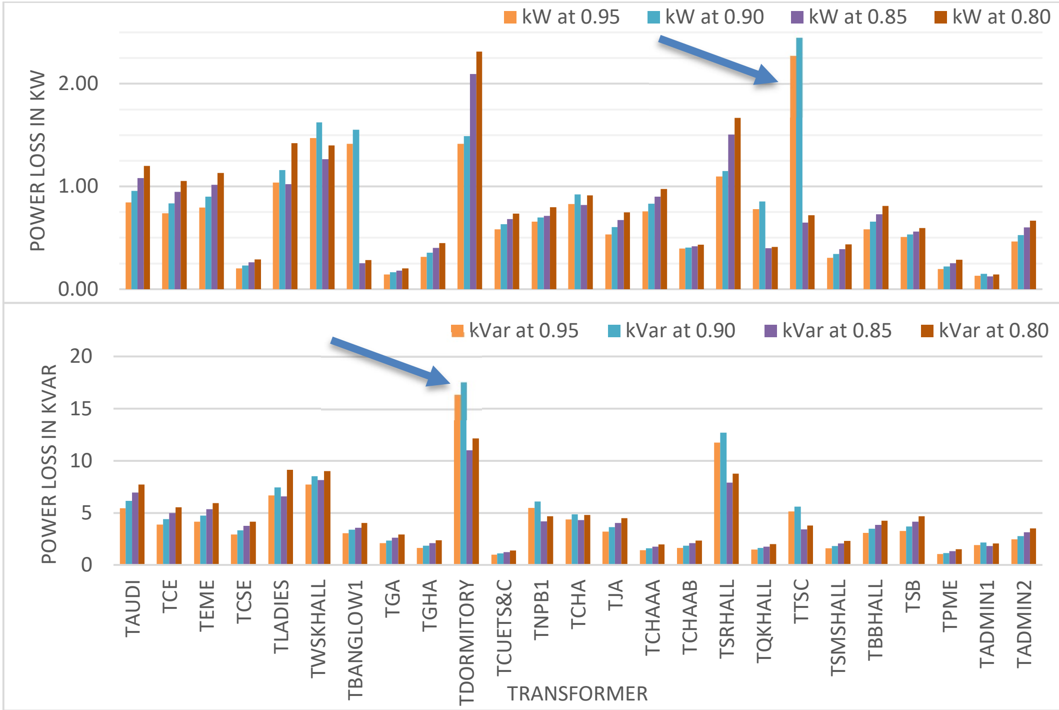


Fig. 4.31. Power Loss of Transformers at Different Power Factor using Cable Model WASP for Horizontal Load Extension Model.

The active and reactive power loss in the transformer shown in Figure 4.31. Maximum loss for both active and reactive power are found at "TTSC" and "TDORMITORY" transformers respectively. Minimum active and reactive loss are found at "TADMIN1" and "TCUETS&C" transformers respectively.

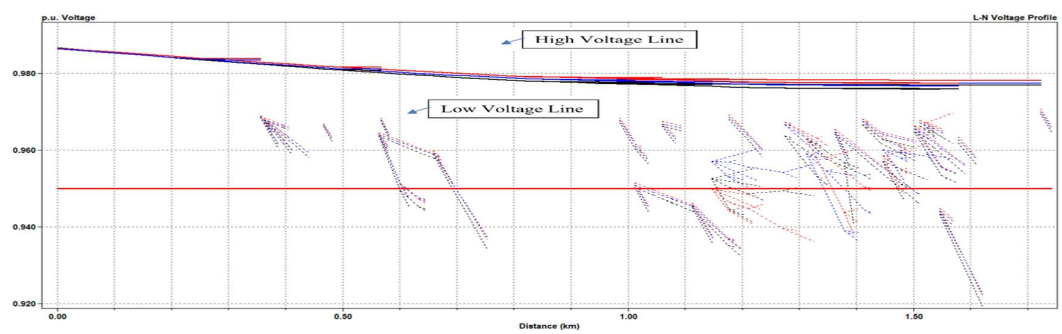
Table 4.10 Summary of CASE#5, Scenario-2

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.64	2.64	2.61	2.61
Reactive Power Flow (MVAR)	1.05	1.46	1.79	2.14
Active Power Loss (MW)	0.061(2.319%)	0.068(2.59%)	0.071(2.71%)	0.080(3.07%)
Reactive Power Loss (MVAR)	0.194	0.22	0.22	0.24

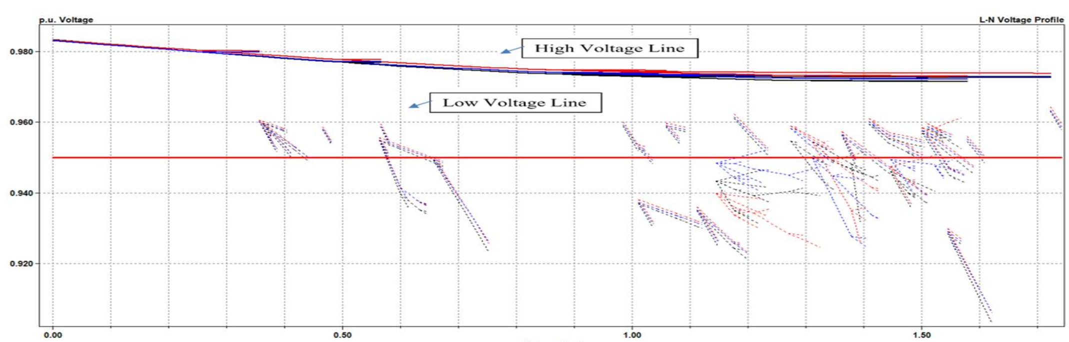
The result summary of simulations using the WASP LT cable model for case#4 has been given in Table 4.10. Power loss has been found much less than scenario-1 for each pf variation.

