TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: M-363-MSREE-2019-2023

Study of Impact on penetration of induction stoves in electrical distribution network of Jorpati, Kathmandu: A case study of Gothatar Feeder

by

Pravin Shrestha

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

OCTOBER, 2023

COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Study of Impact on penetration of induction stoves in electrical distribution network of Jorpati, Kathmandu: A case study of Gothatar Feeder**" submitted by Pravin Shrestha in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

____

Associate Professor Dr. Hari Bahadur Darlami

Supervisor

Department of Mechanical and Aerospace Engineering,

IOE, Pulchowk Campus

____

Assistant Professor Arbin Maharjan

Supervisor

Department of Electrical Engineering, IOE, Pulchowk Campus

____

Mr. Tek Nath Tiwari

External Examiner

Director, Nepal Electricity Authority

____

Assistant Professor Dr. Sudip Bhattrai

Committee Chairperson

Head of Department, Department of Mechanical and Aerospace Engineering, IOE, Pulchowk Campus

Tribhuvan University Institute of Engineering Department of Mechanical and Aerospace Engineering Pulchowk Campus

Date: October 5, 2023

DECLARATION

I declare that the work hereby submitted for Master of Science in Renewable Energy Engineering (MSREE) at IOE, Pulchowk Campus entitled "**Study of Impact on penetration of induction stoves in electrical distribution network of Jorpati, Kathmandu: A case study of Gothatar Feeder**" is my own work and has not been previously submitted by me at any university for any academic award.

I authorize IOE, Pulchowk Campus to lend this thesis to other institution or individuals for the purpose of scholarly research.

Pravin Shrestha
075MSREE013
October, 2023

ABSTRACT

The use of Induction stoves by replacing traditional ways of cooking can be beneficial for improving the health of people and for reducing impact on environment. Due to this Induction stove is gaining massive popularity in new policies initiated by the government. When there is massive insertion of Induction stove, it can be burden to electrical power distribution network. For our study residential area of Gothatar is taken which is supplied by Gothatar feeder of Jorpati Distribution Center. Gothatar feeder is radial feeder having total length of 10.67 kilometer with Dog, Weasel and Rabbit conductors. Gothatar feeder consist of total 4946 consumers and consisting of 36 public transformers and 13 private transformers. This study analyzes the effect of penetration of induction stove in 11 kV Gothatar feeder of Jorpati Distribution Center using DigSILENT powerfactory software. Electrical distribution networks are surveyed in terms of peak power of feeder, active power loss, line loading, voltage deviation, and transformer loading before and after penetration of Induction stove. For the feasibility of study different zones of area are created for induction stove penetration. At base case peak load is seen at 7 p.m. in the month of Poush which is 5.73 MVA with active power loss of 113 kW. Induction stove is penetrated at various operating range at different zones at step of 5 percent. When the penetration level of Induction stove reached 25 percent power demand reached 7.67 MVA and active power loss reached 179 kW. As induction stove penetration level increases the transformers got overloaded. At 25 percent penetration of Induction stove 18 number of the transformer got overloaded at different sections along with conductors. Analysis of results are performed. The results shows that to increase the withstand capacity of distribution network for induction stove penetration mitigation have to be applied. Mitigation is done by changing transformer, cable, protection system to next higher available standard size for the reliable operation of electrical distribution network.

ACKNOWLEDGEMENT

I would like to express my sincere appreciation to my supervisors Associate Professor Dr. Hari Bahadur Darlami and Assistant Professor Arbin Maharjan for their overall guidance throughout my research and spending many hours discussing and reviewing draft manuscript of this thesis. I would like to thank Mr. Tek Nath Tiwari, Director, Nepal Electricity Authority as an external examiner for his invaluable suggestions and feedback, which has helped a lot in improving the quality of this thesis work.

I would also like to express my due respect to Mr. Sabin Oli and Mr. Prakash Budha for advising me on use of software and continual guidance throughout this thesis.

I would like to pay my deep appreciation to all my faculties, staffs and entire Department of Mechanical and Aerospace Engineering and Msc in Renewable Energy Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University.

I acknowledge the cooperation by Mr. Damber Pokhrel and Mr. Sushil Kumar Yadav of Jorpati Distribution Center, Nepal Electricity Authority and Mr. Deepak Lama who provided the essential data for research work.

I am also thankful to my friends Mr. Yadav Nepal, Mr. Sudarshan Acharya, Mr. Suman Aryal, Mr. Ram Shrestha, Mr. Prem Raj Niraula for their continuous support and encouragement.

In addition, I would like to thank my family members without them I am nothing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
ACSR	Aluminum Conductor Steel Reinforced
AAC	All Aluminium Conductor
AEPC	Alternative Energy Promotion Centre
CAIDI	Customer Average Interruption Duration Index
CCA	Conference on Computability and Complexity in Analysis
DC	Direct Current
DG	Distributed Generation
DO	Drop Out
EPC	Electric Pressure Cooker
ESMAP	Energy Sector Management Assistance Program
FY	Fiscal Year
Hz	Hertz
IEC	International Electro Technical Commission
IEEE	Institute of Electrical and Electronic Engineers
kV	Kilo Volt
kW	Kilo Watt
kVA	Kilo Volt Ampere
MW	Mega Watt
LPG	Liquid Petroleum Gas
MCCB	Molded Case Circuit Breaker
MECS	Modern Energy Cooking Services
NEA	Nepal Electricity Authority
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SMPS	Switched Mode Power Supply
Tr	Transformer
WECS	Water and Energy Commission Secretariat
Mtr	Meter
Qty	Quantity
XLPE	Cross Linked Polyethylene

CHAPTER ONE: INTRODUCTION

1.1 Background

Cooking through electric appliances contributes to suitable time in order to approach clean cooking. To protect the health of people and reduce impact on environment there is need in change in current cooking methods. This relates to 4 billion people out of which 2.7 billion people have no clean cooking facility and also 1.3 billion people with no proper clean cooking standard. This means that 4 billion people cannot cook effectively, efficiently , favorably, reliably, harmlessly, cheaply (ESMAP and MECS. 2020, n.d.). There have been many approaches to improve traditional cookstove, biogas stoves, replacing those with LPG but now cooking through electric have become trend for cooking purpose. This can be an opportunity for low-income households. Electricity cooking can be beneficial but challenges that electric cooking brings should be kept in mind. Adopting electric cooking is an important approach for sustainable goal achievement for clean cooking practice. Most benefit that could be taken will be by women from electric cooking, which is clean, reliable and safe. Therefore, electric cooking can be transition to sustainable energy for all.

In budget speech FY 2022/23 in article 252, Government of Nepal declared to promote biogas, electric stove, improved stoves, and other suitable modern and economical technologies in order to replace firewood, animal dungs and LPG gas, which are used at primary cooking fuel. In addition, a quite LPG gas campaign was carried out. It is estimated that by doing so it can generate access to clean cooking energy for around 100 thousand households. Policies are also being made to reduce electricity consumption gradually thereby reducing subsidies provided to LPG gas.

Nepal is landlocked country, and no research is made for fossil fuel reserves. About 1.5 million tons of LPG is imported every year for cooking purposes. Experts suggest that if LPG could be replaced by electric cooking at household, it can vastly reduce the country's trade deficit burden (Chitrakar 2019; Nakarmi 2019, n.d.). Consumers are encouraged to increase to use the induction stove by replacing the LPG stove by Nepal Electricity Authority (The Himalayan Times, August 2020).

Electric cooking stoves are better than using LPG and are being highlighted by many factors such as clean, easy to use, simple, reliable, cheaper, etc. (Roshan et al, 2014 and R.M. Shrestha, G.B. Bhattarai, 1995). Out of total consumption the residential sector account for 60.59% in national level (WECS (2023). Energy Synopsis Report 2023, Singha Durbar Kathmandu, Nepal, n.d.). According to NEA's fiscal year 2022/2023 report among the total consumers domestic consumer accounts for 92.32%. This shows that cooking can be a main factor for energy consumption. Hence, it can be relatable to check possibility of induction stove in electric power system network.

Fuelwood based cooking is a common and effective solution in rural segments of the country because of cost effectiveness, ease of access and even social and cultural reasons. Mechanism of market and accessibility issues can be controlled to achieve the desired result of having electric cooking stoves that can benefit the end users as well as the nation. This can only be achieved successfully if supported by a scientific and evidence-based approach.

Electric stove is a non-linear device. With a sustained increase in the use of non-linear load devices distortion can appear in voltage and current waveform in distribution network requiring standard policies (Suarez et al. 2005). Electric utility must fulfill power quality of certain standards along with electrical power supply to ensure customer satisfaction. Voltage level, frequency, flickers in voltage, harmonics, balancing of voltage and current, power factor, gaps and surges and active and reactive power are some of the electrical standards which need to be fulfilled (Kit et al. 2012).

International organizations, such as the Institute of Electrical and Electronic Engineers (IEEE), International Electro technical Commission (IEC), and others set power quality standard. Each country or region accepts or reformulates these standards applying those. (Kit et al. 2012). In Nepal, electricity rules 2050 sets power quality regulations for electricity sector.

Home appliances uses power electronics devices that creates distortion to distribution and transmission networks affecting reliability factors such as Customer Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI), and System Average Interruption Frequency Index (SAIFI). Other equipment connected to the same home such as computers, motor, fridge etc. are affected by this distortion. Besides that, cables and transformers of distribution network get heated (Wagnerl. 1993).

1.2 Problem Statement

Nepal is a developing country. Energy is the key source of development for any country. Energy consumption in Nepal is in increasing trend. The total energy consumption, which was 626 PJ in FY 2020/21, has reached 640 PJ by FY 2021/22. Out of the total energy consumption, the ratios of traditional, commercial, and renewable energy consumption have been 64.17 percent, 28.35 percent, and 2.52 percent respectively FY 2021/22 (Ministry of Energy, Water Resources and Irrigation, FY 2021/22). Also, out of total energy consumption in Nepal, 60.59 percent of energy is consumed in residential sector, 10.49 percent in transportation sector, 22.17 percent in industrial sector, 4.79 percent commercial and 0.49 percent in agricultural sector (WECS (2023). Energy Synopsis Report 2023, Singha Durbar Kathmandu, Nepal, n.d.). As per the energy synopsis report, 2010, out of total residential energy consumed only 14.5 percent is consumed by urban household. Mainly the energy consumption is dominated by commercial resources like electricity and petroleum products according to energy resource type. The report indicated that only for cooling purpose 52% of urban energy is used which is followed by electric appliance (14%), Lighting (13%), heating and cooling (10%), animal feeding (8%) and agricultural processing (3%) (WECS, 2010). As per the report of Nepal living standards 59% of urban households used LPG for cooking (CBS, 2011). Now, urban household cooking in LPG has increased to 70% (CBS, 2014). WECS (2010) also indicated that the demand for LPG in urban areas increased at rate of 23% whereas demand for electricity increased at the rate of 10%. As most of the cooking technology is made through LPG, biomass, biogas, etc. As petroleum products like diesel, petrol, LPG, are imported from India which has made a major loss for country in terms of economy. In the other hand Induction stove is technology that uses electricity to cook food. In present situation Nepal Electricity Authority have surplus power to supply to consumers and consumers could use induction stove that uses electricity for cooking. If use of Induction stoves is increased then we can replace LPG in coming years so that country's economy can sustain. Recently the use of induction stoves is in increasing trend. As per the customs data 700,000 induction stoves have been imported to date. The use of induction stove was increased significantly during earthquake in Nepal in the year 2072 B.S. After several times this use was reduced but now due to Covid 19 there is again a significant rise in the use of the Induction stove. The government of Nepal has been encouraging general public to use electric stove in order to replace the use of LPG cookstove. Nepal Electricity Authority is also providing discount up to use of 150 units for domestic consumers in order to encourage use of electric stove. There is lot to do to promote the use of Induction stoves in residential sector. There should be proper Government policy regarding enforcement of using Induction stoves, reliability of supply, cheap electricity, and others, which may hinder the use of induction stoves in households of Nepal.

In the proposed research, Gothatar feeder of Jorpati Distribution Center has been considered to see whether the penetration of Induction stove in households could hamper the power quality of distribution Network.

1.3 Research Gap

Penetration of induction stoves in household is an interesting topic. Different types of induction cooktop are available in the market. To quantify the implementation benefits of induction, stove some researchers focused on electrical studies (Martínez-Gómez et al., 2016). Government of Kerala, India has conducted feasibility study of Induction stove in city of Kerala (Government of Kerala, 2014). Also, in 2014 India's northern state Himalchal Pradesh programmed name 'Access to clean cooking alternatives in rural India' was launched focusing on Induction stove implementation where four thousand rural households were provided with induction stoves (Banerjee et al., 2016). Biomass and LPG based stoves were displaced by induction stove being the cities the most important shifting spots, because of lower electricity costs and energy availability (Smith and Sagar, 2014), (Banerjee et al., 2016). Also, as per the "Indonesia kitchen appliances market forecast and opportunities, 2019" report, due to increasing price of LPG the induction stoves will be adopted in the majority of the country (Banerjee et al., 2016). A detailed study would be required to evaluate the additional loading on the distribution of power infrastructure as majority of consumers are opting for electric cooking appliances(Chhetri et al., 2021).

In Nepal, the study by Maharjan (2016) has obtained the experimental electrical and thermal performances of cooking appliances available in Kathmandu. The research concluded that the power displayed by the device does not resemble the real power consumed in case of induction and infrared cooker. A study has been performed by Kit (2012), to show the effects of Switched Mode Power Supply driven home appliances to show the effects of voltage distortion on current harmonics in smart grid networks. In this proposed thesis proposal, we are going to research the impact the induction stove could have in distribution network in terms of voltage drop, power loss, loading of transformer, loading of conductor.

1.4 Objectives

Main objective of this study is to analyze the effect on technical parameters of distribution network due to induction stoves.

Specific objectives of the study are:

- To determine initial loading condition of feeder without induction stove penetration.
- To analyze the technical parameters of distribution system before and after penetration of induction stove by simulating electrical system in DIgSILENT software.
- To analyze suitable mitigation measures of electrical distribution network after penetration of induction stove at different level.
- To perform financial analysis after penetration of induction stove in distribution system.

1.5 Limitations

- Induction stoves are considered only as lumped load.
- At end of distribution transformer, the residential loads are considered to be connected as merged load.
- Future load growth has not been considered.

CHAPTER TWO: LITERATURE REVIEW

Technology that Induction heating uses is a completely different method to generate heat as compared with conventional electric heaters. In an induction heater, the cooking vessel itself generates heat (Stanley Zinn and Semiatin Lee et al, 1988). Electrical appliances such as electric kettle, microwave oven and rice cooker are used for specific purposes where electric power supply is available but due to low efficiency and high-power consumption, a good policy option is not considered for electric coil stoves (Smith and Sager, 2014). The above-mentioned limitations can be overcome by Induction stove, which is a new generation electric cooking appliance. Induction stoves can be used for all cooking purposes and considered fifty percent more efficient than electric coil stove (Smith and Sager, 2014). Magnetic coil and ceramic plate are the major components in an induction stove. Induction stoves operate by generating high frequency filed by magnetic coil. Coil is operated at 20 to 50 kilohertz frequency that generates alternating magnetic field in the cooking zone (http://en.tdk.eu, as of September 2015). Ferrous cookware such as stainless-steel vessels is penetrated by magnetic field that sets up eddy current generating heat at the base of metallic cookware, which is further transferred to its contents (Wong and Fong, 2013). Main advantage of induction stove is that as soon as the cookware is removed, or device is turned the heat generation stops immediately. According to meal types of induction stoves reportedly utilize between 28% and 79% of the total energy that is required by the traditional electric stove to prepare the same meal (Hajer and Morawicki, 2013).

There are two reasons electric cooking is gaining importance in Nepal. One is production of electricity generation is increasing gradually. There are much hydropower projects which will be completed in the near future. Clearly, greater the electricity generation, the more energy will be required to consume such generated energy. One way to consume such generated energy is by increasing the use of electric cooking in households. And second is the import of petroleum products. Nepal's trade deficit can be reduced greatly when LPG can be replaced with electric cooking alone (Chitrakar and Nakarmi, 2019). Suggestion made by fuel economics (based on the cost to end consumers), showed cooking through electric appliance in household could be beneficial. Cooking through electric appliance like induction stove is cheaper and could be a better option than conventional cooking (CCA 2019; Koirala 2019; Nakarmi 2019).

Many programmes had been allocated for promotion of induction stove in Nepal. Fourteen thousand induction stove were distributed by smaller programs and twenty-five thousand induction have distributed through two large programmes via Nepal Renewable Energy Programme, and AEPC Terai cookstoves programme, have distributed with 500 thousand stoves, can have large-scale impacts in distribution network in the coming years.

With the introduction of such massive induction stoves in residential households withstand capacity of distribution network can be diminished. Power loss and voltage deviations could be high. So, impact analysis has to be performed on power distribution networks.

2.1 Distribution system

The electrical distribution network consisting of medium voltage (11 kV) and low voltage (400V- three phase and 230V-single phase) supply power to residential, commercial, industrial consumers etc. These distribution systems start from substation and end at consumer end. The operation, management and construction of distribution lines is performed by distribution system operator (Grigsby, 2012 n.d.). The configuration of the distribution system is of different types. They are radial, loop, network etc. In a radial type of distribution system one source is connected for all consumers. This type of distribution is less reliable. If some problem appears in such radial system can interrupt supply to whole system connected by it (Gonen, 2014). In the loop distribution system consumers are fed by two lines. If one line gets faults, then other line gives supply to consumer. Also, the network distribution system is the most reliable among all the system. In network distribution system the distribution line is supplied by two or more power sources (Gonen, 2014).

In Nepal, normally there are two types of distribution system. One is radial and other is loop distribution system. In our research work we selected radial feeder, which is 11kV Gothatar feeder of Jorpati distribution center, Kathmandu for integration of induction stove in residential households of that area and its impact study on parameters of distribution system. The detailed parameters of distribution system are given in another section.

2.2 Induction stove impact in distribution system

Electricity is generated at power generating center located far away from load center which is transmitted over long distance through conductors called transmission lines. Finally, electric power is distributed to large numbers of small and big consumers through a distribution network. The supply system can be broadly classified into (i) dc or ac system (ii) overhead or underground system. Nowadays, 3-phase, 3-wire AC system is universally adopted for generation and transmission of electric power as an economical proposition. However, distribution of electric power is done by 3-phase, 4-wire act system, usually 230/400V for customers.

The study conducted by (Rodriguez et al., 2019), on Ecuadorian households in prototype house to determine possible effects of induction stove have resulted that induction stove does not create considerable harmonic distortion levels in residential sector. The induction stove shows a better response during the heating process and better energy efficiency than LPG based stoves (Martínez-Gómez et al., 2016). Following are the Impact on distribution system when different rating of electric cooking appliances was used in distribution system (Soltowski et al., 2020):

- 300 watts rice cooker can be operated by a hundred percent of connected user without exceeding substation capacity.
- Forty five percent of households can be equipped with one-kilowatt electric pressure cookers without violating network constraints, six hundred watts can be used by seventy-five percent households.

In terms of time and energy consumption Induction cooktop is prompt and preferable, yet the life is little as the electronic components get harmed due to heat (Chhetri et al., 2021, n.d.). The study performed for transferring LPG cooking to induction stove in Indonesia concluded that transfer to induction stove from LPG stoves is feasible economically(Al Irsyad et al., 2022). The study conducted in Nagarkot feeder for determining the impact of integration of induction cooker of 1500 watts had obtained maximum penetration of 25% of total peak load by DG of 5965 kVA at 0.8 power factor lagging having active power loss of 477.7 kW. Also by bundling maximum penetration was found to be 40% of total peak load contribution power loss of 477.7 kW (Bhattarai and Maharjan, 2021).

CHAPTER THREE: METHODOLOGY

The research work will begin with studying the research paper related to Induction stove and its impact on power distribution network. The load flow of electric distribution system will be performed by modelling it in DigSILENT powerfactory software.

3.1 Research process

The basic research process for this research work is shown in Figure 3.1:

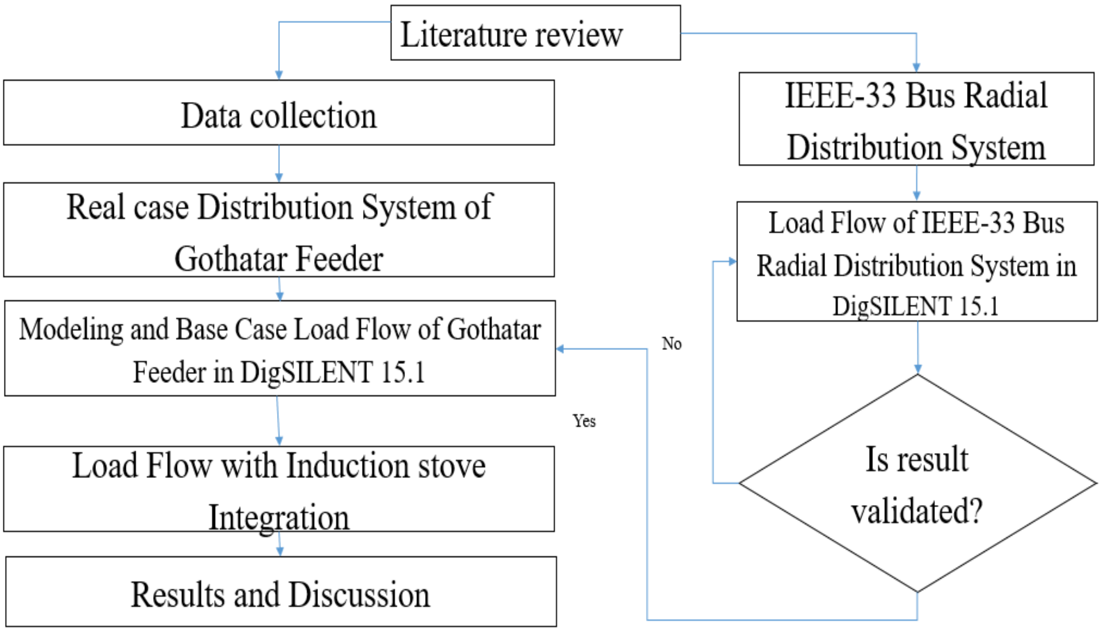


Figure 3.1: Process flow chart

3.2 Collection of data

The primary and secondary data were collected from Jorpati Distribution Center, NEA, NEA annual reports, and private costumers having transformer connected.

3.2.1. Distribution system

The related research work is mainly focused in penetration of Induction stove in residential households. For this distribution, system having residential loads have to be chosen. Gothatar area have many number of residential loads. Therefore, Gothatar area is chosen for research work. Power supply to this area is provided by Jorpati Distribution Center situated in Kathmandu district, Nepal. The data for load center is collected from respective distribution centers. The GIS map of the feeder is shown in Figure 3.2 below:

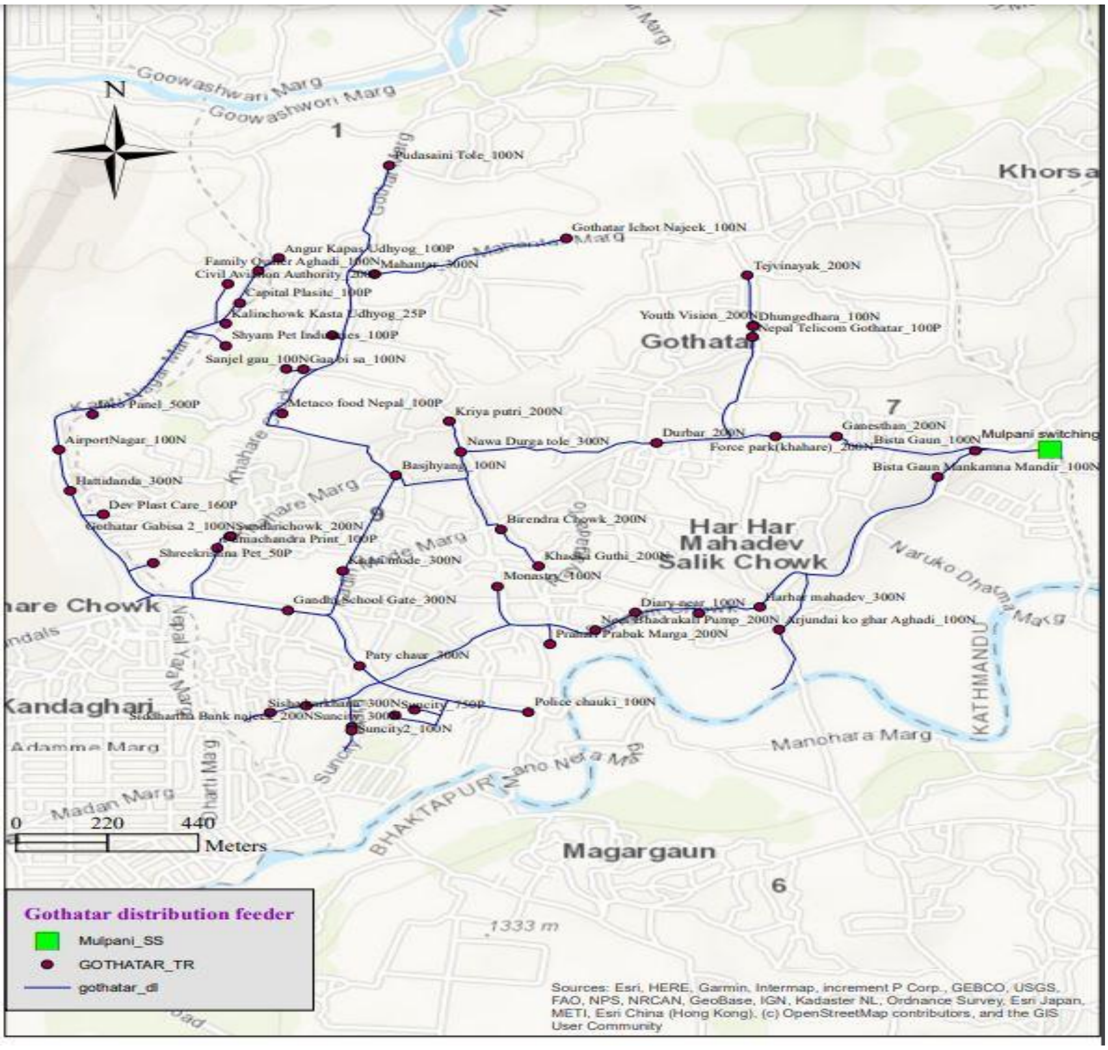


Figure 3.2: Single Line diagram of Gothatar Feeder

3.3 Overhead line

Arc map software was used to extract the geographic information system (GIS) of Gothatar feeder. From geographic information system, conductor type, conductor length, transformer location, transformer rating, number of buses are obtained. Gothatar feeder consists of Dog, Rabbit, Weasel and HT abc cables. Obtained data showed that the feeder length is 10.67 km. Specifications of different conductors are listed in Table 3.1.

