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THESIS NO: M-331-MSREE (2019-2021)

Impact Assessment of the Plug-in-Electric Vehicles on Distribution System

(A Case Study of Bageshwori Feeder Nepalgunj, Nepal)

by

Ganesh Bhandari

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

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

September, 2021

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Impact Assessment of Plug-in-Electric Vehicles on Distribution System of Nepal, A Case Study of Bageshwori Feeder Nepalgunj, Nepal"** submitted by **Ganesh Bhandari** in partial fulfillment of the requirements for the degree of Master in Renewable Energy Engineering.

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ABSTRACT

Global environmental issues have brought several international agreements to reduce carbon emission. In this context, electric vehicles can be the best alternatives to reduce petroleum consumption and carbon emission simultaneously. Electric vehicles getting massive popularity with new policies initiated by several governments. But the rapid deployment of EVs can be a burden to the power distribution network. This research is focused on the impacts of plug-in-electric vehicles on distribution systems with stochastic behaviors of PEVs. Stochastic load profile of PEVs is modeled depending upon daily driving distance and home arrival time. The distribution system is analyzed in terms of feeder peak, total power loss and energy loss, voltage deviation, transformer loading, and line loading before and after the penetration of PEVs over a wide range considering residential charging and public charging scenario. The results are analyzed to determine the withstand capacity of the distribution system for PEVs. The line loading reached 104.63% violating the limit with 80% of PEVs but the voltage deviation is under the limit for residential charging. However, in the public charging scenario line loading reached 104.26% with only 60% PEVs and violate the standard limit.

ACKNOWLEDGEMENT

I wish to express my profound gratitude to my supervisors Associate Professor Dr. Nirmal Paudel, and Assistant Professor Dr. Sanjeev 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 Er. Sagar Mani Gnawali, Assistant Manager, Nepal Electricity Authority and Project Manager of Electric Vehicle Charging Station Project Nepal as an external examiner for his valuable feedbacks. The preparation of this thesis would never have been possible without their constructive suggestions, continual encouragement and assistance.

I would also like to thank Dr. Samundra Gurung and Er. Sabin Oli for advising me on use of software and continual guidance throughout this thesis.

I wish to pay my great 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 Er. Narayan Paudel, Nepalgunj Distribution Center, Nepal Electricity Authority, Mr. Dipesh Paudel, Sipradi trading who provided the essential data for research work.

I am also thankful to my friends Er. Paras Subedi , Er. Bishal Rimal, Er. Sagar Bhusal, Er. Himal Chaulagain for their continuous support and encouragement.

Finally, I like to thanks to my family without them I am nothing.

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LIST OF ABBREVIATIONS

AC	Alternating Current
BEV	Battery Electric Vehicle
DC	Direct Current
DPL	DigSILENT Programming Language
EV	Electric Vehicle
EPDS	Electric Power Distribution System
EPRI	Electric Power Research Institute
GIS	Geographic Information System
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IEC	International Electrotechnical Commission
kV	Kilo Volt
kVA	Kilo Volt Ampere
MCS	Monte Carlo Simulation
Mtoe	Millions of tons of oil equivalent
MW	Mega Watt
MVA	Mega Volt Ampere
NHTS	National Household Travel Survey
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
RDS	Radial Distribution System
V2G	Vehicle to Grid

CHAPTER ONE: INTRODUCTION

1.1 Background

Recent research in the power and energy sector is focused mainly on to use of zero-emission. According to the BP statistical review of world energy 2019, Crude oil consumption of the world grew up by 1.5% (4607.0 motes (million tons of oil equivalents) in 2017 to 4662.1 mote in 2018). As a result, carbon emission grew up by 2% in 2018 which is the fastest growth for the last seven years (Energy, 2019). Petroleum products are the most used fuel in the energy market. Most of the petroleum consumption is by the transportation sector. US petroleum consumption by transportation is 69% which is 14.16 million barrels per day in 2018 (EIA, 2019). Fossils fuels are the reasons for carbon emission and global warming which threatens the world. Global Environmental issues have brought several international agreements such as the Kyoto Protocol and Paris Agreement. These all focus on switching towards renewable or zero-emission. In this scenario, Electric vehicles (EVs) are the best alternatives to reduce the increasing oil demands and mitigating emissions. Replacement of the conventional Internal Combustion Engine (ICE) vehicles by electric vehicles will be boon to both environment and economics.

Electric vehicles (EVs) have gained massive popularity in recent years, and this trend seems to keep growing in the near future until the transportation sector penetrates maximum EVs, as per the new policies initiated by several governments worldwide (IEA, 2017). Advancement in battery technologies and power electronics increased the choice of EVs. For the transportation industry, electricity is the cheapest alternatives to petroleum oil which reduces the greenhouse gases and nations dependence on imported fuel (Duvall, 2003). The different types of Electric vehicles (EVs) are all-electric vehicles or Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEVs), and Plug-in- Electric Vehicles (PEVs). Major manufacturers of EVs including Nissan, Tesla, GM, Honda, Toyota, BMW, Mercedes, etc. have introduced their plug-in-electric vehicles in the U.S market. In 2018 global electric car fleet exceeded 5.1 million with an increment of 2 million from the previous year. Norway is the leader in the electric car market share (46%) in 2018. According to Global EV outlook 2019, EV sales reach 43 million in 2030 nearly double the present condition. The projected share of EV in China will be 57% by 2030 and becomes the leading nation in the world (IEA, 2019). Despite, the Covid pandemic, 10 million electric cars were on the world roads in 2020 (IEA, 2021). Electric cars are creating a buzzing sensation in the streets of Nepal in recent years. Some electric vehicles available in Nepalese market in 2020/21 is listed in Table 1.1.

Table 1.1: EVs in Nepal

Electric Vehicles	**Battery Capacity (kWh)**	**All-electric Range (km)**	**Charging Standards**
Nexon EV	30.2	312	CCS
BYD M3	50.3	310	GB/T
BYD E6	61.4	300	GB/T
MG ZS Lux	44.5	428	CCS
Hyundai Kona	39	312	CCS
Hyundai Ioniq	38.3	311	CCS
Nissan Leaf	40	285	CCS
Kia Niro	64	455	CHAdeMO
Hyundai Kona Long Range	64	482	CCS

The integration of PEV can be both an opportunity and a challenge to power system operators. It can increase the overloading of transformers and lines so that the existing system may not withstand (Palomino & Parvania, 2018). There can be the impact of uncontrolled charging on grid stability and demand. Uncontrolled charging of PEV can lead to an increase in peak demand rapidly. Also, the controlled charging scenario helps to shift the PEVs charging to midnight thus helps in reducing feeder peak (Dias, et al., 2018). The increasing penetration of EVs will increase electricity consumption causing the burden on the power distribution network (Wu, et al., 2011) (Salihi, 1973). The extensive penetration of plug-in EVs in the distribution system can create different issues such as voltage unbalance, voltage deviation, transformer overloading, and feeder loss (Dubey & Santoso, 2015). One of the major concerns for distribution networks is whether the existing system infrastructure would be able to support the massive introduction of plug-in EVs. To avoid several issues distribution system operators and utilities need to reinforce their system and EV users should also follow the strategic management of utilities for effective integration of EVs (Czechowski, 2015). Distribution system operators would also apply financial incentives for off-peak charging or utilize the concept of smart charging which enables the regular communication between utilities and vehicles to control the charging pattern (Maitra, et al., 2009).

1.2 Problem Statement

The impact assessment of the new technology should be done prior to its implementation. Rapid integration of plug-in electric vehicles will change the load profile of the distribution system. As the number of vehicles increases several power qualities issues such as voltage deviation, voltage unbalance, increased line loss and transformer overloading will arise. PEVs are a new type of transportation that uses the energy from the distribution network while charging their battery for providing electric propulsion energy to the vehicle. So, this can be considered as a part of the power system load. The characteristics of PEVs depends on customers choice and behaviors such as charging voltages, modes, location, driving time, and distance. These characteristics are very stochastic which creates challenges during the modeling of PEV. This also creates challenges to the distribution system planning and operation. The load profile of PEVs is different from other power system loads and its unique characteristics should be included while modeling PEV. On the other hand, variation in charging and driving behaviors between one vehicle to another vehicle will also impact system performance. A different study on the impact analysis of the PEVs on the distribution system has already been done on the different test systems and real distribution systems.

In the context of the Nepalese distribution system, electric vehicles are in an emerging phase and government strategies are promoting the share of PEVs for transportation. It is very necessary to study the effects of increasing penetration level of electric vehicles on the change in load curve, voltage deviation, line and transformer loading under the different scenarios of penetration level. So that the distribution system operator will know whether the existing system can support the large penetration of PEVs or the system need to be reinforced.

1.3 Objectives

1.3.1 Main Objective

The main objective of this thesis is to evaluate the impact of plug-in electric vehicles (PEVs) battery charging through residential and public charging stations on Bageshwori feeder of Nepalgunj substation Nepal.

1.3.2 Specific Objectives

Following are the specific objectives of this research

- To model stochastic load profile of Plug-in electric vehicles (PEVs).
- To perform the load flow of standard IEEE-33- bus radial distribution system in DigSILENT 15.1
- To analyze base case load flow of Bageshwori Feeder without PEVs for summer and winter peak.
- To analyze the distribution system parameters in terms of feeder peak load, power loss, voltage deviation, line loading, transformer loading, and total energy loss with residential Charging of PEV.
- To evaluate the distribution system parameter with public charging scenario of PEV

1.4 Limitations

Following are the limitations of this research work

- PEVs are considered only as power system positive load
- All connected PEVs load are considered as a lumped load at end of the distribution transformer.
- The effect of the time-of-day tariff is not considered

CHAPTER TWO: LITERATURE REVIEW

2.1 Electric Vehicle

Electric vehicle is a vehicle that uses an electric motor for propulsion. Recent advancement in the battery technology has increased the market share of electric vehicles. Several strategies of incentives and tax exemptions from different governments have promoted the use of electric vehicles. Tax exemptions in Norway in along with free parking for EVs has led to a 37% market share of EVs (Lambert, 2017). Two major technologies that can dominate the EVs market in near future are plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). PHEVs is an electric vehicle that has an internal combustion engine in addition to its battery. BEVs depend solely on the electric energy stored in the battery (Papadopoulos, et al., 2012). It is forecasted that number of electric vehicles including two-wheeler in Kathmandu valley, Nepal will reach 10,00,000 within 2022 (Paudel, et al., 2019). The specifications of the common electric vehicles are as shown in Table 2.1.

Table 2.1: Specifications of EVs (Ahmadian, et al., 2020)

Vehicle Model	EV Types	Charging Rate (kW)	Charging Time (hr)	Trip Length (Km)	Battery Capacity (kWh)
Mitsubishi iMiEV E	EV	3.1	7	100	16
Nissan leaf	EV	3.3	8	118	24
Tesla model S	EV	11	8.5	425	85
Chevrolet volt	PHEV	3.3	5	61	16.5
Toyota Prius	PHEV	3.3	1.5	18	5.2
Ford fusion	PHEV	3.3	2.5	34	7.5

2.2 Energy Storage System

Energy storage (battery) is another major component of the plug-in electric vehicle. The electric vehicles use the energy stored in the battery. Recent development in battery technology has reduced its size and cost. There has been a series of development in battery technology over two decades which results in high energy density batteries, durable, cost-effective, and compact size. The two most commonly used batteries in EVs are Lithium-ion (Li-Ion) batteries and Nickel-metal hydride (Ni-

MH). Development of the Lithium-ion batteries has advanced the electric vehicle with high range and power. In the present context, most of EV uses Li-Ion batteries because it has higher energy density, long-range, low cost, nontoxic and special characteristics of acceptance of the fast charge (Yong, et al., 2015). The comparison between the Ni-MH and Li-ion batteries is shown in Table 2.2.

Table 2.2: Characteristics of Li-Ion and Ni-MH Battery

Characteristics	Li-Ion	Ni-MH
Energy Density (Wh/kg)	94	57
Power Density (W/kg)	540	250
Life Cycles (cycle)	>3200	>3000

2.3 Charging Infrastructure

Plug-in electric vehicles are charged from the distribution network through wall socket or specific charging stations. Distribution network have AC supply while battery need DC power for charging. Rectifier in the chargers converts the AC supply of distribution network into DC form. Charger can be on-board and off-board depending upon charging levels. On-board charger is of low power rating and they are installed inside vehicle so they have compact and light size. Off-board charger are installed on the specified location and have high charging level.

There are some sets of standards defined by the Society of Automotive Engineers (SAE), International Electrotechnical Commission (IEC), and CHAdeMO EV standards (Foley, 2010) (Young, et al., 2013) (Pang, et al., 2012). The standards charging system, plugs, and sockets, contained in the IEC 61851 is given in Table 2.3.

Table 2.3: IEC 62851 Standards (Akbari, et al., 2018) (Azadfar, 2015)

Charging Mode	IEC 61851 Standards
Mode 1	250V AC 1-phase or 480V AC 3-phase and current up to 16A
Mode 2	250V AC 1-phase or 480V AC 3-phase and current up to 32A
Mode 3	480V AC 3-phase and current up to 63A
Mode 4	500V DC and current up to 125A

Table 2.4 represents charging levels according to the electric power research institute (EPRI) and society of automotive engineers (SAEJ1772).

Table 2.4: EPRI and SAEJ1772 Standards (Darabi & Ferdowsi, 2011)

Charging Level	EPRI Standards	SAEJ1772
1	120 V AC, 16A (12A),1.44 kW	120 V AC, 12A, single phase, 1.44kW

Charging Level	EPRI Standards	SAEJ1772
2	240 V AC, 40A single Phase	208-240 V AC, 32A, single phase, 6.66-7.68kW
3	480V AC, three phase, 60 to 150kW	208-600 VAC, 400A, three phase, >7.68kW

The electric vehicle charging infrastructure development project of Nepal electricity authority has aimed to install 50 charging stations of capacity 142kW, each compatible to charge EV batteries (Li-ion) with voltage range 200V to 750V. The charging station will be compatible with combine charging station (CCS) 2.0, CHAdeMo, GB/T, and AC type 2 with facilities of CAN/PLC communication between electric vehicle service equipment (EVSE) and electric vehicles (NEA, 2021).

2.4 PEV Load Modeling

PEV load directly depends upon the driving behavior and driving distance of the vehicles. Different research use deterministic and probabilistic approaches to model PEV loads. In (Wang, et al., 2014) modeling of PEV load considering driving pattern and energy consumption in a stochastic framework considering the random charging start time, initial state-of-charge of battery. The reliability model of PHEV-30 has been modeled, using important characteristics of PHEV-30 including daily driving distance and arrival time of national household travel survey (NHTS) 2009 survey. The individual PHEV model is then aggregated to model PHEV fleet (Wang & Karki, 2017). PEV charging load was modeled by considering arrival time of PEVs as non-homogeneous Poisson process where arrival rates vary with time including two scenarios, one with customer convenience and other depending upon charging price (Hafez & Bhattacharya, 2015). In (Ahmadian, et al., 2015) the charging of batteries has been studied considering both linear and nonlinear characteristics where nonlinear modeling of batteries have a significant effect.

The approach used by (Wang & Karki, 2017) in PHEV-30 is implemented in this thesis with the essential characteristics of PEVs to obtain the stochastic load profile of PEVs. The detail modeling of load profile of PEVs is included in Section 3.2.

2.5 Distribution System

The power distribution network consists of medium voltage and low voltage lines for supplying residential areas, commercial building and industries. It begins from the distribution substation and feed consumer ends. The distribution system operator (DSO) or utility is responsible for constructing, operating, and maintaining the distribution system. It can be an overhead or underground cable system. Depending upon the locations, the underground cable system is used in urban areas (Grigsby, 2012). The distribution system can be a radial, loop, or network type. The radial type distribution system is only connected with one source for all consumers. It is the system with the least reliability. Failure in single point can interrupt the whole feeder (Gonen, 2014). The loop distribution system feeds the consumer through a two-conductor which meets with a normally open switch. If the fault occurs in one then the other line feeds the consumers. The network distribution system is the most reliable and expensive because this system is connected with two power supplies. In a network distribution system, the system is fed with different distribution systems operating in parallel (Gonen, 2014).

The distribution system of Nepal comprises of radial and ring main distribution. A particular 11kV radial distribution system of Bageshwori feeder, Nepalgunj substation is considered for the integration of PEVs and impact study on distribution system parameters. The detail parameters of distribution system are given in Section 3.1.2

2.6 Impacts of Plug-in Electric Vehicles (PEVs) on Distribution System

Widespread penetration of the plug-in electric vehicle will cause an impact on the distribution system. With the uncertainty in charging behavior and driving habits, it is very difficult to predict the impact of PEVs on the distribution system. An increment in the penetration percentage of PEVs will impose huge load demand in the distribution network which will cause different problems such as increased power losses, phase imbalances, and power quality problems with overloading and aging of transformer (Goebel & Voß, 2012). A similar study of the distribution network in Hungary shows the violation of transformer and feeder thermal loading at 60% penetration of PEVs under uncoordinated charging (Ramadan, et al., 2018).

Different penetration percentage ranging from 8% to 50 % of PEVs under different scenario has been simulated on standard grids and the result shows the acceptable penetration level in terms of bus voltage and total grid loss (Rezaee, et al., 2013). Another study on the real case of Gothenburg shows that overloading of lines and transformer at simultaneous charging of vehicle at peak load time but there was no problem with voltage drop (Babaei, et al., 2010). The penetration of PEV will affect the distribution network and their aspects such as increased demand, increased losses, deviation of voltage, and change in load pattern (Bin Humayd & Bhattacharya, 2015). In (Leou, et al., 2014) worst case is studied using deterministic approach but average loss, voltage drop and line congestions are unavailable in uncertain conditions. Monte Carlo simulations are used to consider several uncertainties for probabilistic approach. It compares deterministic and stochastic approach and impacts of controlled and uncontrolled charging are analyzed. In (Clement-Nyns, et al., 2010) analysis of charging of PHEVs on the residential distribution system is performed and concluded, coordinated charging of plug-in hybrid electric vehicles can reduce peak load, power losses and voltage deviations. Large-scale integration of PHEVs and BEVs will affect the distribution system design parameters and operation. All distribution system may not accept the same level of PHEV. The impacts on the system depend upon the PHEV penetration level and charging behaviors of PHEV owners. Very high penetration and coincidental charging behaviors result in loads beyond the distribution system capacity. Utilities must determine distribution feeder capacity to penetrate the electric vehicles (Taylor, et al., 2009).