4.5.3 Scenario-3: Horizontal Load Extension Model using ANT Cable Type

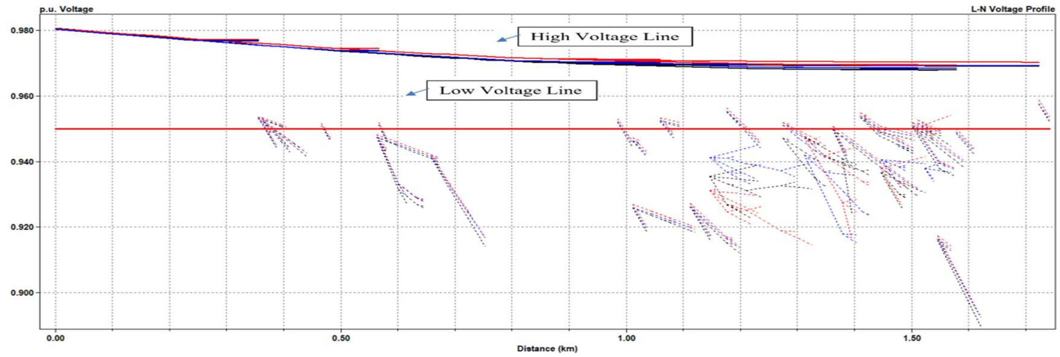
In this scenario, an optimized distribution network with extended future load has been designed and simulated with LT cable ANT and analyzed by varying load power factor. The following Figure 4.32 shows the p.u. L-N voltage profile of the simulation.



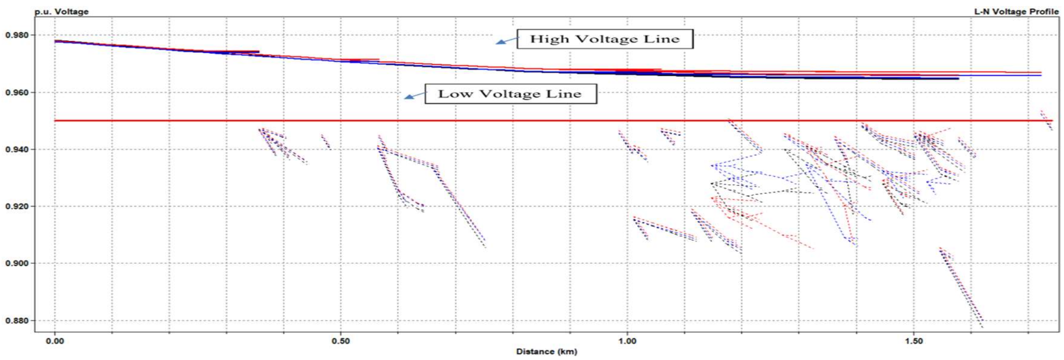
(a) L-N voltage profile for each bus at 0.95 pf



(b) L-N voltage profile for each bus at 0.90 pf

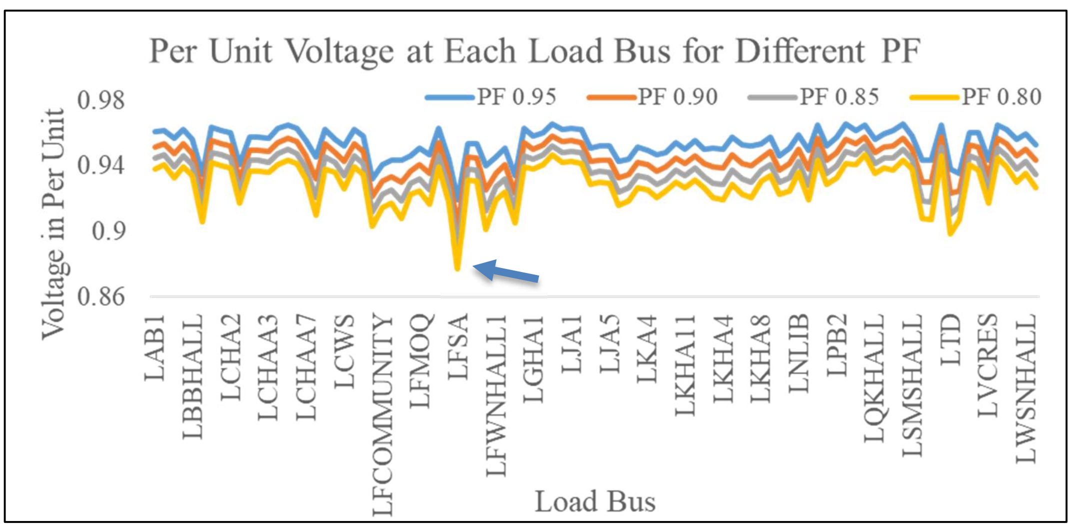


(c) L-N voltage profile for each bus at 0.85 pf

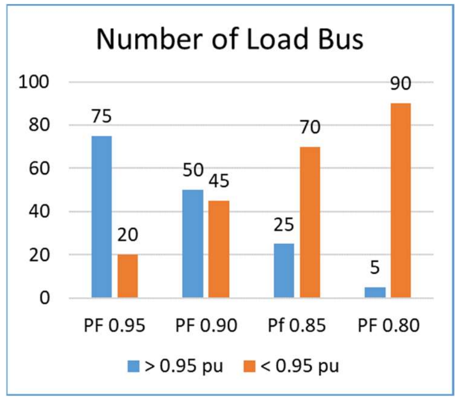


(d) L-N voltage profile for each bus at 0.80 pf

Fig. 4.32. Per Unit (P.U) L-N Voltage Profile at Each Bus at Different Pf for Horizontal Load Extension Model using ANT LT Cable.



(a)



(b)

Fig. 4.33. (a) Per Unit (P.U) Voltage for L-N at Each Bus for Different Power Factor using Cable Model ANT for Horizontal Load Extension Model. (b) Number of Load Bus Above and Under 0.95 per unit voltage.

Figure 4.33(a) gives the comparison of p.u. voltage for each power factor. The lowest voltage is 0.92 p.u. at pf 0.95 and 0.88 p.u. at 0.80 pf which is found on "LFSA" bus, which is at 10 storied Future Studio Apartment building for the Teachers'. Figure 4.33(b) represents that total 50 load points out of 95 at 0.90 pf are above 0.95 per unit voltage and rest of are under that level.