Table 3.1: Conductor details

S.N.	Conductor Name	Material	Resistance (R) (Ω/km)	Reactance (X) (Ω/km)	Ampacity (A) at 65˚C	Line Voltage (kV)
1.	Dog	Al	0.5426	0.006459	239	11
2.	Rabbit	Al	0.5524	0.3	157	11
3.	Weasel	Al	0.9289	0.3	114	11

3.4 Transformer Detail

Gothatar feeder consists of 36 utility transformers and 13 private transformers. Data for each transformer is collected. The transformers have a voltage transformation ratio of 11kV/400-230V. The details of capacity of public transformer and private transformer is given in annex below. Figure below shows the details of number and total capacity of utility transformers and private transformers.

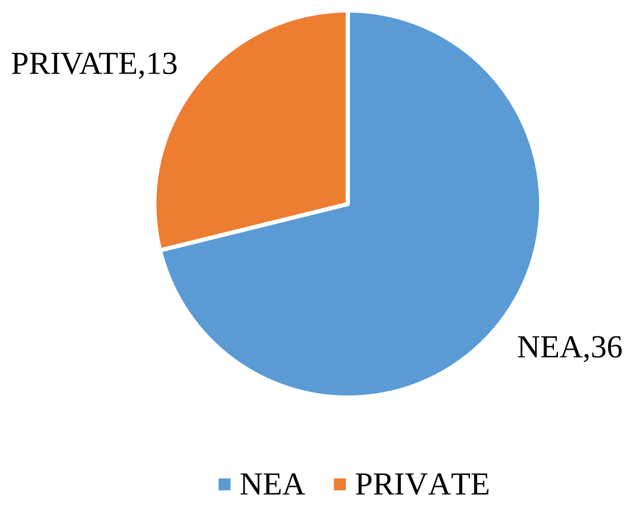


Figure 3.3: Consumer group by transformer number

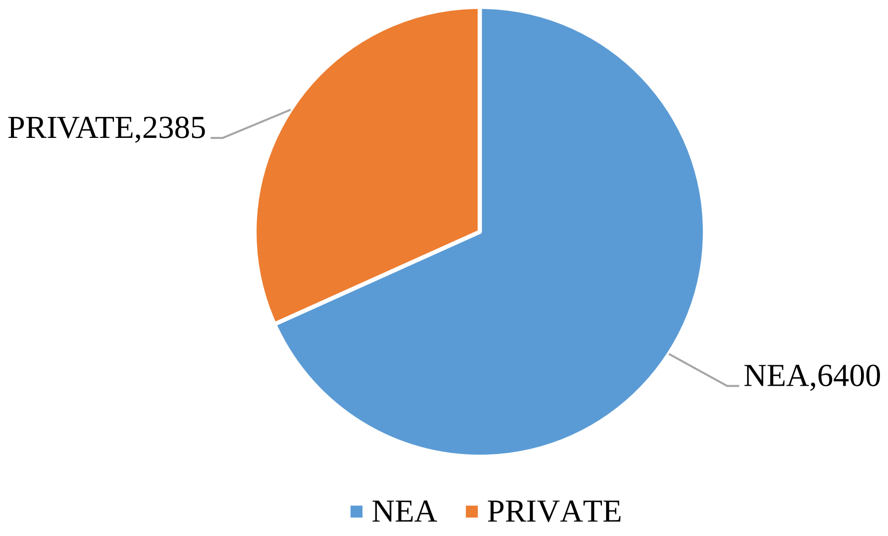


Figure 3.4: Consumer group by transformer capacity

3.5 Details of Residential Consumer

Total consumers of Jorpati Distribution Center are 25680 as of Jestha 2080. Among them total consumers fed by Gothatar feeder is 4946. Among them total domestic consumers are 3960 as of Jestha 2080. As per NEA these domestic consumers are categorized as 5A, 15A, and 32A respectively. Category wise domestic consumer fed by gothatar feeder is given in table below:

Table 3.1: Consumer details of gothatar feeder

S. N.	Consumers	Number
1.	5A Consumers	170
2.	15 A Consumers	3507
3.	30A Consumers	1269
4.	Total Consumers	4946

Among these consumers 5A consumers can be neglected as Induction cooktop cannot by operated at full rated 2000 watts capacity for such consumer. Now, total remaining consumer will be listed for our research work for penetration of Induction stove.

We consider three consumer categories. Low category LPG user, middle category LPG user and High category LPG user. LPG cylinder used by low category consumers is six.

Similarly, twelve LPG cylinders are used by middle category consumers and thirty LPG cylinders are used by high category consumers in one year.

The loading on feeder is taken from mulpani switching station from 2079 Asar to 2080 Jestha, and found the yearly peak loading occurred in 2079 Poush 16 at 7 pm. The monthly peak loading of feeder is presented below:

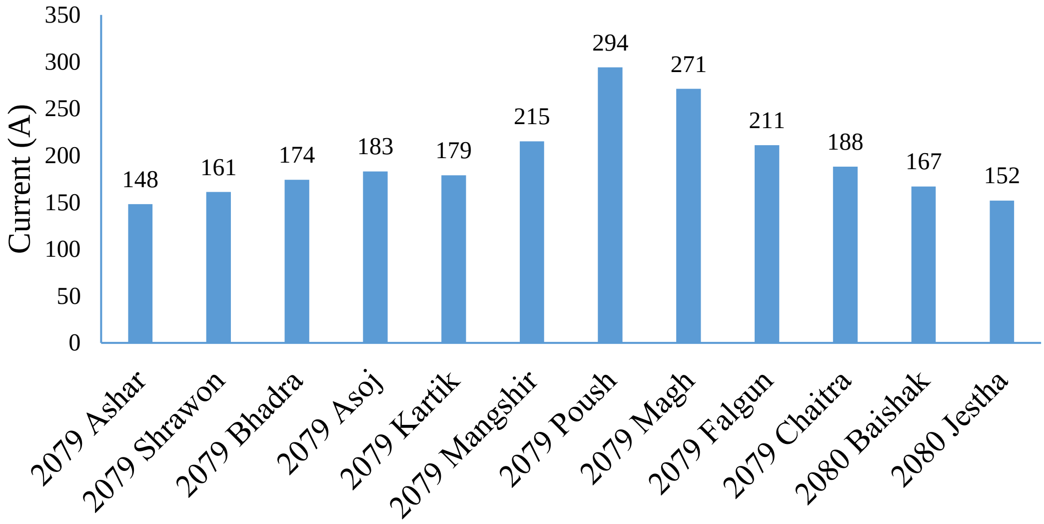


Figure 3.5: Monthly Peak load of Gothatar feeder

A small survey was performed in Gothatar feeder. In the survey cooking time and cooking hours were asked by several consumers. The survey showed that cooking hours were 2 to 3 hours between 6:00 a.m. to 9:00 a.m. in morning and from 6:00 p.m. to 8 p.m. evening. Therefore, in this study we consider dynamic operation condition of induction stove. One condition is morning operating hours and other is for evening operating hour.

Monthly peak load of feeder from 2079 Asar to 2080 Jestha will be presented in Appendix C and daily transformer loading for Poush month is presented in Appendix D below. There are several induction stoves available in market. Baltra 2000 watts induction stove price at Rs. 3030/- (Www.Daraz.Com.Np/Products/Baltra Induction-Cooker_-2000-Watt-n.d.), 2100 watts Philips Induction Cooktop priced at 14699/- (Www.Daraz.Com.Np/Products/Philips-Induction-Cooktop 2100watt, n.d.), etc.

There are different modes of operating range in Induction stove. They can operate in 200W, 400W, 800W, 1000W, 1300W, 1600W, 1800W, 2000W etc. as per induction cooking stove design specification. As per cleancooking.org and ENERGIA

International network induction cooktop was operated maximum at 1600 watts for their project work.

For the purpose of our study, we used 2000 watts induction stove(Datasheet of Induction Stove, n.d.) of prestige company which we considered that it could operate at maximum of 2000 watts during cooking hour and have frequency of 50Hz, power factor of 0.8.

3.6 Integration of Induction stove in Gothatar Feeder

An induction stove is taken to be penetrated in each household of Gothatar feeder. It is considered that one consumer can use only one induction stove. As load is considered lumped load Induction stove is penetrated in secondary side of each public transformer.

3.6.1. Induction Penetration Scenario

The analysis of distribution system of Gothatar feeder is performed in different penetration levels in distribution transformers. Induction Cooktop penetration at different level is in Table 3.2:

Table 3.2: Penetration of induction cooktop at different level

S. N.	Induction Cooktop Penetration Level
1.	0 % Induction Cooktop
2.	5 % Induction Cooktop
3.	10% Induction Cooktop
4.	15% Induction Cooktop
5.	20% Induction Cooktop
6.	25% Induction Cooktop

3.6.2. Creation of different Zones of areas for Induction Cooktop Penetration

Gothatar feeder is categorized into different zones of area for induction stove penetration. The purpose of creating different zones of area is to make separate sections of feeder branches separating consumers so that the research study is feasible and truthful. Zones are created by sectionalizing outgoing tree branches of feeder. By this way four zones of areas are created for Induction Cooktop penetration. Name of such zones of areas are zone1, zone2, zone3 and zone4. In zone1 there are 13 transformers for Induction Cooktop penetration. Similarly, in zone2, zone3 and zone4 there are 8, 9 and 6 transformers respectively. In each areas Induction stoves are operated at different capacity rating such as 500 watts, 1000 watts, 1600 watts and 2000 watts respectively.

3.6.3. Induction stove penetration location

Since there are 36 distribution transformers, Induction stove are integrated at these distribution transformers. Integration of Induction Cooktop at different buses and their naming is given in table 3.3 below.

Table 3.3: Integration of Induction Cooktop at different transformer location

S. N.	Name of Transformer	Symbol of Transformer	Bus
1.	Airport Nagar Nea Tr	Tr-42	42
2.	Arjun Dae ko Ghar Nea Tr	Tr-3	3
3.	Basjhyang Nea Tr	Tr-27	27
4.	Birendra Chowk Nea Tr	Tr-25	25
5.	Bista Gaun Nea Nea Tr	Tr-1	1
6.	Dairy Near Nea Tr	Tr-5	5
7.	Dhungedhara Nea Tr	Tr-19	19
8.	Durbar Nea Tr	Tr-22	22
9.	Family quarter Nea Tr	Tr-48	48
10.	Force Park Nea Tr	Tr-17	17
11.	Gaabisa Nea Tr	Tr-29	29
12.	Gaandhi Nea Tr	Tr-35	35
13.	Ganesthan Nea Tr	Tr-16	16
14.	Gothatar Gaabisa2 Nea Tr	Tr-39	39
15.	Gothatar Ichot Najik Nea Tr	Tr-32	32
16.	Harhar Mahadev Nea Tr	Tr-4	4
17.	Hattidanda Nea Tr	Tr-41	41
18.	Khadka Guthi Nea Tr	Tr-26	26
19.	Khasi Mod Nea Tr	Tr-34	34
20.	Kriya Putri Nea Tr	Tr-24	24

S. N.	Name of Transformer	Symbol of Transformer	Bus
21.	Manakamana Mandir Tr	Tr-2	2
22.	Monastry Tr	Tr-8	8
23.	Nawo Durga Nea Tr	Tr-23	23
24.	Near Bhadrakali Nea Tr	Tr-6	6
25.	Patychaur Nea Tr	Tr-9	9
26.	Police Chauki Nea Tr	Tr-10	10
27.	Prahari Prabhag Marg Nea Tr	Tr-7	7
28.	Pudasaini Tole Nea Tr	Tr-33	33
29.	Sanjel Gaun Nea Tr	Tr-30	30
30.	Siddhartha Bank Najik Nea Tr	Tr-15	15
31.	Sishakarkhana Nea Tr	Tr-14	14
32.	Suncity 100N Tr	Tr-13	13
33.	Suncity 300N Tr	Tr-12	12
34.	Sundarichowk NeaTr	Tr-37	37
35.	Tej Vinayak Nea Tr	Tr-21	21
36.	Youth Vision Nea Tr	Tr-20	20

3.7 DigSILENT Powerfactory Software

DigSILENT power factory is an advanced power system analysis software. It is used for analyzing generation, transmission, distribution and industrial systems. Different range of features are incorporated in this software from wind power, distribution generation, real-time simulation to performance monitoring for system testing and supervision. It is simple, reliable, easy and compatible to windows. It is a flexible system with modelling capabilities having state of art of algorithms and unique database concept. It is highly suited for highly automated and integrated solutions business applications. The details about the software and its features are available at Powerfactory, 2020 manual.

3.7.1. DigSILENT Powerfactory Software to model distribution network

DigSILENT power factory 15.1 software is used to model electric power distribution network. Time characteristics for each load is made in order to perform 24- hour load flow of distribution system. The load flow results are extracted by performing load flow from 1 hour to 24 hour. Method of software application in this research work is shown in flow diagram in Figure 3.9.

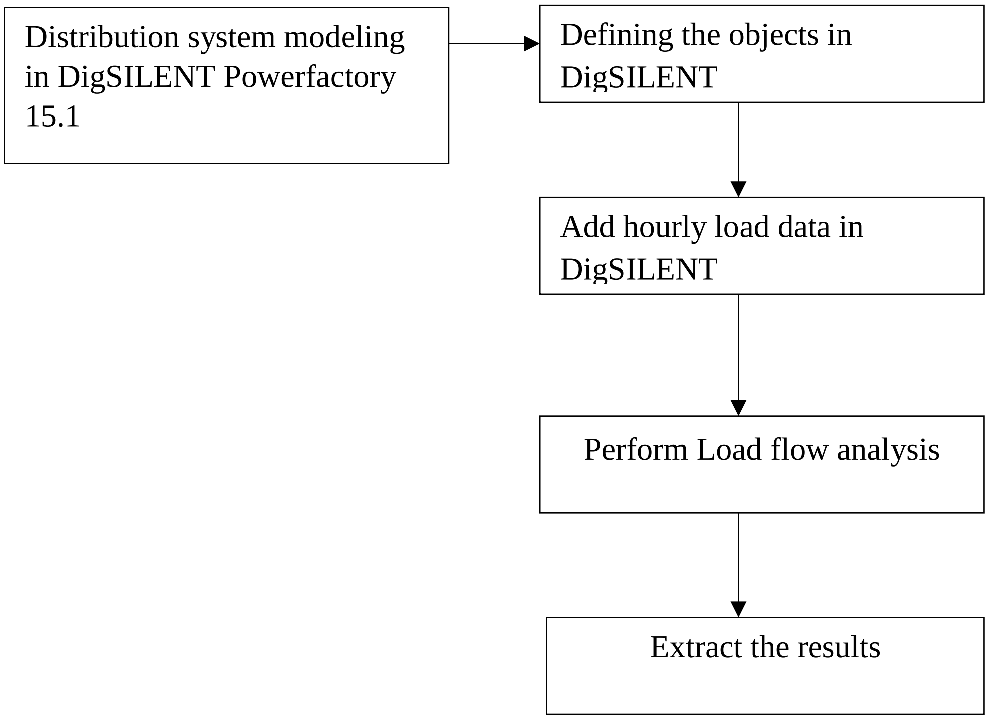


Figure 3.6: Software Modeling

3.7.2. IEEE-33 Bus Radial Distribution System Modeling in DigSILENT

DigSILENT power factory software 15.1 is used to model standard IEEE-33 bus radial distribution system. Standard active power and reactive power of IEEE-33 bus distribution are 3715 kW and 2300 kVAR respectively. Validation of Results of IEEE-33 bus distribution systems in DigSILENT results of data from (Abdelaziz et al., 2016) (Venkatesh et al., 2004) are taken. Parameters for line and load of IEEE-33 bus distribution system are given in Appendix E. IEEE-33 bus radial distribution system single line diagram is shown in Appendix F.

3.7.3. Modeling of Gothatar feeder in DigSILENT

Modeling of Gothatar feeder is performed in DigSILENT power factory 15.1 software. Model consist of line type, line length, buses, transformer rating, and loads. The single line diagram of Gothatar feeder which is modelled in DigSILENT powerfactory software is shown in Appendix H.

3.8 Load flow analysis

Computational procedure which is required to determine the steady state operating characteristics of a power system network is called load flow analysis. Load flow analysis is very essential for planning purpose (generation, transmission and distribution expansion planning) and to study the current state of the system and at which direction after the implementation of any electrical load or generation in the system.

3.8.1. Load Flow in DigSILENT Software

Load flow analysis in the DigSILENT can be performed using Newton-Rapson method. Newton Raphson Method is the powerful technique for solving equations numerically. Newton Raphson Method involves iteratively defining an initial guess to converge it toward the desired root. However, the method is not efficient to calculate the roots of the polynomials or equations with higher degrees but in the case of small-degree equations, this method yields very quick results.

AC Newton Raphson method (balanced and unbalanced) and linear DC method load flow analysis can be performed in DigSILENT powerfactory software. The algorithm used in DigSILENT has excellent provident and stability. The power flow equation is given by Equation 3.1 and Equation 3.2.

$$P_i = \sum_{k=1}^{N} |Vi||Vk||Yik|\cos(\theta ik + \delta k - \delta i) \qquad \text{Equation 3.1}$$

$$Q_i = -\sum_{k=1}^{N} |Vi||Vk||Yik|\sin(\theta ik + \delta k - \delta i) \qquad \text{Equation 3.2}$$

where,

- P_i and Q_i are real power and reactive power injected at bus i.
- V_i and V_k are magnitude of bus voltages and δi and δk are bus voltage phase angle respectively.
- Y_{ik} bus admittance matrix corresponding to ith row and kth column.
- θ_{ik} is the difference between voltage angle between ith row and kth column.

Newton Raphson method for load flow begins with initial assumptions of all unknown variables such as voltage magnitude and angles at load buses whereas voltage angles at generator buses.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$$

Where ΔP and ΔQ are real and reactive power mismatch vectors on the bus respectively given by Equation 3.3 and Equation 3.4

$$\Delta Pi = -P_i + \sum_{k=1}^{N} |Vi||Vk||Yik|\cos(\theta ik + \delta k - \delta i) \quad \text{Equation 3.3}$$

$$\Delta Qi = -Qi - \sum_{k=1}^{N} |Vi||Vk||Yik|\sin(\theta ik + \delta k - \delta i) \quad \text{Equation 3.4}$$

$\Delta|V|$ and $\Delta\delta$ are incremental bus voltage magnitude and angle vectors and J1 through J4 are referred as Jacobian matrices

$$\begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} = \begin{bmatrix} \partial\Delta P/\partial\delta & [\partial\Delta P/\partial|V| \\ \partial\Delta Q/\partial\delta & \partial\Delta Q/\partial|V| \end{bmatrix}$$

$$\delta^{m+1} = \delta + \Delta\delta$$

$$|V|^{m+1} = |V|^{m} + \Delta|V|$$

The process is repeat until the convergence.

3.8.2. Load Flow of IEEE-33 Bus Radial Distribution System

IEEE-33 bus radial distribution system load flow is done in DigSILENT powerfactory application using Newton Raphson Algorithm. Its results are validate with other similar Newton Raphson's Algorithm.

3.8.3. Load Flow of Gothatar Feeder

After validating software using IEEE-33 bus radial distribution system twenty four hour load flow of Gothatar feeder is performed in DigSILENT powerfactory software. First load flow is carried out at base case scenario i.e. initial condition without induction stove insertion. Then load flow is carried out at different level of penetration ranging from 0% to 25%. If there is any overloading of materials at 25% penetration than we will take necessary steps to mitigate it.

CHAPTER FOUR: RESULT AND DISCUSSION

Result of our study are discussed in this chapter. First base case scenario is presented and then penetration of induction cooktop is highlighted.

4.1 Case I: Load flow of IEEE-33 bus Radial Distribution system

After performing the load flow of IEEE-33 bus radial distribution system its results were analyzed. Active power loss of the system was found to be 210 kW and the minimum voltage was found at bus 17 and 18 which was 0.904 p.u. The voltage profile of IEEE- 33 bus radial distribution system is shown in Figure 4.1

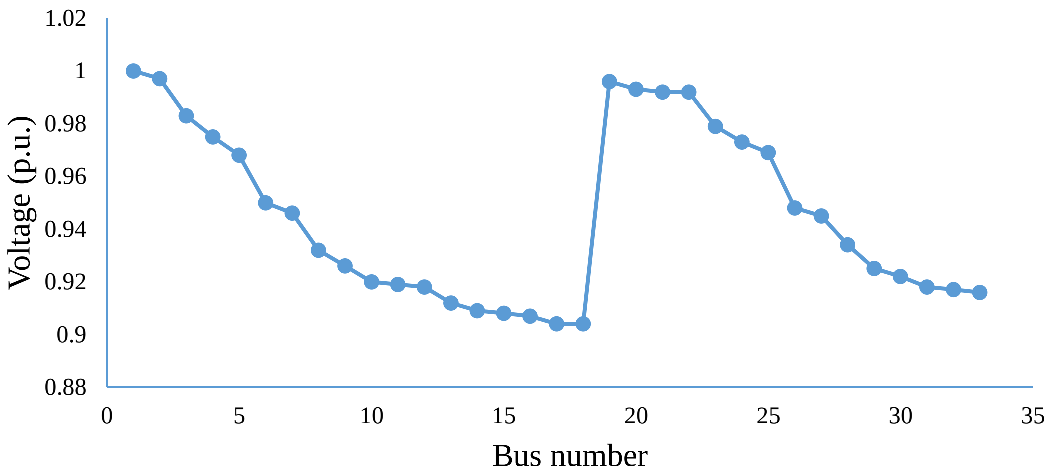


Figure 4.1: Voltage profile of IEEE-33 bus system

Validation of results from DigSILENT has been performed by comparing with other algorithms. Table 4.1 shows that when compared with other algorithms similar data has been seen.

Table 4.1: Validation of Newton Raphson Algorithm in IEEE-33 bus RDS

Algorithm	Power Loss (kW)	Voltage of Bus (p.u.)
Newton Raphson in DigSILENT	210	0.904
Newton Raphson (Abdelaziz et al., 2016)	202.66	0.9131
Newton Raphson (Venkatesh et al., 2004)	211.22	0.9038

4.2 Case II: Gothatar feeder initial condition

Load flow of Gothatar feeder was performed at base case condition. Existing condition of electricity distribution system was determined for the month of poush. Initial condition of Gothatar feeder at evening peak is shown in table below:

Table 4.2: Initial condition of feeder

Before Mitigation	
Gothatar feeder status at evening peak	
MVA	5.73
MW	4.83
MVAR	3.09
Voltage (kV)	11
Power factor (%)	0.843
Maximum current (A)	301
Power loss (MW)	0.139

The load flow clearly shows that initial outgoing conductor is operating at its maximum level. This makes impossible for induction stove penetration in feeder so mitigation was applied making the feeder feasible for penetration of induction stove.

For mitigation purpose, Dog conductor is strung on existing distribution feeder poles from Mulpani Substation to bus 1. Equipment required for running conductor are conductor itself, channels, insulator, nuts, bolts, and other necessary materials.

Table 4.3: Feeder condition after mitigation

After Mitigation	
Gothatar feeder status at evening peak	
MVA	5.73
MW	4.83
MVAR	3.09
Voltage (kV)	11
Power factor (%)	0.843
Conductor1 Current(A)	150
Conductor2 Current(A)	150
Power loss (MW)	0.113

4.2.1. Feeder load curve

Power demand at different time at the base case scenario has been analyzed which is shown in Figure 4.2.

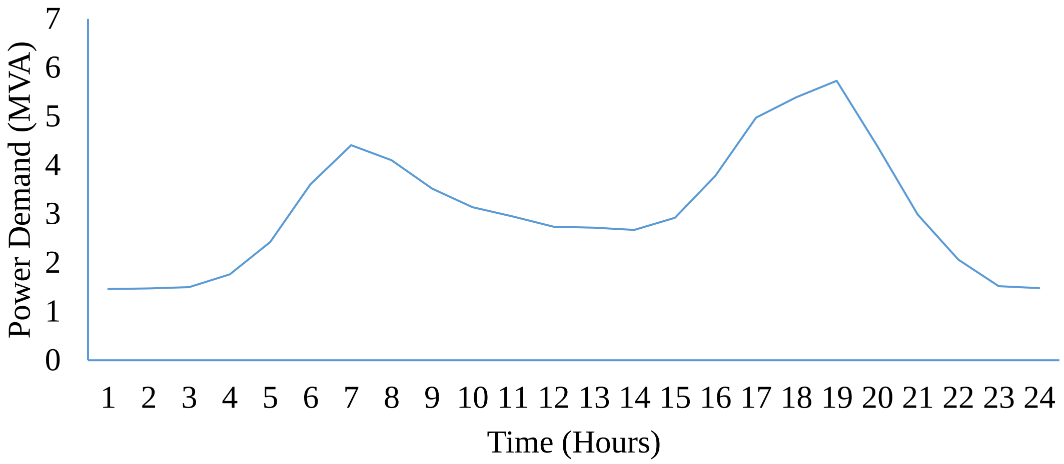


Figure 4.2: Load profile at base case scenario

Figure 4.2 shows the 24 hour load profile of gothatar feeder at base case scenario. The load curve shows that minimum demand was found to be 1.46 MVA at 1 a.m. Then demand tend to increase gradually. At 7 a.m. it reached 4.41 MVA in the morning and again it gradually decreased. Then again at evening it gradually increased and peak demand of feeder was found to be 5.73 MVA at 7 pm. in evening.

4.2.2. Feeder active power loss

Feeder active power loss at different time at the base case scenario has been analyzed which is shown in Figure 4.3.