In the Indian scenario, the impact study of PEVs on electric power distribution system (EPDS) on major cities (Delhi, Mumbai, Kolkata, Chennai, Bengaluru and Hyderabad). Multiple scenarios have been studied with the EV load and general load forecast for 2025 and 2030. The results show that EPDS will face high load stress when EVs are charged through the distribution system. Frequent connection and disconnection of fast DC chargers can bring various power quality issues and generation of harmonics. So, the proper planning is required by EPDS to manage the scenario of 2030 (Sharma, et al., 2019).

Indonesian distribution system study also shows an increment in voltage drop and line loading significantly with the overnight charging of EVs. The line loading can exceed 100 % loading if PEV penetration continues to increase and overloading can lead to overheating of conductor and impact on the life of distribution system equipment (Hadith Mangunkusumo, et al., 2019).

Integration of vehicle-to-grid technology (V2G) allows the power generation as a distributed generation which helps in peak shaving. Also, V2G with high charging rate is safer on power system from point of view of stability and power quality (Alghsoon, et al., 2017). PEVs with V2G facility in the smart grid can have additional energy leveling potential and can manage the peak demand (Nunna, et al., 2018).

2.7 DigSILENT Powerfactory Software

DigSILENT power factory is the advanced power system analysis software for analyzing generation, transmissions, distribution, and industrial applications. It covers various standard features for integration of wind power, distributed generation, real-time simulation, and for system testing and analysis. Power factory is simple, fully windows compatible, and have reliable and flexible system modeling capabilities with a unique database concept. The detail about the software and its features is available at (Powerfactory, 2020)

2.7.1 DigSILENT Programming Language

DigSILENT programming language (DPL) is a scripting language similar to C which allows the control to model developed on DigSILENT. The major advantage of scripting language is simple syntax and versatile usage of commands and functions. (Gonzalez-Longatt & Rueda, 2014).

DigSILENT powerfactory is used to model distribution system network and DPL is used to feed the 24-hour load profile of Bageshwori feeder distribution transformers. The results are also handled through DPL. The detail flow diagram of software implementation is given in Section 3.3.

CHAPTER THREE: RESEARCH METHODOLOGY

The basic methodological approach for this research is research work is shown in Figure 3.1. The research starts with the modeling of stochastic charging profile of PEV, modelling, load flow, and validation of standard IEEE- 33 bus radial distribution test system and implementation in the real case of the Nepalese distribution system.

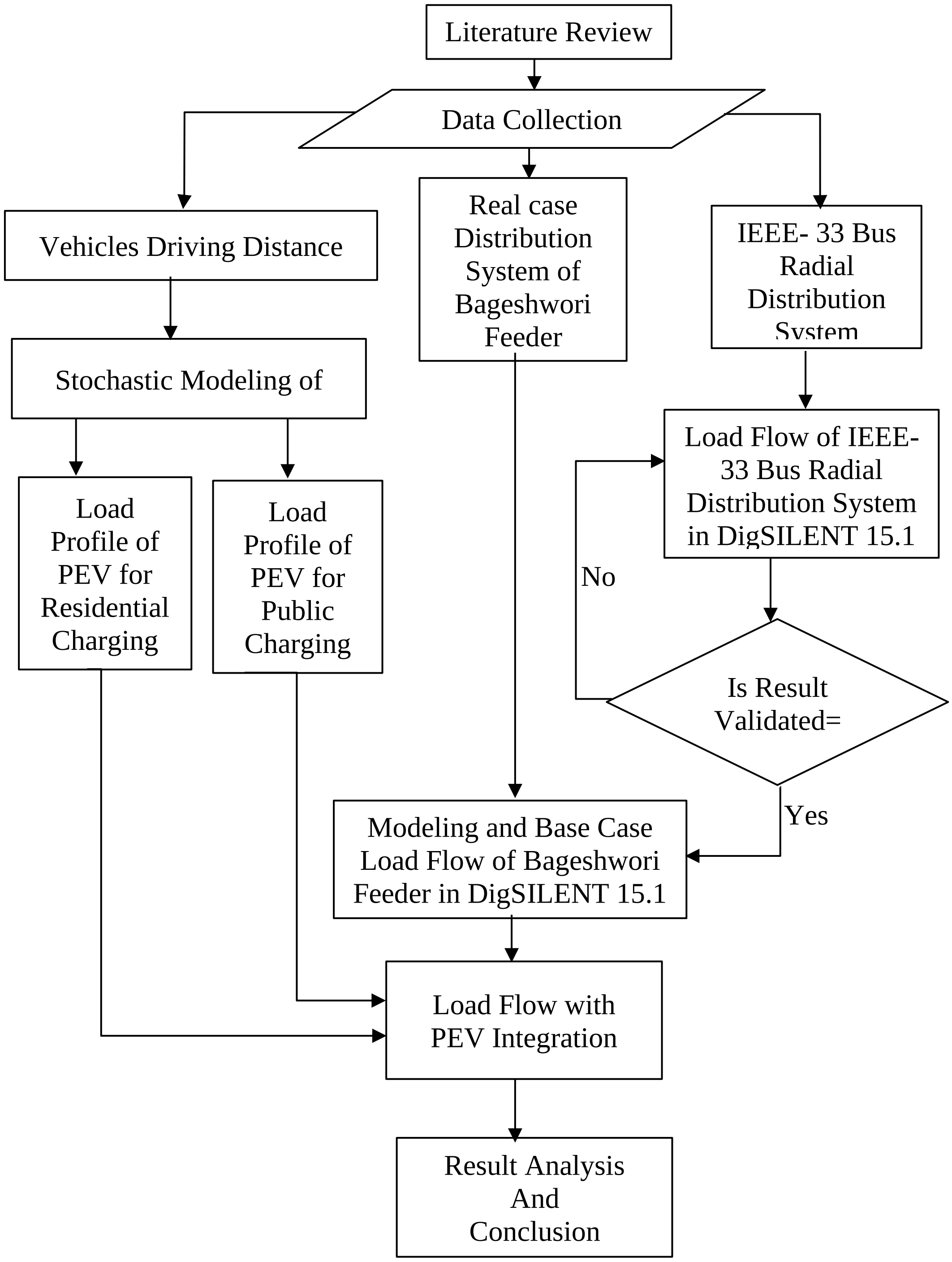

Figure 3.1: Flow Chart of Methodology

3.1 Data Collection

3.1.1 Daily Driving Distance and Arrival Time

For the modeling of a plug-in electric vehicle, driving behaviors play a vital role. Average Daily driving distance and the arrival time of vehicle can be obtained from the survey throughout the whole year. For the case study of research work traveling route is traced around the distribution system up to which the vehicle can travel. The travel route of Nepalgunj city is traced on Arc Geographic information system (GIS) software which is shown in Figure 3.2. After this, the average daily driving distance is calculated using permutations. Similarly, the home arrival time of the vehicle is assumed 17.4 hours with standard deviation of 3.3 hours based on the office hours of Nepal. In (Wang & Karki, 2017) vehicle arrival time is determined considering the home arrival time after office hours for residential charging.

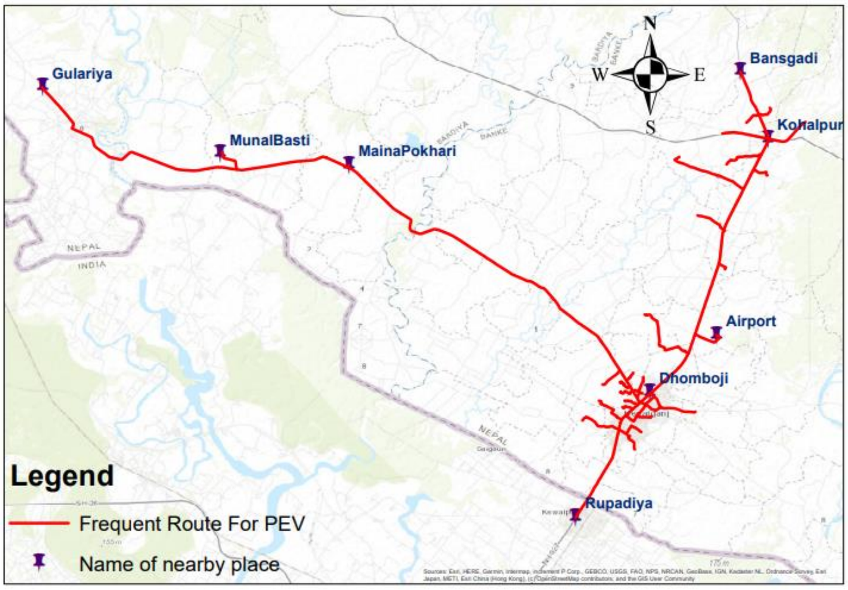

Figure 3.2: Route Map for PEV Travel around Nepalgunj City

3.1.2 Distribution System

Bageshwori feeder of Nepalgunj substation, Nepal is selected as the distribution system for an impact study of PEVs. Different data of feeder such as line length, conductors, distribution transformer load profile are collected from Nepal Electricity Authority, Distribution and consumer service office, Nepalgunj Nepal. Following data of distribution system are collected from the respective distribution center. The line routing and location of different distribution transformers including private and utility are shown in Figure 3.3.

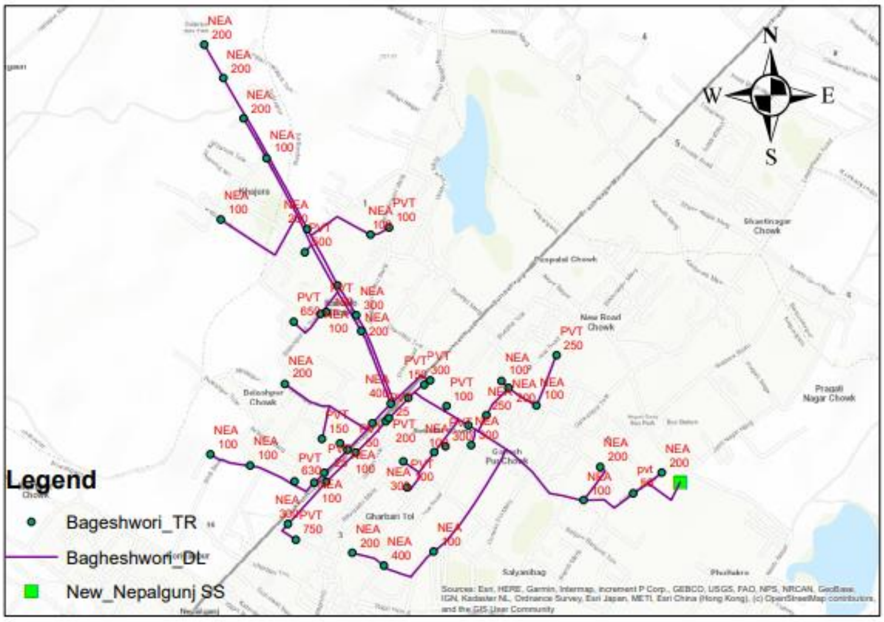

Figure 3.3: Line Route and Location of Distribution Transformers

a) Lines Parameter

The conductors and cables used in the Bageshwori feeder are mainly Dog, Rabbit, Weasel, and XLPE 95. The length of line and location of distribution transformer are extracted from geographic information system (GIS) route map using Arc map software. The total length of feeder is 9.64 km and radial length is 3.0 km. Different specifications of conductor are listed in Table 3.1.

Table 3.1: Conductor and Cable Specifications

S. N.	Conductor Name	Resistance (R) (Ω/km)	Reactance (X) (Ω/km)	Ampacity (A)	Line Voltage (kV)
1	Dog	0.2792	0.3	291	11
2	Rabbit	0.5524	0.3	190	11
3	Weasel	0.9289	0.3	138	11
4	XLPE 95	0.3200	0.177	277	11

b) Distribution Transformer and Load Profile

This feeder consists of 35 utility transformers and 19 private transformers whose capacity and rating along with the 24-hour load profile of each transformer are collected. The 24-hour load profile of each distribution transformer for the month of Ashad and Poush is given in Appendix A and Appendix B respectively.

c) Load Profile of Bageshwori Feeder

The load profile of the Bageshwori feeder is collected from the substation and the overall load profile for summer peak and winter peak is given in Appendix C and shown in Figure 3.4. The peak of feeder for summer is 4.325 MVA and winter is 3.163 MVA.

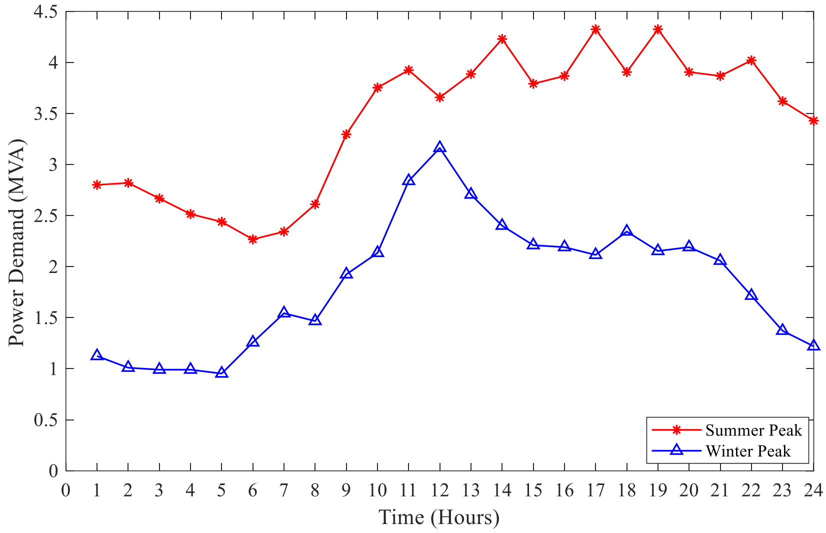

Figure 3.4: Load Curve of Bageshwori Feeder

3.2 Modeling of PEV and Charging Demand Profile

3.2.1 Parameters for PEV Modeling

When PEVs are plugged into the distribution system for charging, they act as a power system load with specific characteristics different from the normal load. The load profile of PEVs depend upon different characteristics and vehicles owner behaviors such as,

a) Vehicle Model
b) Daily Driving Distance
c) Battery Performance during Driving
d) Battery Performance during Charging
e) Charge Start Time

a) Vehicle Model

In this study, Nissan Leaf plug-in electric vehicles (PEVs) with a battery capacity of 24kWh is selected. The vehicle has an all-electric range of 100 miles (161 km) with specific energy consumption of 0.24kWh/miles. The minimum state of charge is considered as 5% (K.Gray & G.Morsi, 2016). The battery of the vehicle is charged through a 3.3kW on-board charger at home (230V/16A) (Yilmaz & Krein, 2012). The charger for public charging is considered 22kW (NEA, 2020). The charger efficiency is considered as 88%. (Ramadan, et al., 2018).

b) Daily Driving Distance

The daily driving distance of PEVs plays a vital role in modeling PEV and its load profile. Daily driving distance of PEVs varies from vehicle to vehicle and day to day and significantly depends upon the vehicle owner. The daily driving distance of PEVs is determined by routing the path around the Nepalgunj city taking the shortest and longest distance that can be traveled by the vehicle owner. Such obtained data are analyzed and the probability distribution is obtained. MATLAB best curve fit tools are used to obtain the lognormal distribution of daily driving distance with a mean value (μ) of 3.416 that is 30.45 km and standard deviation (σ) of 2.928. The distribution (lognormal) shown in Figure 3.5 expressed by Equation 3.1 is obtained. Similarly, the data obtained from various service centers of ICEV and PEVs, the daily driving distance of Kathmandu valley is also analyzed and the probability distribution is obtained. MATLAB Best curve fit tools are used to obtain the lognormal distribution of daily driving distance with a mean value (μ) of 3.53 that is 34.14 km and a standard deviation (σ) of 4.108. Vehicle travel data published in National Household Travel Survey (NHTS) 2009 was analyzed in (Wang & Karki, 2017) to obtain probability distribution of daily driving distance and similar distribution was obtained.

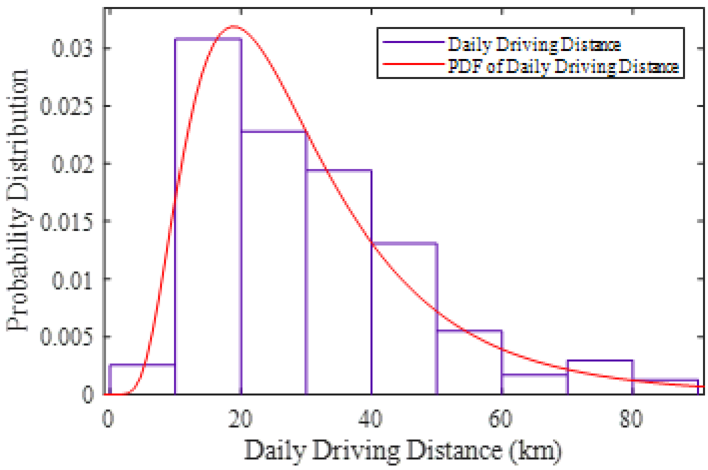

Figure 3.5: PDF of Daily Driving Distance of Nepalgunj City

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-(\ln x-\mu)^2/2\sigma^2} \quad \text{Equation 3.1}$$

c) Battery Performance during Driving

The battery performance of electric vehicles depends on the driving distance and efficiency of the electric vehicle. The Lithium-ion battery of 24 kWh used in Nissan Leaf gives the range of 100 miles (161 km) after a full charge. The specific energy consumption of this vehicle is 0.24kWh/mile. The maximum value of depth of discharge of selected vehicle and battery is 95%. The state of charge (SOC) of the battery after a certain trip can be estimated by Equation 3.2 (Angelim & de M. Affonso, 2019).

$$SOC = 1 - \frac{D_i * E_c}{\text{Battery Capacity}} \quad \text{Equation 3.2}$$

where D_i = Daily Distance travelled

E_c = Specific Energy consumption (kWh/km)

Battery Capacity in kWh

d) Battery Performance during Charging

The battery of the vehicle during charging acts as a load to the distribution system when connected to the charger. The time required to charge the battery completely depend upon its state of charge after driving and the type of charger. For this study 3.3kW charger with 230V/16A is considered for home charging. The charging time required to the battery after the plug-in is given by Equation 3.3 (Angelim & de M. Affonso, 2019).

$$\text{Charging Time (CT)} = (1 - soc)\frac{\text{Battery Capacity}}{P_{ch} * Eff_{ch}} \quad \text{Equation 3.3}$$

where P_{ch}= Power rating of charger

Eff_{ch} = Efficiency of charger

SOC= State of charge before plug-in

e) Charge Start Time

Charging start time also plays a major role in the modeling of PEVs charging profile. For the case of home charging, the arrival time of the vehicle at home will be considered as the charge start time. The vehicle arrival time is dependent upon the vehicle owner and is highly stochastic. The probability distribution of daily arrival time for the data of NTHS 2009 is described by the normal distribution (Wang & Karki, 2017) (Ramadan, et al., 2018) (Leou, et al., 2014). In this research, the mean value of arrival time is taken μ=17.4 hours with a standard deviation (σ) of 3.3 hours.