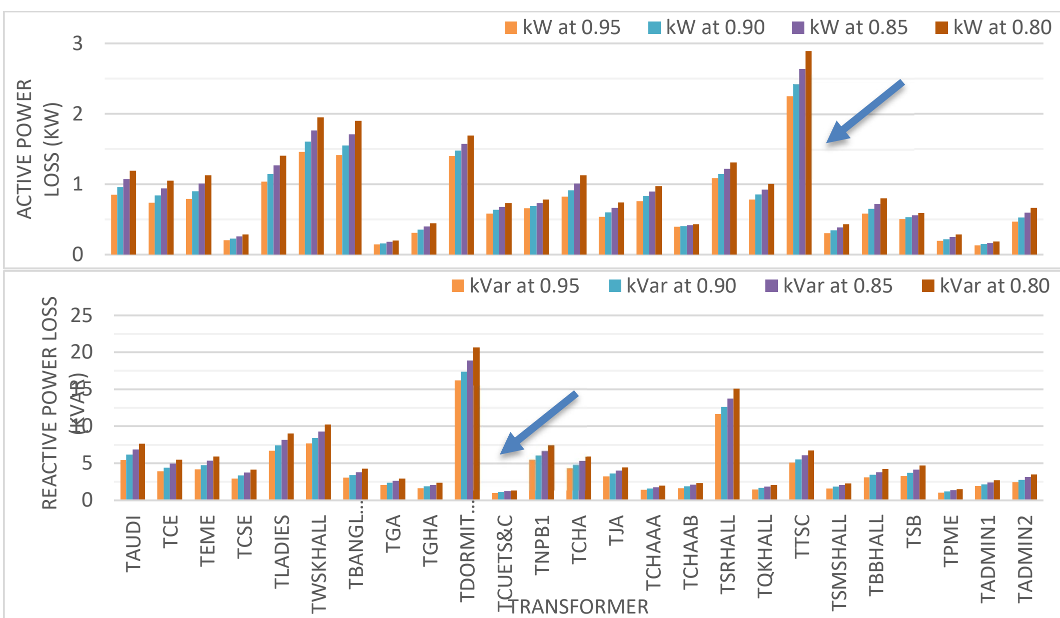


Fig. 4.34. Power Loss of Transformers at Different Power Factor using Cable Model ANT for Horizontal Load Extension Model.

The active and reactive power loss in the transformer shows in Figure 4.34. Maximum active power loss and maximum reactive power loss are found at "TTSC" and "TDORMITORY" transformers respectively. Minimum active and reactive loss are found at "TADMIN1" and "TCUETS&C" transformer respectively.

Table 4.11 Summary of Case#5, Scenario-3

Parameter	**Power Factor 0.95**	**Power Factor 0.90**	**Power Factor 0.85**	**Power Factor 0.80**
Active Power Flow (MW)	2.65	2.63	2.60	2.57
Reactive Power Flow (MVAR)	1.04	1.45	1.80	2.12
Active Power Loss (MW)	0.071 (2.67%)	0.078 (2.97%)	0.086 (3.31%)	0.096 (3.71%)
Reactive Power Loss (MVAR)	0.20	0.22	0.24	0.27

The result summary of simulations by using ANT model cable for case#5 scenario-3 has been given in Table 4.11. Power loss has been found much less than case#4 scenario-1 system but slightly greater than scenario-2 for each pf variation.

4.5.4 Comparison of L-N per unit voltage of Horizontal Load Extension Model Case for Different Cable Models:

The following Figure 4.35 represents the per unit voltage at different power factors for three types of cable models against each bus.