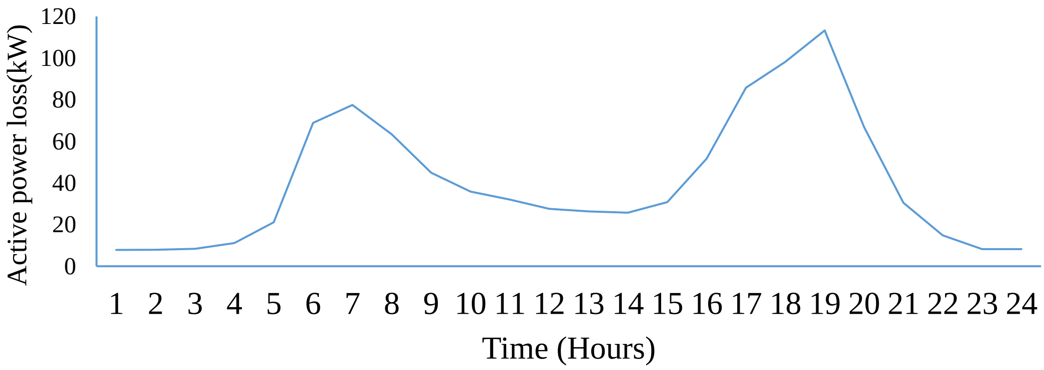


Figure 4.3: Active power loss

Figure 4.3 shows the 24 hour active power loss of gothatar feeder at base case scenario. Minimum active power loss was seen at 1 a.m. which is 7.95 kW. When demand tend to increase active power loss also increased gradually. At 7 a.m. it reached 77.52 kW in the morning and again it gradually decreased. Then again, at evening, it gradually increased and at peak demand of feeder, active power loss was found to be 113 kW at 7 p.m. in evening.

Since, for the feasibility of our study we introduced different zone of area. We analyzed our study for voltage drop, line loading and transformer loading at different zones of area.

4.2.3. Voltage profile of 11kV bus at peak time

Voltage profile of buses at various zones of area is described below.

4.2.3.1. Voltage profile at Zone1

The voltage profile of the different 11kV Bus on zone1 at peak time 19:00 hours in the feeder is shown in Figure 4.4.

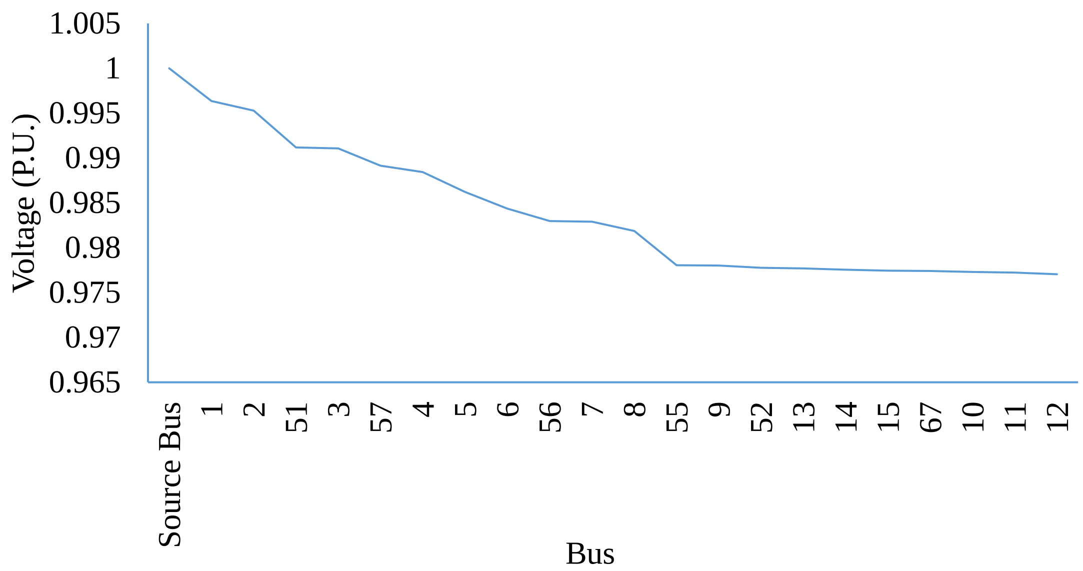


Figure 4.4: Zone1 voltage at base load condition

Load flow of Gothatar feeder was performed and voltage drop at different sections of buses were determined at Zone1. Since the radial feeder, the lowest voltage is obtained at end of laterals. The minimum voltage occurs at the end of lateral at Bus 12 which is 0.9770418 p.u. This shows the voltage profile is within the limit.

4.2.3.2. Voltage profile at Zone2

The voltage profile of the different 11kV Bus on zone2 at peak time 19:00 hours in the feeder had been taken as shown in Figure 4.5.

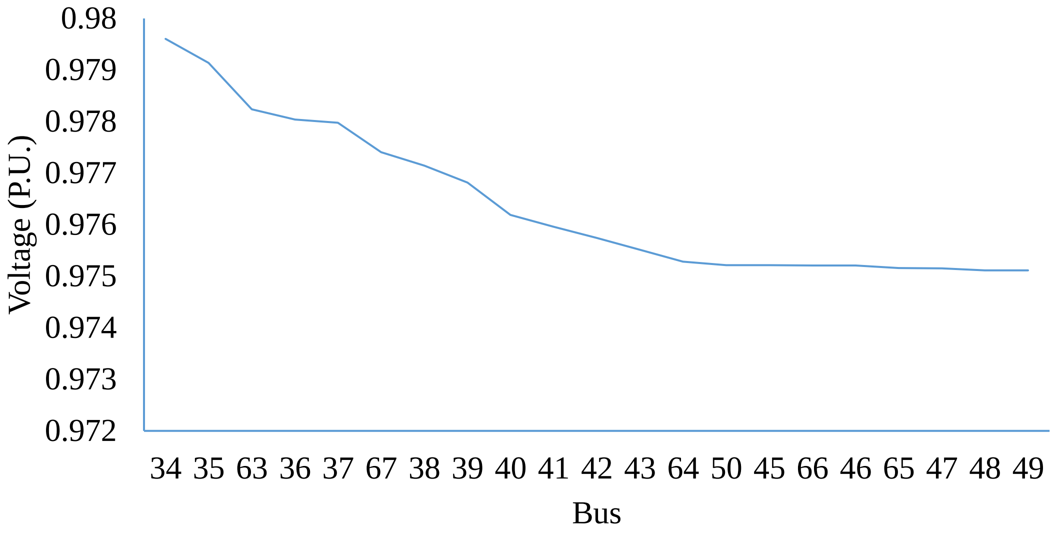


Figure 4.5: Zone2 voltage at base load condition

Load flow of Gothatar feeder was performed and voltage drop at different sections of buses were determined at Zone2. Since the radial feeder, the lowest voltage is obtained at end of laterals. The minimum voltage occurs at the end of lateral at Bus 49 which is 0.975113 p.u. This shows the voltage profile is within the limit.

4.2.3.3. Voltage profile at Zone3

The voltage profile of the different 11kV Bus on zone3 at peak time 19:00 hours in the feeder is shown in Figure 4.6.

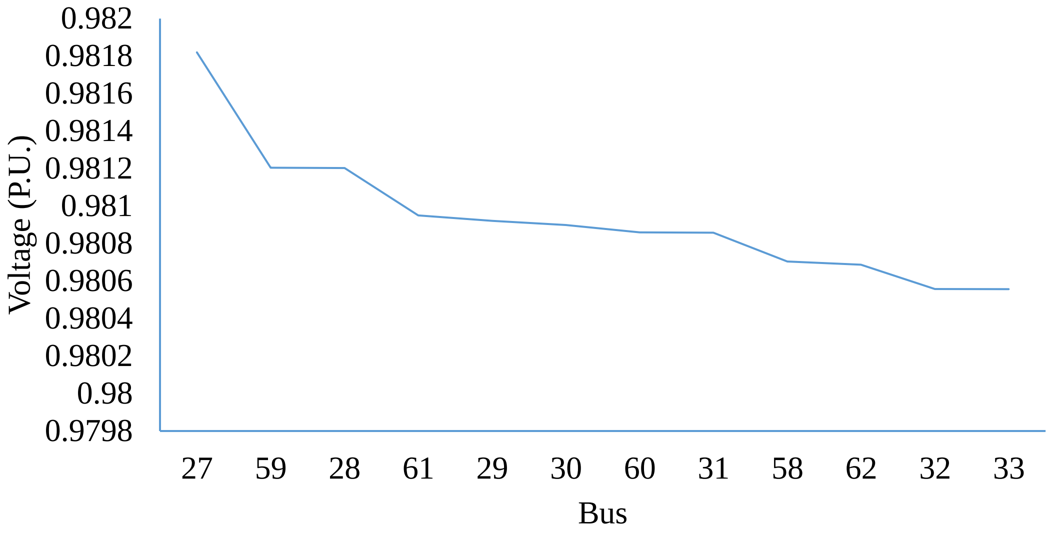


Figure 4.6: Zone3 voltage at base load condition

Load flow of Gothatar feeder was performed and voltage drop at different sections of buses were determined at Zone3. Since the radial feeder, the lowest voltage is obtained at end of laterals. The minimum voltage occurs at the end of lateral at Bus 33 which is 0.980556 p.u. This shows the voltage profile is within the limit.

4.2.3.4. Voltage profile at Zone4

The voltage profile of the different 11kV Bus on zone4 at peak time 19:00 hours in the feeder is shown in Figure 4.7.

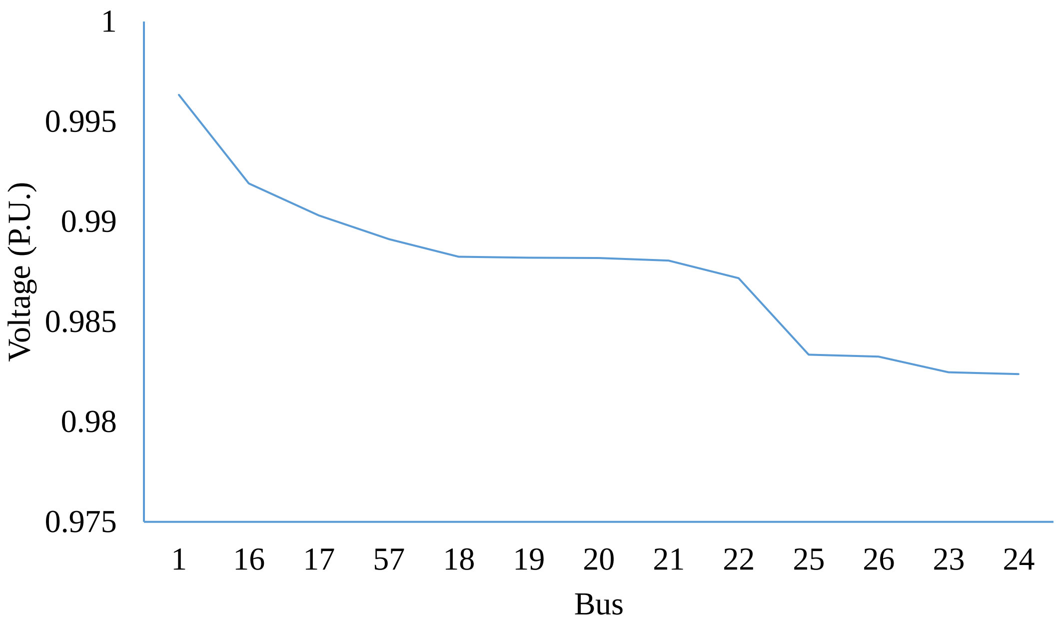


Figure 4.7: Zone4 voltage at base load condition

Load flow of Gothatar feeder was performed and voltage drop at different sections of buses were determined at Zone4. Since the radial feeder, the lowest voltage is obtained at end of laterals. The minimum voltage occurs at the end of lateral at Bus 24 which is 0.982383 p.u. This shows the voltage profile is within the limit.

4.2.3.5. Voltage profile of all bus at peak time

The voltage profile of the different 11kV Bus at peak time 19:00 hours in the feeder is shown in Figure 4.8.

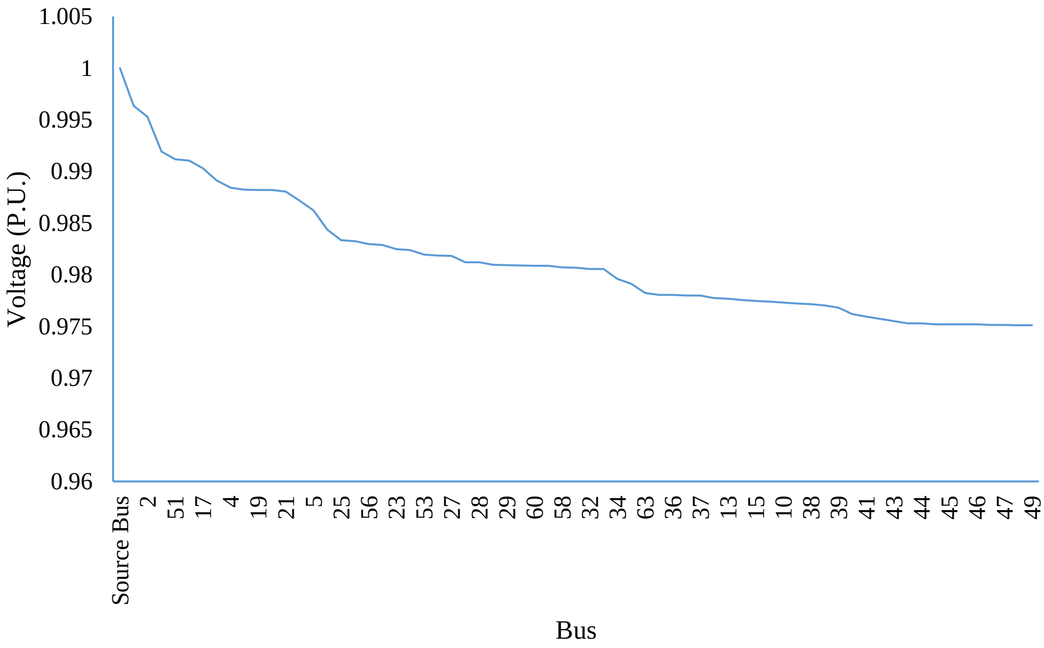


Figure 4.8: Overall voltage profile at base condition

Load flow of Gothatar feeder was performed and voltage drop at different sections of buses were determined. The minimum voltage occurs at the end of lateral at Bus 49 which is 0.975113 p.u. Since the radial feeder, the lowest voltage is obtained at end of laterals. This shows the voltage profile is within the limit.

4.2.4. Line loading

As the Induction Cooktop is integrated into the feeder, the loading of the conductor increase. It increases with an increase in the penetration percentage of Induction Cooktop.

4.2.4.1. Line loading at Zone1

The line loading of the different 11kV line on zone1 at peak time 19:00 hours in the feeder is shown in Figure 4.9.

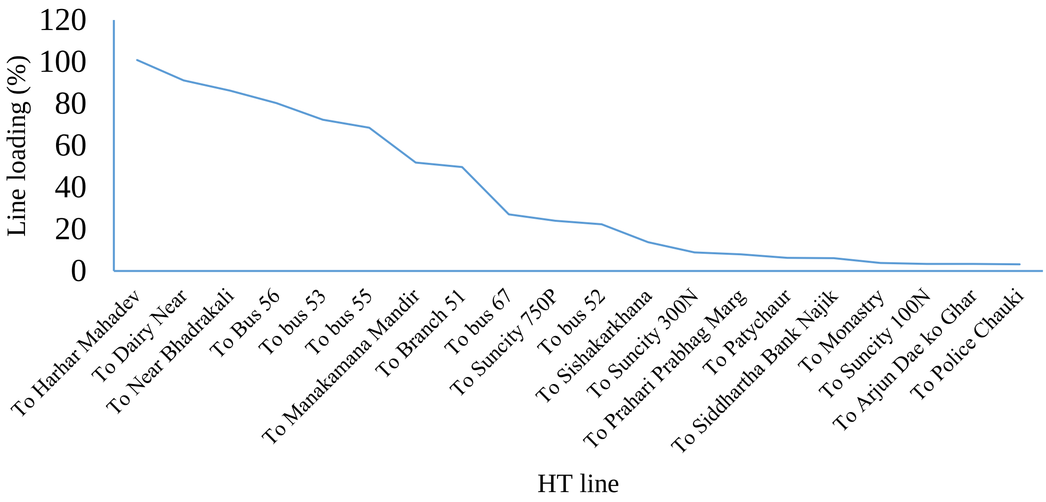


Figure 4.9: Zone1 Conductor loading at base case

Figure 4.9 shows the loading of 11 kV Gothatar feeder at zone1. It was found that maximum loading was seen at conductor named To Harhar Mahadev operating at 101% which is more than operating limit but all other conductors are operating normally.

4.2.4.2. Line loading at Zone2

The line loading of the different 11kV line on zone2 at peak time 19:00 hours in the feeder is shown in Figure 4.10.

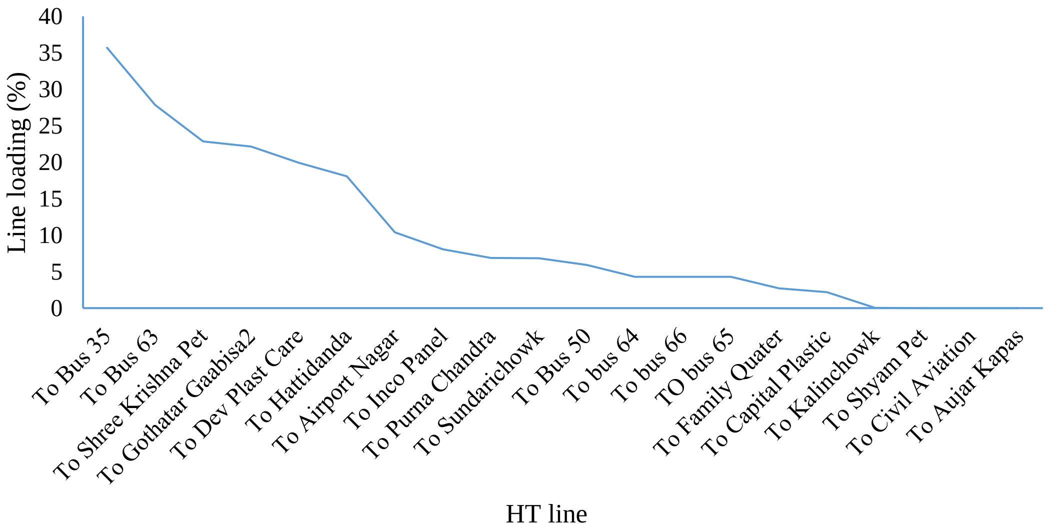


Figure 4.10: Zone2 Conductor loading at base case

Figure 4.10 shows the loading of 11 kV Gothatar feeder at zone2. It was found that maximum loading was seen at conductor named To Bus 35 operating at 36%. It shows that all of the conductors are operating normally.

4.2.4.3. Line loading at Zone3

The line loading of the different 11kV line on zone3 at peak time 19:00 hours in the feeder is shown in Figure 4.11.

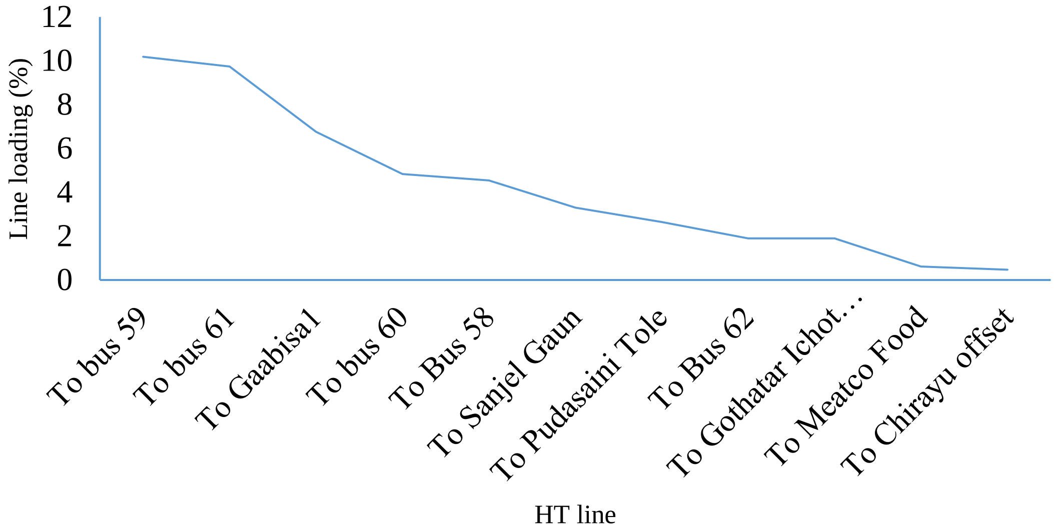


Figure 4.11: Zone3 conductor loading at base case

Figure 4.11 shows the line loading of 11 kV Gothatar feeder at zone3. It was found that maximum loading was seen at conductor named To bus 59 operating at 10%. It shows that all of the conductors are operating normally.

4.2.4.4. Line loading at Zone4

The line loading of the different 11kV line on zone4 at peak time 19:00 hours in the feeder is shown in Figure 4.12.

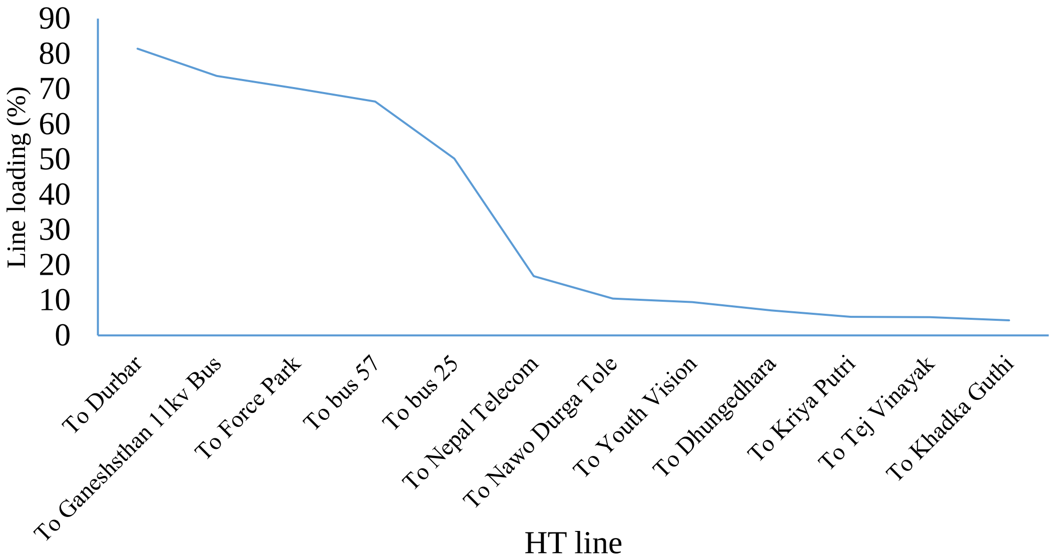


Figure 4.12: Zone4 conductor loading at base case

Figure 4.12 shows the line loading of 11 kV Gothatar feeder at zone4. It was found that maximum loading was seen at conductor named To Durbar operating at 81%. It shows that all of the conductors are operating normally.

4.2.4.5. Over line loading at base case

The overall line loading of the different 11kV line at peak time 19:00 hours in the feeder are shown in Figure 4.13.

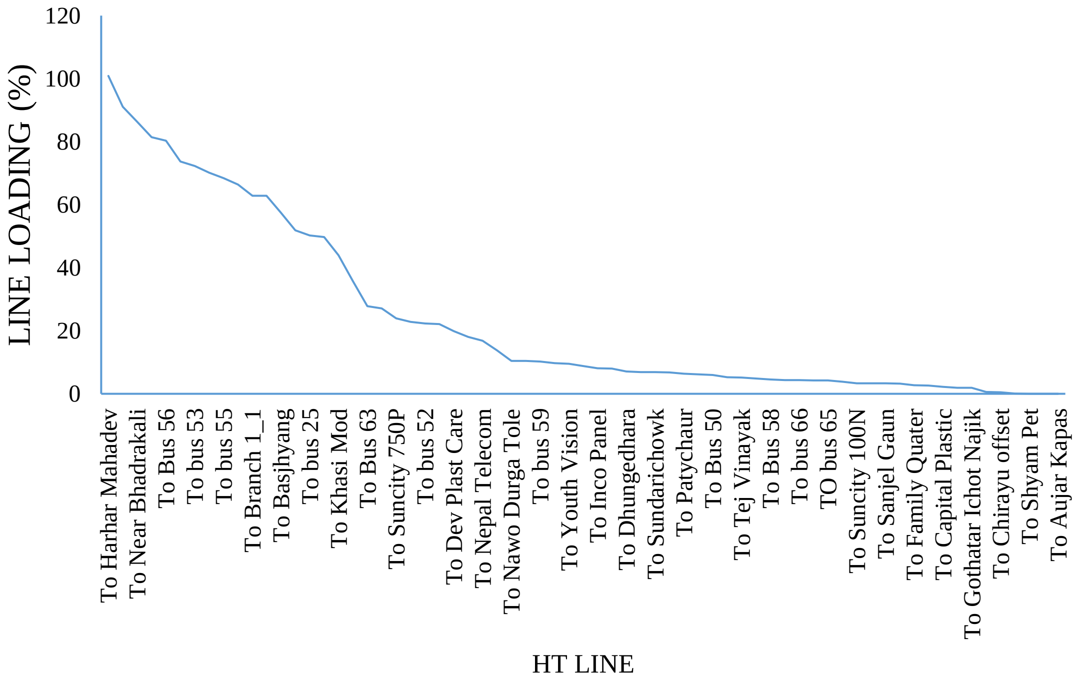


Figure 4.13: Overall loading of conductor

Figure 4.13 shows the overall line loading of conductor at peak time. It was found that maximum loading was seen at conductor named To Harhar Mahadev operating at 81%. The remaining other conductors were operating normally.

4.2.5. Transformer loading

The loading of transformer at base case in different zones of area were analyzed.

4.2.5.1. Transformer loading at zone1

The loading of the different transformers on zone1 at peak time in the feeder is shown in Figure 4.14.