3.2.2 PEV Individual Modeling

The charging of PEV depends upon the initial SOC of battery before charging and power rating of charger. The driving distance after a trip gives the SOC value. Then time required to full charge is calculated and charge start time is included to determine the demand profile of single PEV. The single PEV charging profile is given by sequential diagram shown in Figure 3.6.

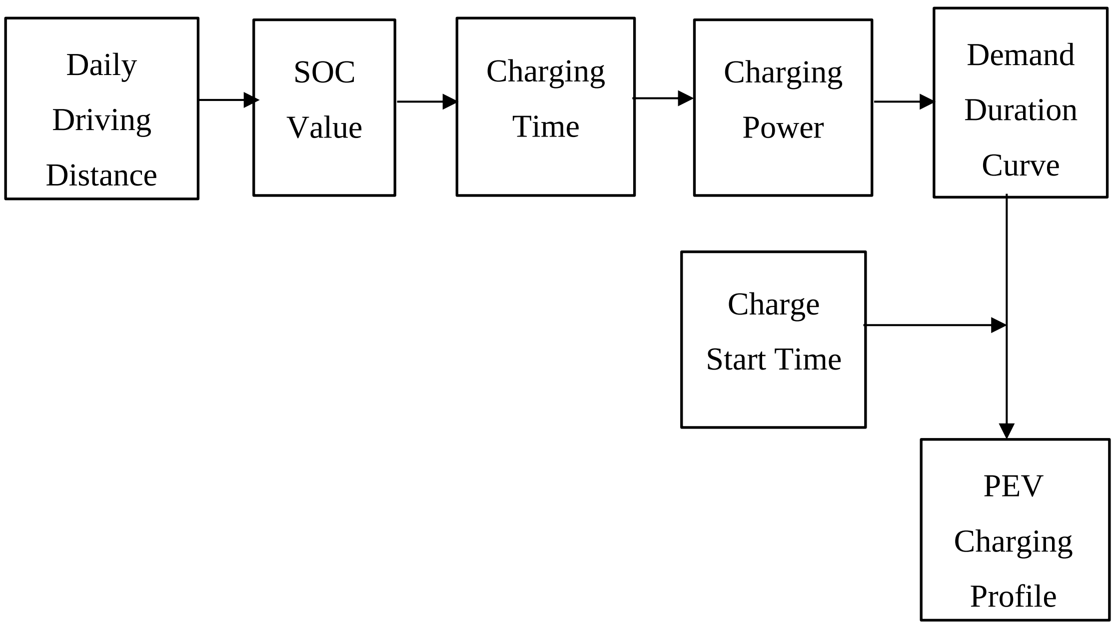

Figure 3.6: Sequential Diagram of PEV Modeling

3.2.3 PEVs Fleet Modeling

There can be several EVs connected to the distribution transformer, so the charging load profile of the fleet should be determined. A fleet can consist of several vehicles with different driving and charging behavior which are very stochastic. A model developed for a single PEV is aggregated with the appropriate method to determine the overall fleet model. This research uses Monte- Carlo Simulation (MCS) method to develop an overall model of the fleet by combining a single PEV model using python 3.0 (Wang & Karki, 2017). The basic flow chart for fleet modeling of PEV is shown in Figure 3.7. Figure 3.8 shows the demand profile of 100 PEVs with the peak demand of 121.52 kW at 20:00 hours for the residential charging scenario. Similarly, the charging load profile for the public charging scenario is also determined by changing the charging parameters.

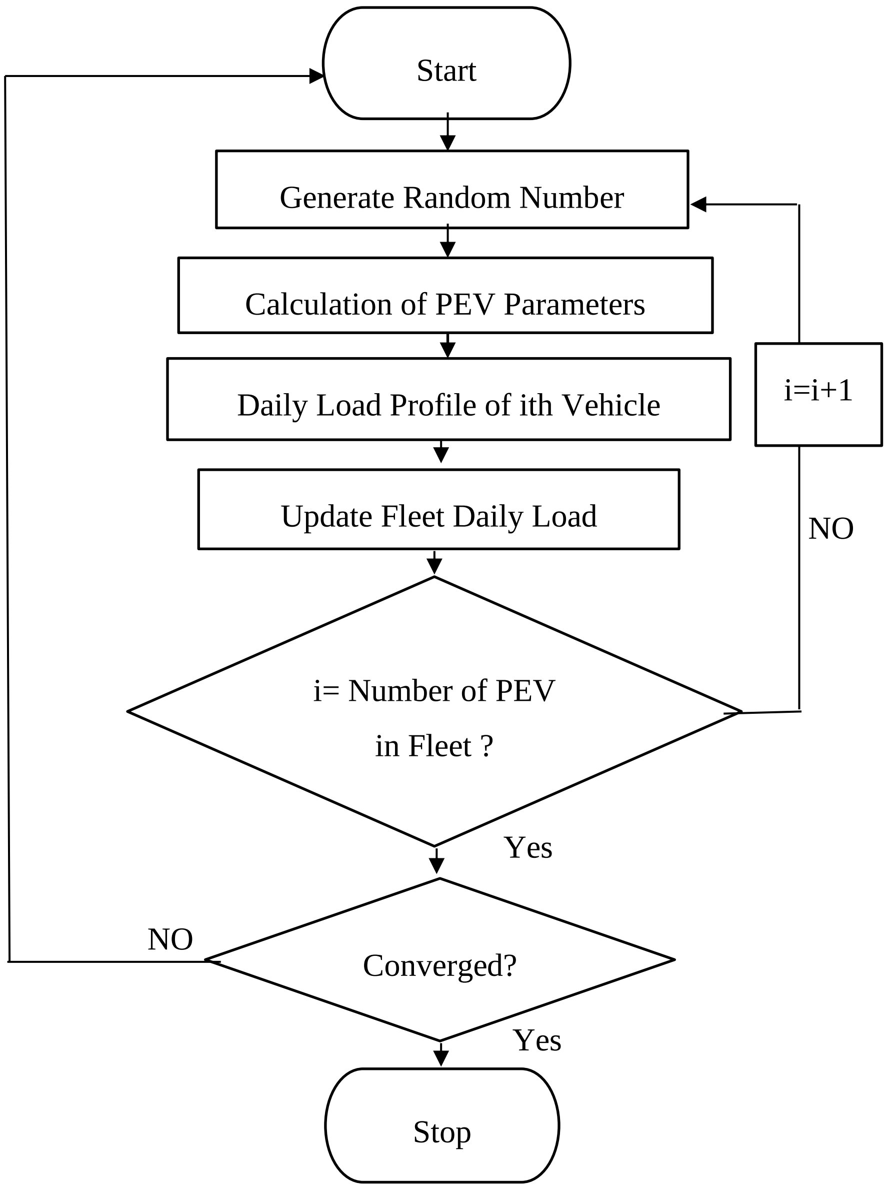

Figure 3.7: PEV Fleet Modeling Procedure

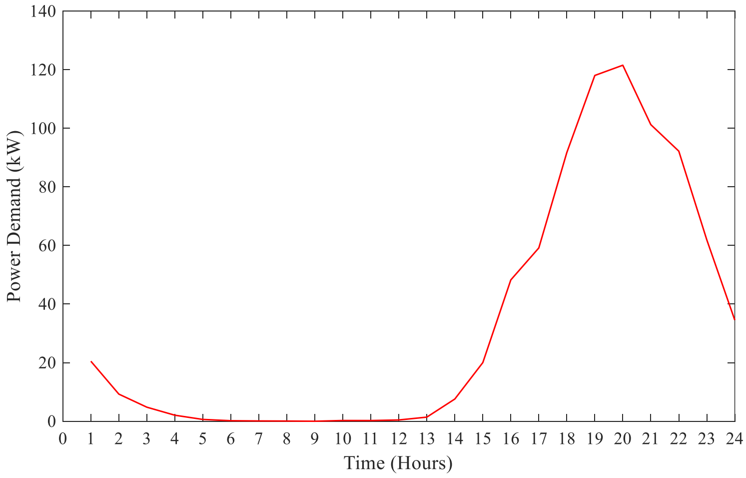

Figure 3.8: Daily Load Profile of 100 PEVs for Residential Charging

3.3 Modeling of Distribution System on DigSILENT Powerfactory Software

The distribution system is modeled in DigSILENT power factory 15.1. For 24-hour load flow of distribution system, load profile of distribution transformer is given by defining vector and matrix through DPL. The load flow results are also extracted by defining the vector and matrix for simplicity in data extraction. The basic flow diagram of software implementation in thesis is shown Figure 3.9.

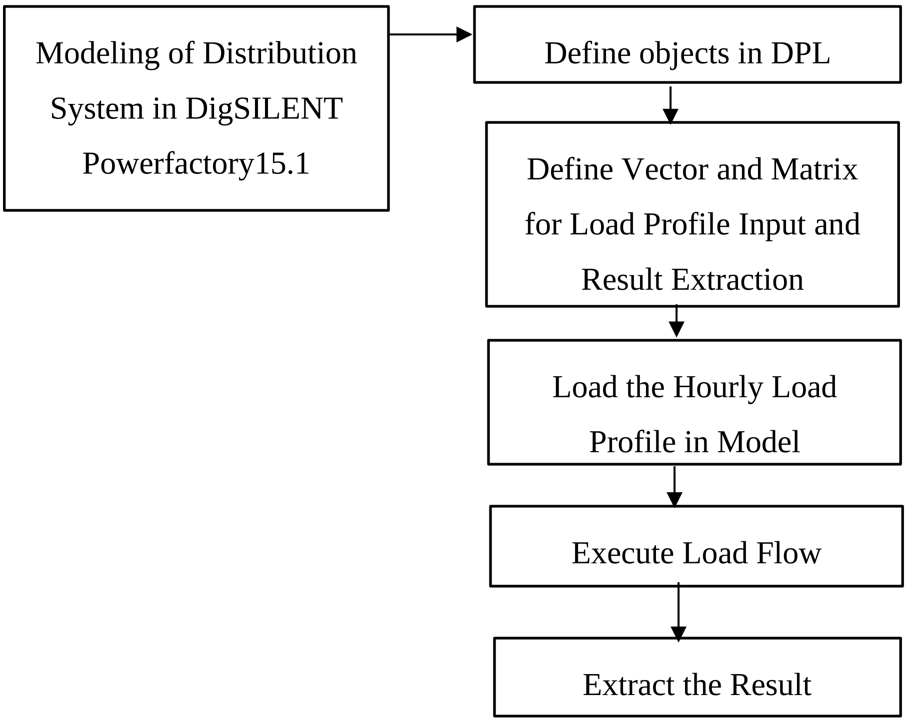

Figure 3.9: Software Implementation Approach

3.3.1 Modeling of IEEE-33 Bus Radial Distribution System in DigSILENT

The standard IEEE-33 bus radial distribution system is modeled in DigSILENT power factory software 15.1. The data for 33 bus distribution systems are taken from (Venkatesh, et al., 2004) (Bhat & Manjappa, 2018). The system consists of a total of 3715 kW and 2300 kVAR active and reactive power load respectively. The line parameter and load are given in Appendix D. The single line diagram of the IEEE-33 bus radial distribution system is shown in Appendix E.

3.3.2 Modeling of Bageshwori Feeder in DigSILENT

The distribution system of Bageshwori feeder with parameters such as line type, line length, the capacity of distribution transformer, and load profile of each distribution transformer is modeled in DigSILENT power factory 15.1 software. The single line diagram of the distribution system is shown in Appendix F.

3.4 Load Flow Analysis

Load flow is defined as steady-state analysis of the power system which evaluates the operating state of the system. The result of the load flow analysis is voltage, phase angle, active and reactive power, total line losses, and slack bus power. Load flow analysis is very essential for planning the power system and to study the state of the system after the implementation of any electrical load or generation in the system.

3.4.1 Load Flow in DigSILENT Software

DigSILENT powerfactory software makes the use of wide range of load flow calculation methods. It uses AC Newton-Raphson technique (balanced and unbalanced) and a linear DC method for load flow analysis. The implemented algorithm in DigSILENT exhibits excellent stability and convergence. The power flow equation is given by Equation 3.4 and Equation 3.5.

$$P_i = \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \quad \text{Equation 3.4}$$

$$Q_i = \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \quad \text{Equation 3.5}$$

where

- P_i is active power and Q_i is reactive power injected at bus i.
- G_{ik} is the real part of element in bus admittance matrix

- B_{ik} is the imaginary part of element in bus admittance matrix corresponding to ith row and kth column
- θ_{ik} is the difference between voltage angle between ith row and kth column

The 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.

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

where ΔP and ΔQ are mismatch equations given by Equation 3.6 and Equation 3.7

$$\Delta P_i = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \qquad \text{Equation 3.6}$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \qquad \text{Equation 3.7}$$

where J is the Jacobian matrix of partial derivatives

$$J = \begin{bmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{bmatrix}$$

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

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

The process will continue until the stopping criterion is met.

3.4.2 Load Flow of IEEE-33 Bus Radial Distribution System

The power flow of standard IEEE-33 bus RDS is performed in DigSILENT powerfactory software using the Newton Raphson Algorithm and results is validated with similar Newtons Raphson Algorithm and backward forward sweep algorithm.

3.4.3 Load Flow of Bageshwori Feeder

After the validation of results of IEEE-33 bus RDS, 24-hour load flow of Bageshwori feeder is performed in DigSILENT powerfactory software using DPL script, and distribution system parameters are analyzed in a real case of Nepal. The power flow is performed at the base case without PEV and with PEV at a different level of penetration ranging from 10% to 80%.

3.5 Integration of PEV on Distribution System

3.5.1 PEV Penetration Scenario

The distribution system analysis of Bageshwori feeder is performed under two cases of summer and winter peak with residential and public charging. The scenario of PEV penetration is according to Table 3.2.

Table 3.2: PEV Penetration Level

S.N	Residential Charging Scenario		Public Charging Scenario	
	Summer Peak	Winter Peak	Summer Peak	Winter Peak
1	10% PEV	10% PEV	10% PEV	10% PEV
2	30% PEV	30 % PEV	30% PEV	30 % PEV
3	60% PEV	60% PEV	60% PEV	60% PEV
4	80% PEV	80% PEV	N/A	N/A

3.5.2 Residential Charging Scenario

In a residential charging scenario, all vehicles are charged at home with a slow charger. The load of PEVs on the distribution transformer is aggregated until the criterion of penetration is achieved.

10 % PEV penetration means PEV will be added until the transformer peak load increases by 10%. For example, if 200kW is the peak load of the transformer, PEV will be added to transformer until the new peak of the transformer reaches 220kW.

PEV Location

For residential charging scenario, PEVs are integrated at 15 random utility transformers which are listed in Table 3.3. The PEVs are penetrated at each transformer according to the percentage of their peak load.

Table 3.3: Location of PEV

S.N	Name of Transformer	Transformer Symbol	Bus Name
1	AG Bank NEA Tr	Tr-1	Bus 1
2	Bageshwori Mandir vitra NEA Tr	Tr-4	Bus 4
3	Dailekhi Tol NEA Tr	Tr-8	Bus 8
4	Dewa Fulbari NEA Tr	Tr-9	Bus 9
5	Dhomboji Chowk 2 NEA Tr	Tr-11	Bus 11
6	Gulariya Buspark NEA Tr	Tr-19	Bus 19
7	Gumba Nera NEA Tr	Tr-21	Bus 21
8	Hotel Shrinet NEA Tr	Tr-25	Bus 25
9	Jumli Tole NEA Tr	Tr-28	Bus 28
10	Plywood Industries NEA Tr	Tr-37	Bus 37

S.N	Name of Transformer	Transformer Symbol	Bus Name
11	Regional West NEA Tr	Tr-43	Bus 43
12	Senthomas School NEA Tr	Tr-46	Bus 46
13	Seto BK Chowk New NEA Tr	Tr-48	Bus 48
14	Shiva Mandir 1 NEA Tr	Tr-49	Bus 49
15	Subodh Sir Ghar NEA Tr	Tr-52	Bus 52

The location of PEV is also shown in the Figure 3.10.

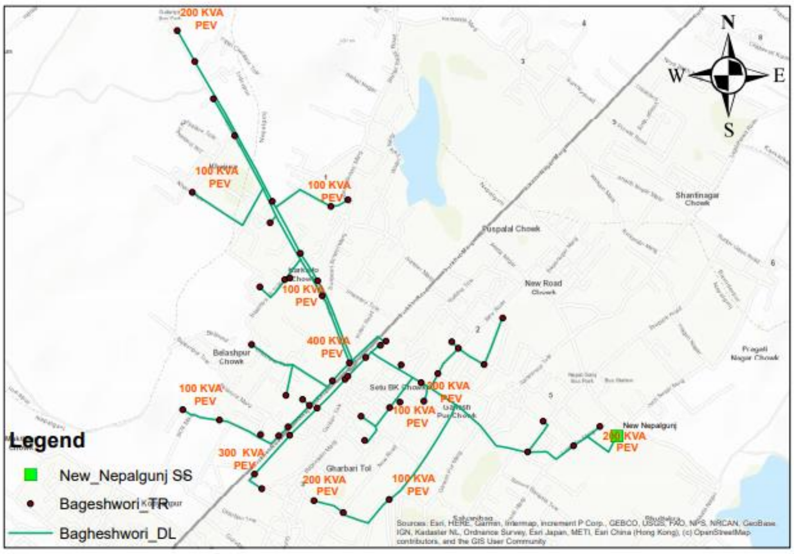

Figure 3.10: Location of PEV Fleet for Residential Charging

The modeling of PEVs load profile gives the number of PEVs integrated at each penetration percentage of PEV. Figure 3.11 shows the number of PEVs at a different transformer at different penetration for summer peak.