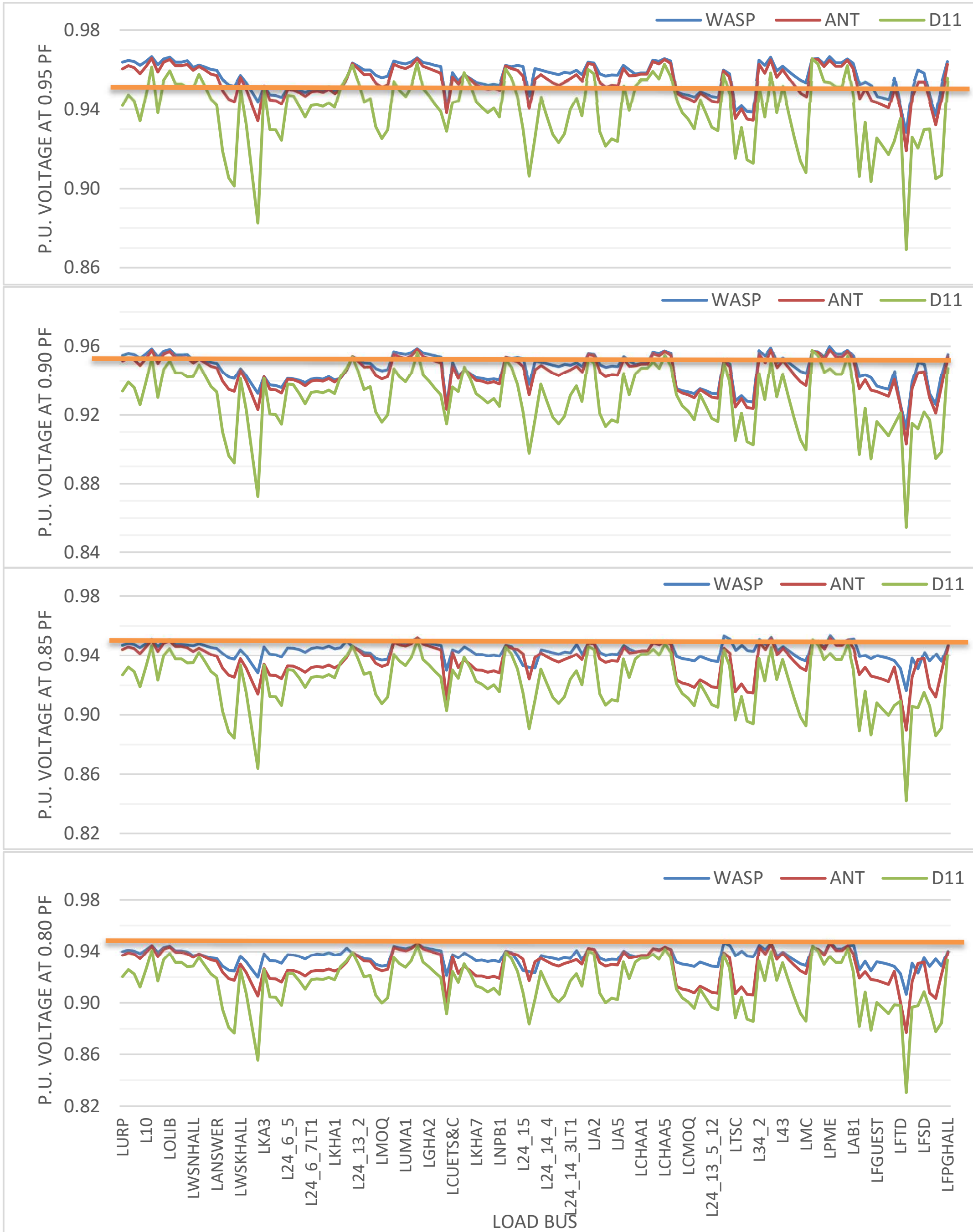


Fig. 4.35. Comparison of L-N p.u. voltage at Different PF for Different Cable for Horizontal Load Extension Model.

From the figure, it is clear that the best performance has been given by the WASP model cable at 0.95 power factor. Although the per-unit voltage value is very poor as the transformer could not provide sufficient power to the load.

A comparison of different loss parameters has shown in Figure 4.36 among the case#5 scenario#1, case#5 scenario#2 and case#5 scenario#3.

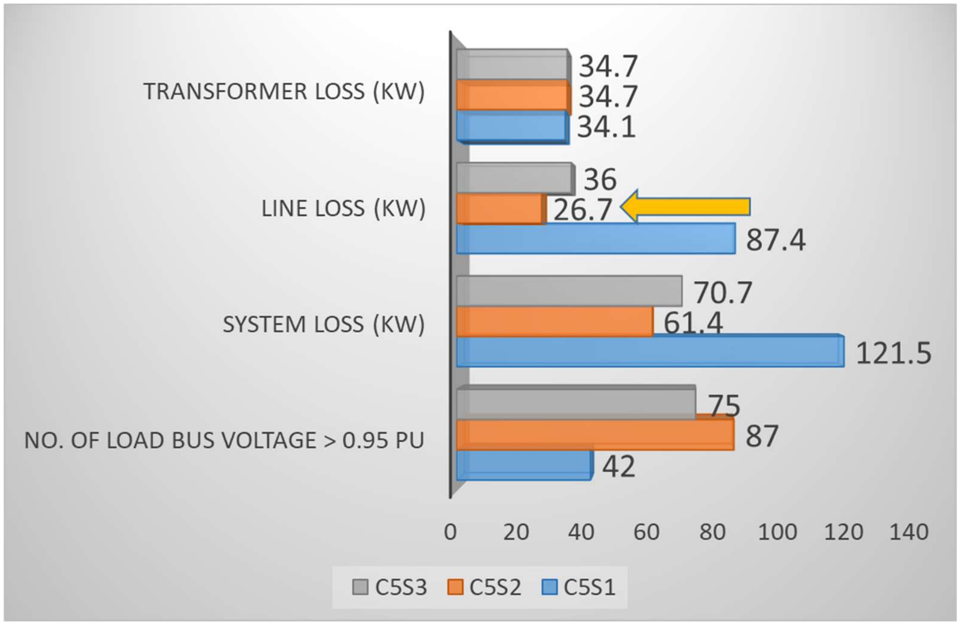


Fig. 4.36. Comparison of Different Parameters between C5S1, C5S2 and C5S3

From the figure it is clearly seen that case#5 scenario#2 has shown a better result than other scenarios.

4.6 RESULT IN COMPARISON AMONG THE CASES

In this section, a comparison has built up among the cases by comparing the power losses and other parameters and presented in Table 4.12, Table 4.13 and Table 4.14.

LT cable type D-11 has been used in Existing Model (Case#1 Scenario#1), Optimized Model (Case#2 Scenario#2) and Future Model (Case#5 Scenario#1) and summarized in Table 4.12.

Table 4.12 Line Loss Comparison among the Scenarios using LT Cable Type D-11

Parameter	Power Factor	Case#1 Scenario#1	Case#2 Scenario#2	Case#5 Scenario#1
Line Loss (kW)	0.95	35.8	54.5	87.4
	0.90	40.2	60.5	96.1
	0.85	45.1	67.2	105.7
	0.80	48.8	75.1	117.3
Transformer Loss (kW)	0.95	43	19.3	34.1
	0.90	45.5	21.3	37.2
	0.85	47.8	23.6	40.7
	0.80	49.6	26.2	44.9
Total Loss (kW)	0.95	78.9	73.8	121.9
	0.90	85.4	81.9	133.2
	0.85	93	90.8	146.4
	0.80	98.4	101.3	162.2
% of Loss	0.95	3.93%	3.70%	4.85%
	0.90	4.27%	4.13%	5.39%
	0.85	4.66%	4.63%	6.02%
	0.80	5.11%	5.22%	6.77%

Results from Table 4.12 indicates that modeling with D-11 type LT cable reduces the total loss in the proposed model but in a future model, the loss has increased. For the Optimized model (Case#2 Scenario#2) the total loss has decreased as the number of transformers has reduced but the line loss increased than the Existing model (Case#1 Scenario#1).

LT cable type WASP has been used in Existing Model (Case#4 Scenario#2), Optimized Model (Case#3 Scenario#2) and Future Model (Case#5 Scenario#2) and summarized in Table 4.13.