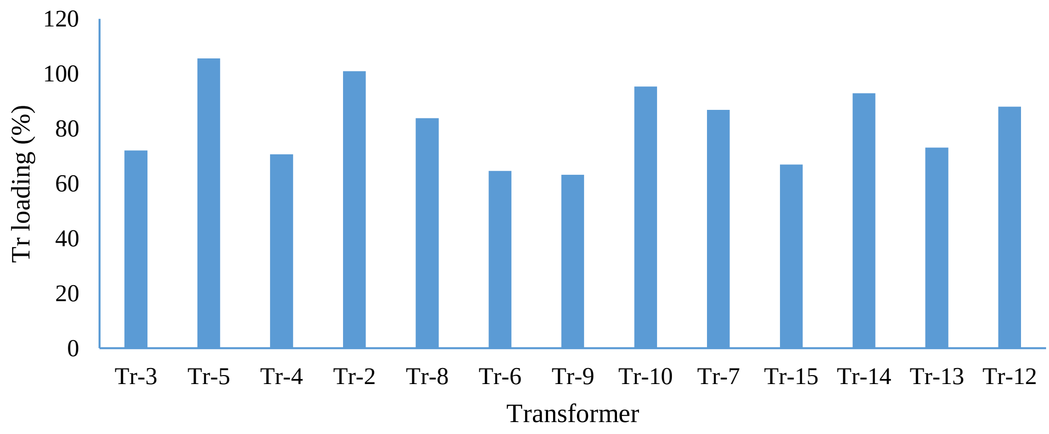


Figure 4.14: Transformer loading at zone1

Figure 4.14 shows the transformer loading on Zone1. As load flow of Gothatar feeder was performed and percentage loading of transformer was determined. It was seen that minimum transformer loading was at Tr-9 which is 63% and maximum loading was at Tr-5 which is 106%. In addition, transformer naming Tr-5 is operating at 106% and Tr-2 was operating at 101% and remaining transformer were operating normally.

4.2.5.2. Transformer loading at zone2

The loading of different transformer at zone2 during peak time in the feeder is shown in Figure 4.15

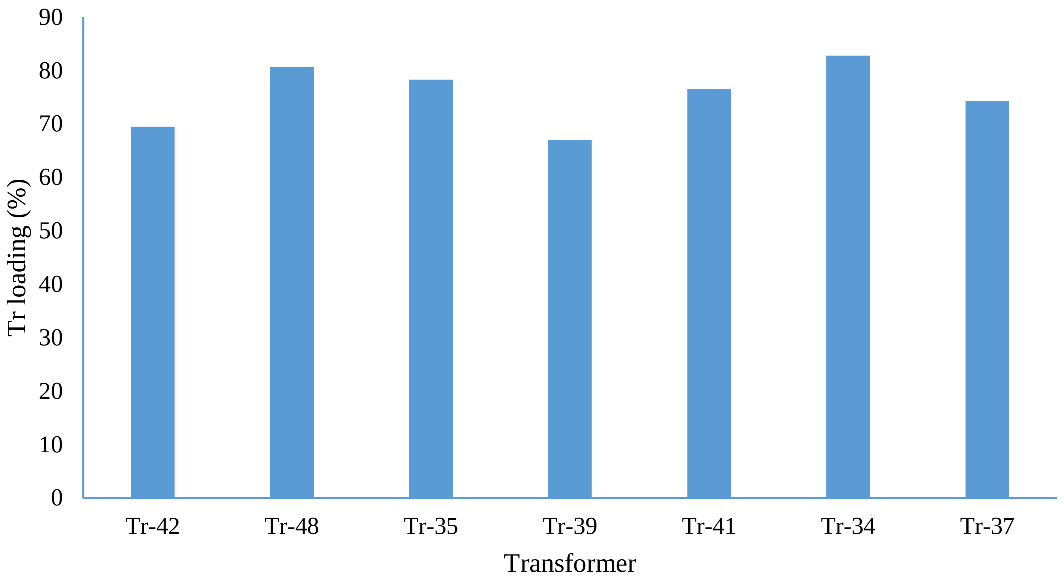


Figure 4.15: Transformer Loading at Zone2

Figure 4.15 shows the transformer loading on Zone2. As load flow of Gothatar feeder was performed and percentage loading of transformer was determined. It was seen that minimum transformer loading was at Tr-39 which is 67% and maximum loading was at Tr-34 which is 87%. This shows that all the transformers were operating normally.

4.2.5.3. Transformer loading at zone

The loading of different transformer at zone2 during peak time in the feeder is shown in Figure 4.16.

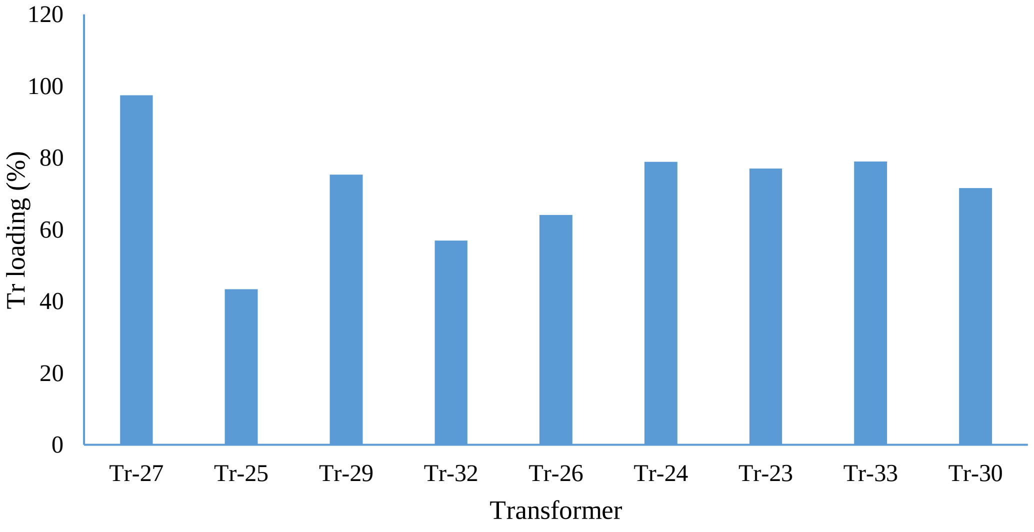


Figure 4.16: Loading of transformer at zone3

Figure 4.16 shows the transformer loading on Zone3. As load flow of Gothatar feeder was performed and percentage loading of transformer was determined. It was seen that minimum transformer loading was at Tr-25 which is 43% and maximum loading was at Tr-27 which is 97%. This shows that all the transformers were operating normally.

4.2.5.4. Transformer loading at zone4

The loading of different transformer at zone2 during peak time in the feeder is shown in Figure 4.17.

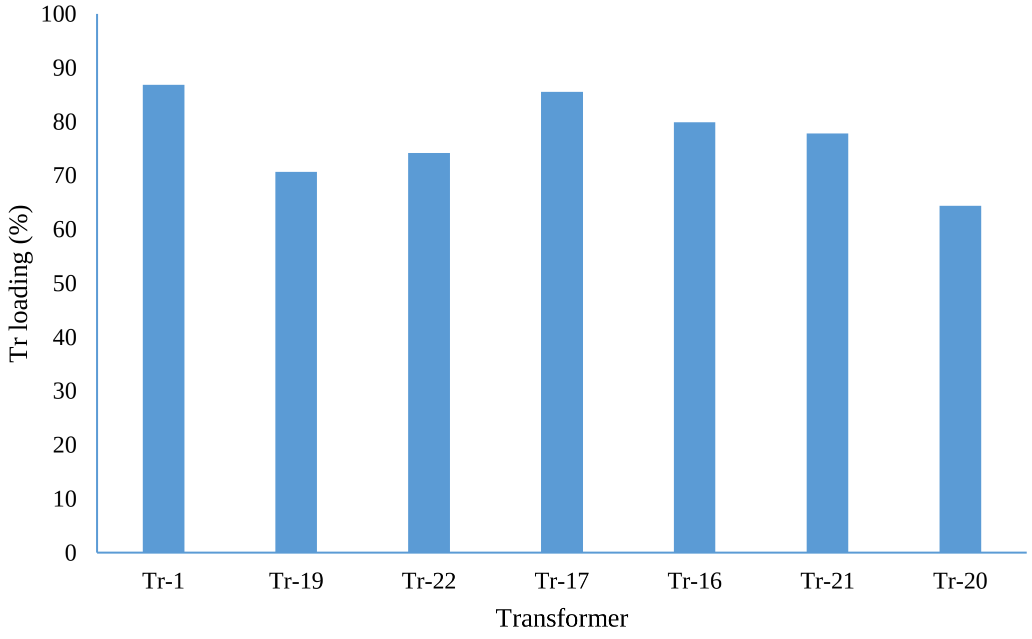


Figure 4.17: Transformer loading at zone4

Figure 4.16 shows the transformer loading on Zone4. As load flow of Gothatar feeder was performed and percentage loading of transformer was determined. It was seen that minimum transformer loading was at Tr-20 which is 64% and maximum loading was at Tr-1 which is 87%. This shows that all the transformers were operating normally.

4.2.5.5. Overall Transformer loading

The overall loading of the different transformers at different zones at peak time in the feeder is shown in Figure 4.18.

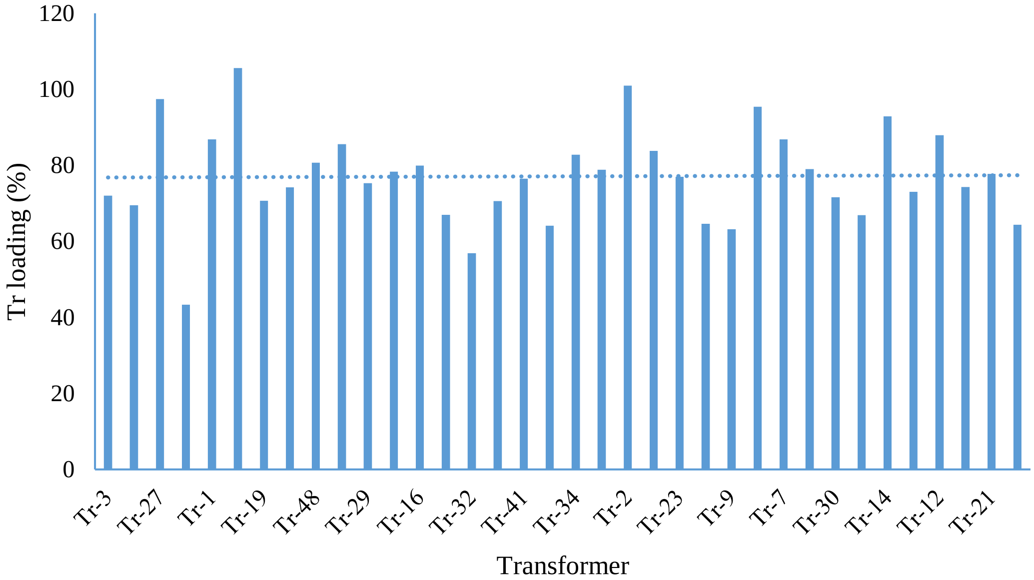


Figure 4.18: Overall transformer loading

Figure 4.18 shows the overall transformer loading in the feeder. As load flow of Gothatar feeder was performed and percentage loading of transformer was determined. Loading of transformer was seen from 43% at Tr-25 to 106% at Tr-5 giving an overall average transformer loading to be 78%. It was also found that transformer Tr-5 was operating at 106% and transformer Tr-2 was operating at 101% and all the other transformers were operating normally.

4.3 Case III: Loading of feeder at different Penetration level of Induction cooktop

After penetration of induction stove from 5 percent to 25 percent in 36 public transformers following results were obtained and analysis of results were done.

4.3.1. Feeder load curve:

When the Induction stoves were integrated in Gothatar feeder at different penetration percentages, it was observed that peak coincides at 7 p.m. The peak load of the feeder increases from 5.73 MVA at 0% penetration of Induction stove to 7.27 MVA at 25% penetration. Table below shows the feeder peak load at a different penetration level.

Table 4.4: Peak load at different penetration level

Penetration %	Peak Load (MVA)	Time (Hours)
0	5.73	7 p.m.
5	6.08	7 p.m.
10	6.48	7 p.m.
15	6.88	7 p.m.
20	9.19	7 p.m.
25	7.27	7 p.m.

The load curve of feeder for different penetration of Induction Cooktop in terms of MVA is shown in Figure 4.19.

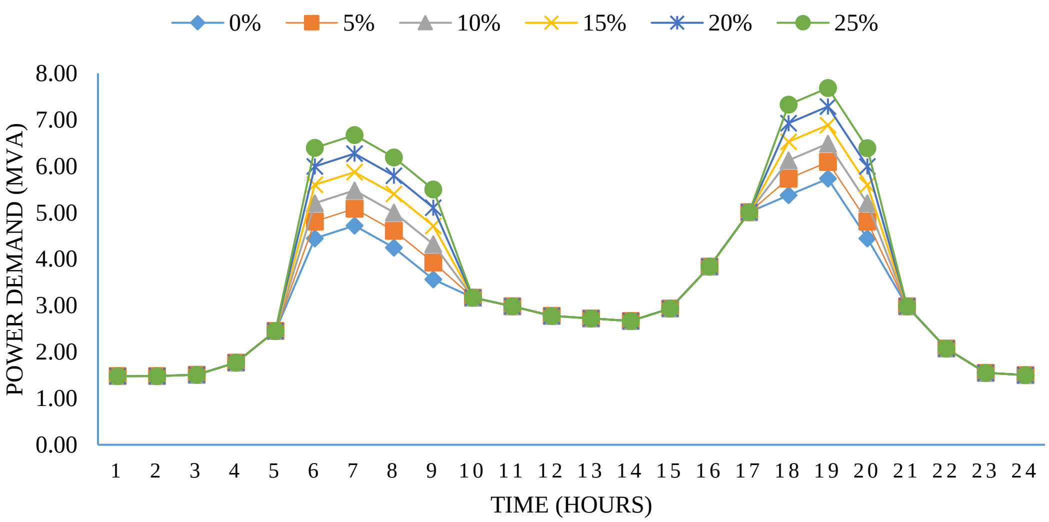


Figure 4.19: Apparent Power

Figure 4.19 shows the 24-hour load profile of feeder at different penetration level of induction stove. Initially peak load of feeder was 5.73 MVA at 7 p.m. At 5% penetration level it increased to 6.09 MVA, at 10% it increased to 6.49 MVA, at 10% it increased to MVA, at 15% it increased to 6.88 MVA, at 20% increased to 7.28 MVA and at 25% penetration level it reached 7.68 MVA respectively.

As load flow was performed at different penetration level of induction stove. The level of transformer loading, total loss, minimum voltage, conductor loading was tabulated for different penetration percentage at peak hour condition.

4.3.2. Feeder active power loss

The peak power loss for a feeder at different penetration levels is shown in Figure 4.20.

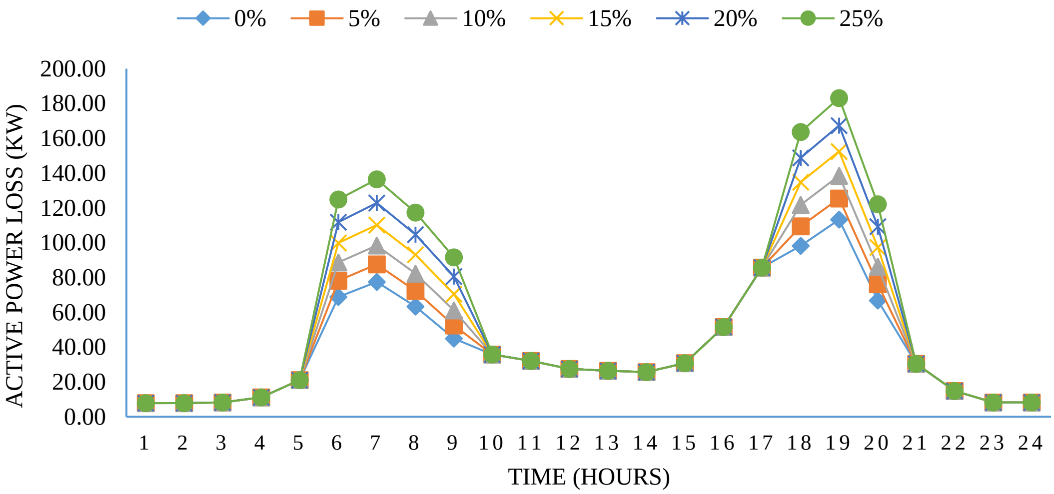


Figure 4.20: Active power loss at different loading condition

Figure 4.20 shows feeder's 24 hour active power loss profile. It was seen that initially feeder active power loss was 0.113 MW at 0% level of Induction Cooktop penetration. As penetration increases the loss in feeder also increased. At 25% penetration level active power loss reached 0.179 MW.

4.3.3. Voltage profile of 11kV bus

The details of the voltage profile of different 11kV bus at different zones of locations at different penetration level of induction stove is explained in following section.

4.3.3.1. Voltage profile of Zone1

Voltage profile of different 11 kV bus at zone1 at different level of penetration is shown in Figure 4.21.

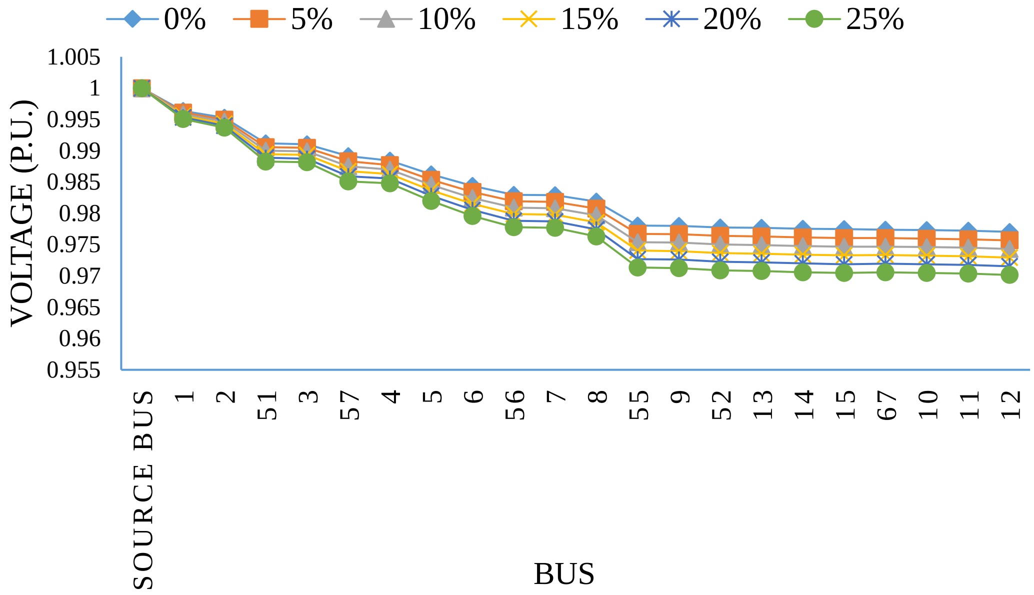


Figure 4.21: Voltage profile at zone1

When the Induction stove was penetrated, the voltage started to get reduce at different bus. As penetration level increased voltage drop at different buses started to increase but no any voltage violation was observed at any bus in any penetration level. Initially lowest voltage was seen at bus 12 which is 0.97704 p.u. to 0.9701147 p.u. at 25% penetration level.

4.3.3.2. Voltage profile of Zone2

Voltage profile of different 11 kV bus at zone2 at different level of penetration is shown in Figure 4.22.

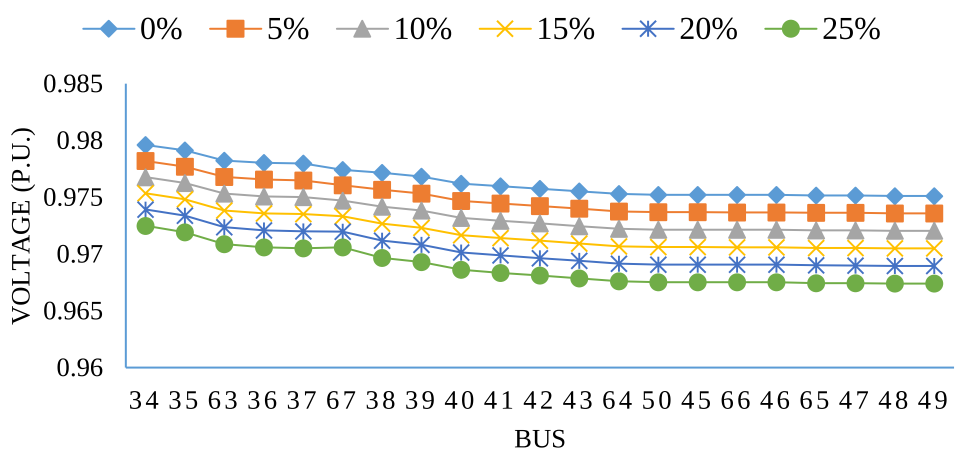


Figure 4.22: Voltage profile at zone2

When the Induction stove was penetrated, the voltage started to get reduce at different bus. At different levels of penetration,no voltage violation was observed. Initially the lowest voltage was seen at bus 49 which is 0.975113 p.u. to 0.967395 p.u. at 25% penetration level.

4.3.3.3. Voltage profile of Zone3

Voltage profile of different 11 kV bus at zone3 at different level of penetration is shown in Figure 4.23.

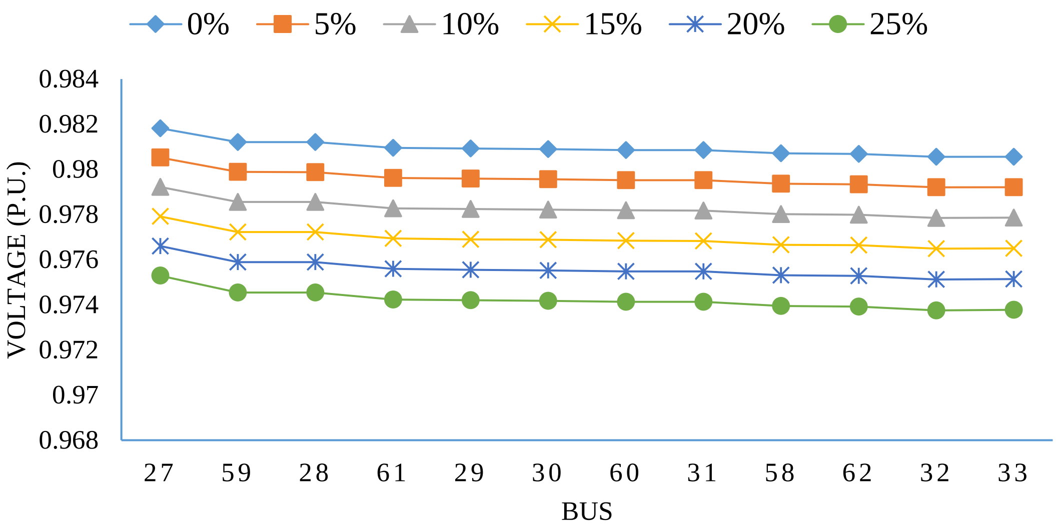


Figure 4.23: Voltage profile at zone3

When the Induction stove was penetrated, the voltage started to get reduce at different bus. At different level of penetration, no any voltage violation was observed. Initially lowest voltage was seen at bus 33 which is 0.980556 p.u. to 0.973778 p.u. at 25% penetration level.

4.3.3.4. Voltage profile of Zone4

Voltage profile of different 11 kV bus at zone4 at different level of penetration is shown in Figure 4.24.

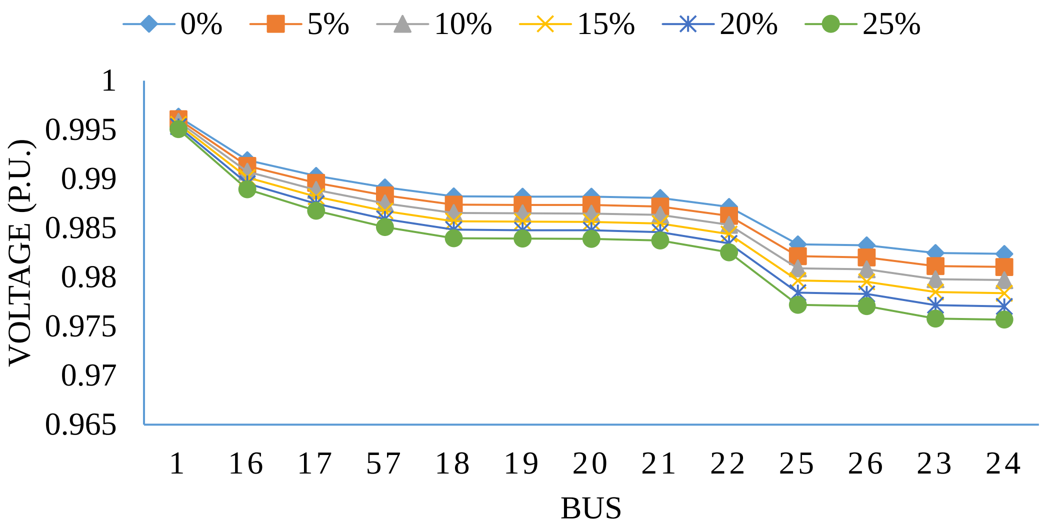


Figure 4.24: Voltage profile at zone4

When the Induction stove was penetrated, the voltage started to get reduced at different bus. At different level of penetration, no voltage violation was observed. Initially the lowest voltage was seen at bus 24 which is 0.982383 p.u. to 0.975682 p.u. at 25% penetration level.