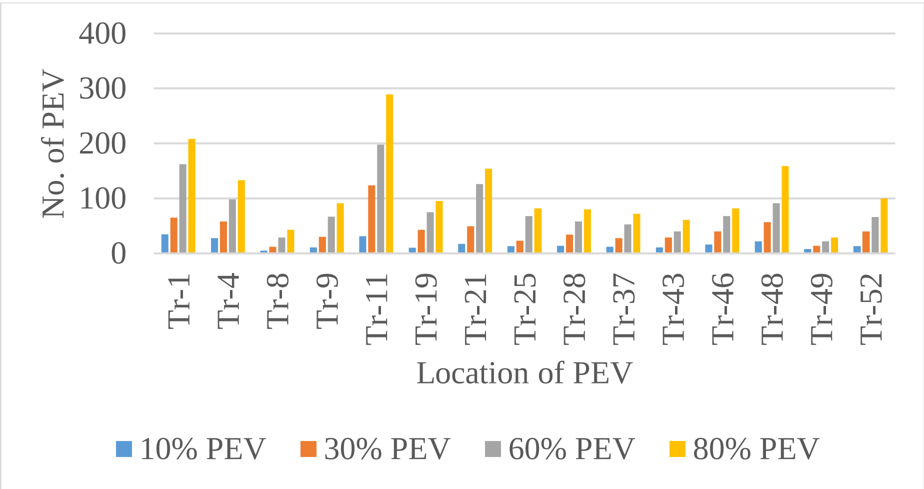

Figure 3.11: No. of PEVs at 15 Transformer for Summer Peak

The total number of PEVs at feeder on different penetration of PEVs for summer peak is shown in Table 3.4.

Table 3.4: No. of PEVs at Feeder for Summer Peak

S.N	PEV Penetration (%)	Number of PEV on Feeder
1	10	246
2	30	646
3	60	1221
4	80	1678

The Figure 3.12 shows the number of PEVs at different transformer at different penetration for winter peak.

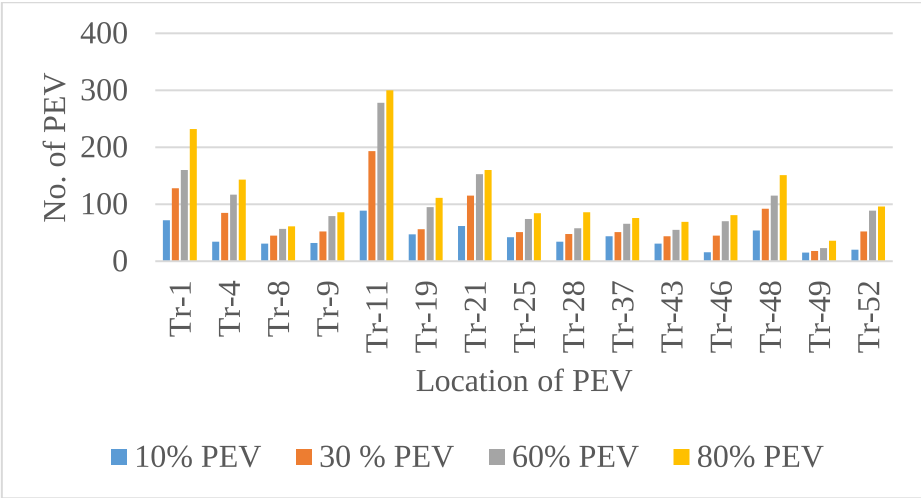

Figure 3.12: No. of PEVs at 15 Transformer for Winter Peak

The total number of PEVs on feeder at different penetration level for winter peak is given in Table 3.5.

Table 3.5: No. of PEVs at Feeder for Winter Peak

S.N	PEV Penetration (%)	Number of PEV on Feeder
1	10	623
2	30	1075
3	60	1489
4	80	1772

3.5.3 Public Charging Scenario

In Public charging scenario, all the PEVs are charged at two specified charging stations located in the feeder. The charging station is located at Bus 11 and Bus 19. It is assumed that 50% of vehicles go-to charging station 1 located at Bus 11 and the rest 50% of PEVs go to charging station 2 located at Bus 19. The location of the public charging station is shown in Figure 3.13.

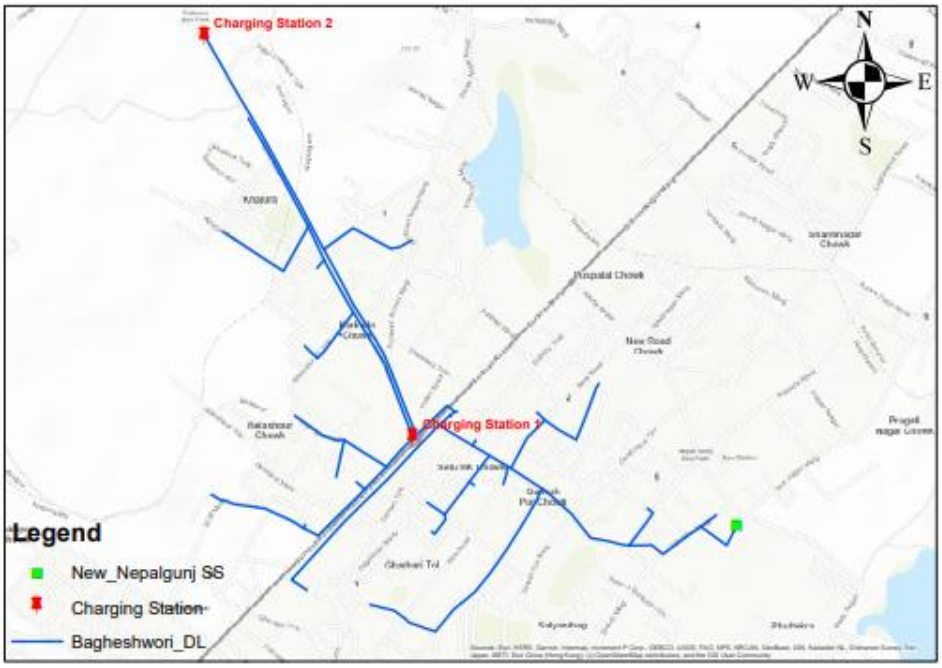

Figure 3.13: Location of Charging Station

The number of PEVs on two charging stations at a different level of penetration for summer and winter peak is shown in Table 3.6 and Table 3.7 respectively.

Table 3.6: No. of PEVs on Charging Station for Summer Peak

S.N	PEV Penetration (%)	Number of PEV on Feeder	
		Charging Station 1	Charging Station 2
1	10	123	123
2	30	323	323
3	60	610	611

Table 3.7: No. of PEVs on Charging Station for Winter Peak

S.N	PEV Penetration (%)	Number of PEV on Feeder	
		Charging Station 1	Charging Station 2
1	10	312	311
2	30	537	538
3	60	744	745

3.6 Distribution System Parameters

The distribution system parameters need to be studied to determine the existing condition of the distribution system. For base case study load curve, power loss, voltage profile and line loading are studied. After the penetration of PEV, distribution parameters change and may violate the limit, So, for residential charging scenario load curve, power loss, voltage profile line loading, transformer loading, daily energy loss, and load factor is studied. In public charging scenario except transformer loading all the parameters studied for residential charging are analyzed. The distribution system parameters of Bageshwori feeder analyzed in this thesis under different scenario are listed in Table 3.8.

Table 3.8: System Parameters to be Studied

Distribution System Parameters	**Base Case**		**Residential Charging**		**Public Charging**	
	Summer Peak	**Winter Peak**	**Summer Peak**	**Winter Peak**	**Summer Peak**	**Winter Peak**
Load Curve	✓	✓	✓	✓	✓	✓
Power Loss	✓	✓	✓	✓	✓	✓
Voltage Profile	✓	✓	✓	✓	✓	✓
Line Loading	✓	✓	✓	✓	✓	✓
Transformer Loading			✓	✓		
Energy Loss			✓	✓	✓	✓
Load Factor			✓	✓	✓	✓

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Case I: Load Flow of IEEE- 33 Bus Radial Distribution System

The power flow analysis of standard IEEE-33 bus RDS is performed and results are analyzed. The total power loss of the system is found to be 210 kW and the minimum voltage is found at bus 18 which is 0.90400 pu. The voltage profile of IEEE-33 bus RDS is shown in Figure 4.1.

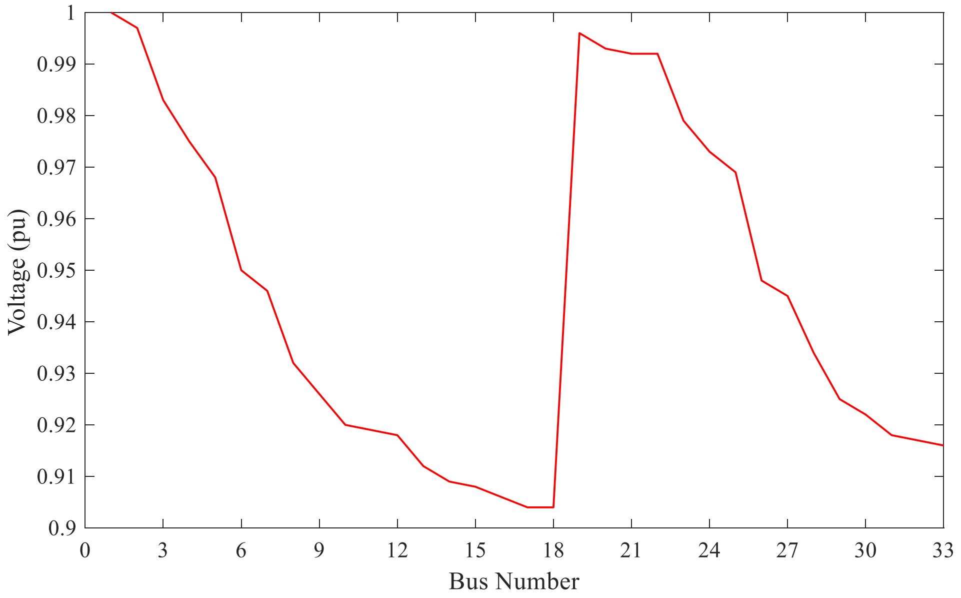

Figure 4.1: Voltage Profile of IEEE-33 Bus RDS

The results obtained from DigSILENT are compared and validated with other algorithms too which is shown in Table 4.1. The newtons Raphson algorithm used by DigSILENT show the effective results.

Table 4.1: Validation of Newtons Raphson Algorithm in IEEE-33 Bus RDS

Algorithm	**Power Loss (kW)**	**Minimum Bus Voltage (pu)**
Newton Raphson in DigSILENT	210.00	0.9040
Newton Raphson (Venkatesh, et al., 2004)	211.22	0.9038
Backward Forward Sweep (Bhat & Manjappa, 2018)	202.70	0.9130

4.2 Case II: Base Case Study of Bageshwori Feeder

The load flow analysis of the Bageshwori feeder is performed to determine the existing condition of the distribution system considering summer and winter peaks separately.

4.2.1 Base Case Load Flow Analysis of Bageshwori Feeder for Summer Peak

The load flow result of the base case for Bageshwori feeder for summer peak in the month of Ashad (July) is obtained and analyzed as follows.

a) Feeder Load Curve

The peak of active power is 3.892 MW at 17:00 hours. Similarly, the load curve of the feeder in terms of total MVA is obtained with a peak value of 4.325 MVA at 17:00 hours which is shown in Figure 4.2.

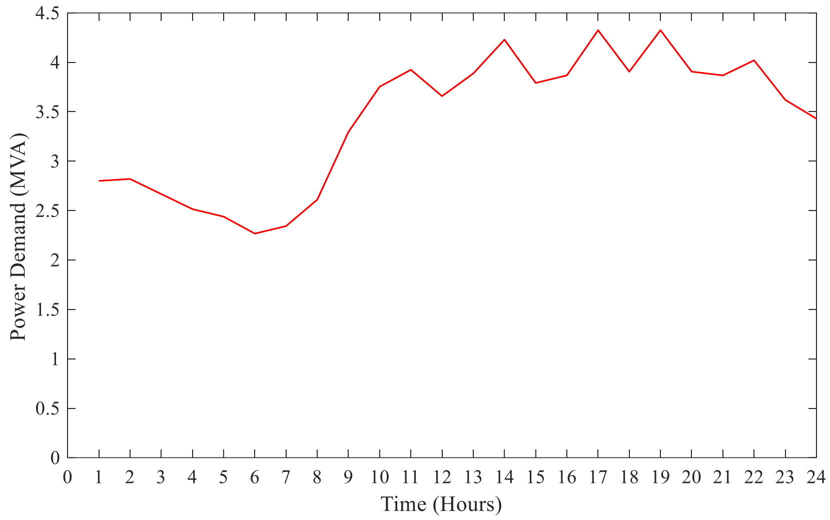

Figure 4.2: Apparent Power (Base Case Summer Peak)

b) Feeder Power Loss

The load flow studies show the peak power loss of 0.0478 MW at 17:00 hours for the base case study. Figure 4.3 shows the 24-hour total system loss for Bageshwori feeder for the summer peak case. This shows the maximum power loss occurs at the peak load time.

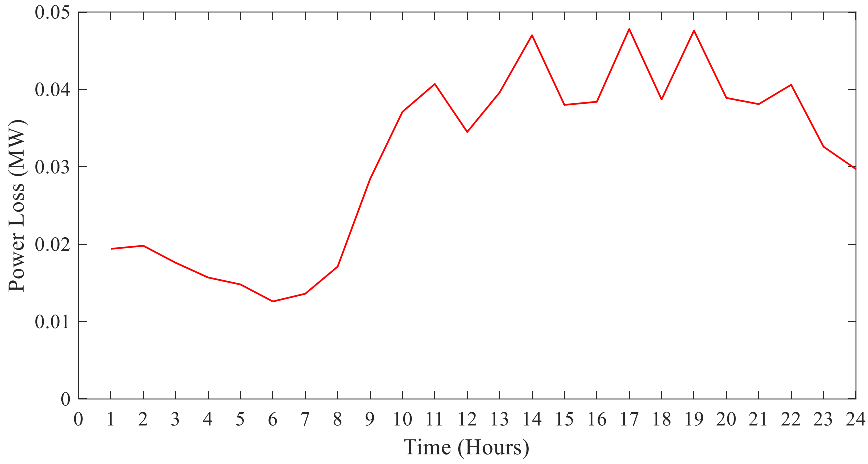

Figure 4.3: Active Power Loss (Base Case Summer Peak)

c) Voltage Profile of 11kV Bus at Peak Time

The voltage profile of the different 11kV Bus at peak time 17:00 hours in the feeder is shown in Figure 4.4. The minimum voltage occurs at the end of lateral at Bus 46 which is 0.98182 pu. Since the radial feeder, the lowest voltage is obtained at end of laterals. This shows the voltage profile is within the limit.

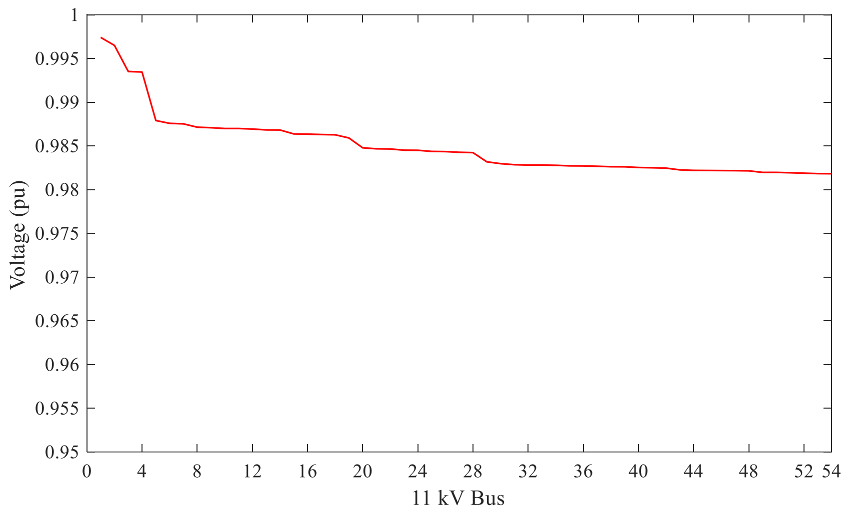

Figure 4.4: Voltage Profile of 11kV Bus at 17:00 Hours (Base case Summer Peak)

d) Line Loading

The initial outgoing line of the radial feeder is highly loaded. The loading of the line is maximum at 17:00 which is 79.84%. Further 24 hours loading of the line is shown in Figure 4.5.

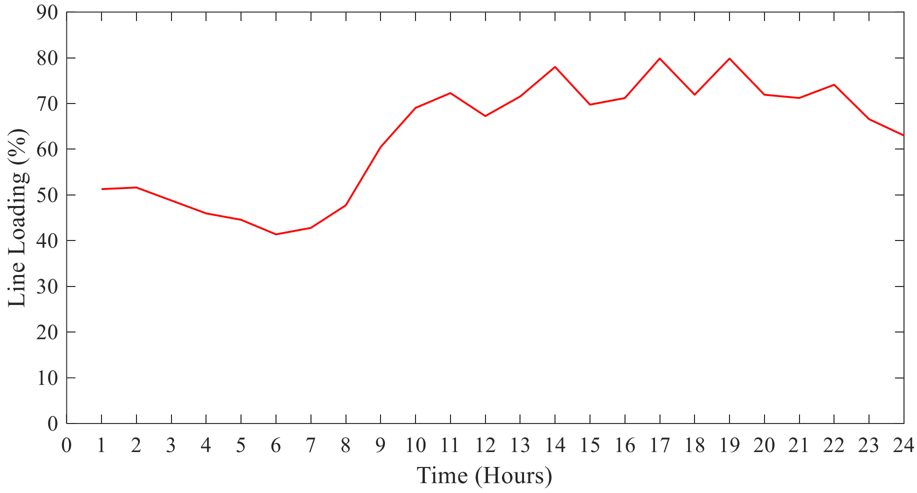

Figure 4.5: Line Loading (Base Case Summer Peak)

4.2.2 Base Case Load Flow Analysis of Bageshwori Feeder for Winter Peak

The base case load flow without PEVs is performed for the winter peak. The results are analyzed in terms of the following distribution system parameters.

a) Feeder Load Curve

The load curve of the feeder in terms of apparent power is shown in Figure 4.6. The peak load of the feeder is 2.846 MW and 3.163 MVA at 12:00 hrs. This feeder curve shows the maximum peak at midday. It is because of high commercial load during day time than the residential load in the evening time because of the winter season.