Table 4.13 Line Loss Comparison among the Scenarios using the WASP model

Parameter	Power Factor	Case#4 Scenario#2	Case#3 Scenario#1	Case#5 Scenario#2
Line Loss (kW)	0.95	13.6	15.3	26.7
	0.90	15.3	17.3	29.8
	0.85	17.3	19.5	32.8
	0.80	19.7	22.2	37.2
Transformer Loss (kW)	0.95	42.8	18.9	34.7
	0.90	45.1	21.1	38.4
	0.85	47.7	23.7	38.1
	0.80	50.9	22.2	42.8
Total Loss (kW)	0.95	56.3	34.2	61.4
	0.90	60.4	38.5	68.2
	0.85	65.1	43.4	70.9
	0.80	70.6	49.2	80.0
% of Loss	0.95	2.80%	1.70%	2.37%
	0.90	3.01%	1.91%	2.66%
	0.85	3.24%	2.16%	2.79%
	0.80	3.52%	2.46%	3.17%

Results accumulated in Table 4.13 indicates that, if WASP type LT cable is used in any model of any case the total system loss has been reduced than the existing network. Moreover, the voltage profile has improved.

LT cable type ANT has been used in Existing Model (Case#4 Scenario#1), Optimized Model (Case#3 Scenario#3) and Future Model (Case#5 Scenario#3) and summarized in Table 4.14.

Table 4.14 Line Loss Comparison among the Scenarios using the ANT model

Parameter	Power Factor	Case#4 Scenario#1	Case#3 Scenario#2	Case#5 Scenario#3
Line Loss (kW)	0.95	16.7	21	36
	0.90	18.9	23.7	39.9
	0.85	21.4	26.8	44.2
	0.80	24.2	30.2	49.0
Transformer Loss (kW)	0.95	42.8	19	34.7
	0.90	45.1	21.3	38.3
	0.85	47.8	24	42.2
	0.80	50.9	26.9	46.5
Total Loss (kW)	0.95	59.6	40	70.7
	0.90	64	45	78.2
	0.85	69.1	50.7	86.3
	0.80	75.1	57.1	95.6
% of Loss	0.95	2.96%	1.99%	2.74%
	0.90	3.19%	2.24%	3.06%
	0.85	3.45%	2.53%	3.43%
	0.80	3.75%	2.86%	3.85%

Results from the simulation indicate that, ANT type LT cable use in any model of any case the total system loss has been reduced than the present network but the performance lightly decrease than the WASP model.

4.7 COST ANALYSIS BETWEEN EXISTING AND PROPOSED MODEL

Cost analysis has been done in the case of transformer and cable buying. Table 4.15 and Table 4.16 presents the tentative price of cable and transformers respectively collected from the manufacturer. From the table, a comparison can be done easily in terms of cost analysis.

Table 4.15 Price List of Cable [40], [41]

Serial No.	Cable Model	Price Per Meter (Taka)
1.	D-11	55 – 65
2.	WASP	100 – 120
3.	ANT	80 - 100

Table 4.16 Price List of Transformer [42]

Serial No.	Transformer Rating (kVA)	Phase	Price (Taka)
1.	10	1	50,200
2.	15	1	60,000
3.	25	1	85,000
4.	37.5	1	1,20,000
5.	50	1	1,55,000
6.	75	1	2,20,000
7.	100	3	2,80000
8.	150	3	3,45000
9.	200	3	4,20000
10.	250	3	4,90000

Table 4.17 and Table 4.18 gives information about the cost related to transformer buying for the Existing model (Case#1, Scenario-1) and Proposed Model (Case#2, Scenario-2).

Table 4.17 Cost Estimation of Transformers in Existing Network

Serial No.	Transformer Rating (kVA)	Quantity	Single Unit Price (Taka)	Total Price (Taka)
1.	10	12	50,200	6,02,400/=
2.	15	21	60,000	12,60,000/=
3.	25	15	85,000	12,75,000/=
4.	37.5	12	1,20,000	14,40,000/=
5.	50	27	1,55,000	41,85,000/=
6.	75	42	2,20,000	92,40,000/=
7.	100	10	2,80000	28,00,000/=
The total purchasing price of Transformers				2,08,02,400/=

Table 4.18 Cost Estimation of Transformers in Proposed Network

Serial No.	Transformer Rating (kVA)	Quantity	Single Unit Price (Taka)	Total Price (Taka)
1.	100	2	2,80000	5,60,000/=
2.	150	7	3,45000	24,15,000/=
3.	200	12	4,20000	50,40,000/=
4.	250	4	4,90000	19,60,000/=
Total purchasing price of Transformers				99,75,000/=

From the above information, it is clearly said that 52.04% less money needs to buy all the transformers for the proposed model.

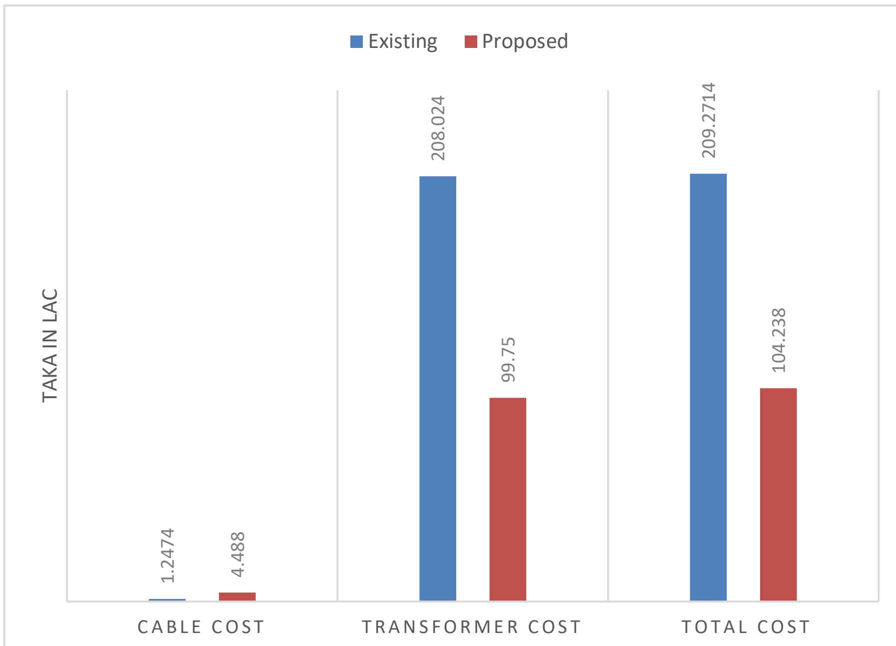


Fig. 4.37. Cost Comparison Between Models

Figure 4.33 represents the cost associated with the cable, transformer and total system for both the existing network and the proposed network. Almost half of the money needs to establish the proposed network.