4.3.3.5. Overall voltage profile

Overall voltage profile at different zones of different 11 kV bus at different level of penetration is shown in Figure 4.25

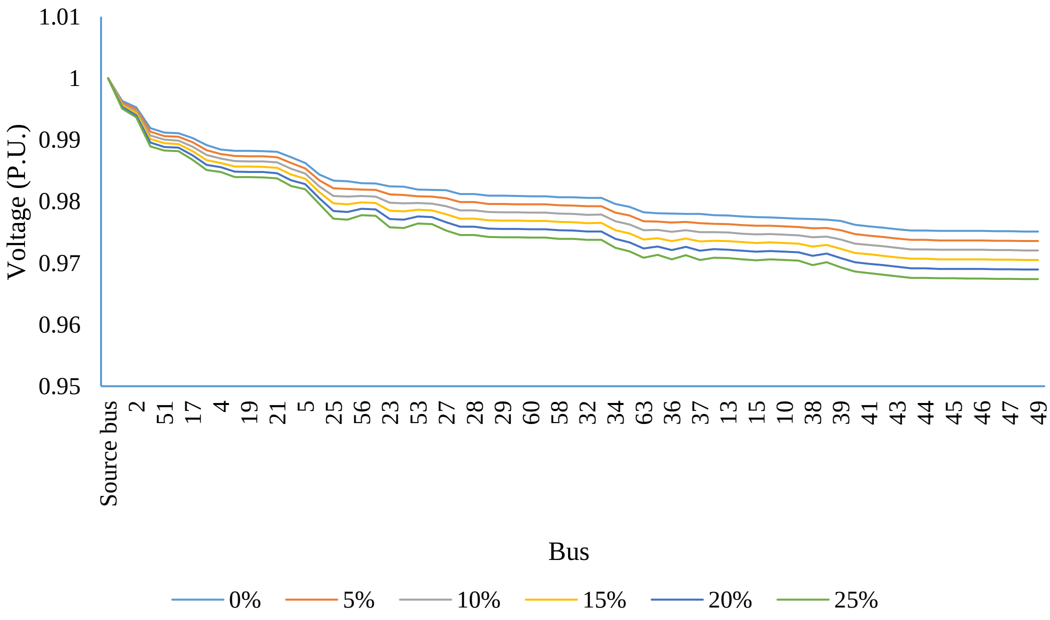


Figure 4.25: Overall voltage profile

When the Induction was penetrated, the voltage started to get reduce at different bus. At different level of penetration, no any voltage violation was observed. Initially lowest voltage was seen at bus 49 which is 0.975113 p.u. to 0.967395 p.u. at 25% penetration level.

4.3.4. Line Loading

Loading of line at different level of penetration of Induction cooktop at different zones is described below.

4.3.4.1. Line loading at zone1

The loading of line at Zone1 at different level of penetration is shown in Figure 4.26.

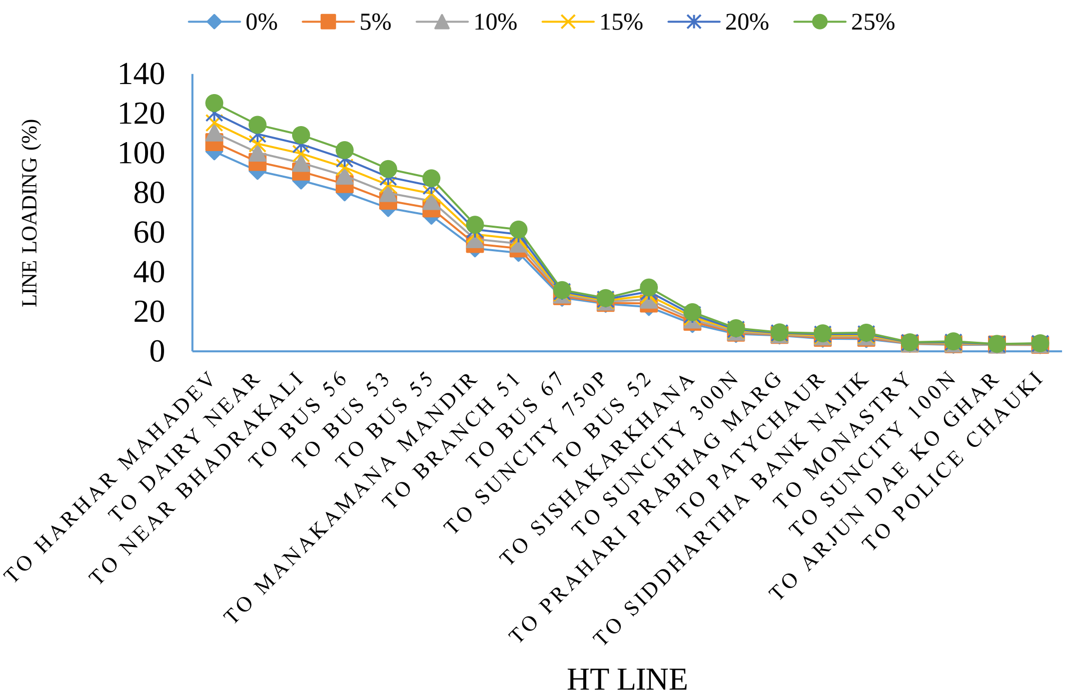


Figure 4.26: Line loading at Zone1

When the Induction was penetrated, the loading on conductor started to increase. It was seen that some of the conductor were overloaded when penetration level fof Induction Cooktop increased. At 25% penetration level conductors To Harhar Mahadev was operating at 125%, to Dairy Near was operating at 114%, To Near Bhadrakali was operating at 109%, To Bus 56 was operating at 102%. So, mitigation have to be applied for these conductors.

4.3.4.2. Line loading at zone2

The loading of line at Zone2 at different level of penetration is shown in Figure 4.27.

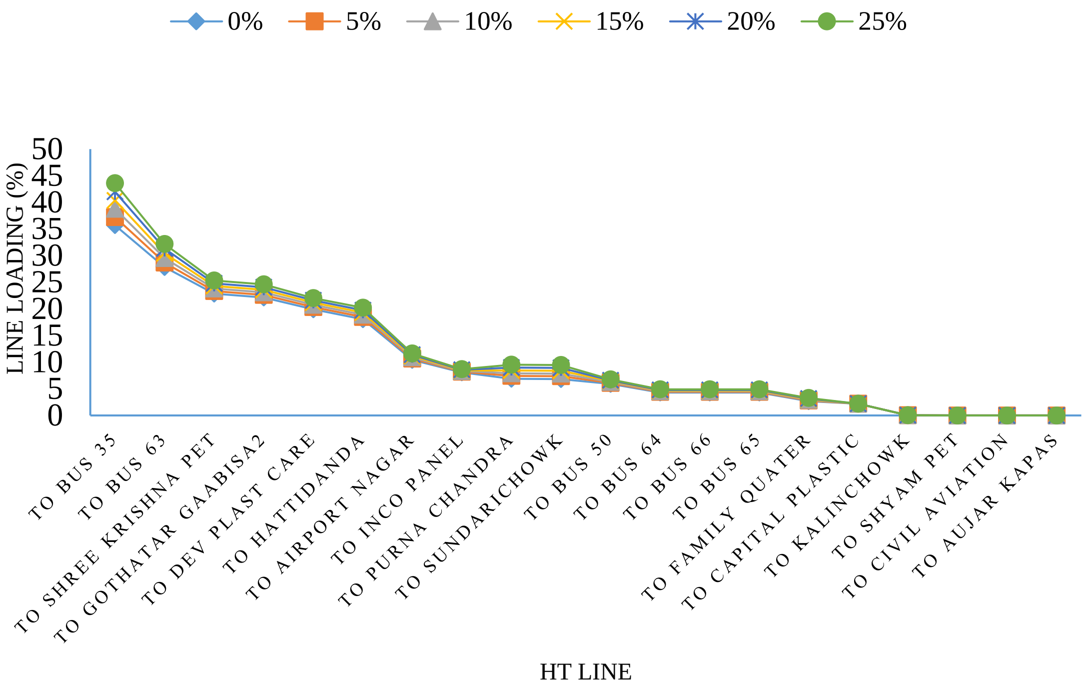


Figure 4.27: Line loading at zone2

When the Induction was penetrated, the loading on the conductor started to increase. It was seen that no conductors were overloaded upto 25% of penetration of induction cooktop and maximum loading was seen at conductor To Bus 35 operating at 44%.

4.3.4.3. Line loading at zone3

The loading of line at Zone3 at different level of penetration is shown in Figure 4.28.

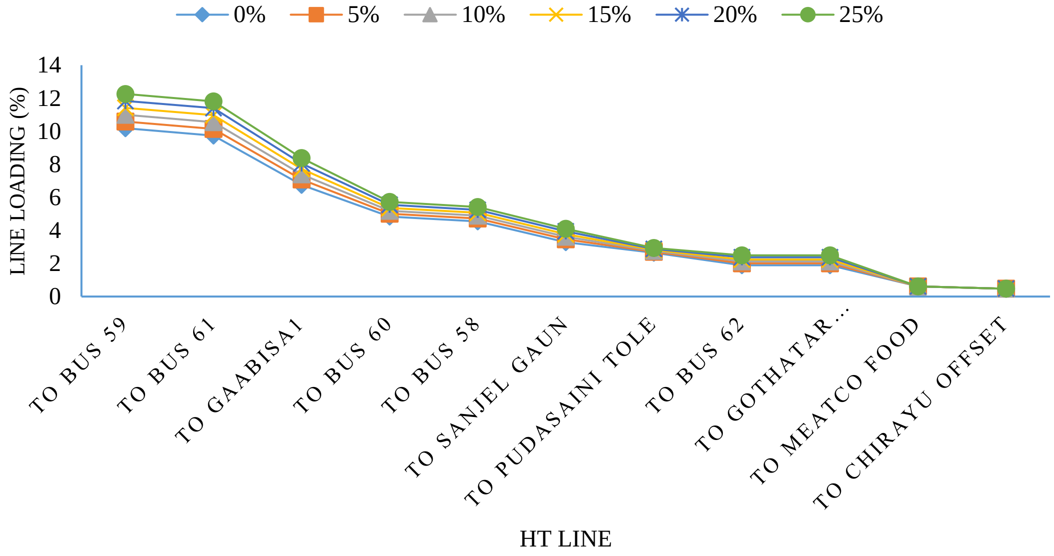


Figure 4.28: Line loading at zone3

When the Induction was penetrated, the loading on the conductor started to increase. It was seen that some no conductor were overloaded upto 25% of penetration of induction cooktop and maximum loading was seen at conductor To Bus 59 operating at 12%.

4.3.4.4. Line loading at zone4

The loading of line at Zone4 at different level of penetration is shown in Figure 4.29.

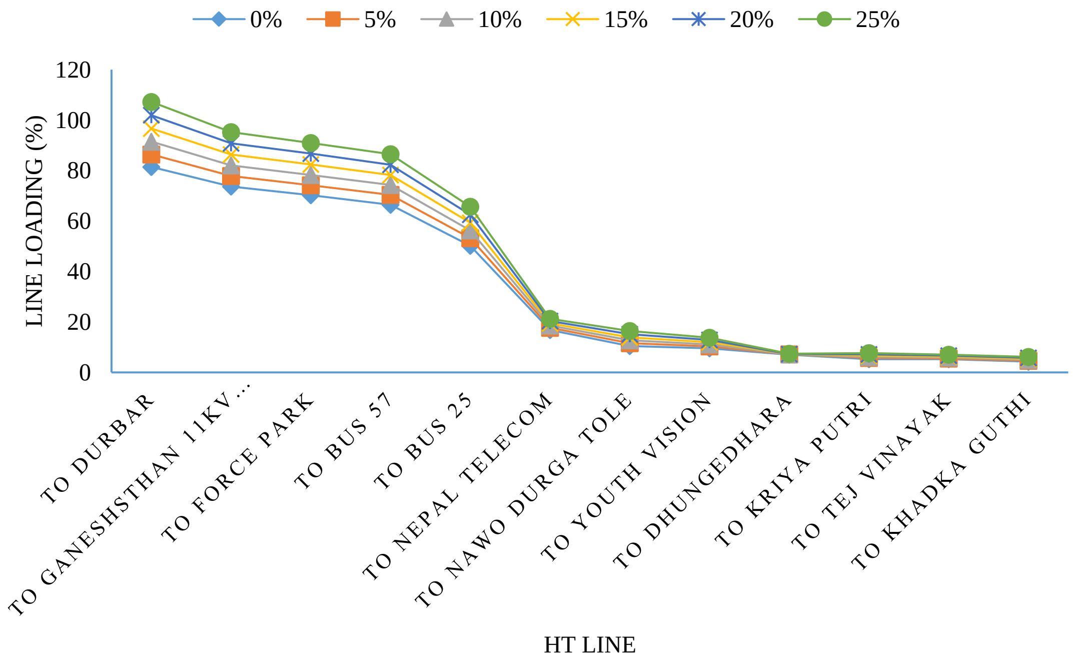


Figure 4.29: Line loading at zone4

When the Induction was penetrated, the loading on the conductor started to increase. It was seen that some of the conductor were overloaded when penetration level of Induction Cooktop increased. At 25% penetration level conductor named To Durbar was operating at 107.2%. So mitigation have to be applied for this conductor.

4.3.4.5. Overall line loading

The loading of line at Zone1 at different level of penetration is shown in Figure 4.30.

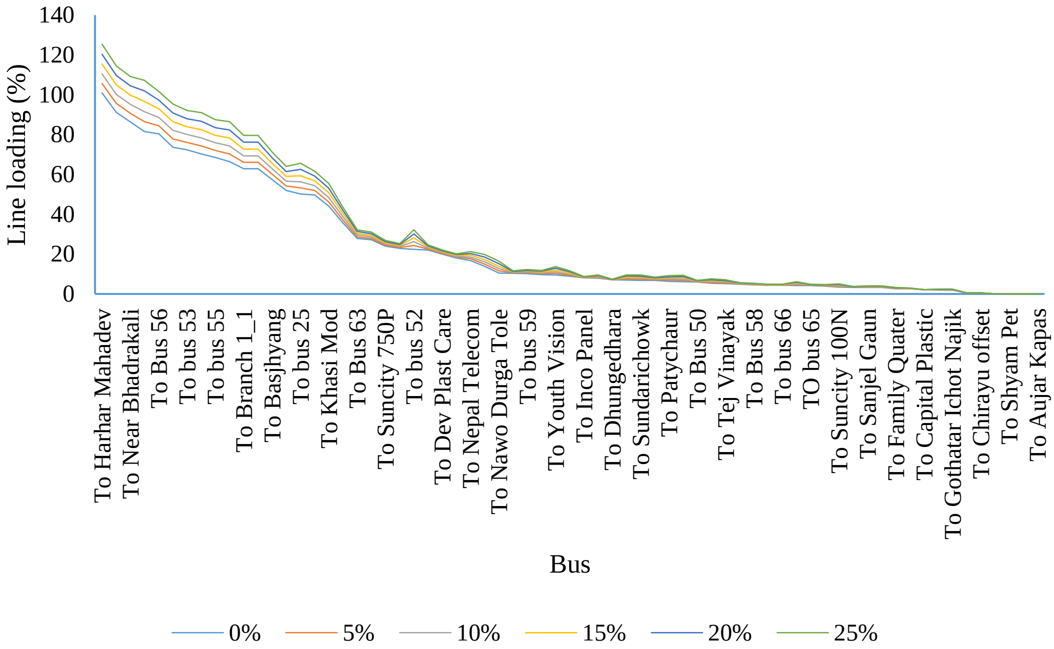


Figure 4.30: Overall loading of line

When the Induction was penetrated, the loading on the conductor started to increase. It was seen that some of the conductors were overloaded when penetration level of Induction Cooktop increased. At 25% penetration level conductors naming To Harhar Mahadev was operating at 125%, To Dairy Near was operating at 114%, To Near Bhadrakali was operating at 109%, To Durbar was operating at 107% and To Bus 56 was operating at 102%. So, mitigation must be applied for these conductors.

4.3.5. Transformer loading

Induction cooktops were inserted at 36 different locations of distribution transformers of radial distribution system. The loading of transformer needed to be studied after insertion of induction stove.

4.3.5.1. Transformer loading at zone1

The loading of transformer at Zone1 at different level of penetration is shown in Figure 4.31.

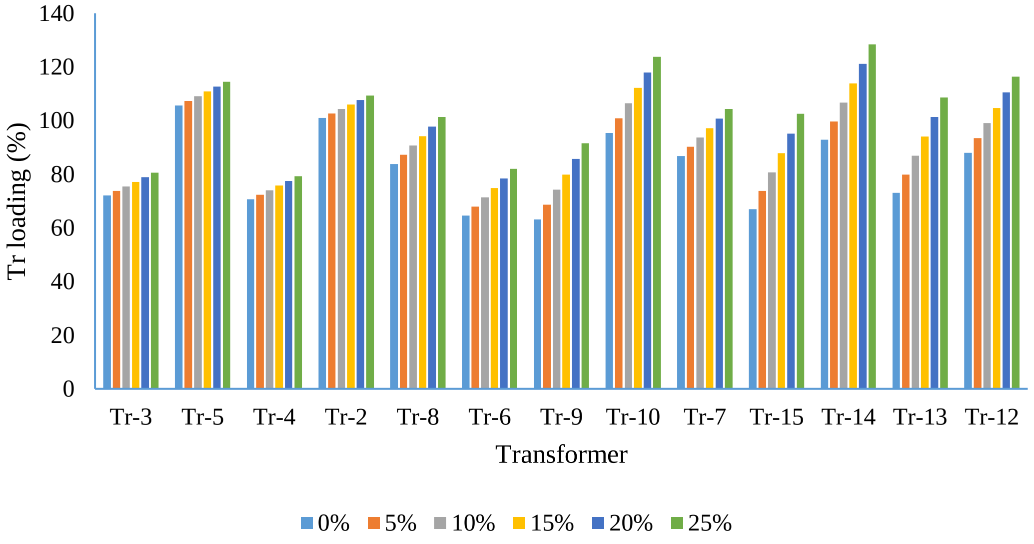


Figure 4.31: Transformer loading at zone1

Initially, Tr-5 and Tr-2 were overloaded at base case condition. As the penetration of Induction Cooktop increases the loading of transformer is increased. At 10% penetration of Induction cooktop Tr-5, Tr-2, Tr-10 and Tr-14 were overloaded. At 15% penetration of Induction Cooktop Tr-5, Tr-2, Tr-10, Tr-14 and Tr-12 were overloaded. At 20% penetration of Induction Cooktop Tr-5, Tr-2, Tr-10, Tr-12, Tr-7, Tr-14 and Tr-13 were overloaded and at 25% penetration Tr-5, Tr-2, Tr-8, Tr-10, Tr-12, Tr-7, Tr-13, Tr-14, and Tr-15 were overloaded. Since, in our study we opt for condition of distribution at 25% penetration of Induction Cooktop. The result showed that in order to maintain the withstand capacity of distribution system we have to increase the size of transformer.

4.3.5.2. Transformer loading at zone2

The loading of transformer at Zone2 at different level of penetration is shown in Figure 4.32.

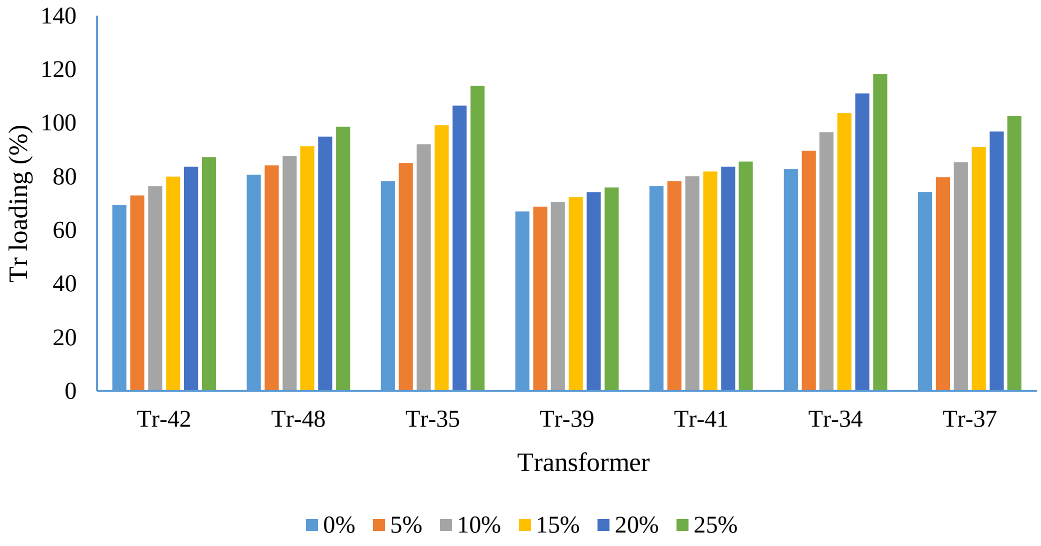


Figure 4.32: Transformer loading at zone2

Initially, no transformers were overloaded at base case condition. As the penetration of Induction Cooktop increases the loading of transformer is increased. At 15% penetration of Induction cooktop Tr-34 was overloaded. At 20% penetration of Induction Cooktop Tr-34 and Tr-35 were overloaded. And at 25% penetration Tr-34, Tr-35, and Tr-37 were overloaded. Since, in our study we opt for condition of distribution at 25% penetration of Induction Cooktop. The result showed that in order to maintain the withstand capacity of distribution system we have to increase the size of transformer.

4.3.5.3. Transformer loading at zone3

The loading of transformer at Zone3 at different level of penetration is shown in Figure 4.33.

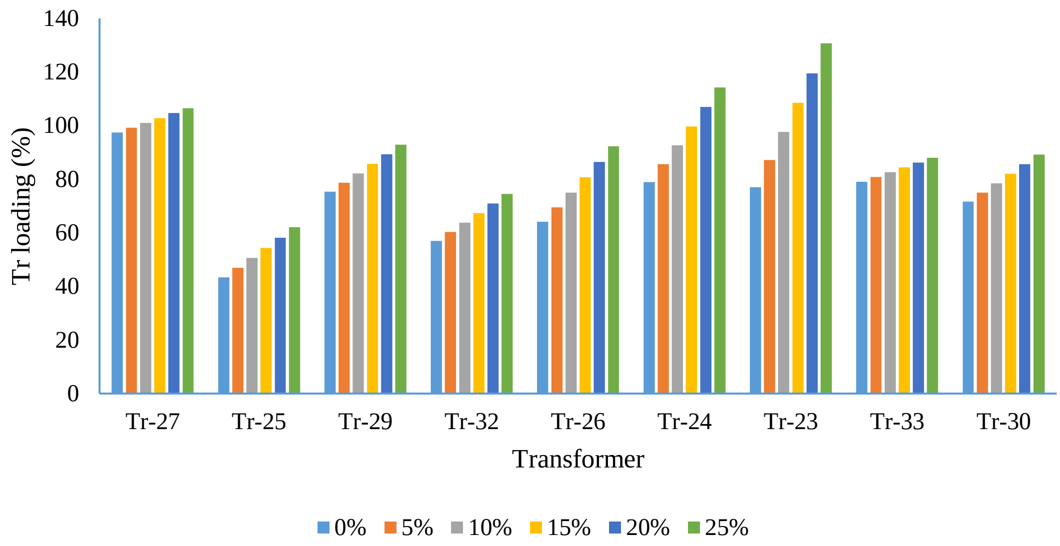


Figure 4.33: Transformer loading at zone3

Initially, no transformers were overloaded at base case condition. As the penetration of Induction Cooktop increases the loading of transformer is increased. At 10% penetration of Induction cooktop Tr-27 was overloaded. At 15% penetration of Induction Cooktop Tr-27, and Tr-23 were overloaded. At 20% penetration of Induction Cooktop Tr-27, Tr-23 and Tr-24 were overloaded. And at 25% penetration Tr-27, Tr-23 and Tr-24 were overloaded. Since, in our study we opt for condition of distribution at 25% penetration of Induction Cooktop. The result showed that in order to maintain the withstand capacity of distribution system we have to increase the size of transformer.

4.3.5.4. Transformer loading at zone4

The loading of transformer at Zone4 at different level of penetration is shown in Figure 4.34.

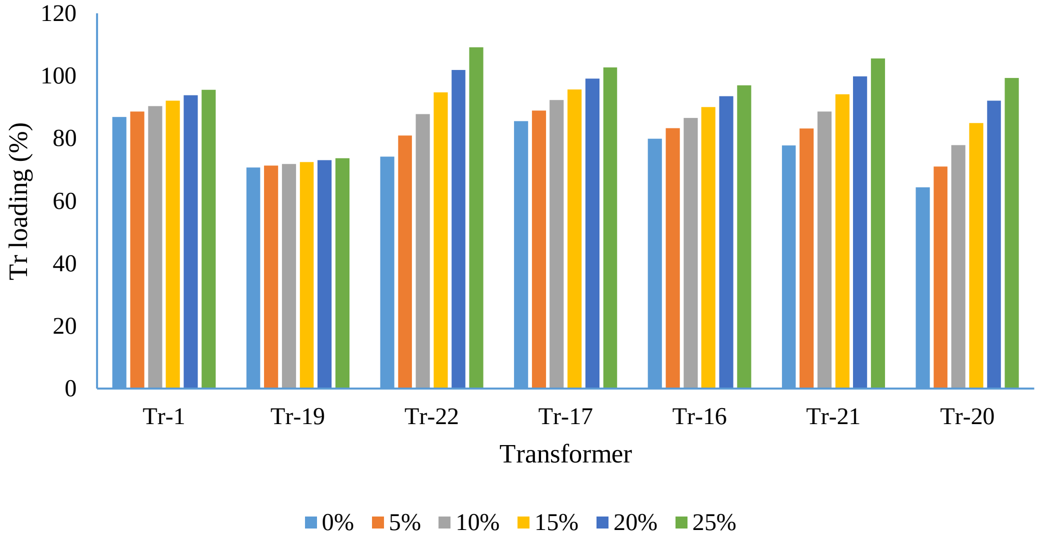


Figure 4.34: Transformer loading at zone4

Initially, no transformer was overloaded at base case condition. As the penetration of Induction Cooktop increases the loading of transformer is increased. Transformer started to get overload at 20% penetration level. At 20% penetration Tr-22 was overloaded. At 25% penetration of Induction cooktop Tr-22, Tr-17, and Tr-21 were overloaded. Since, in our study we opt for condition of distribution at 25% penetration of Induction Cooktop. The result showed that in order to maintain the withstand capacity of distribution system we have to increase the size of transformer.

4.3.5.5. Overall Transformer loading

The overall loading of transformer at different level of penetration is shown in Figure 4.35.