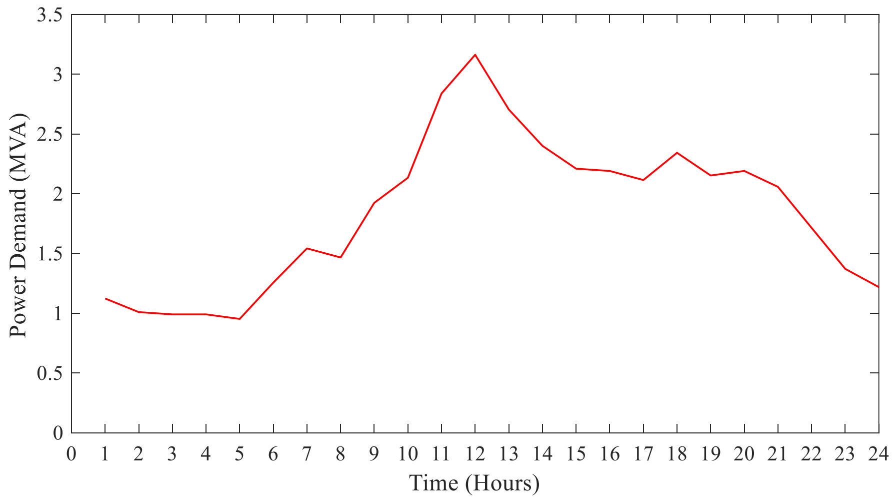

Figure 4.6: Apparent Power (Base Case Winter Peak)

b) Feeder Power Loss

The active power loss of the feeder is determined for 24 hours through continuous load flow. The peak loss is 0.0254 MW at noon at the time of peak loading. Figure 4.7 shows the curve for active power loss through 24 hours and signifies the loss increases as the load on the feeder increases.

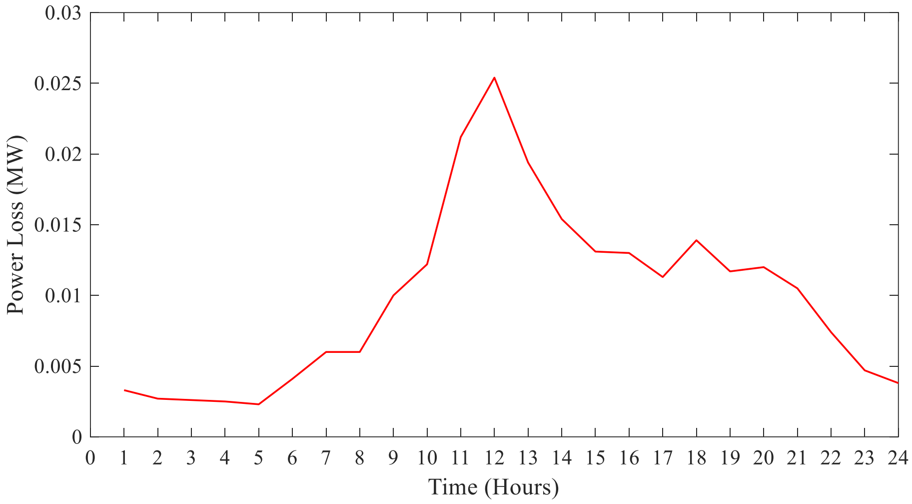

Figure 4.7: Active Power Loss (Base Case Winter Peak)

c) Voltage Profile of 11kV Bus at Peak Time

The voltage profile of all 11kV buses in the feeder at peak time is determined and found minimum voltage at Bus 19 which is 0.98673 pu. The voltage profile of the feeder is found within the limit. The voltage profile of all buses at 12:00 hours is shown in Figure 4.8.

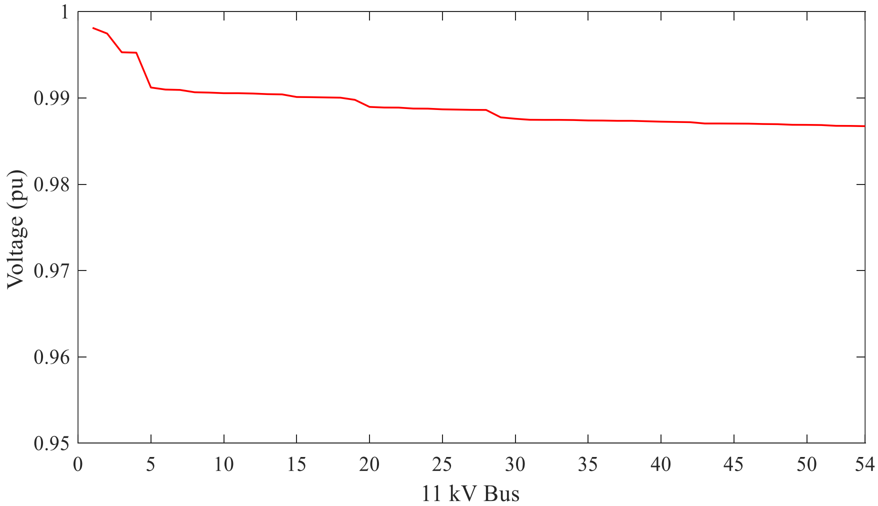

Figure 4.8: Voltage Profile of 11kV Bus at 12:00 Hours (Base Case Winter Peak)

d) Line Loading

The loading of the feeder line at base condition without PEV for winter case is studied and found to be maximum loading of 58.02 at peak time noon. The winter case shows the light loading of the line at an off-peak hour. The overall loading of the line for 24 hours is shown in Figure 4.9.

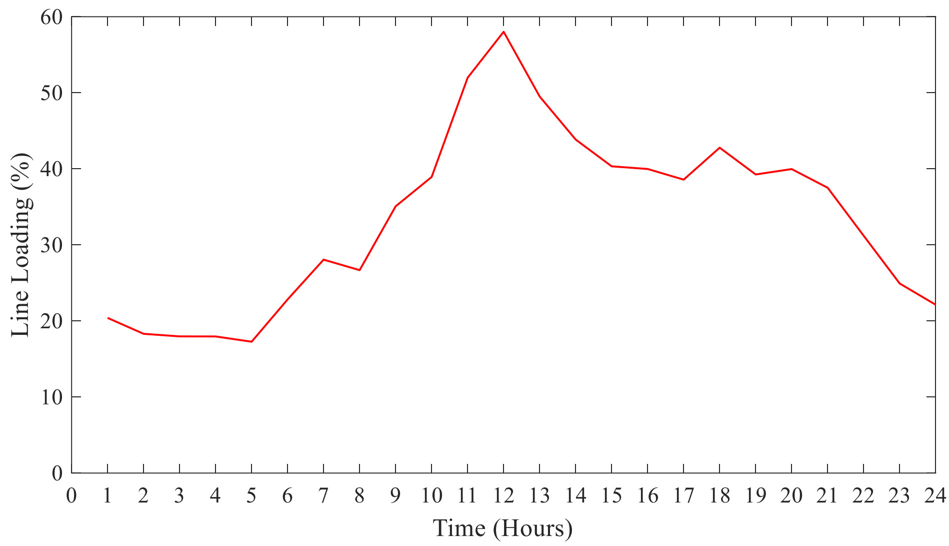

Figure 4.9: Line Loading (Base Case Winter Peak)

4.3 Case III: PEV with Residential Charging Scenario

4.3.1 Load Flow Analysis with PEV Penetration for Summer Peak

After the integration of PEV at different random 15 utility transformers under various penetration percentage ranging from 10% to 80%, load flow is performed and following results are obtained and analyzed.

a) Feeder Load Curve

When the PEVs are integrated with a feeder at different penetration percentages, it is observed that peak coincides at 17:00 hours for 10% PEV but after that peak shift towards 19:00 hours. The peak load of the feeder increases from 4.325 MVA at 0% PEVs to 5.615 MVA at 80% PEVs. Table 4.2 shows the peak load of the feeder at a different penetration level.

Table 4.2: Feeder Peak Load with PEVs (Residential Charging Summer Peak)

Penetration Percentage (%)	**Peak Load (MVA)**	**Time (Hours)**
0	4.325	17:00
10	4.498	17:00
30	4.841	19:00
60	5.308	19:00
80	5.615	19:00

The load curve of feeder for different penetration of PEV in terms of MVA is shown in Figure 4.10.

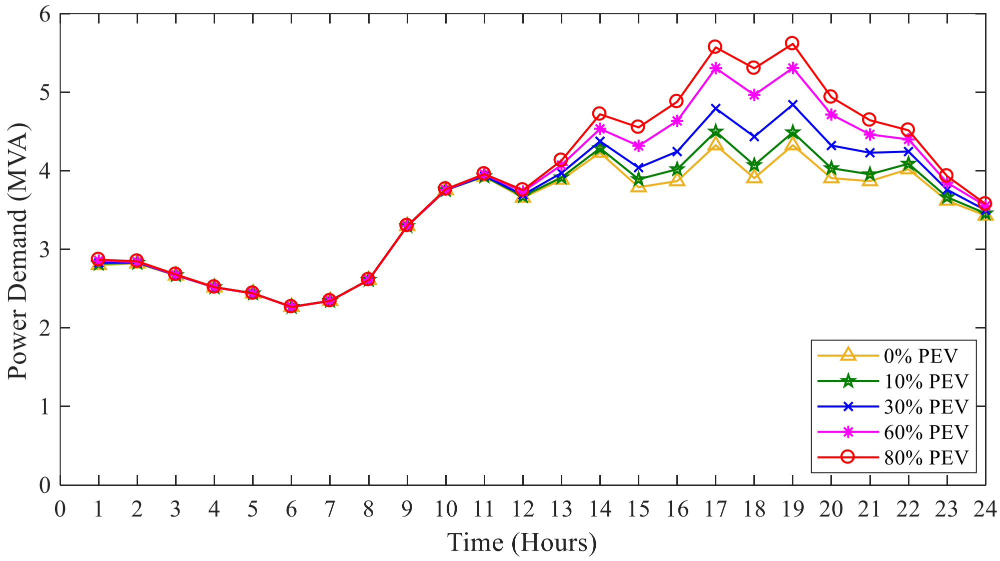

Figure 4.10: Apparent Power with PEVs (Residential Charging Summer Peak)

b) Feeder Active Power Loss

With the integration of PEV loss of the feeder is seen to be increased. With the increasing penetration of PEV peak loss of the feeder increases from 0.0478 MW at 0% PEV to 0.0824 MW at 80% of PEV. The peak loss for a feeder at different penetration levels is shown in Table 4.3.

Table 4.3: Peak Power Loss with PEVs (Residential Charging Summer Peak)

PEV Penetration (%)	**Peak Power Loss (MW)**	**Time (Hours)**
0	0.0478	17:00
10	0.0518	17:00
30	0.0604	19:00
60	0.0734	19:00
80	0.0824	19:00

The 24 hours loss of the feeder at different penetration percentages of PEV is shown in Figure 4.11. It represents the loss of feeder is increases when vehicle peak coincides with the feeder peak.

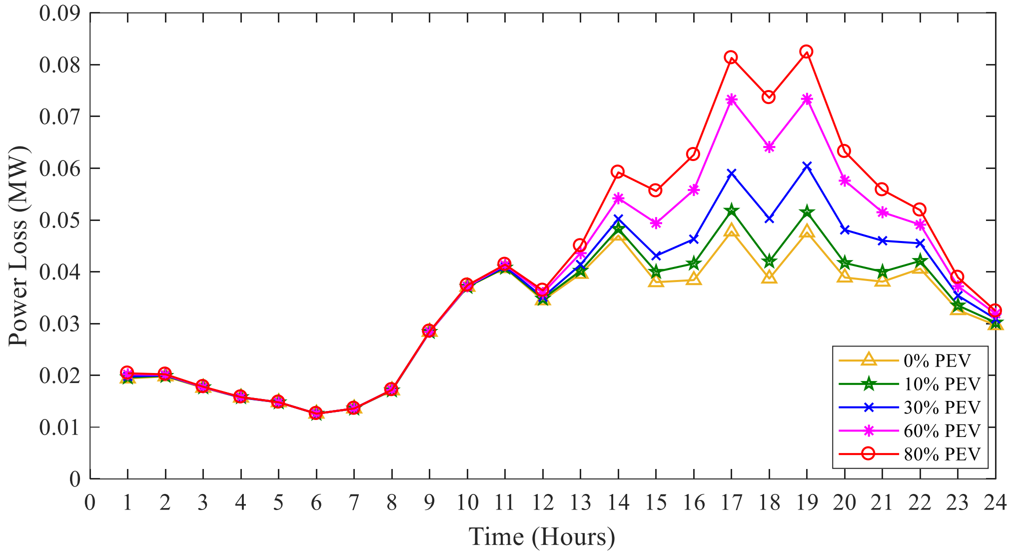

Figure 4.11: Active Power Loss with PEVs (Residential Charging Summer Peak)

c) Voltage Profile of Different 11 kV Bus

As the PEV is penetrated, the voltage starts to reduce. In the radial feeder, the last point gets the poorest voltage, but due to the shorter length of the feeder, its voltage is within the limit. The main lateral end is observed for analysis of voltage deviations.

i) Voltage Profile of Bus 46 (Senthomas School)

The lateral end of the feeder at Bus 46 bus is facing the lowest voltage before penetration of PEV and up to 10% Penetration of PEV. As the penetration level increases the low voltage is observed at Bus 46 after 30 % up to 80% PEVs. The minimum voltage at bus 46 at different penetration is given in Table 4.4.

Table 4.4: Minimum Voltage at Bus 46 with PEVs (Residential Charging Summer Peak)

Penetration Percentage (%)	Minimum Bus Voltage (pu)	Time (Hours)
0	0.98182	17:00
10	0.98103	17:00
30	0.97955	19:00
60	0.97738	19:00
80	0.97606	19:00

The voltage profile of bus 46 at different percentage of PEV is shown in Figure 4.12.

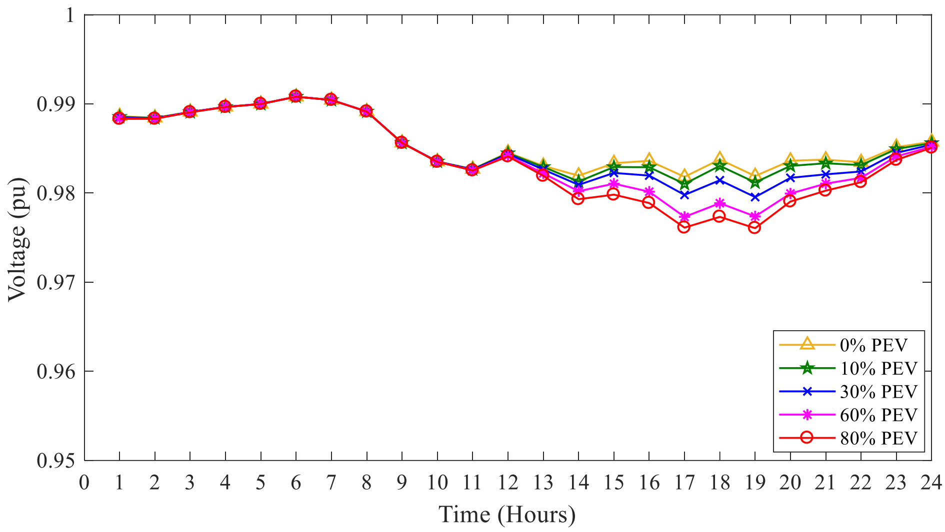

Figure 4.12: Voltage Profile of Bus 46 with PEVs (Residential Charging Summer Peak)

ii) Voltage Profile of Bus 19 (Gulariya Buspark)

Observing bus 19 as the farthest end, the minimum voltage obtained at different penetration is given in Table 4.5. It is because bus 19 is the farthest end of the radial feeder. The minimum voltage at 80% of PEVs is 0.97588 pu. Here the minimum voltage is also under limit because of the short length of the feeder.

Table 4.5: Minimum Voltage at Bus 19 with PEVs (Residential Charging Summer Peak)

Penetration Percentage (%)	Minimum Bus Voltage (pu)	Time (Hours)
0	0.98183	17:00
10	0.98107	17:00
30	0.97948	19:00
60	0.97730	19:00
80	0.97588	19:00

The voltage profile of bus 19 for 24 hours for different penetration percentages of PEV is shown in Figure 4.13. This shows the voltage is decreasing significantly at the time of penetration of the vehicle that is at evening time.

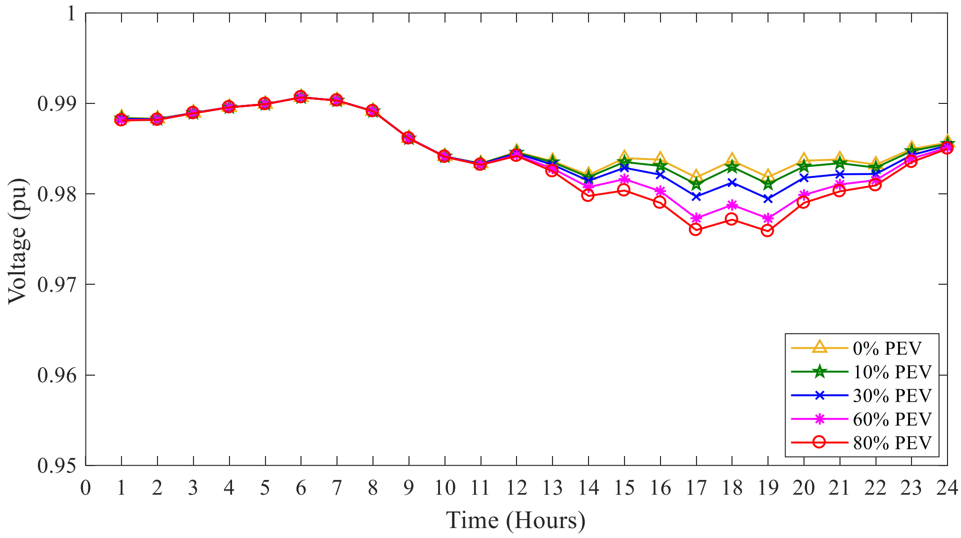

Figure 4.13: Voltage profile of Bus 19 with PEVs (Residential Charging Summer Peak)

d) Line Loading

As the PEV is integrated into the feeder, the loading of the conductor increase. It increases with an increase in the penetration percentage of PEV. The loading of the line at the peak hour is shown in Table 4.6.

Table 4.6: Maximum Line Loading with PEVs (Residential Charging Summer Peak)

Penetration Percentage (%)	Maximum Line Loading (%)	Time (Hours)
0	79.84	17:00
10	83.13	17:00
30	89.67	19:00
60	98.67	19:00
80	104.63	19:00

This shows the loading of the line increases with the increases in the penetration percentage of PEV. The line loading reaches 104.63 %. at 80% of PEV penetration. This signifies no more PEV can be penetrated into this feeder. The 24-hour loading of the line at different penetration levels is shown in Figure 4.14.