Chapter 5: Conclusions

The methodology behind the development of a proposed model and the simulation with result analysis are presented in the previous chapter 3 and chapter 4 respectively. This chapter summarizes the research in brief. Section 5.1 presents the essence of this research without detailing it. Section 5.2 includes the key findings of this research work. Section 5.3 finds the limitations of this study. Finally, some recommendations for future research scopes are in section 5.4.

5.1 GENERAL

Numerous processes are used to generate electricity in power plants, and an interconnected network transports it from the plant to the user. A proper design is necessary by taking into account many parameters and methodologies to reduce power loss and preserve voltage quality.

The goal was to manage voltage quality as effectively as possible by minimizing the number of transformers. The study proved the efficacy of the suggested strategy through the use of mathematical optimization techniques and algorithms.

After putting all the parameters of the existing distribution network in OpenDss, I have found the existing system's total loss is 3.97% at a load power factor of 0.95. Simulating the network with a minimal number of transformers, the total loss has found 3.70% at 0.95 load power factor. The model has reduced total loss by 6.80% than the existing system.

After that, another model has been developed by changing the LT cable configuration with a minimal number of transformers. Among the scenarios, the best result was 1.70% found at 0.95 load pf. This model reduces the total loss by 56.74% than the existing model.

So, according to the questions that arise in section 2.7, the answers can be,

1. The total loss of the existing system is on the border of the permissible limit.
2. The voltage profile of the existing system is good. At some bus points, it is below the permissible level. During the load pf decrement, the number of bus points below the permissible range has increased.
3. Transformer banks are running only one-third of their load capacity. As maximum transformers are running under load so the redundancy of some transformers is possible by proper relocating.

The study highlighted the importance of considering both technical and economic factors in voltage quality management strategies. The utilization of a minimal number of transformers for voltage quality management in distribution networks presents a viable and cost-effective solution

5.2 KEY FINDINGS

The key findings of this thesis work are listed below case by case

- In this research, the overall bus-feeder model of CUET has been explored.
- The performance and redundancy possibility of the transformer has been analyzed and only 25 three-phase transformers can supply the power to the system instead of the existing 52 three-phase transformer bank.
- Total losses and cost of the system have been reduced by a proposed economic model.

Under Case#1 existing scenario has been generated, the key findings are listed below-

- Assuming all the residential, academic and administrative load it is found that load demand is around 2.3 MW.
- The whole feeder is of 11 kV high voltage line, power is delivered to the load at the load center by stepping down the voltage. So, the length of the low-voltage cable is around 1.89 km.
- A total of 52 three-phase transformer-bank have been designed for the load. The sum of the capacity of all the banks is a total of 6647.5 kVA.
- Total system loss led to 3.93%, loss component largely contributed by the transformers. Maximum transformers are running at one-third of their rated load.
- The total cost of buying a transformer and cable is around 209.27 Lac Taka.

To find an optimized model Case#2 scenario has been generated to find the minimal number of transformers, the key findings are listed below-

- The simulation model has been created by varying the number of transformers located in a suitable place to supply proper power.
- A minimum of 25 three-phase transformers of a total 4650 kVA rating needs to supply power.
- The total length of LT cable is 3.74 km and scenarios are formed by using D-11 type cable.
- In scenario-1 four different models were developed and the least total system loss was found at 4.17%. In scenario-2, results were

observed by the optimal placement of the transformer. Finally, the minimal loss has been found at 3.70% at 0.95 load pf.

By altering the low voltage cable type, two scenarios have been created using the optimal model found in case 2 scenario-2. The key points are listed below-

- Scenario-1 was designed with the WASP cable model and the total loss was found 1.70%.
- The voltage profile at each bus improved more than the optimized case.
- Secnario-2 was designed with the ANT cable model and the loss is 1.99%.
- System loss has reduced by 56.74% and 49.36% for WASP and ANT cable respectively.
- The cost could be around 109 Lac Taka to buy transformers and cable. Almost 48% initial cost has been reduced by implementing this model.

By altering the low voltage cable type, two scenarios have been created in case#4 using the existing model found in case 1 scenario-1. The key points are listed below-

- The loss could be reduced by 28.75% and 24.68% for WASP and ANT models respectively.
- LT cable WASP and ANT model has low resistance and high current carrying capacity, so total loss has been reduced.
- In both scenarios, the voltage profile is better than in Case#1.

Case#5 has 3 scenarios for three types of cable. The key points are,

- Assuming horizontal load extension of around 700 kW in the future by 2035.
- Total System loss was found at 4.85%, 2.37% and 2.74% for D-11, WASP and ANT models respectively.
- Voltage profile at some point decrease below the permissible range, as the transformer gets overloaded.

5.3 LIMITATIONS OF THE STUDY

The limitations of this study are listed below-

- Assumptions have been made about the distance from one bus point to another bus point. The wire length can therefore vary by up to or down to 5%.
- The distance between the secondary transformer and the load point (service main) may vary for some load centers.
- Calculating the real load demand was impossible. The load was viewed as the total of each house's load demands within a building. The demand for all academic, residential, and administrative loads has been assumed at a standard level. For the performance study, the system power factor was only taken at four distinct levels (0.95, 0.90, 0.85, and 0.80).
- Each transformer may eventually have a load connected that is 20% of its rated capacity or a sudden load may build up. Transformer overloading may happen at loads greater than 20%.
- In this research voltage profile improvement has been done only by changing the parameters of the cable and transformer. Single-phase or three-phase capacitor banks did not utilize to give reactive power assistance to the feeder at important nodes.

- The losses due to circuit parameters like – circuit breaker, current transformer, potential transformer resistance, etc. did not take into account during the simulation.
- During cost analysis, costs related to the transformer and cable have been taken into consideration. Costing due to transportation, commissioning and maintenance did not analyze in this study.