Figure 4.35: Overall transformer loading

Initially, Tr-5 and Tr-2 were overloaded at base case condition. As the penetration of Induction Cooktop increases the loading of transformer is increased. At 10% penetration of Induction cooktop additional Tr-10, Tr-14 and Tr-27 were overloaded. At 15% penetration of Induction Cooktop additional Tr-34, Tr-24, Tr-23 and Tr-12 were overloaded. At 20% penetration of Induction Cooktop additional Tr-22, Tr-35, Tr-7, Tr-13 and Tr-21 were overloaded. And at 25% penetration total of transformer that were overloaded are Tr-5, Tr-2, Tr-8, Tr-10, Tr-14, Tr-27, Tr-34, Tr-24, Tr-23, Tr-12, Tr-22, Tr-35, Tr-7, Tr-13, Tr-21, Tr-17, Tr-15 and Tr-37 were overloaded. The result shows that we have to increase the size of transformer. Since, in our study we opt for condition of distribution at 25% penetration of Induction Cooktop. We have to replace the transformer by their next higher size for reliable operation of system.

4.4 Case IV: Loading of feeder after mitigation

When induction stove penetration level was increased the loading in distribution network was increased. At 25 percent of Induction stove penetration most of transformers and conductors were operating more than their capacity. It was considered that it could be technically and financially feasible to increase the withstanding capacity of distribution network at 25 percent penetration level. So, mitigation was performed for overloaded transformers and conductors and again load flow was performed. For mitigation purpose we upgraded the size of transformers. In case of conductors we change the conductor by higher size or connect same size of conductor in parallel.

4.4.1. Feeder power loss

Active power loss of feeder after mitigation is shown in Figure 4.36.

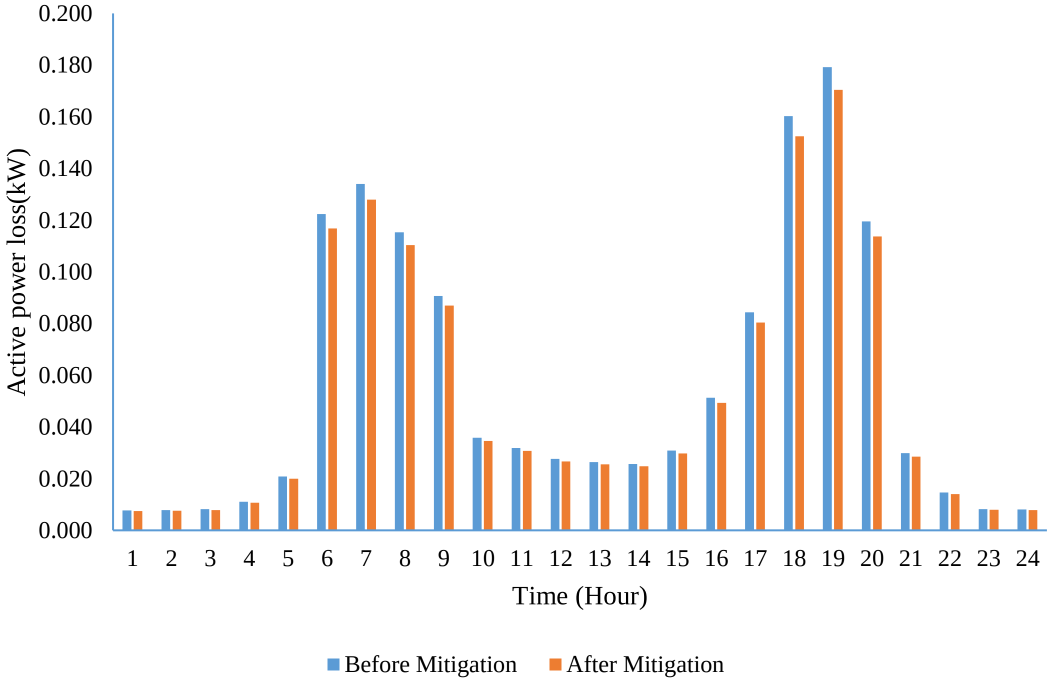


Figure 4.36: Comparison of Feeder active power loss

When mitigation was performed in the existing distribution system feeder active loss was found to be reduced as shown in figure 4.36. Before mitigation at 25% penetration of Induction Cooktop power loss was 0.179 MW and after mitigation feeder active power loss was reduced to 0.170 MW.

4.4.2. Voltage profile after mitigation

Voltage profile at different zones of area after mitigation are described below.

4.4.2.1. Voltage profile at zone1

Voltage profile of zone1 after mitigation is shown in Figure 4.37. This voltage profile was compared to voltage profile before mitigation.

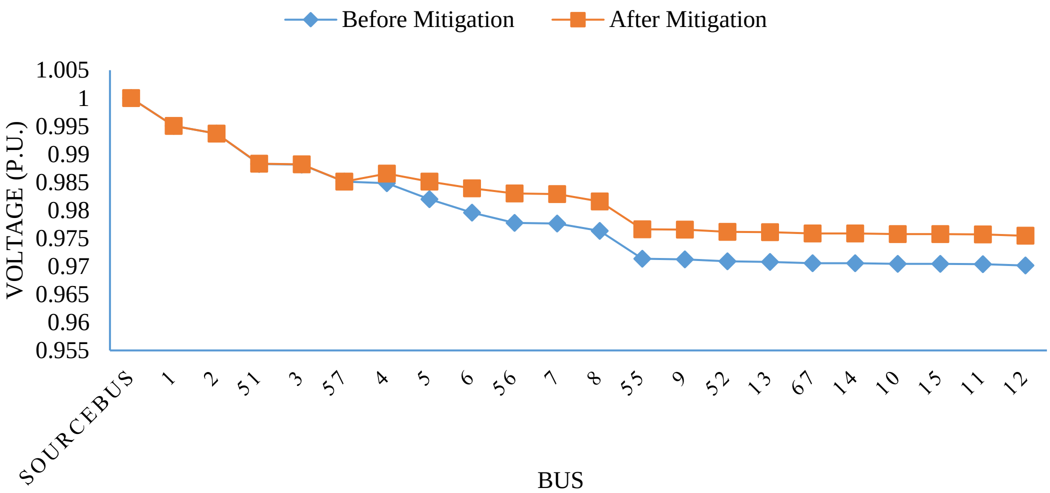


Figure 4.37: Bus voltage at zone1 before and after mitigation

After mitigation it was seen that voltage of buses are increased. Lowermost voltage seen at bus 12 which was 0.9701 p.u. was increased to 0.9754 p.u.

4.4.2.2. Voltage profile at zone2

Voltage profile of zone2 after mitigation is shown in Figure 4.38. This voltage profile was compared to voltage profile before mitigation.

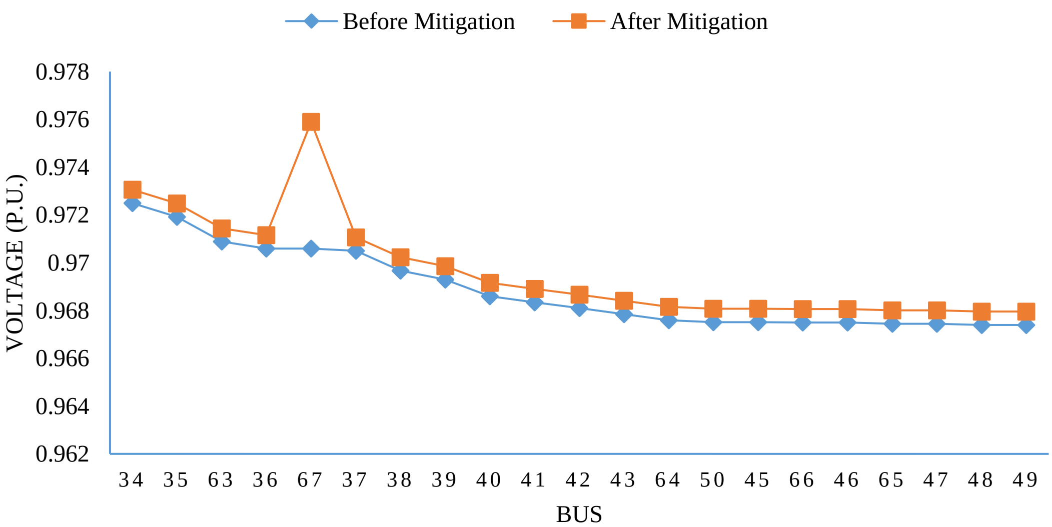


Figure 4.38: Bus voltage at zone2 before and after mitigation

After mitigation it was seen that voltage of buses are increased. Lowermost voltage seen at bus 49 which was 0.9673 p.u. was increased to 0.9779 p.u.

4.4.2.3. Voltage profile at zone3

Voltage profile of zone3 after mitigation is shown in Figure 4.39. This voltage profile was compared to voltage profile before mitigation.

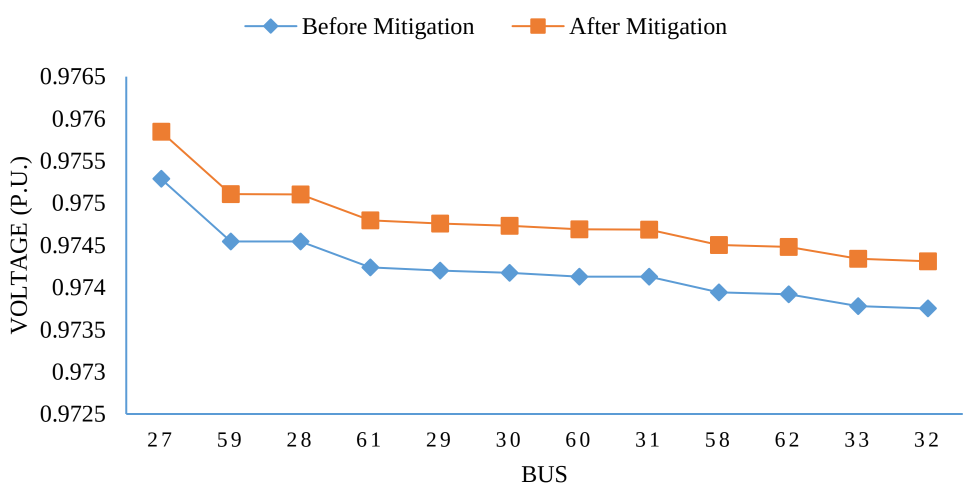


Figure 4.39: Bus voltage at zone3 before and after mitigation

After mitigation it was seen that voltage of buses are increased. Lowermost voltage seen at bus 32 which was 0.9737 p.u. was increased to 0.9743 p.u.

4.4.2.4. Voltage profile at zone4

Voltage profile of zone4 after mitigation is shown in Figure 4.40. This voltage profile was compared to voltage profile before mitigation.

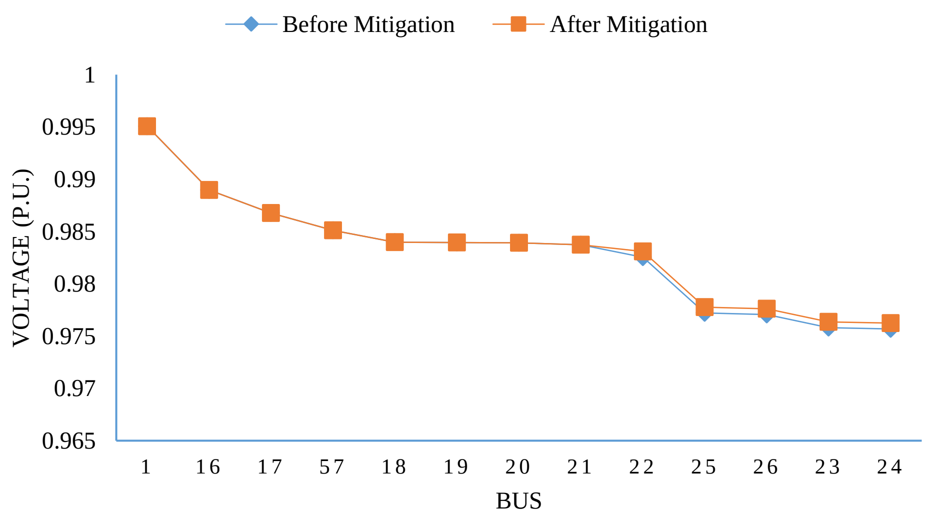


Figure 4.40: Bus voltage at zone4 before and after mitigation

After mitigation it was seen that voltage of buses are increased. Lowermost voltage seen at bus 32 which was 0.9757 p.u. was increased to 0.9762 p.u.

4.4.2.5. Overall Voltage profile

Overall voltage profile of after mitigation is shown in Figure 4.41. This voltage profile was compared to voltage profile before mitigation.

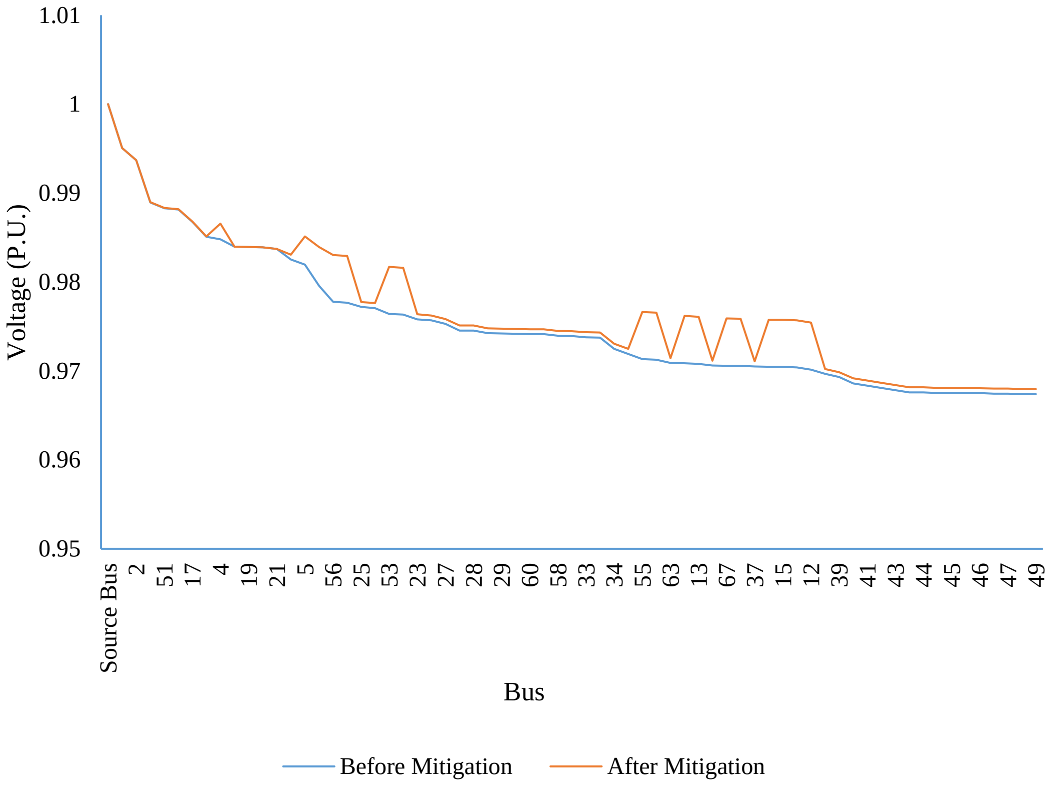


Figure 4.41: Overall voltage profile before and after mitigation

After mitigation it was seen that voltage of buses increased. The lowermost voltage seen at bus 49 which was 0.967395 p.u. was increased to 0.967958 p.u. As no voltage violation was seen in buses even after the penetration of Induction Cooktop due to short length of line.

4.4.3. Transformer loading after mitigation

Loading of transformer after mitigation at different zones of area is described below.

4.4.3.1. Transformer loading at zone1

Transformer loading at zone1 after mitigation is shown in Figure 4.42. This transformer loading was compared to transformer loading before mitigation.

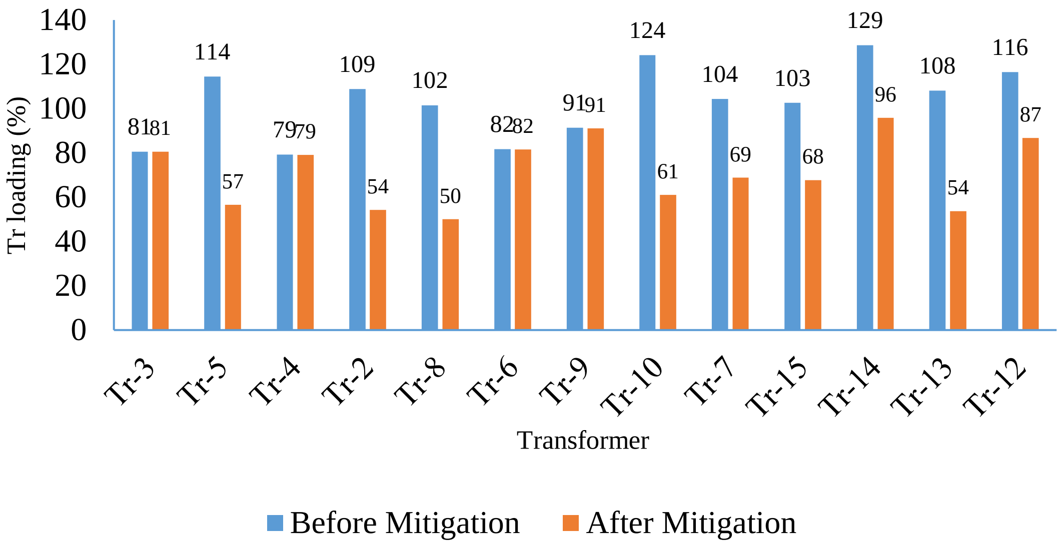


Figure 4.42: Transformer loading at zone1 before and after mitigation

After mitigation loading of Tr-5 was reduced from 114% to 57%, Tr-2 was reduced from 109% to 54%, Tr-8 was reduced from 102% to 50%, Tr-10 was reduced from 124% to 61%, Tr-7 was reduced from 104% to 69%, Tr-15 was reduced from 103% to 68%, Tr-14 was reduced from 129% to 96%, Tr-13 was reduced from 108% to 54% and Tr-12 was reduced from 116% to 87%.

4.4.3.2. Transformer loading at zone2

Transformer loading at zone2 after mitigation is shown in Figure 4.43. This transformer loading was compared to transformer loading before mitigation.

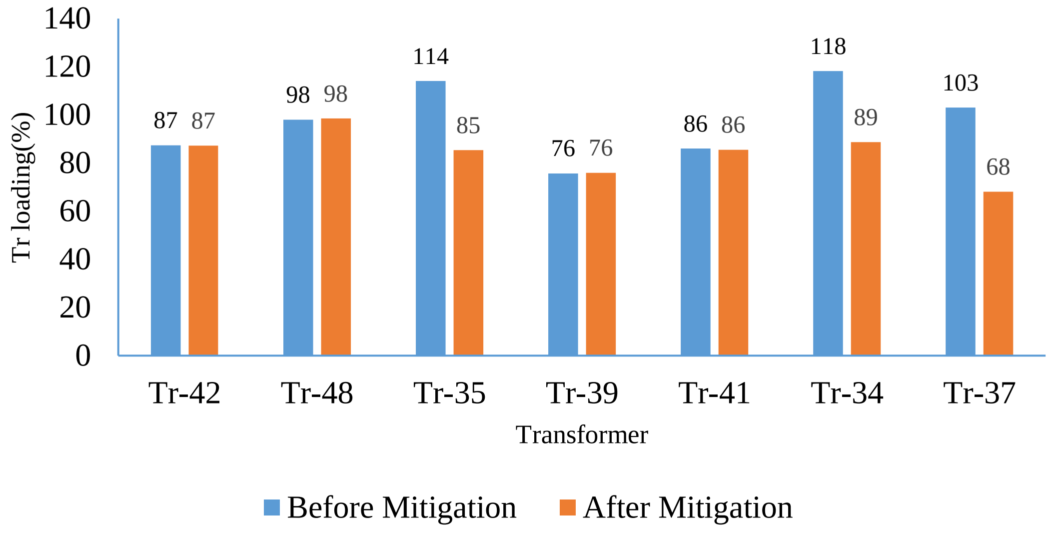


Figure 4.43: Transformer loading at zone2 before and after mitigation

After mitigation loading of Tr-35 was reduced from 114% to 85%, Tr-34 was reduced from 118% to 89%, and Tr-37 was reduced from 103% to 68%.

4.4.3.3. Transformer loading at zone3

Transformer loading at zone3 after mitigation is shown in Figure 4.44. This transformer loading was compared to transformer loading before mitigation.

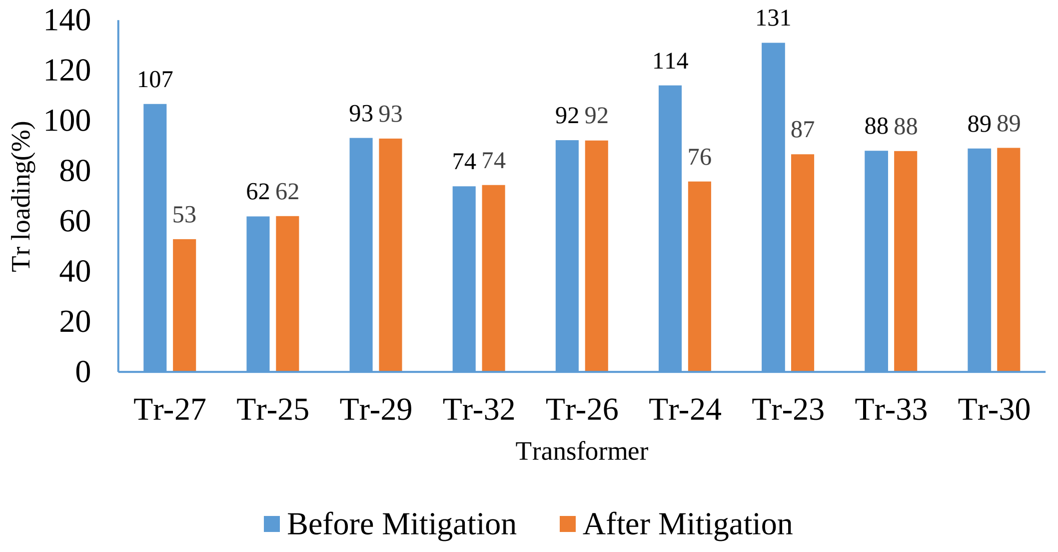


Figure 4.44: Transformer loading at zone3 before and after mitigation

After mitigation loading of Tr-27 was reduced from 107% to 53%, Tr-26 was reduced from 114% to 76%, and Tr-23 was reduced from 131% to 87%.

4.4.3.4. Transformer loading at zone4

Transformer loading at zone4 after mitigation is shown in Figure 4.45. This transformer loading was compared to transformer loading before mitigation.

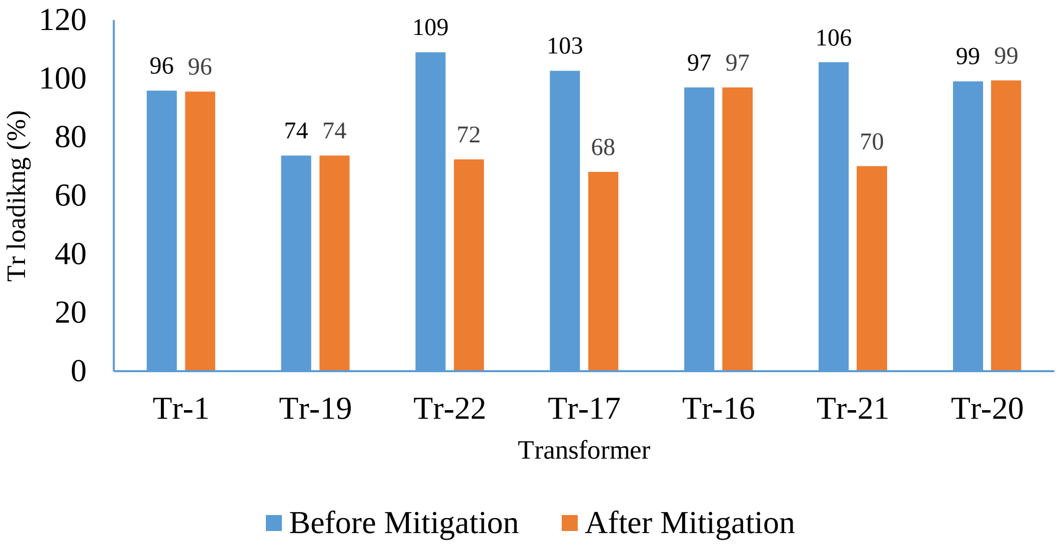


Figure 4.45: Transformer loading at zone4 before and after mitigation

After mitigation loading of Tr-22 was reduced from 109% to 72%, Tr-17 was reduced from 103% to 68%, and Tr-21 was reduced from 106% to 70%.

4.4.3.5. Overall Transformer loading

Overall transformer loading after mitigation is shown in Figure 4.46. This transformer loading was compared to transformer loading before mitigation.