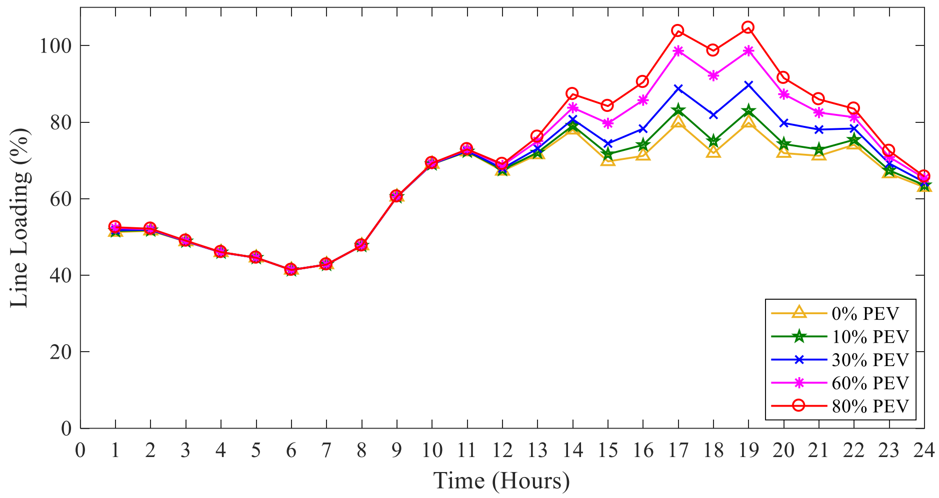

Figure 4.14: Line Loading with of PEVs (Residential Charging Summer Peak)

e) Transformer Loading

PEVs are penetrated at 15 random locations in the feeder. The loading of the transformer needs to be studied where the PEVs are penetrated. As the penetration percentage increases the loading of the transformer is increased. Table 4.7 shows the peak loading of 15 different transformers at different penetration of PEVs.

Table 4.7: Transformer Loading with PEVs (Residential Charging Summer Peak)

Transformer Name.	0% PEV	10% PEV	30% PEV	60% PEV	80% PEV
Tr-1	102.88	114.23	135.28	167.50	189.80
Tr-4	67.94	75.30	90.28	111.07	124.55
Tr-8	58.22	65.67	76.89	95.12	107.19
Tr-9	86.15	97.21	116.14	142.52	158.02
Tr-11	74.75	83.07	98.05	121.33	136.55
Tr-19	51.13	56.70	68.00	82.72	94.59
Tr-21	82.36	91.65	108.66	134.25	151.54
Tr-25	25.82	29.50	34.41	41.88	47.84
Tr-28	86.65	97.86	117.05	143.80	158.86
Tr-37	78.89	90.07	105.42	131.32	147.76
Tr-43	36.22	41.62	48.76	59.65	67.14
Tr-46	79.62	91.01	106.07	129.16	148.89
Tr-48	48.88	54.96	64.67	79.59	89.93
Tr-49	12.91	15.35	17.77	21.46	24.15
Tr-52	93.71	105.07	124.18	154.04	173.37

The transformer Tr-1 is overloaded in the initial condition without PEV. Its loading increases as the penetration of PEV increases. It reaches up to maximum loading of 189.80% at 80 % of PEV, so it is necessary to replace the transformer before any penetration of PEV. The transformer Tr-4 is operating at normal condition up to 30% of PEV but it starts to overload at 60% and 80% of PEV. The transformer Tr-8 is overloaded when 80% PEV is penetrated. Similarly, the transformer of Tr-9 is overloaded when it is penetrated with 30% of PEV. The transformer at Tr-11 starts to overload after 60% of penetration. Similarly, transformer Tr-21 is overloaded after 30% of PEV.

The transformer Tr-28 is overloaded after 30% of PEV. The transformer Tr-37 is at normal working up to 10% PEV but it starts to be overloaded after 30%. The transformer Tr-46 also shows normal working up to 10 % of PEV but is overloaded when there is an increment in PEV. Similarly, the transformer Tr-52 gets overloaded after 10% of PEV. This means these ten transformers are overloading at different penetration levels. So, they need to be replaced for reliable operation. The remaining transformers are working under normal conditions of up to 80% of PEV. Further, the loading of the transformer at different penetration of PEV is shown in Figure 4.15.

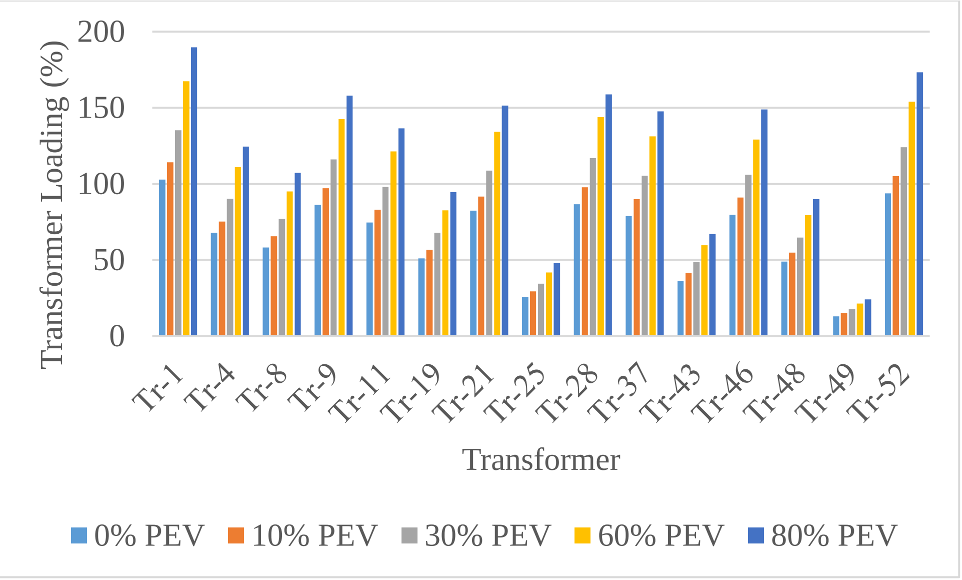

Figure 4.15: Transformer Loading with PEVs (Residential Charging Summer Peak)

f) Energy Loss

Daily energy loss is calculated from the 24-hour load flow of summer peak cases for a different level of penetration of PEVs. The daily energy loss changed from 0.75 MWh to 0.98 MWh at 80 % penetration of PEV. The total energy loss for a day is given in Figure 4.16.

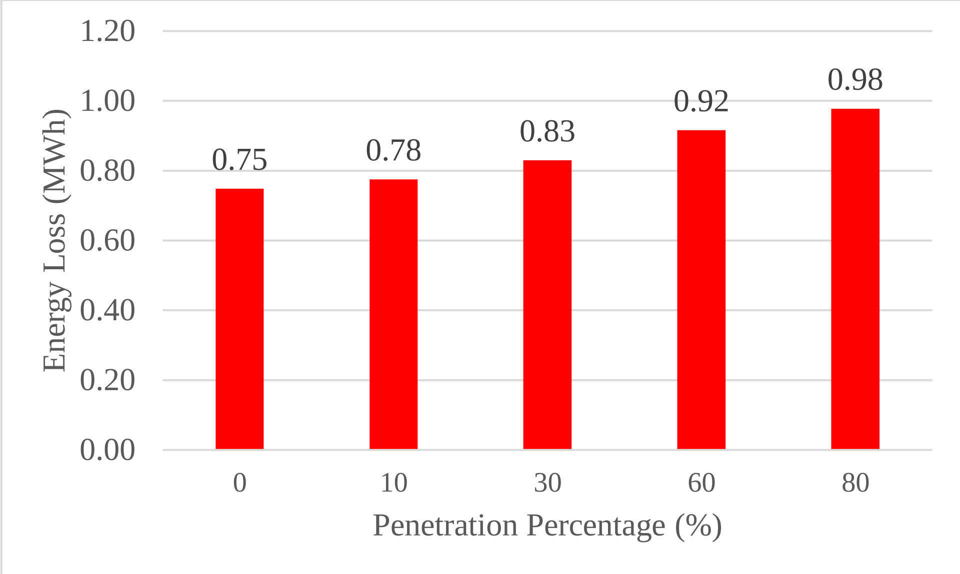

Figure 4.16: Daily Energy Loss with PEVs (Residential Charging Summer Peak)

g) Load Factor

Load factor of feeder degrades with increasing penetration of PEV. It changes from 0.79 (without PEV) to 0.68 at 80 percent of PEV. It shows the degrading nature of the load factor because of the coincidence of residential load and vehicles load. Table 4.8 shows the load factor at a different level of penetration of PEV.

Table 4.8: Load Factor with PEVs (Residential Charging Summer Peak)

Penetration Percentage (%)	Load Factor
0	0.79
10	0.77
30	0.74
60	0.70
80	0.68

4.3.2 Load Flow Analysis with PEV Penetration for Winter Peak

The next study performed is on the winter peak of Bageshwori feeder. with a load of winter peak for the month of Poush (December) with the integration of PEV considering the residential charging. According to the peak of winter for each 15 transformer PEVs are penetrated with different percentage ranging from 10% to 80% and 24-hour load flow is performed and following results are analyzed.

a) Feeder Load Curve

As the feeder curve at the base case is peak at noon, it's because of the dominancy of commercial load. PEVs loads are dominant at evening time, so the peak load of the system shifts towards 18:00 after 60% PEVs. Table 4.9 shows the detailed load of the feeder at 12:00 and 18:00 hours.

Table 4.9: Feeder Load with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	Load (MVA) At 12:00 Hrs	Load (MVA) At 18:00 Hrs	Peak Load (MVA)
0	3.163	2.343	3.163 at 12:00
10	3.205	2.893	3.205 at 12:00
30	3.233	3.077	3.233 at 12:00
60	3.257	3.465	3.465 at 18:00
80	3.293	3.766	3.766 at 18:00

The overall 24 hours load profile of the feeder in terms of MVA is shown in the Figure 4.17.

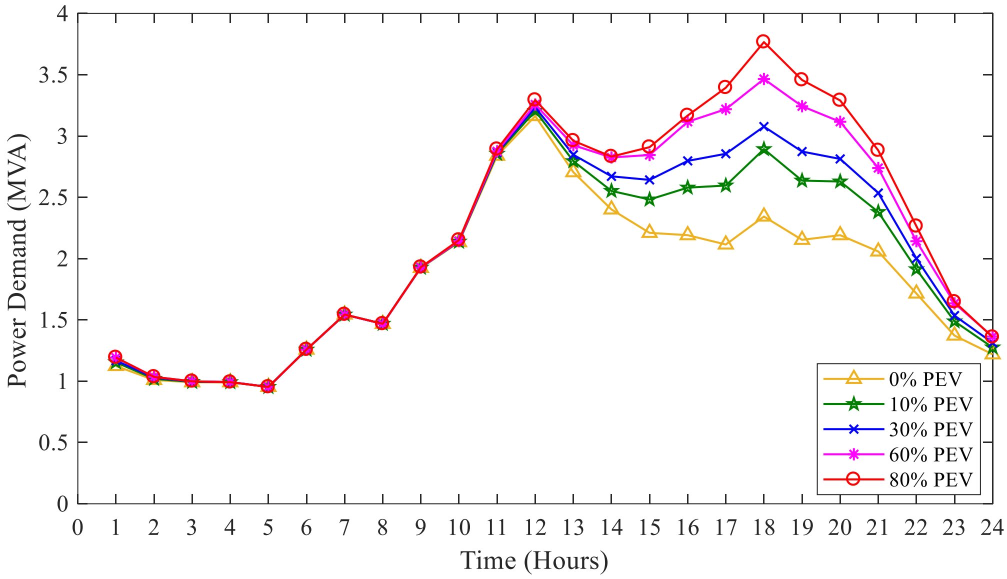

Figure 4.17: Apparent Power with PEVs (Residential Charging Winter Peak)

b) Feeder Power Loss

As the PEV penetration increases the load is increased and loss will also increase. Here in the case of winter peak, PEV load and residential load does not coincide so there is no significant change in loss during noon but at the time 18:00 hours feeder loss increases significantly which is shown in Table 4.10.

Table 4.10: Active Power Loss with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	Power Loss at 12:00 Hrs (MW)	Power Loss at 18:00 Hrs (MW)	Peak Loss (MW)
0	0.0254	0.0139	0.0254 at 12:00
10	0.0261	0.0215	0.0261 at 12:00
30	0.0265	0.0243	0.0265 at 12:00
60	0.0270	0.0310	0.0310 at 18:00
80	0.0277	0.0370	0.0370 at 18:00

The overall curve for 24 hours loss of feeder at different penetration percentage of PEVs is shown in Figure 4.18.

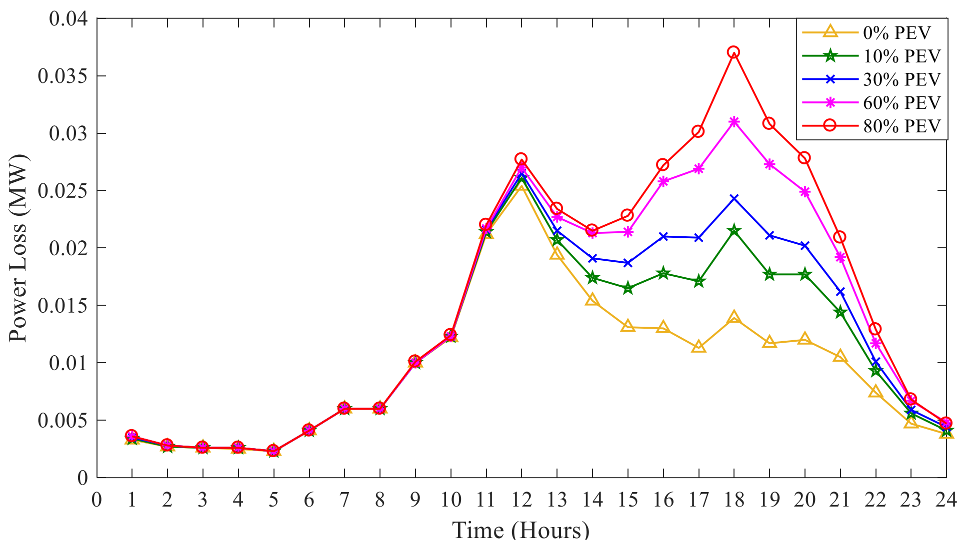

Figure 4.18: Active Power Loss with PEVs (Residential Charging Winter Peak)

c) Voltage Profile of 11kV Bus

The voltage profile of the 11kV bus at two lateral ends, bus 19 and bus 46 is analyzed at a different penetration level of PEVs. In a radial distribution system voltage drop increases as the length increases. The last end of the feeder faces the poorest voltage profile.

i) Voltage Profile of Bus 19 (Gulariya Buspark)

As the PEVs start to penetrate the distribution system, the voltage starts to reduce simultaneously. The minimum voltage at a different level of PEVs at bus 19 is given in Table 4.11.

Table 4.11: Minimum Voltage at Bus 19 with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	**Bus Voltage (pu) At 12:00 Hrs**	**Bus Voltage(pu) At 18:00 Hrs**	**Minimum voltage (pu)**
0	0.98673	0.99027	0.98673 at 12:00
10	0.98653	0.98779	0.98653 at 12:00
30	0.98644	0.98702	0.98644 at 12:00
60	0.98630	0.98526	0.98526 at 18:00
80	0.98611	0.98384	0.98384 at 18:00

The voltage profile of 11 kV bus at Gulariya Buspark is shown in Figure 4.19.

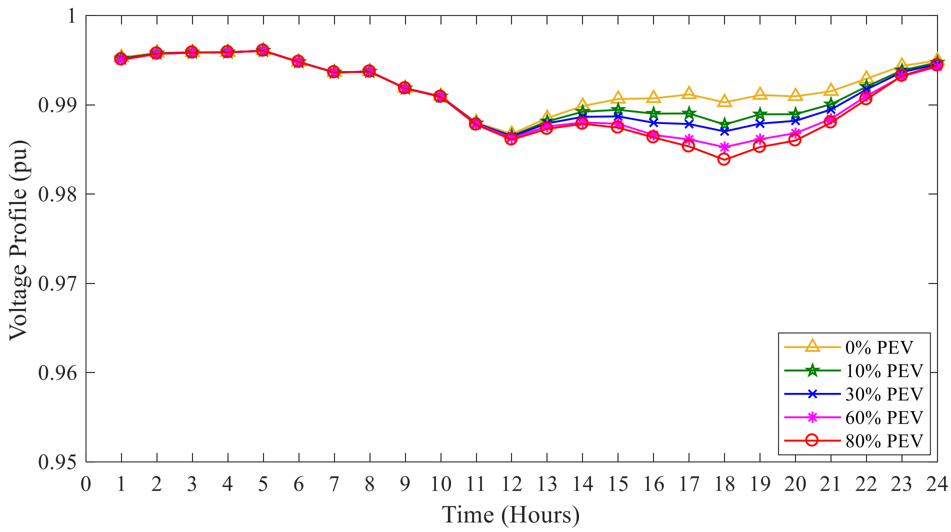

Figure 4.19: Voltage Profile of Bus 19 with PEVs (Residential Charging Winter Peak)

ii) Voltage profile of Bus 46 (Senthomas School)

Another lateral end bus 46 is studied for voltage profile analysis. It is observed that as the penetration increases the minimum voltage is observed. The minimum voltage that appeared at bus 46 is given in Table 4.12.

Table 4.12: Minimum Voltage at Bus 46 with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	**Bus Voltage (pu) At 12:00 Hrs**	**Bus Voltage (pu) At 18:00 Hrs**	**Minimum voltage (pu)**
0	0.98677	0.99014	0.98677 at 12:00
10	0.98657	0.98772	0.98657 at 12:00
30	0.98646	0.98692	0.98646 at 12:00
60	0.98635	0.98523	0.98523 at 18:00
80	0.98614	0.98382	0.98382 at 18:00

The overall voltage profile of bus 46 at different penetration of PEV is shown in Figure 4.20.

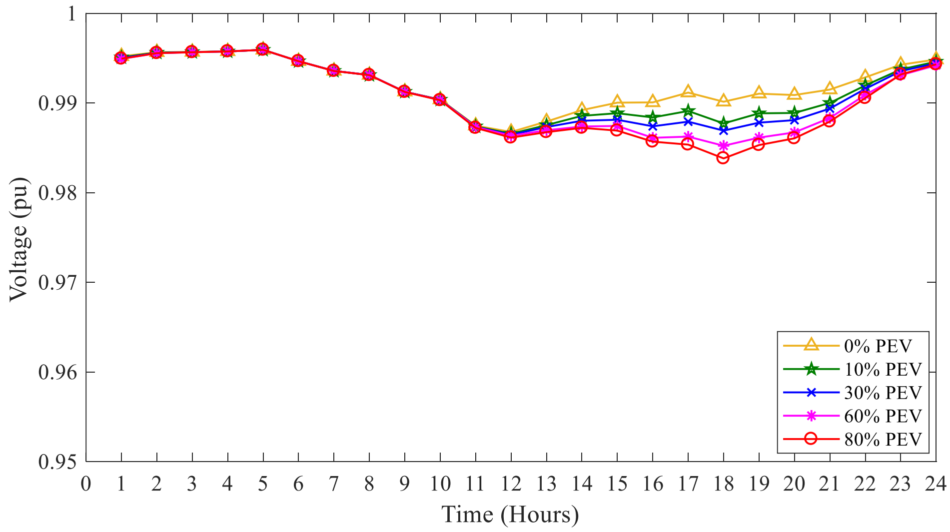

Figure 4.20: Voltage Profile of Bus 46 with PEVs (Residential Charging Winter Peak)

d) Line Loading

The feeder loading increases after the penetration of PEV. As the vehicle penetration are maximum at evening time so the loading of the line changes significantly at 18:00 hours. The loading of the line at time 12:00 and 18:00 hours is shown in Table 4.13. The loading of the line increases from 58.02%% to 69.47 % at 80% of PEVs.