5.4 CONTRIBUTION WITH FUTURE WORK

This study represents a significant advancement in the field of power distribution system optimization. By leveraging the capabilities of OpenDSS simulation software, a comprehensive analysis of the distribution network has been conducted here. An innovative approach of strategically changing the low voltage cable types and transformer ratings while optimizing their positions has led to a remarkable achievement. The findings provide valuable insights for enhancing voltage profiles and minimizing losses in existing distribution networks, with potential implications for real-world applications that can lead to more energy-efficient and cost-effective systems. Reducing the number of transformers from 52 to 25, while concurrently reducing losses by a substantial 56.78%, showcases ability to optimize the distribution network for efficiency and cost-effectiveness. This work stands as a noteworthy contribution to the field, highlighting a practical and effective solution for improving the performance of established distribution networks. This research demonstrates a profound understanding of power distribution systems and ability to optimize the network's efficiency and sustainability. This analysis not only contributes to reducing energy wastage but also demonstrates a sustainable and environmentally conscious approach to power distribution network design, making it a valuable contribution to the field of electrical engineering and power system operation. This research mainly focuses on minimizing the system loss by modeling the optimum number of transformers. Some of the future recommendations are mentioned below-

- Oil-cooling type transformers were taken into consideration in this study. To improve performance, dry-type transformers might be considered in the future.
- Since distributed generation has not been taken into account for this study, distributed generation may be done in the future by installing photovoltaic (PV) on the rooftop.
- A potential area of interest is the underground transmission and distribution system. Thus, the design of this network may utilize underground cables in the future.
- Only three types of cable have been explored here for low-voltage transmission. Other types and models may explore in the future. The high voltage feeder may be re-design and could be the point of interest.
- In the future, current flow analysis, smart metering systems, hybrid power feeder systems and sectionalizing of networks could be the field of interest for network analysis.

Bibliography

[1] Y. P. Soni and E. Fernandez, "Regression modelling of voltage profile in an IEEE 9-bus radial microgrid feeder," in *2020 IEEE Students' Conference on Engineering and Systems, SCES 2020*, 2020. doi: 10.1109/SCES50439.2020.9236753.

[2] H. Ali, S. Ullah, I. Sami, N. Ahmad, and F. Khan, "Economic Loss Minimization of a Distribution Feeder and Selection of Optimum Conductor for Voltage Profile Improvement," in *4th International Conference on Power Generation Systems and Renewable Energy Technologies, PGSRET 2018*, 2019. doi: 10.1109/PGSRET.2018.8686040.

[3] R. B. Magadum and D. B. Kulkarni, "Improvement of voltage profile by using line reconfiguration and distribution transformer placement," in *2016 International Conference on Energy Efficient Technologies for Sustainability, ICEETS 2016*, 2016. doi: 10.1109/ICEETS.2016.7583775.

[4] B. Suechoey and I. Introductlon, "An Analysis and Selection of Distribution Transformer For Losses Reduction," 2000.

[5] P. Kangpeng, "The research for network model of distribution management system," 2010, pp. 1–5.

[6] H. Rudnick and M. Munoz, "Influence of modeling in load flow analysis of three phase distribution systems," in *Proceedings of the 1990 IEEE Colloquium in South America, COLLOQ 1990*, 1990. doi: 10.1109/COLLOQ.1990.152825.

[7] J. Nazarko, "Modelling of electrical power distribution systems by application of experimental design," in *2000 IEEE Power Engineering Society, Conference Proceedings*, 2000. doi: 10.1109/PESW.2000.850103.

[8] Minn.) IEEE Power & Energy Society. General Meeting (2010 : Minneapolis and Institute of Electrical and Electronics Engineers., *IEEE PES General Meeting : [proceedings], July 25-29, 2010, Minneapolis, Minnesota.* IEEE, 2010.

[9] R. Lind, "Distribution System Modelling for Voltage Stability Studies," *IEEE Transactions on Power Systems*, vol. 11, no. 4, 1996, doi: 10.1109/59.544627.

[10] K. Miu and M. Kleinberg, "Impact studies of unbalanced multi-phase distribution system component models," in *IEEE PES General Meeting, PES 2010*, 2010. doi: 10.1109/PES.2010.5589570.

[11] Palo Alto, "Program on Technology Innovation: Distribution Common Information Model (CIM) Modeling of Two North American Feeders.," 2009.

[12] V. Ramachandran, "Modeling of Utility Distribution Feeder in OpenDSS with Steady Modeling of Utility Distribution Feeder in OpenDSS with Steady State Impact Analysis of Distributed Generation State Impact Analysis of Distributed Generation Recommended Citation Recommended Citation," 2011. [Online]. Available: https://researchrepository.wvu.edu/etd

[13] J. S. Paul and E. A. C. Aranha Neto, "Evaluation of Brazilian regulatory parameters in technical losses calculation: a case of study," *International Journal of Energy and Environmental Engineering*, 2022, doi: 10.1007/s40095-022-00504-6.

[14] S. Khushalani and N. Schulz, "Unbalanced distribution power flow with distributed generation," in *Proceedings of the IEEE Power Engineering Society*