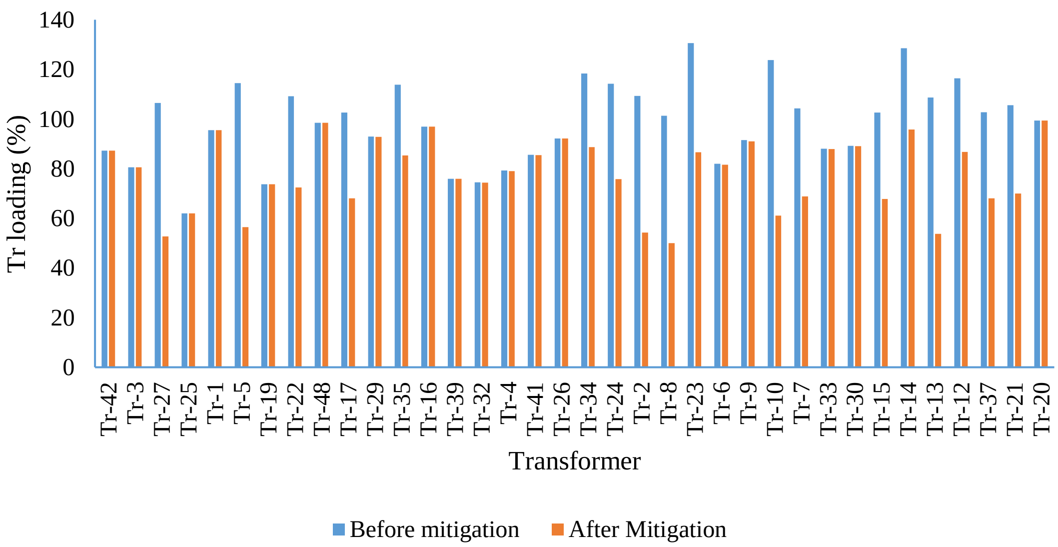


Figure 4.46: Overall transformer loading before and after mitigation

After mitigation loading of Tr-5 was reduced from 114% to 57%, Tr-2 was reduced from 109% to 54%, Tr-8 was reduced from 102% to 50%, Tr-10 was reduced from 124% to 61%, Tr-7 was reduced from 104% to 69%, Tr-15 was reduced from 103% to 68%, Tr-14 was reduced from 129% to 96%, Tr-13 was reduced from 108% to 54%, Tr-12 was reduced from 116% to 87%, Tr-35 was reduced from 114% to 85%, Tr-34 was reduced from 118% to 89%, Tr-37 was reduced from 103% to 68%, Tr-27 was reduced from 107% to 53%, Tr-24 was reduced from 114% to 76%, Tr-23 was reduced from 131% to 87%, Tr-22 was reduced from 109% to 72%, Tr-17 was reduced from 103% to 68%, and Tr-21 was reduced from 106% to 70%.

4.4.4. Line loading

As the Induction Cooktop is integrated into the feeder, the loading of the conductor increases. It increases with an increase in the penetration percentage of Induction. The loading of the line at the peak hour is shown in the figure below.

4.4.4.1. Line loading at zone1

Loading of line after mitigation is shown in Figure 4.47.

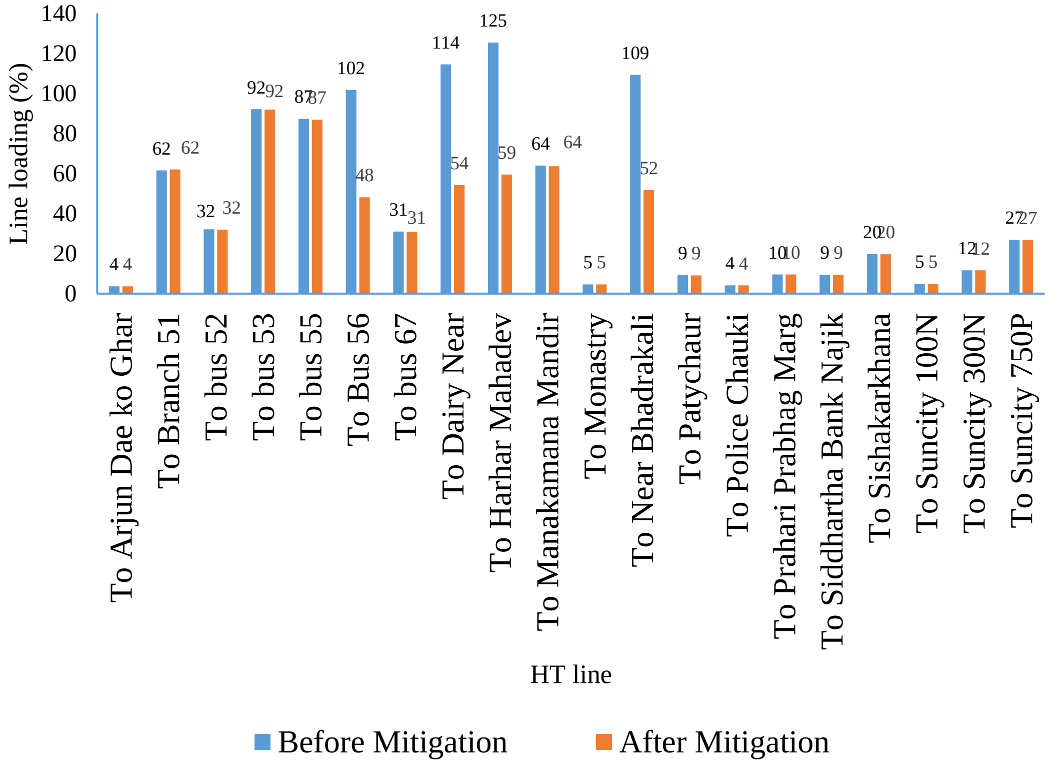


Figure 4.47: Line loading before and after mitigation at zone1

It was seen that at 25% penetration loading of line To Harhar Mahadev was reduced from 125% to 59%, To Dairy Near was reduced from 114% to 54%, To Near Bhadrakali was reduced from 109% to 52% and To bus 56 was reduced from 102% to 48%.

4.4.4.2. Line loading at zone4

Loading of line after mitigation is shown in Figure 4.48.

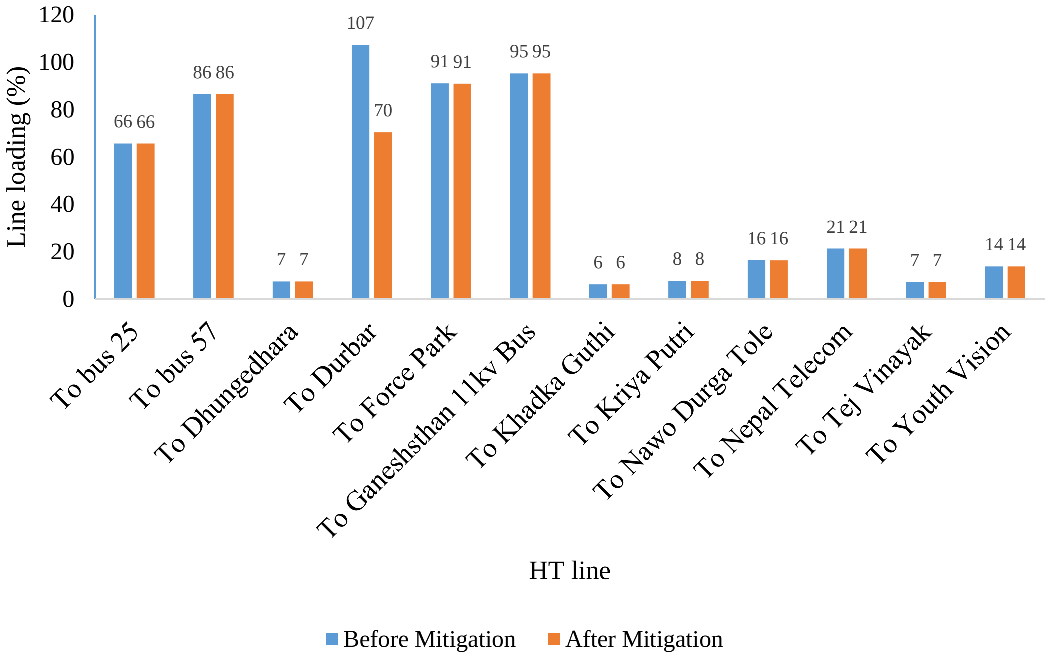


Figure 4.48: Line loading before and after mitigation at zone1

Line loading at zone4 after mitigation is shown in figure 4.48. It is seen that at 25% penetration loading of line To Durbar was reduced from 107% to 70%.

4.4.4.3. Overall Line loading

Overall loading of line after mitigation is shown in Figure 4.49.

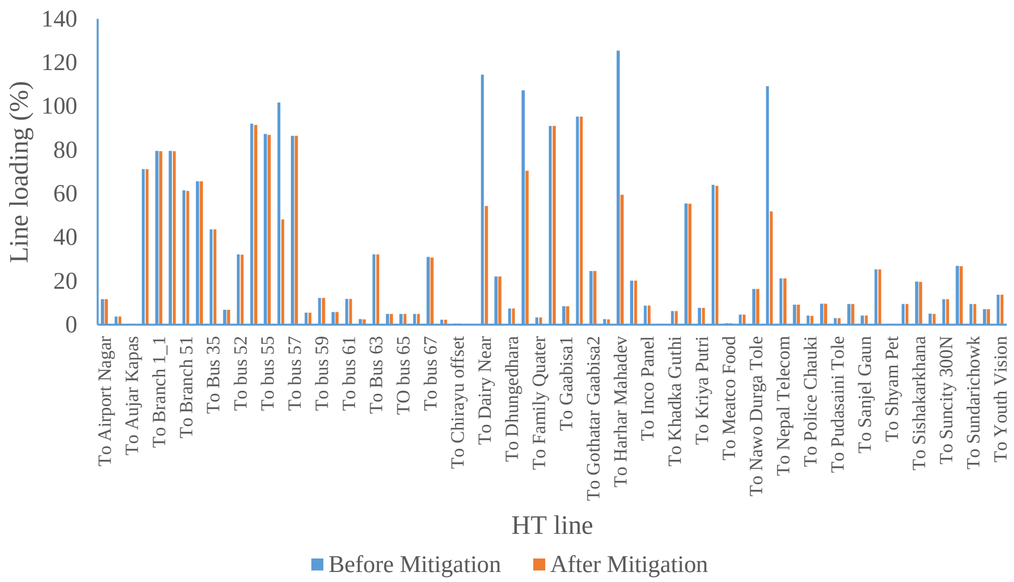


Figure 4.49: Overall Line loading before and after mitigation

It is seen that at 25% penetration loading of line To Harhar Mahadev was reduced from 125% to 59%, To Dairy Near was reduced from 114% to 54%, To Near Bhadrakali was reduced from 109% to 52%, To bus 56 was reduced from 102% to 48% and To Durbar was reduced from 107% to 70%..

4.5 Financial Analysis

Determination of financial analysis is performed in following section.

4.5.1. Financial analysis for preliminary mitigation

Initially Dog conductor was strung in parallel in existing poles between substation to bus1. The costing of this is to be calculated. With the help of Nepal Ekarat Engineering Co. Pvt. Ltd. Nepal, the reference for cost of transformer is taken. The labor charge is determined from district rate of Kathmandu district and Nepal Electricity Authority.

Table 4.5: Conductor details for upgradation

Description	Unit	Quantity	Remarks
Conductor length to upgrade	Mtr	1023	Per phase
Considering sag (3%) (running length)	Mtr	1054	Per phase
Total conductor length (3* phase length)	Mtr	3161	
Span	Mtr	45	
Total number of poles	Nos.	25	

Table 4.6: Conductor material and labor cost for upgradation

Estimation of HT Line (Gothatar Feeder) upgrading					
S. N.	Description	Qty.	Unit	Rate (Rs.)	Amount (Rs.)
A.	HT Line Materials				
1.	Offset Channel Set	25	Nos.	2,600	65,000
2.	XLPE AAC Cover Conductor (100 Sq mm)	3161	Mtr.	150	474,150
3.	11 kV Disk Insulator with tension set Complete	30	Set	2,400	72,000
4.	11 kV Pin Insulator with spindle	75	Nos.	300	22,500
5.	Nut Bolts of Different Sizes	5	Kg.	300	1,500
	Sub-total Materials Cost (A):				635,150
B.	Labor Cost				
1.	Dismantle And Store Return of 0.03 Sq inch ACSR Conductor	800	Mtr.	9.987	7,990
2.	Dismantle And Store Return of 0.05 Sq inch ACSR Conductor	1350	Mtr.	10.67	14,405
3.	Stringing of XLPE AAC Cover Conductor (100 Sq mm)	3161	Mtr.	26.42	83,514
	Sub-total of Labor Charge (B)				105,908
C.	Grand Total (Materials+ Labor = A+B) in Rs.				741,058

Table 4.7: Transformer material and labor cost for transformer upgradation

Transformer Installation and Upgradation Work					
Location: - Lahure Chauk, Tejbinayak Chauk, Srijana Tole, Kursani pati, Madan Aashritnir, Pragati Chauk, Tejbinayak naya, Echot raymajhi tole, Audhogik chhetra, Aarmi Byarek, Nabdurga Tole, force park, Kriya Putri bhawan, Nabdurga Tole					
S. N.	Particulars	Unit	Qty	Rate (Rs.)	Amount (Rs.)
A.	Materials Required	-	-	-	-
1.	200 kVA Transformer	Nos.	6	550,000	3,300,000
2.	300 kVA Transformer	Nos.	8	650,000	5,200,000
3.	400 kVA Transformer	Nos.	6	900,000	5,400,000
4.	MCCB 300 Amp.	Nos.	6	12,000	72,000
5.	MCCB 450 Amp.	Nos.	8	15,000	120,000
6.	MCCB 600 Amp.	Nos.	6	25,000	150,000
7.	MCCB Panel Box set	Nos.	20	15,000	300,000
8.	Earthing Rod	Nos.	4	600	2400
9.	Earthing Wire	Mtr.	35	800	28000
10.	Nut Bolts	Nos.	20	90	1,800
	Sub-Total Materials Cost (A)				14,574,200
B.	Labor Charge				
1.	Installation of 100-400 kVA Distribution Transformer with Earthing and DO, Lightning Set and MCCB	Nos.	20	18,607	372,140
2.	Dismantling of old 100-400 kVA Transformer and Store Submission	Nos.	20	9,304	186,070
	Subtotal of Labor Charge (B)				558,211
C.	Grand Total (Materials+ Labor =A+B) in Rs.				15,132,411

To increase the withstand capacity of distribution system mitigation was purposed for overloaded equipment. The table above shows the costing of conductor and transformer required for upgradation. As per table 4.6 total cost for conductor upgradation is Rs. 741,058 and as per table 4.7 total cost for transformer upgradation is Rs. 15,132,411. The above tables show that in order to operate the distribution network effectively the utility must invest to Rs. 15,873,469.

For performing the financial analysis from consumers perspective three classes of consumers were considered. Small category consumer uses 6 cylinders, medium category consumer class uses 12 cylinders and large category consumer class uses 30 cylinders. Following details are performed for financial analysis.

Total weight of gas in one LPG cylinder = 14.2 kg

1 kg of gas is equivalent to 13.6 kWh

Efficiency of LPG stoves = 49% (Khan & Saxena, n.d.)

Efficiency of Induction stove = 84% (Chhetri et al., 2015)

Rate of LPG Cylinder = Rs. 1895/- (N.O.C)

Rate of unit consumed of electricity is taken from electricity tariff regulatory act, 2078, NEA

MCB connection = 15A minimum requirement

1) Small category consumer using 6 LPG cylinders for purpose of cooking

Total number of LPG Cylinders = 6

1 kg of LPG gas = 13.6 kWh

Efficiency of LPG gas is 49% so,

1 kg of LPG gas = 6.66 kWh

For 14.2 kg of LPG gas = 6.66 *14.2 = 94.572 kWh

For 6 cylinders = 6 * 94.572 = 567.432 kWh

Induction stove efficiency is 84% so,

Required energy to replace LPG = 567.432/0.84 = 675.514 kWh/year

Required energy to replace LPG per month = 56.29 kWh/month

Cost by using induction stove = Rs. 471.5/month

Cost due to induction stove per year = Rs. 5658/-

Comparing cost between induction stove and LPG cylinder

Total cost on LPG cylinder = 6 *1895 = Rs. 11370/year

Cost due to induction stove = Rs. 5658/year

Saving per year = Rs. 5712/-

Saving per month = Rs. 476/-

2) Middle category consumer using 12 LPG cylinders for purpose of cooking

Total number of LPG Cylinders = 12

1 kg of LPG gas = 13.6 kWh

Efficiency of LPG gas is 49% so,

1 kg of LPG gas = 6.66 kWh

For 14.2 kg of LPG gas = 6.66 *14.2 = 94.572 kWh

For 12 cylinders = 12 * 94.572 = 1134.864 kWh

Induction stove efficiency is 84% so,

Required energy to replace LPG per year = 1134.864/0.84 = 1351.02 kWh

Required energy to replace LPG per month = 112.5 kWh

Cost by using induction stove = Rs. 1028.5/month

Cost due to induction stove per year = Rs. 12342/-

Comparing cost between induction stove and LPG cylinder

Total cost on LPG cylinder = 12 * 1895 = 22740/year

Cost due to induction stove = Rs. 12342/year

Saving per year = Rs.10398/-

Saving per month = Rs. 867/-

3) High category consumer using 30 LPG cylinders for purpose of cooking

Total number of LPG Cylinders = 30

1 kg of LPG gas = 13.6 kWh

Efficiency of LPG gas is 49% so,

1 kg of LPG gas = 6.66 kWh

For 14.2 kg of LPG gas = 6.66 *14.2 = 94.572 kWh

For 30 cylinders = 30 * 94.572 = 2837.16 kWh

Induction stove efficiency is 84% so,

Required energy to replace LPG = 2837.16/0.84 = 3377.57 kWh/year

Required energy to replace LPG stove per month = 281.46 kWh/month

Cost by using induction stove = Rs. 2732/month

Cost due to induction stove per year = Rs. 32784/-

Comparing cost between induction stove and LPG cylinder

Total cost on LPG cylinder = 30 *1895 = 56850/year

Cost due to induction stove = Rs. 32784/year

Saving per year = Rs. 24066/-

Saving per month = Rs. 2006/-

From the above analysis consumers can save their money by using Induction cooktop. So, conclusion can be made that if consumer shift from LPG to induction stove for cooking purpose significant amounts of money can be saved by consumer. Consumers annual expenditure can be reduced. Policies set by government and other concerned authorities for clean cooking purpose can be achieved. Expense due LPG import can be reduced. Nations clean energy can be utilized. But initial cost while buying Induction stove must be subsidized by government so that more number of consumers are encouraged to shift from LPG to Induction stove for cooking purpose.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions have been drawn from the study:

- Load flow of IEEE 33 bus radial distribution system was performed in DigSILENT powerfactory software and total active power loss of 210 kW and minimum voltage of 0.904 p.u. at bus 17 and 18 was obtained.
- At base case scenario peak power was found to be 5.73 MVA at 19:00 hours with an active power loss of 0.113 MW. Minimum voltage was seen on bus 49, which is 0.975113 p.u. Also, two transformers were already overloaded before penetration. Initially, the transformer was loaded from 43% to 106% with an average loading of 78%.
- At 5% penetration, four transformers were overloaded, 10% penetration five transformers were overloaded, 15% penetration nine transformers were overloaded, 20% penetration 14 transformers were overloaded and at 25% penetration 18 transformers were overloaded. At the same time, feeder power loss reached 179 kW without violating the voltage limit in different locations of the Gothatar Feeder.
- At 25% penetration level conductors To Harhar Mahadev was operating at 125%, to Dairy Near was operating at 114%, To Near Bhadrakali was operating at 109%, To Bus 56 was operating at 102%. So, mitigation was performed for these conductors for zone1 and same mitigation was followed in other zones.
- At 25% penetration, nine transformers were overloaded at zone1, and three transformers were overloaded at zone2, zone3 and zone4. So, mitigation have been applied for these overloaded transformers in order to increase the withstand capacity of distribution system.
- Utility have to invest total of Rs. 15,873,469 for reliable operation of distribution system at 25% penetration of induction stove. In addition, when consumers are shifted from LPG to induction stove the saving that different category of consumers can make are Rs. 476 per month by lower category consumer, Rs. 867 per month by middle category consumer and Rs. 2006 per month by higher category consumer.

5.2 Recommendations

- Study can be conducted by modelling low voltage circuit that increases the accuracy in transformer loading.
- Conducting the study by considering Kathmandu Valley distribution network can opt for reliable penetration of induction stove with reliable operation of distribution network.
- Load is continuously increasing in feeder so; study can be performed considering load growth thereby making it feasible for planning of 8 to 10 years for reliable operation of distribution network.
- Study can be conducted by splitting large capacity load center into various smaller capacity load center and determine its impact in distribution system.

REFERENCES

Abdelaziz, A. Y., Ali, E. S., & Abd Elazim, S. M. (2016). Flower Pollination Algorithm and Loss Sensitivity Factors for optimal sizing and placement of capacitors in radial distribution systems. *International Journal of Electrical Power & Energy Systems*, *78*, 207–214. https://doi.org/10.1016/j.ijepes.2015.11.059

Al Irsyad, M. I., Anggono, T., Anditya, C., Ruslan, I., Cendrawati, D. G., & Nepal, R. (2022). Assessing the feasibility of a migration policy from LPG cookers to induction cookers to reduce LPG subsidies. Energy for Sustainable Development, 70, 239–246. https://doi.org/10.1016/j.esd.2022.08.003

Banerjee, M., Prasad, R., Rehman, I.H., Gill, B. (2016), Induction stoves as an option for clean cooking in rural India. Energy Policy, 88, 159-167

CBS. (2011). Nepal Living Standards Survey 2010/11. Kathmandu: Central Bureau of Statistics, National Planning Commission Secretariat, Government of Nepal.

CBS. (2014). Annual Household Survey 2012/13. Kathmandu: Central Bureau of Statictics, National Planning Commission Secretariat, Government of Nepal.

Chhetri et al., 2021, Analysis of Infrared stove, Induction Cooktop and LPG for Cooking Selective Dishes in Bhutan Analysis and Modeling of Bhutans Hydropower Plants View project Analyzing the Impact of Air Conditioner on Power Quality of Low Voltage Distribution System. (n.d.).

Chhetri, R., Passang Lham, & Divyash Chhetri. (2021). Analysis of Infrared stove, Induction Cooktop and LPG for Cooking Selective Dishes in Bhutan. https://doi.org/10.13140/RG.2.2.28555.21288

Chitrakar, A. 2019. Look what’s cooking in Nepal: Using electric rice cookers instead of LPG could save the country a whole lot of money. The Nepali Times, August 6, 2019. Available on https://www.nepalitimes.com/opinion/look-whats-cooking-in-nepal/ (accessed December 27, 2019). (n.d.).

Datasheet of induction stove. (n.d.). https://shop.ttkprestige.com/prestige-swish-2000w-easy-store-design-induction-cooktop-black-with-omega-deluxe-induction-compatible-non-stick-kitchen-set-3-pcs-byk-maroon-1.html

ESMAP and MECS. 2020. The State of Access to Modern Energy Cooking Services. Washington, DC: World Bank. (n.d.).

Gonen, T., 2014. Electric power distribution engineering. 3rd ed. S.l.:CRC Press. (n.d.).

Government of Kerala. (2014). Available from: ttp://www.keralaenergy.ov.inemc_reports/Induction%20Cooker_a%20brief%20investigation.pdf.

Grigsby, L. L., 2012. Electric power generation, transmission and distribution. 3rd ed. S.l.:CRC Pres. (n.d.).

Hajer T.J., Morawicki, R.,2013. Energy consumption during cooking in the residential sector of developed nations: a review. Food policy 40, 54-63.

Https://www.daraz.com.np/products/baltra-bic-124-active-induction-cooker_-2000-watt-with-button-control-panel-i105643165-s1027462161.html?spm=a2a0e.searchlistcategory.list.6.485e3ab4B573cs&search=1. (n.d.).

Https://www.daraz.com.np/products/philips-induction-cooktop-black-touch-anel hd491100-2100watt-5power-levels i121117s1154858.html?spm=a2a0e.searchlistcategory.list.23.485e3ab4B573cs&search=1. (n.d.).

Khan, Mohd & Saxena, Anupriya & Katiyar, Jyoti. (2015). Performance of LPG Burner with different Size of Ball Bearing as a Porous Medium.

Martínez-Gómez, J., Ibarra, D., Villacis, S., Cuji, P., & Cruz, P. R. (2016). Analysis of LPG, electric and induction cookers during cooking typical Ecuadorian dishes into the national efficient cooking program. Food Policy, 59, 88–102. https://doi.org/10.1016/j.foodpol.2015.12.010

Nakarmi, A.M. 2019. Energy Security Issues/Challenges and Transitioning to Cleaner Cooking in Nepal. National Campaign Launching Ceremony for Market-led Promotion of Electric Cooking in Community Rural Electrification Areas. ABF/NACEUN. Kathmandu, Nepal. (n.d.).

R.M. Shresthra, G.B. Bhattarai, “Utility planning implications of efficient electric cooking in a developing country: case of Nepal, Energy,” Vol. 20, Issue 3, 1995, pp. 195–203.

Rodriguez, D., Guerron, G., Martinez Gomez, J., Riofrio, A., & NARVÁEZ C. , R. (2019). Impact of induction stoves penetration over power quality in Ecuadorian households. 7-8.

Sanjip Bhattarai and Sanjeev Maharjan. Impact analysis of residential induction cooking on medium voltage distribution network system: A case study of nagarkot feeder, bhaktapur, nepal. Journal of Innovations in Engineering Education, 4(2):49–55, 2021. (n.d.).

Soltowski, B., Galloway, S., Coley, W., & Strachan, S. (2020). Impact of New Electric Cooking Appliances on the Low Voltage Distribution Network and Off-Grid Solar Microgrids.

WECS (2023), Energy Synopsis Report 2023, Singha Durbar Kathmandu, Nepal

Wong A.K., Fong, N.,2013. Expermental study of induction cooker fire hazard. Procedia Eng. 52, 13-22.