Table 4.13: Line Loading with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	**Line Loading (%) at 12:00 Hrs**	**Line Loading (%) at 18:00 Hrs**	**Maximum Loading (%)**
0	58.02	42.78	58.02 at 12:00
10	58.80	53.01	58.80 at 12:00
30	59.33	56.44	59.33 at 12:00
60	59.79	63.76	63.76 at 18:00

Penetration Percentage (%)	Line Loading (%) at 12:00 Hrs	Line Loading (%) at 18:00 Hrs	Maximum Loading (%)
80	60.45	69.47	69.47 at 18:00

The 24 hours line loading with different level of penetration of PEVs is shown in Figure 4.21.

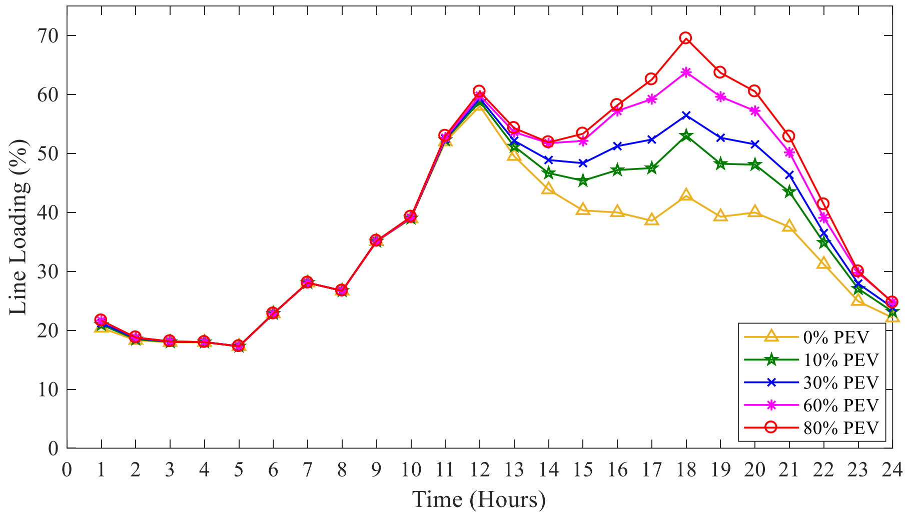

Figure 4.21: Line Loading with PEVs (Residential Charging Winter Peak)

e) Transformer Loading

After the penetration of PEV, loading of the transformer is observed. As the penetration percentage of a vehicle is increased the loading of the transformer is increased which is given in Table 4.14. The transformer Tr-1, Tr-9, and Tr-28 get overloaded at 60% of PEVs whereas Tr-21 and Tr-37 are overloaded after 80% penetration of PEV. But remaining transformers are operating at normal conditions until 80% of PEV penetration.

Table 4.14: Transformer Loading with PEVs (Residential Charging Winter Peak)

Transformer	0% PEV	10% PEV	30% PEV	60% PEV	80% PEV
Tr-1	75.12	83.24	97.90	121.71	137.32
Tr-4	49.74	55.15	66.42	81.61	91.18
Tr-8	42.63	50.43	57.68	69.37	79.75
Tr-9	63.03	71.38	82.75	104.33	117.22
Tr-11	54.65	60.28	71.49	88.04	99.51
Tr-19	37.40	41.42	48.84	61.63	68.06
Tr-21	60.25	67.68	79.05	97.10	109.69
Tr-25	18.91	21.34	24.69	31.14	34.99
Tr-28	63.30	71.67	83.11	104.58	117.87
Tr-37	57.64	64.17	75.97	93.71	106.38

Transformer	0% PEV	10% PEV	30% PEV	60% PEV	80% PEV
Tr-43	26.62	30.44	35.85	43.44	49.03
Tr-46	58.17	65.11	76.58	95.36	109.15
Tr-48	35.81	39.69	46.92	57.62	64.88
Tr-49	9.46	10.65	12.37	15.60	17.21
Tr-52	68.44	78.85	89.83	111.91	127.22

The Figure 4.22 shows the loading of transformer after penetration of PEV at different level.

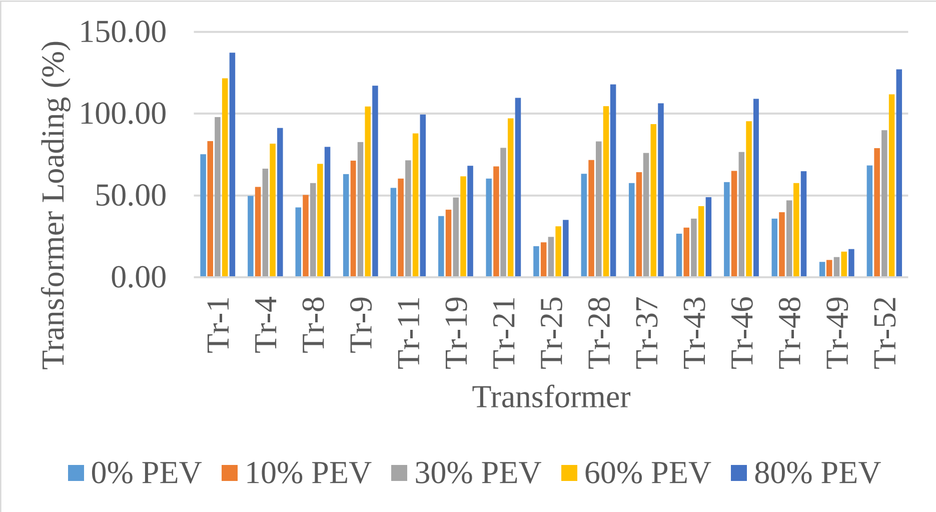

Figure 4.22: Transformer Loading with PEVs (Residential Charging Winter Peak)

f) Energy Loss

The daily energy loss of the feeder is calculated with a 24-hour load flow analysis. The total daily energy loss is 0.23 MWh without PEV and it increases up to 0.37 MWh at 80 % of PEV. Figure 4.23 shows the energy loss at a different penetration level.

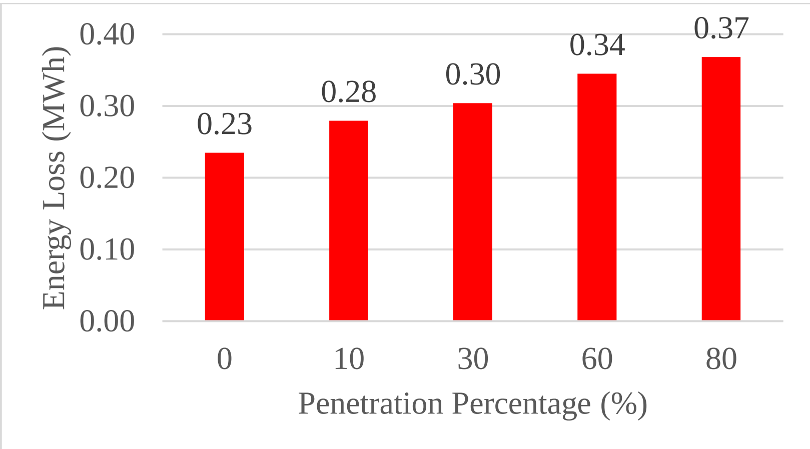

Figure 4.23: Daily Energy Loss with PEVs (Residential Charging Winter Peak)

g) Load Factor

Load factor during winter peak significantly increases up to 30% of PEV because residential peak and vehicle peak does not coincide and load profile is improved. But at 60% and 80% of PEV new peak is obtained at 18:00 hours and again load factor is decreased. The Table 4.15 shows the load factor at different penetration level.

Table 4.15: Load Factor with PEVs (Residential Charging Winter Peak)

Penetration Percentage (%)	Load Factor
0	0.58
10	0.62
30	0.64
60	0.63
80	0.59

4.4 Case IV: PEV Penetration at Public Charging Station

4.4.1 Load Flow Analysis with PEV Penetration for Summer Peak

The load flow analysis after the penetration of PEVs at two different charging stations is performed at different penetration levels ranging from 10% to 60% and the following parameters are analyzed.

a) Feeder Load Curve

As the PEVs are integrated at only two charging stations the feeder peak increases rapidly due to the higher rating of the charger in comparison to the residential charging scenario. It increases from 4.325 MVA without PEV to 5.726 MVA at 60% PEV. The overall feeder peak at different penetration levels is shown in Table 4.16. The result shows the shift in peak load with a change in penetration percentage of the vehicle. Figure 4.24 shows the 24-hour load curve of the feeder at different penetration levels through public charging.

Table 4.16: Feeder Peak Load with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Peak Load (MVA)	Time (Hours)
0	4.325	17:00
10	4.644	17:00
30	5.236	19:00
60	5.726	19:00

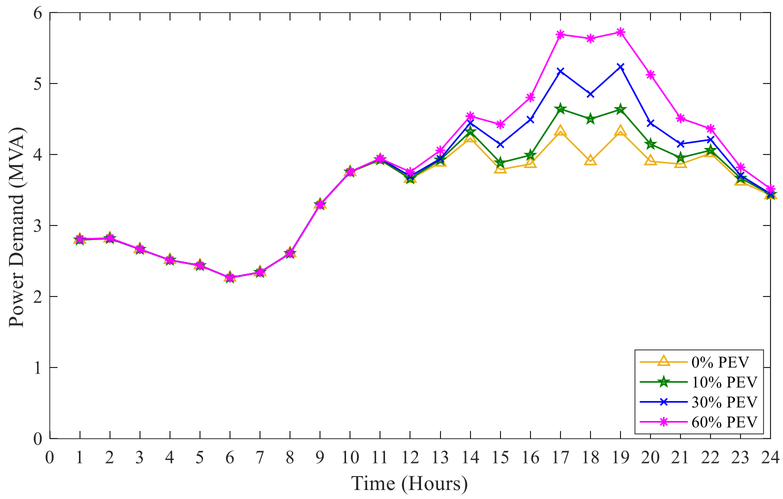

Figure 4.24: Apparent Power with PEVs (Public Charging Summer Peak)

b) Feeder Active Power Loss

Along with the increasing penetration level of PEVs the total power loss of feeder increases. The peak power loss increases from 0.0478 MW at 0% PEV to 0.0943 MW at 60 % of PEV penetration. The peak power loss of feeders at different penetration levels is shown in Table 4.17. Figure 4.25 shows the 24-hour loss of feeder.

Table 4.17: Peak Power Loss with PEVs (Public Charging Summer Peak)

PEV Penetration (%)	Power Loss (MW)	Time (Hours)
0	0.0478	17:00
10	0.0568	17:00
30	0.0748	19:00
60	0.0943	18:00

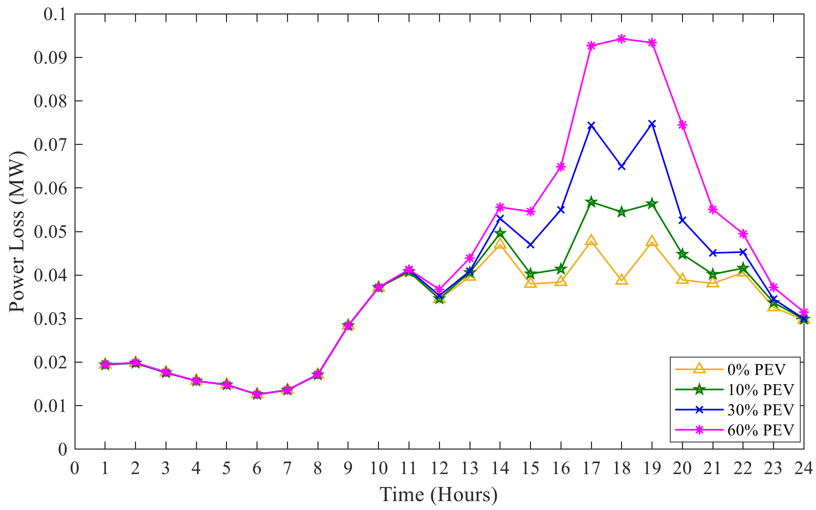

Figure 4.25: Active Power Loss with PEVs (Public Charging Summer Peak)

c) Voltage Profile of 11kV Bus

With the increase in load, voltage drop along with the line increases. Hereafter the penetration of PEVs voltage, the voltage reduces but the limit doesn't exceed because of the shorter length of the feeder.

i) Voltage Profile of Bus 46 (Senthomas School)

The lateral end bus 46 faces the poorest voltage at the initial condition without PEV which is 0.98182 pu. It decreases with the increment in PEVs. The minimum voltage at bus 46 at different penetration levels of PEVs is shown in Table 4.18.

Table 4.18: Minimum Voltage at Bus 46 with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Minimum Bus Voltage (pu)	Time (Hours)
0	0.98182	17:00
10	0.98025	17:00
30	0.97743	19:00
60	0.97501	19:00

The voltage profile of bus 46 at different level of penetration is shown in Figure 4.26.

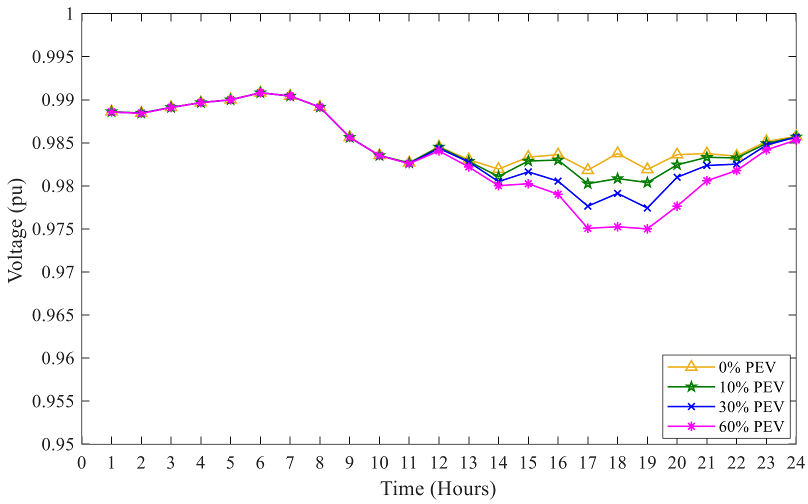

Figure 4.26: Voltage Profile of Bus 46 with PEVs (Public Charging Summer Peak)

ii) Voltage Profile of Bus 19 (Gulariya Buspark)

Public Charging station 2 is located at this bus and it is the farthest end of the feeder so voltage profile is studied. After the PEVs penetration, there is a fall in voltage and the minimum voltage appears at this bus which is shown in Table 4.19. The 24-hour voltage profile is shown in Figure 4.27.

Table 4.19: Minimum Voltage at Bus 19 with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Minimum Bus Voltage (pu)	Time (Hours)
0	0.98183	17:00
10	0.97923	18:00
30	0.97491	17:00
60	0.97060	18:00

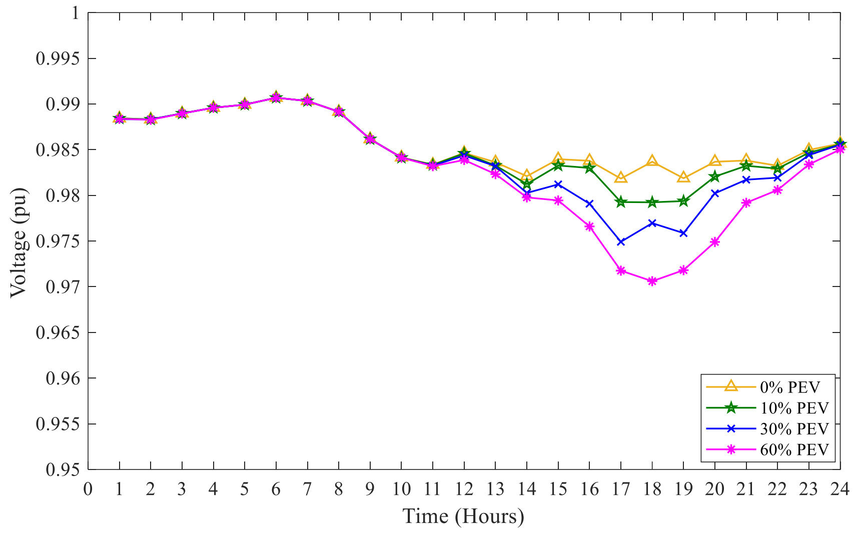

Figure 4.27: Voltage Profile of Bus 19 with PEVs (Public Charging Summer Peak)

iii) Voltage Profile of Bus 11 (Dhomboji Chowk 2)

Public charging station 1 is located at this bus which is in the center of city and feeder. As the load increases after penetration of PEVs, the voltage starts to deviate. The minimum voltage that appeared at this bus is shown in Table 4.20. And 24-hour voltage profile of bus 11 is shown in Figure 4.28.

Table 4.20: Minimum Voltage at Bus 11 with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Minimum Bus Voltage (pu)	Time (Hours)
0	0.98318	17:00
10	0.98162	17:00
30	0.97874	19:00
60	0.97632	19:00

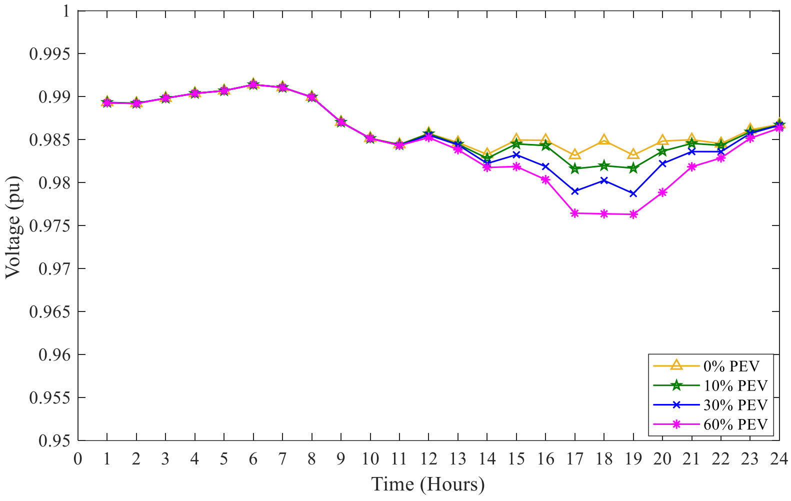

Figure 4.28: Voltage Profile of Bus 11 with PEVs (Public Charging Summer Peak)

d) Line Loading

With the increment in penetration level of PEVs, the line loading also increases. It exceeds the limit at 60% PEV with a line loading of 106.24%. The maximum line loading at different PEVs levels is shown in Table 4.21.