Transmission and Distribution Conference, 2006. doi: 10.1109/TDC.2006.1668508.
[15] "Bangladesh Power System Enhancement and Efficiency Improvement Project (RRP BAN 49423) Initial Environmental Examination Bangladesh: Bangladesh Power System Enhancement and Efficiency Improvement Project," 2017.
[16] S. Yifan, L. Hongtao, and S. He, "Voltage Sag Propagation Model Considering Transformer Operation Parameters," in *2022 4th Asia Energy and Electrical Engineering Symposium, AEEES 2022*, 2022. doi: 10.1109/AEEES54426.2022.9759558.
[17] G. G. Karady and K. E. Holbert, *Electrical Energy Conversion and Transport*. 2015. doi: 10.1109/9780471681991.
[18] S. F. Bush, *Smart Grid: Communication-Enabled Intelligence for the Electric Power Grid*, vol. 9781119975809. 2014. doi: 10.1002/9781118820216.
[19] K. Li, S. Li, D. Li, and Q. Niu, "Intelligent computing for sustainable energy and environment," *Communications in Computer and Information Science*, vol. 355, 2013.
[20] H.-Y. Chien, J. Chen, Y. Chen, P. Lin, Y. Chang, and R. Chen, *Advances in Intelligent Information Hiding and Multimedia Signal Processing*, vol. 82. 2018.
[21] S. David and S. David, "Economics of distribution feeder conditioning: Modelling and analysis-A case study," in *2017 International Conference on Nascent Technologies in Engineering, ICNTE 2017 - Proceedings*, 2017. doi: 10.1109/ICNTE.2017.7947984.
[22] A. Iqbal, S. Moinoddin, and B. P. Reddy, *Electrical Machine Fundamentals with Numerical Simulation using MATLAB/SIMULINK*. 2021. doi: 10.1002/9781119682684.
[23] R. Billinton, S. Aboreshaid, and M. Fotuhi-Firuzabad, "Well-being analysis for hvdc transmission systems," *IEEE Transactions on Power Systems*, vol. 12, no. 2, 1997, doi: 10.1109/59.589765.
[24] "CONDUCTOR DATA SHEET ALUMINUM CONDUCTORS STEEL REINFORCED (ACSR)." [Online]. Available: www.midalcable.com
[25] F. E. P. Marcos *et al.*, "A review of power distribution test feeders in the United States and the need for synthetic representative networks," *Energies*, vol. 10, no. 11. 2017. doi: 10.3390/en10111896.
[26] L. Moreno-Diaz, E. Romero-Ramos, A. Gomez-Exposito, E. Cordero-Herrera, J. R. Rivero, and J. S. Cifuentes, "Accuracy of electrical feeder models for distribution systems analysis," in *2018 International Conference on Smart Energy Systems and Technologies, SEST 2018 - Proceedings*, 2018. doi: 10.1109/SEST.2018.8495716.
[27] B. Das, "Estimation of parameters of a three-phase distribution feeder," *IEEE Transactions on Power Delivery*, vol. 26, no. 4, 2011, doi: 10.1109/TPWRD.2011.2165858.
[28] N. C. Yang, R. Huang, and M. F. Guo, "Distribution Feeder Parameter Estimation Without Synchronized Phasor Measurement by Using Radial Basis Function Neural Networks and Multi-Run Optimization Method," *IEEE Access*, vol. 10, 2022, doi: 10.1109/ACCESS.2021.3140123.
[29] L. Alhmoud and W. Marji, "Optimization of Three-Phase Feeder Load Balancing Using Smart Meters," *Canadian Journal of Electrical and Computer Engineering*, vol. 45, no. 1, 2022, doi: 10.1109/ICJECE.2021.3113521.
[30] lidlmrl Munshiganj Palli Bidyut Samity Shipahipara, "Electrification Docu ment Code-5431 1 00 I 03137 of Rural System."

[31] R. H. A. Zubo, G. Mokryani, H. S. Rajamani, J. Aghaei, T. Niknam, and P. Pillai, “Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review,” *Renewable and Sustainable Energy Reviews*, vol. 72. 2017. doi: 10.1016/j.rser.2016.10.036.
[32] S. Nekkalapu, V. Vittal, J. Undrill, B. Keel, B. Gong, and K. Brown, “Synthesis of load and feeder models using point on wave measurement data,” *IEEE Open Access Journal of Power and Energy*, vol. 8, 2021, doi: 10.1109/OAJPE.2021.3079724.
[33] M. Hajiaghapour-Moghimi, E. Hajipour, N. Farzin, M. Vakilian, and M. H. Moghimi, *A Distribution Transformer Comprehensive Optimal Planning and Sizing Method Presenting Practical Solutions to Mitigate the Effects of Fault Induced Delayed Voltage Recovery (FIDVR) Phenomenon on the Special Protection Systems of Iran Bulk Power Network View project High-Temperature Superconducting (HTS) Transformer Design View project A Distribution Transformer Comprehensive Optimal Planning and Sizing Method SV TrC*. 2016. [Online]. Available: https://www.researchgate.net/publication/327981287
[34] “KJV ALLOY CONDUCTORS P. LTD.-An ISO 9001:2008 Company,” 2010.
[35] R. C. Dugan and D. Montenegro, “Reference Guide The Open Distribution System Simulator™ (OpenDSS),” 2020.
[36] X. Wang, M. Yue, M. Villaran, R. Lofar, H. Li, and J. Smith, “Grid impacts of utility-scale solar PV systems installed at both subtransmission and distribution levels simultaneously,” in *IEEE Power and Energy Society General Meeting*, 2018. doi: 10.1109/PESGM.2017.8273946.
[37] V. Ramachandran, “Modeling of Utility Distribution Feeder in OpenDSS with Steady Modeling of Utility Distribution Feeder in OpenDSS with Steady State Impact Analysis of Distributed Generation State Impact Analysis of Distributed Generation Recommended Citation Recommended Citation,” 2011. [Online]. Available: https://researchrepository.wvu.edu/etd
[38] W. Rone, W. Saab, and P. Ben-Tzvi, “Design, modeling and optimization of the universal-spatial robotic tail,” in *ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE)*, 2017. doi: 10.1115/IMECE201771463.
[39] R. K. Lian, R. K. Subroto, V. Andrean, and B. H. Lin, *Harmonic Modeling of Voltage Source Converters using Basic Numerical Methods*. 2022. doi: 10.1002/9781119527190.
[40] “Overhead Conductor :: Service Drop Cable :: D11- Duplex.” https://bizli.com.bd/overhead-conductor/service-drop-cable/bizli-cables-d11-duplex/ (accessed Jun. 10, 2023).
[41] “AAC ANT, China AAC ANT, AAC ANT Manufacturers, China AAC ANT catalog.” https://www.made-in-china.com/productdirectory.do?subaction=hunt&style=b&mode=and&code=0&comProvince=nolimit&order=0&isOpenCorrection=1&org=top&keyword=&file=&searchType=0&word=AAC+ANT (accessed Jun. 10, 2023).
[42] “Single Phase Distribution Transformer- 25 KVA Price in Bangladesh | bdstore24.” https://www.bdstore24.com/products/details/63916/-single-phase-distribution-transformer-25-kva/ (accessed Jun. 10, 2023).