Venkatesh, B., Ranjan, R., & Gooi, H. B. (2004). Optimal Reconfiguration of Radial Distribution Systems to Maximize Loadability. IEEE Transactions on Power Systems, 19(1), 260–266. https://doi.org/10.1109/TPWRS.2003.818739

APPENDIX A: Details of public transformers

S. N.	Transformer Location	Capacity (kVA)
1.	Bista Gaun	100
2.	Suncity	300
3.	Sisha karkhana	300
4.	Harhar mahadev	300
5.	Mankamana Mandir	100
6.	Diary near	100
7.	Near Bhadrakali Pump	200
8.	Monastry	100
9.	Pudasaini Tole	100
10.	Gandhi School Gate	300
11.	Khasi mode	300
12.	Basjhyang	100
13.	Police chauki	100
14.	Sundarichowk	200
15.	Gaa bi sa	100
16.	Sanjel gau	100
17.	Hattidanda	300
18.	Paty chaur	300
19.	Gothatar Ichot Najeek	100
20.	Birendra Chowk	200
21.	Khadka Guthi	200
22.	Nawa Durga tole	300
23.	Kriya putri	200
24.	Durbar	200
25.	AirportNagar	100
26.	Ganesthan	200
27.	Force Park(khahare)	200
28.	Tejvinayak	200
29.	Youth Vision	200

S. N.	Transformer Location	Capacity (kVA)
30.	Dhungedhara	100
31.	Family Quater Aghadi	100
32.	Gothatar Gabisa 2	100
33.	Siddhartha Bank najeek	200
34.	Suncity2	100
35.	Prahari Prabak Marga	200
36.	Arjundai ko ghar Aghadi	100
Total		6400

APPENDIX B: Details of private transformer

S. N.	Transformer Location	Capacity (kVA)
1.	Suncity	750
2.	Nepal Telicom Gothatar	100
3.	Shreekrishna Pet	50
4.	Purnachandra Print	100
5.	Dev Plast Care	160
6.	Inco Panel	500
7.	Metaco food Nepal	100
8.	Chirayou Offset Press	100
9.	Angur Kapas Udhyog	100
10.	Capital Plasitc	100
11.	Civil Aviation Authority	200
12.	Kalinchowk Kasta Udhyog	25
13.	Shyam Pet Industries	100
Total		2385

APPENDIX C: Monthly peak demand of Gothatar feeder

Month	Currrent (A)	Time
2079 Ashar	148	8 P.M.
2079 Shrawon	161	7 P.M.
2079 Bhadra	174	7 P.M.
2079 Asoj	183	7 P.M.
2079 Kartik	179	7 P.M.
2079 Mangshir	215	6 P.M.
2079 Poush	294	7 P.M.
2079 Magh	271	6 P.M.
2079 Falgun	211	7 P.M.
2079 Chaitra	188	7 P.M.
2080 Baishak	167	7 A.M.
2080 Jestha	152	12 P.M.

APPENDIX D: Load profile of distribution transformer for Poush month

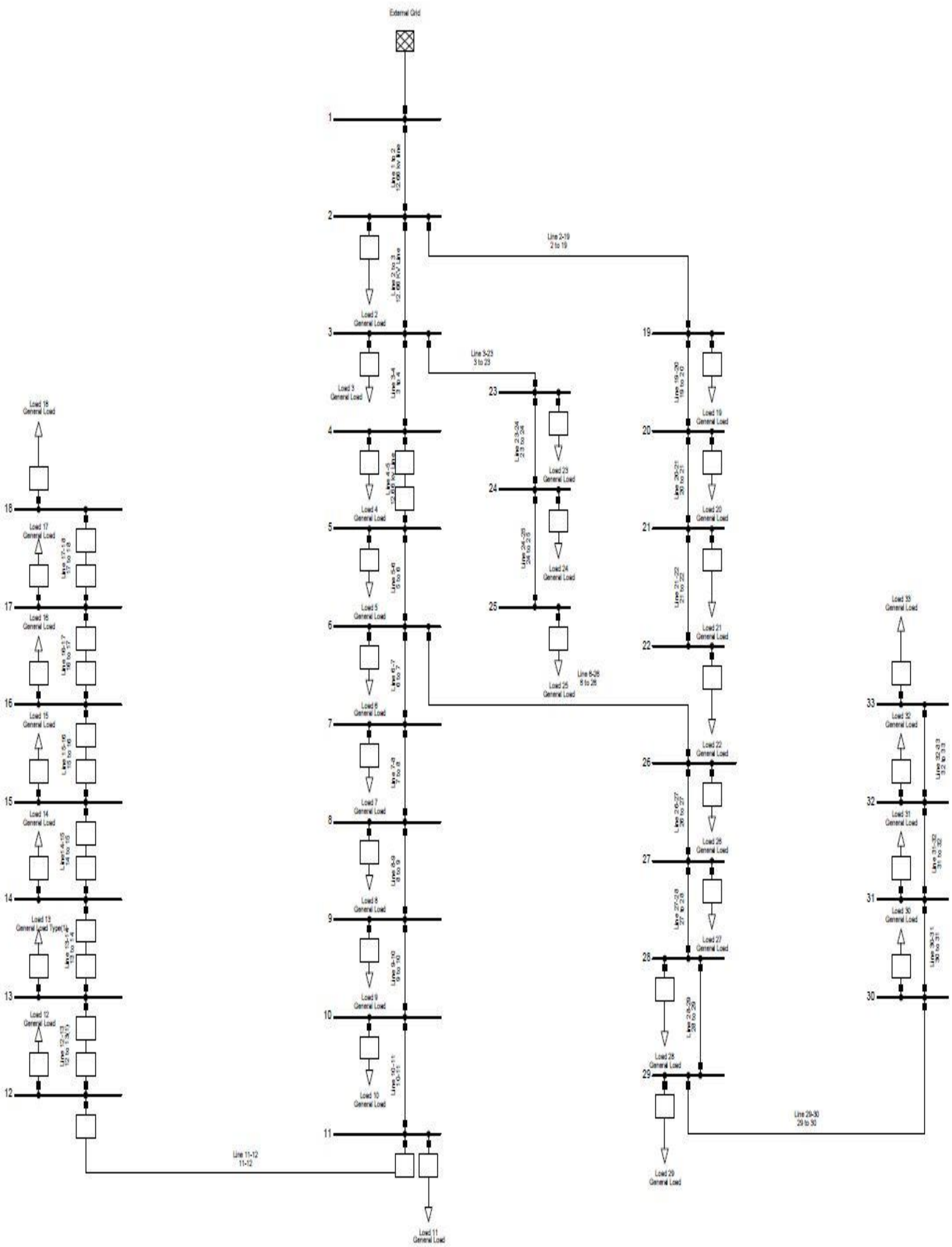
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Load	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
Airport Nagar	13	13	13	16	22	42	45	39	31	27	25	24	23	23	25	35	50	54	57	45	29	19	14	13
Arjun Dae	16	15	15	18	25	45	56	42	34	30	28	26	26	25	28	38	53	57	60	48	32	22	17	16
Aujar Kapas	0	0	0	24	27	33	20	29	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Basjhyang	18	18	18	22	31	59	63	54	44	38	35	33	32	32	36	49	70	76	80	63	40	27	20	18
Birendra Chowk	24	24	24	29	42	79	80	73	59	51	47	45	43	43	48	66	95	103	108	85	54	36	26	24
Bista Gaun	16	15	15	18	26	47	61	56	53	57	55	44	44	26	29	40	56	84	72	51	33	23	17	16
CAAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capital Plastic	42	40	47	39	39	13	19	35	35	39	40	59	40	50	49	49	24	1	39	38	39	35	39	53
Chirayu offset	0	0	0	0	0	0	0	1	1	1	10	10	9	1	7	10	1	0	10	1	0	0	0	0
Dairy Near	22	21	21	25	35	64	63	60	49	42	40	37	36	36	40	54	76	83	86	69	45	31	23	21
Dev Plast	25	25	25	24	23	37	44	44	44	53	53	44	53	45	36	45	53	43	45	18	20	22	23	24
Dhungedhara	40	39	39	48	68	129	140	120	97	84	78	73	71	70	79	108	155	168	176	139	89	59	43	40
Durbar	28	27	27	33	48	90	80	83	67	58	54	51	49	49	55	75	108	117	123	97	62	41	30	28
Family quarter	17	17	17	20	29	55	60	51	41	35	33	31	30	30	33	46	65	58	66	59	38	25	18	17
Force Park	32	32	32	39	55	104	108	97	78	68	63	59	57	56	63	87	125	136	142	112	72	48	35	32
Gaabisa1	14	14	14	17	24	46	54	42	34	30	27	26	25	25	28	38	55	59	62	49	31	21	15	14
Gaandhi	44	43	43	53	75	142	165	132	106	92	85	80	78	77	86	118	170	185	193	153	98	65	47	43
Ganesthan	30	30	30	36	52	97	99	90	73	63	59	55	53	53	59	81	117	127	133	105	67	45	33	30
Gothatar Gaabisa2	26	26	26	31	45	84	84	78	63	55	51	48	46	46	51	54	60	57	55	51	50	39	28	26
Gothatar Ichot	15	14	15	18	25	48	57	44	36	31	29	27	26	26	29	40	48	45	47	43	33	22	16	15
Harhar Mahadev	44	43	43	52	73	135	140	126	102	89	83	78	76	75	84	114	162	176	176	146	94	64	47	44
Hattidanda	23	23	23	28	40	160	169	155	141	134	130	128	126	126	131	148	90	183	188	81	52	35	25	23
Inco	68	70	68	66	56	55	62	70	71	73	72	45	39	44	46	54	79	70	93	3	4	5	5	64
Kalinchowk	1	1	1	1	1	1	7	9	5	1	0	10	1	4	1	4	5	1	1	1	1	1	1	1
Khadka Guthi	24	24	24	29	41	78	80	72	58	50	47	44	43	42	47	65	93	101	106	84	54	36	26	24
Khasi Mod	46	45	46	55	79	149	150	139	112	97	90	85	82	81	91	125	179	194	204	161	103	69	50	46

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Load	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
Kriya Putri	31	30	30	37	53	99	96	92	74	64	60	56	54	54	61	83	119	129	130	107	69	46	33	30
Manakamana Mandir	22	21	21	25	34	62	70	58	47	41	39	37	36	35	39	52	74	80	84	67	44	30	23	21
Meatco Food	11	11	15	10	10	12	12	19	12	31	40	22	42	32	8	8	8	5	11	5	11	2	2	17
Monastry	17	17	17	20	28	51	65	48	39	34	32	30	29	29	32	43	61	66	69	55	36	25	19	17
Nawo Durga	29	28	28	34	49	93	93	86	70	60	56	53	51	50	56	77	111	121	127	100	64	43	31	28
Near Bhadrakali	40	39	39	47	66	123	156	114	93	81	75	71	68	68	76	103	108	106	107	103	85	58	43	40
NTC	5	5	6	5	5	5	5	5	6	6	4	3	6	5	5	4	3	3	5	5	6	6	6	5
Paty Chaur	46	45	46	55	79	149	151	139	112	97	90	85	82	81	91	125	151	163	156	154	103	69	50	46
Police Chauki	19	19	19	23	31	58	54	54	44	38	35	33	32	32	36	49	69	75	78	62	40	28	20	19
Prahari Prabhag Marg	34	33	33	40	56	105	110	98	79	69	64	60	58	58	65	88	126	137	143	113	73	49	36	33
Pudasaini	17	17	17	21	30	56	63	52	42	36	34	32	31	30	34	47	67	63	64	60	39	26	19	17
Purna Chandra	5	27	27	5	26	26	13	23	34	11	39	5	5	16	36	16	5	1	1	30	32	34	33	15
Sanjel Gaun	13	13	13	16	23	43	53	40	32	28	26	24	24	23	26	36	52	56	59	46	30	20	14	13
Shree Krishna Pet	0	0	0	24	28	14	24	19	43	51	33	50	50	53	64	64	25	18	24	24	17	25	23	0
Shyam	0	0	0	0	0	0	0	0	0	18	0	0	19	8	0	8	1	0	0	0	0	0	0	0
Siddhartha Bank Najik	28	27	27	32	45	82	84	76	62	54	50	48	46	46	51	69	97	105	110	87	57	39	30	27
Sishakarkhana	46	45	46	55	77	143	168	133	108	94	87	82	80	79	88	120	171	186	228	154	100	68	50	46
Suncity 100N	31	31	31	37	51	59	54	63	63	62	57	54	53	52	58	56	55	53	60	59	51	45	33	31
Suncity_300N	48	47	47	57	79	147	170	137	111	97	90	85	82	81	91	123	175	199	216	158	102	70	51	47
Sundarichowk	37	36	36	44	63	120	120	111	90	78	72	68	66	65	73	100	143	114	122	114	82	55	40	37
Tej Vinayak	29	29	29	35	50	95	98	88	71	61	57	54	52	51	58	79	113	123	129	102	65	44	32	29
Youth Vision	24	24	24	29	41	78	74	72	59	51	47	44	43	42	48	65	94	102	107	84	54	36	26	24
Suncity_750P	88	86	87	104	147	274	270	254	206	179	166	157	152	150	168	229	327	355	372	294	190	129	95	87

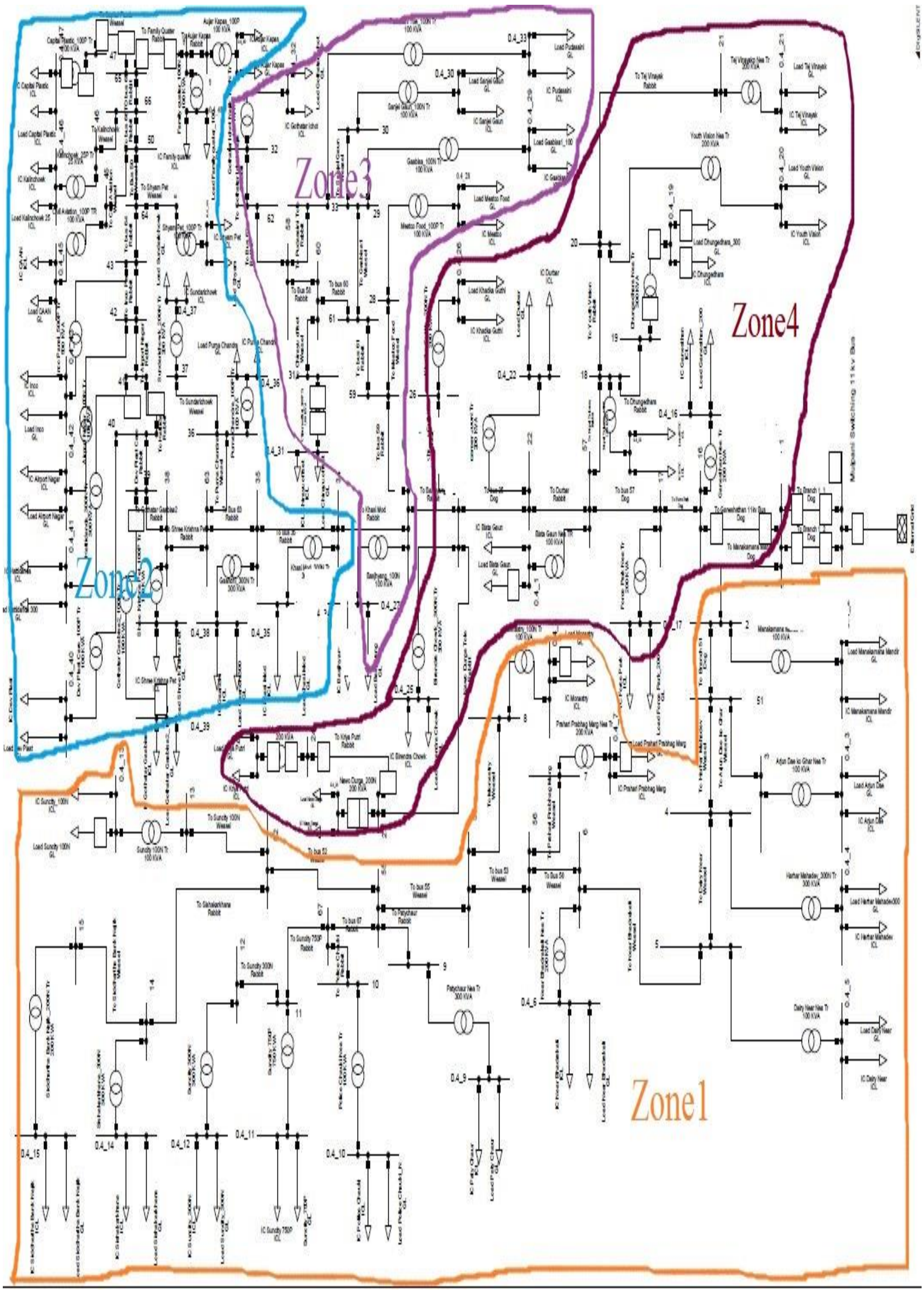
APPENDIX E: Line data and Load of IEEE-33 Bus RDS

S. N.	From	To	Receiving end bus load		R (Ω)	X (Ω)
			Active Power kW	Reactive Power kVAR		
1.	1	2	100	60	0.0922	0.0477
2.	2	3	90	40	0.493	0.2511
3.	3	4	120	80	0.366	0.1864
4.	4	5	60	30	0.3811	0.1941
5.	5	6	60	20	0.819	0.707
6.	6	7	200	100	0.1872	0.6188
7.	7	8	200	100	1.7114	1.2351
8.	8	9	60	20	1.03	0.74
9.	9	10	60	20	1.04	0.74
10.	10	11	45	30	0.1966	0.065
11.	11	12	60	35	0.3744	0.1238
12.	12	13	60	35	1.468	1.155
13.	13	14	120	80	0.5416	0.7129
14.	14	15	60	10	0.591	0.526
15.	15	16	60	20	0.7463	0.545
16.	16	17	60	20	1.289	1.721
17.	17	18	90	40	0.732	0.574
18.	2	19	90	40	0.164	0.1565
19.	19	20	90	40	1.5042	1.3554
20.	20	21	90	40	0.4095	0.4784
21.	21	22	90	40	0.7089	0.9373
22.	3	23	90	50	0.4512	0.3083
23.	23	24	420	200	0.898	0.7091
24.	24	25	420	200	0.896	0.7011
25.	6	26	60	25	0.203	0.1034
26.	26	27	60	25	0.2842	0.1447
27.	27	28	60	20	1.059	0.9337
28.	28	29	120	70	0.8042	0.7006
29.	29	30	200	600	0.5075	0.2585
30.	30	31	150	70	0.9744	0.963
31.	31	32	210	100	0.3105	0.3619
32.	32	33	60	40	0.341	0.5302

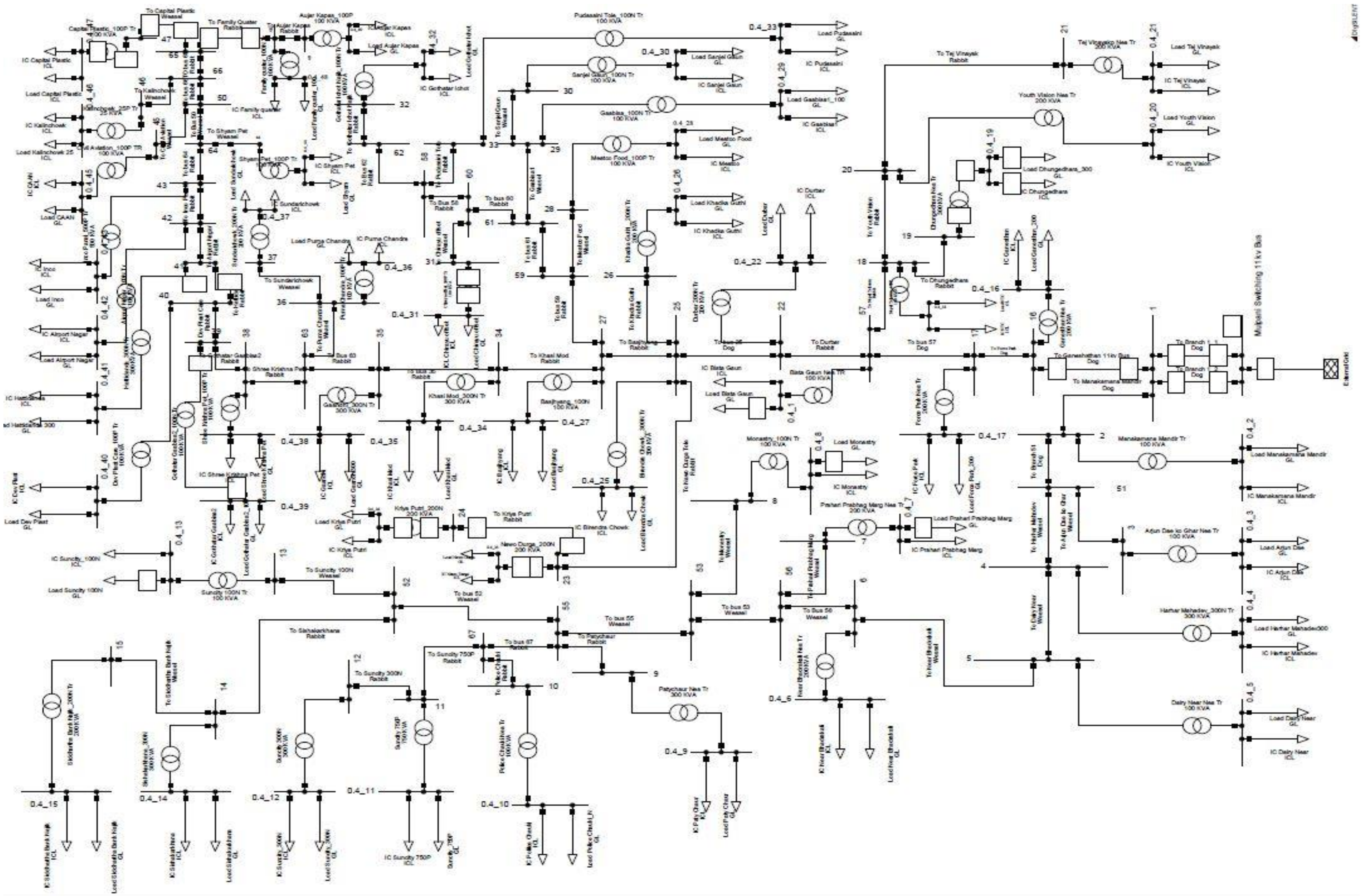
APPENDIX F: Single line diagram of IEEE-33 Bus RDS



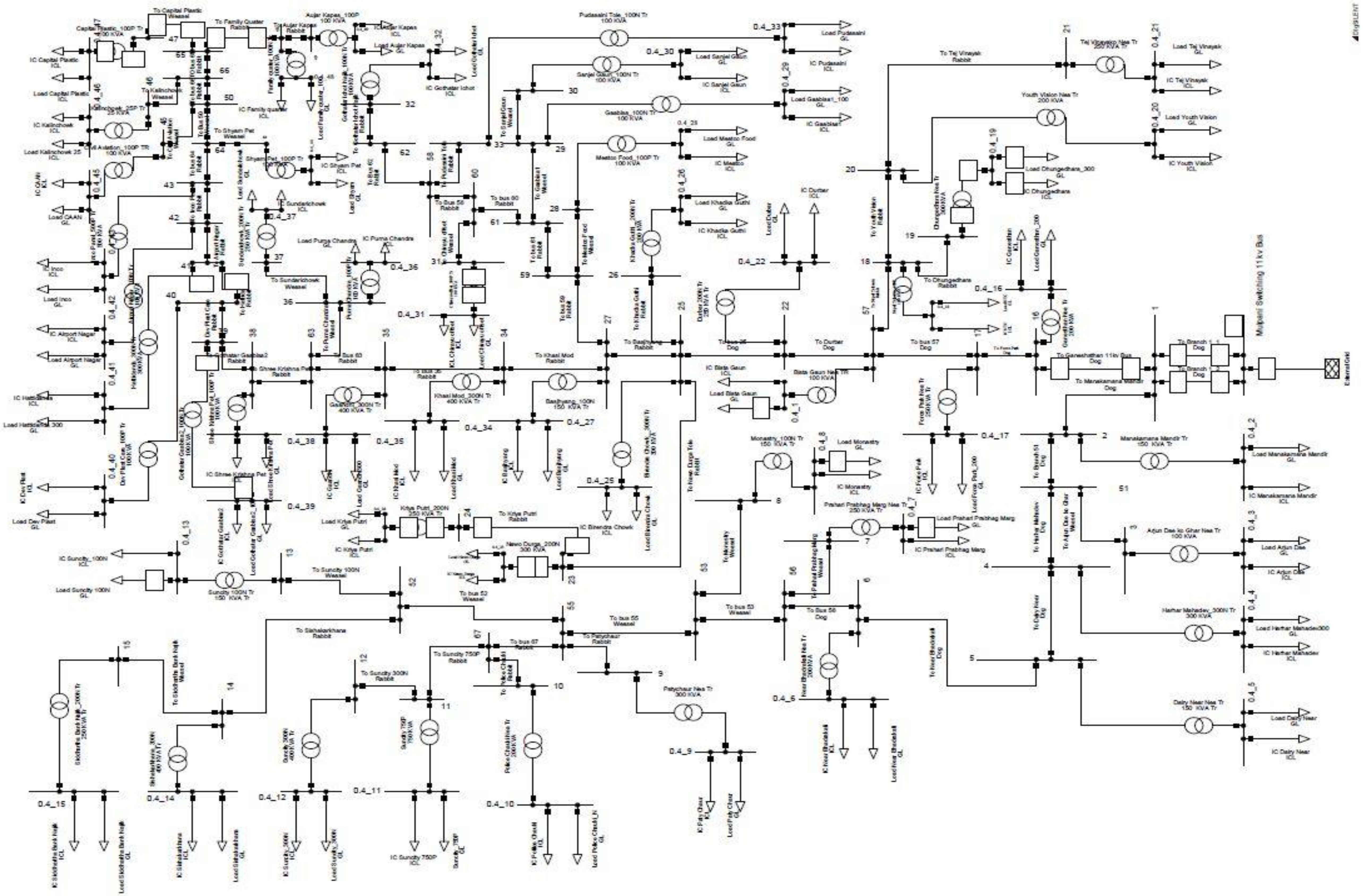
APPENDIX G: Creation of different zones of areas



APPENDIX H: Gothatar Feeder Single Line Diagram in DigSILENT Powerfactory Before Mitigation



APPENDIX I: Gothatar Feeder Single Line Diagram in DigSILENT Powerfactory After Mitigation



Study of Impact on penetration of induction stoves in electrical distribution network of Jorpati, Kathmandu: A case study of Gothatar Feeder

ORIGINALITY REPORT

12%
SIMILARITY INDEX

PRIMARY SOURCES

1	conference.ioe.edu.np Internet	91 words — 1%
2	www.coursehero.com Internet	87 words — 1%
3	Banerjee, Manjushree, Rakesh Prasad, Ibrahim H Rehman, and Bigsna Gill. "Induction stoves as an option for clean cooking in rural India", Energy Policy, 2016. Crossref	81 words — 1%
4	www.nepjol.info Internet	66 words — < 1%
5	ro.uow.edu.au Internet	60 words — < 1%
6	econjournals.com Internet	57 words — < 1%
7	elibrary.tucl.edu.np Internet	49 words — < 1%
8	www.geeksforgeeks.org Internet	47 words — < 1%