Table 4.21: Maximum Line Loading with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Line Loading (%)	Time (Hours)
0	79.84	17:00
10	85.83	17:00
30	96.95	19:00
60	106.24	19:00

The 24-hour line loading of the feeder at different penetration of PEVs is shown in Figure 4.29.

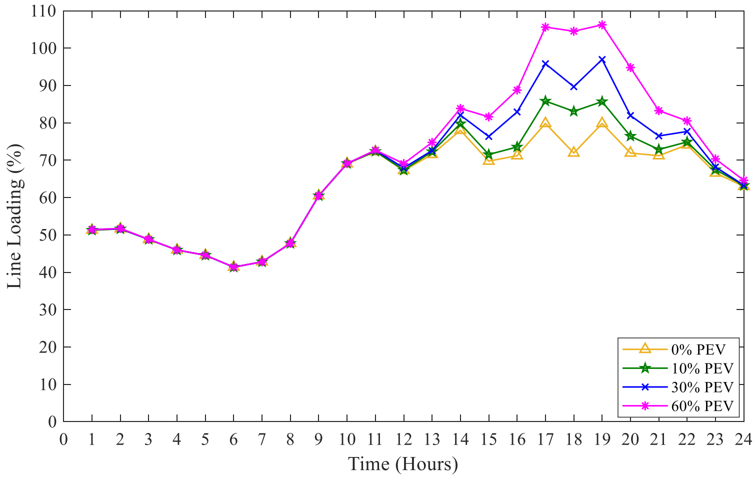

Figure 4.29: Line Loading with PEVs (Public Charging Summer Peak)

e) Energy Loss

The daily energy loss of the feeder is calculated after the 24-hour load flow with the integration of PEV. The total daily energy loss increased from 0.75 MWh to 1.02 MWh after 60% penetration of PEVs. Figure 4.30 shows total energy loss at a different penetration level.

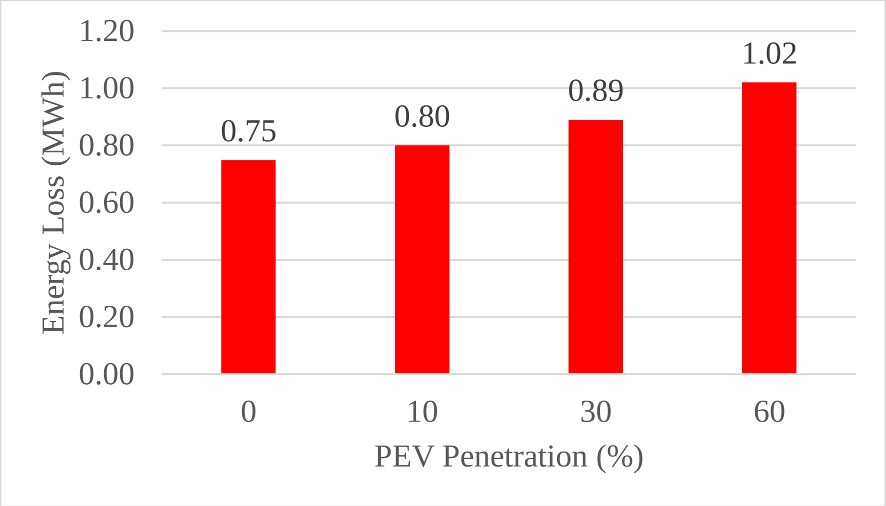

Figure 4.30: Daily Energy Loss with PEVs (Public Charging Summer Peak)

f) Load factor

The load factor of the feeder decreases as the PEVs are integrated through the charging station as the load of the vehicle coincides with the residential load. It decreases from 0.79 without PEV to 0.67 with 60% of PEVs. The load factor of the feeder at different penetration levels of PEVs is shown in Table 4.22.

Table 4.22: Load Factor with PEVs (Public Charging Summer Peak)

Penetration Percentage (%)	Load Factor
0	0.79
10	0.76
30	0.70
60	0.67

4.4.2 Load Flow Analysis with PEV Penetration for Winter Peak

With the charging station located at two different locations, load flow analysis is performed considering the winter peak case for the month of Poush and the following parameters of the distribution system are analyzed.

a) Feeder Load Curve

The feeder load increases with the integration of PEVs. During the winter peak, the vehicle peak and the residential peak do not coincide. Without PEV the feeder peak is 3.163 MVA at noon but it shifts towards evening after 30% of PEV which is shown in Table 4.23. Figure 4.31 shows the load curve of the feeder at different penetration of PEVs.

Table 4.23: Feeder Load with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Load (MVA) At 12:00 Hrs	Load (MVA) At 18:00 Hrs	Peak (MVA)
0	3.163	2.343	3.163 at 12:00
10	3.182	3.051	3.182 at 12:00
30	3.217	3.899	3.899 at 18:00
60	3.235	4.816	4.816 at 18:00

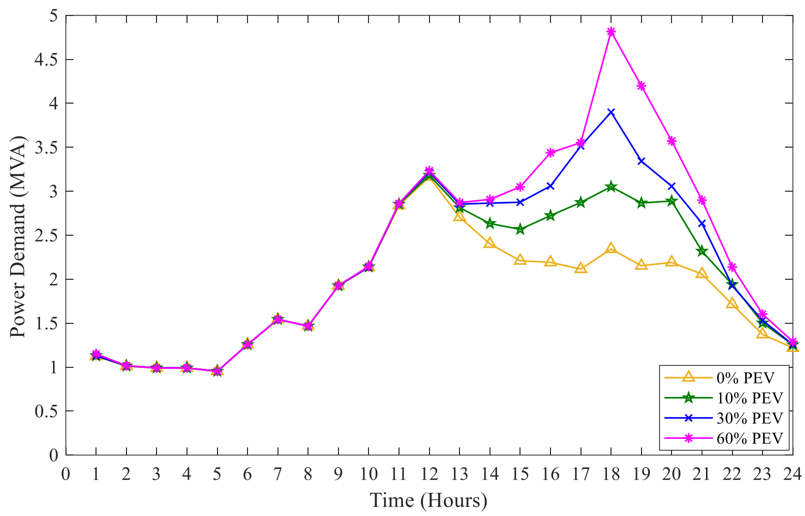

Figure 4.31: Apparent Power with PEVs (Public Charging Winter Peak)

b) Feeder Active Power Loss

As the PEV is penetrated in the distribution system the total loss of feeder is increases. The peak power loss in the feeder is observed at 12:00 hours without PEVs but as the PEV increases the peak power loss is observed at 18:00 hours. The peak power loss of feeders at a different level of PEVs is given in Table 4.24. Figure 4.32 shows the 24-hour loss of the feeder at different penetration of PEVs.

Table 4.24 Active Power Loss with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Power Loss at 12:00 Hrs (MW)	Power Loss at 18:00 Hrs (MW)	Peak Loss (MW)
0	0.0254	0.0139	0.0254 at 12:00
10	0.0258	0.0260	0.0260 at 18:00
30	0.0264	0.0479	0.0479 at 18:00
60	0.0268	0.0780	0.0780 at 18:00

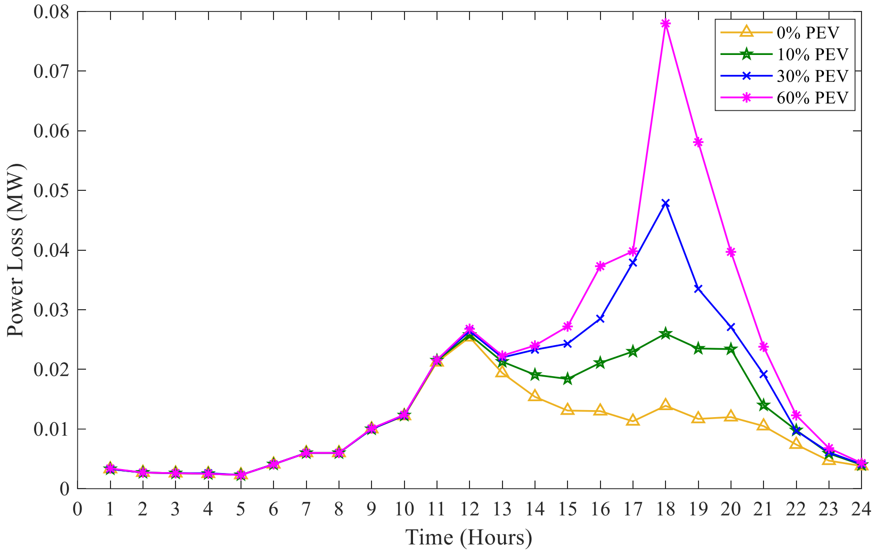

Figure 4.32: Active Power Loss with PEVs (Public Charging Winter Peak)

c) Voltage Profile of 11kV Bus

After the integration of PEVs at charging station at winter peak case the voltage profile of farthest end bus and bus with charging station is observed.

i) Voltage Profile of Bus 19 (Gulariya Buspark)

As bus 19 is the endpoint of the feeder and charging station 2 is connected to this bus, the minimum voltage is appeared before PEVs and after PEVs too. The minimum voltage at different PEV percentages is given in Table 4.25. Figure 4.33 shows the overall voltage profile of bus 19.

Table 4.25: Minimum Voltage at Bus 19 with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Bus Voltage (pu) At 12:00 Hrs	Bus Voltage (pu) At 18:00 Hrs	Minimum voltage (pu)
0	0.98673	0.99027	0.98673 at 12:00
10	0.98659	0.98528	0.98528 at 18:00
30	0.98637	0.97825	0.97825 at 18:00
60	0.98619	0.97170	0.97170 at 18:00

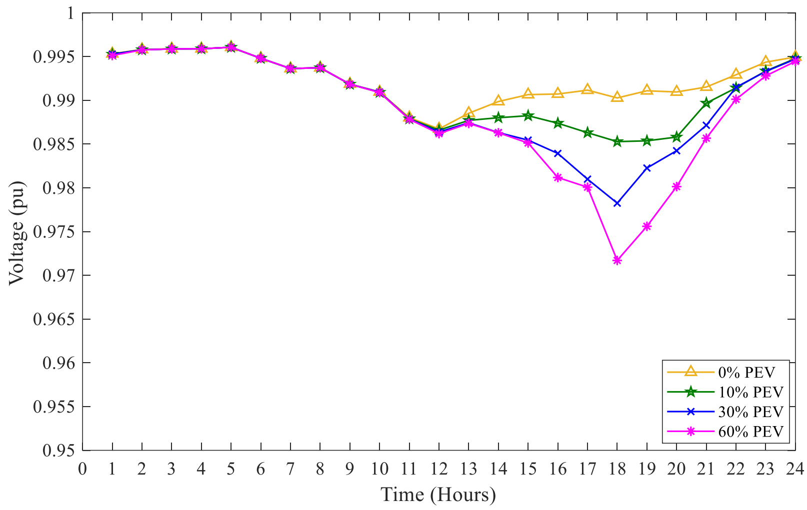

Figure 4.33: Voltage Profile of Bus 19 with PEVs (Public Charging Winter Peak)

ii) Voltage Profile of Bus 46 (Senthomas School)

The lateral end of the feeder also faces the minimum voltage with the increment of load in the feeder. The minimum voltage appeared at bus 46 with a different penetration level of PEV is shown in Table 4.26. Similarly, the 24-hour load profile of bus 46 is shown in Figure 4.34.

Table 4.26: Minimum Voltage at Bus 46 with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Bus Voltage (pu) At 12:00 Hrs	Bus Voltage (pu) At 18:00 Hrs	Minimum Voltage (pu)
0	0.98677	0.99014	0.98677 at 12:00
10	0.98668	0.98673	0.98668 at 12:00
30	0.98651	0.98259	0.98259 at 18:00
60	0.98642	0.97807	0.97807 at 18:00

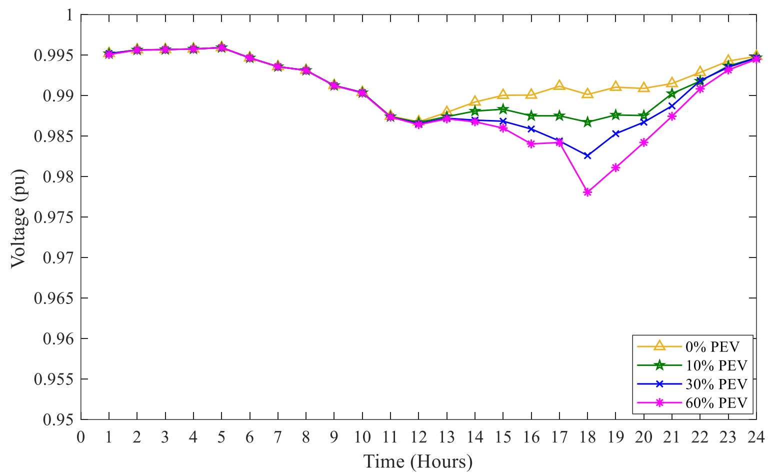

Figure 4.34: Voltage Profile of Bus 46 with PEVs (Public Charging Winter Peak)

iii) Voltage Profile of Bus 11 (Dhomboji Chowk 2)

The charging station1 is located at bus 11 and the voltage profile is observed. The minimum voltage that appeared at a different level of penetration is given in Table 4.27. Similarly, the overall 24-hour voltage profile is shown in Figure 4.35.

Table 4.27: Minimum Voltage at Bus 11 with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Bus Voltage (pu) At 12:00 Hrs	Bus Voltage (pu) At 18:00 Hrs	Minimum Voltage (pu)
0	0.98775	0.99094	0.98775 at 12:00
10	0.98766	0.98753	0.98753 at 18:00
30	0.98749	0.98340	0.98340 at 18:00
60	0.98740	0.97888	0.97888 at 18:00

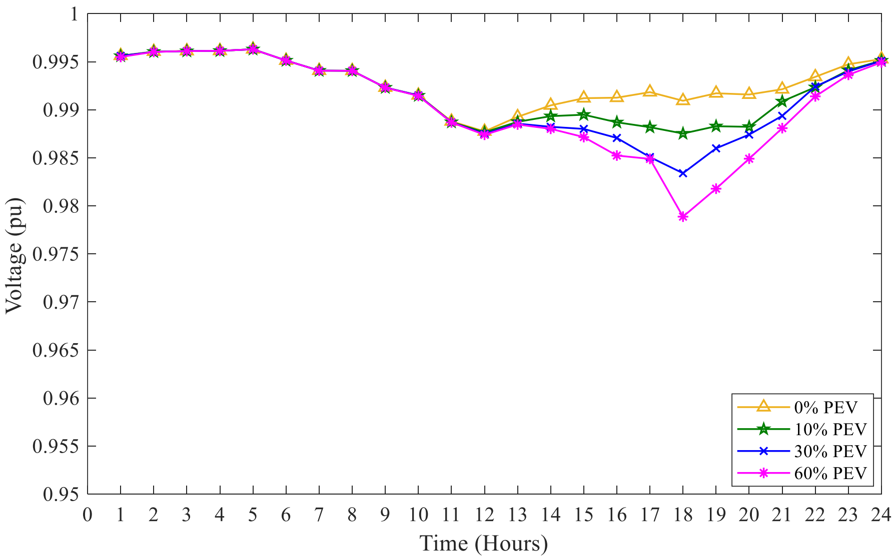

Figure 4.35: Voltage Profile Bus 11 with PEVs (Public Charging Winter Peak)

d) Line Loading

The line loading of the feeder increases with an increase in the penetration level. The maximum loading of the feeder conductor does not exceed the limit of up to 80% of PEV in winter cases. The maximum loading of the line at a different level of PEVs is given in Table 4.28. Figure 4.36 shows the 24-hour loading of the line.

Table 4.28: Line Loading with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Line Loading (%) at 12:00 Hrs	Line Loading (%) at 18:00 Hrs	Maximum Loading (%)
0	58.02	42.78	58.02 at 12:00
10	58.38	55.84	58.38 at 12:00
30	59.02	71.68	71.68 at 12:00
60	59.36	88.97	88.97 at 18:00

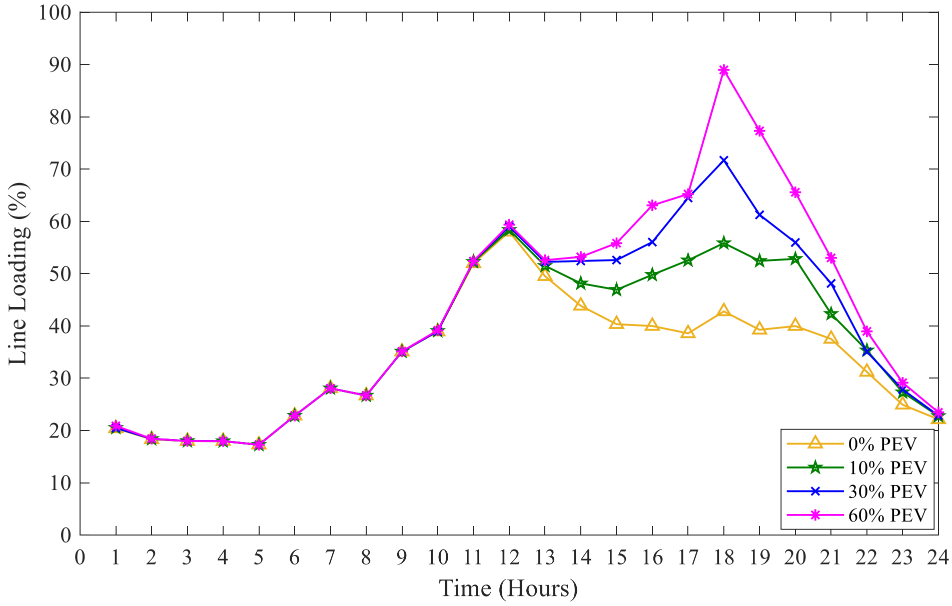

Figure 4.36: Line Loading with PEVs (Public Charging Winter Peak)

e) Energy Loss

The daily energy loss is also calculated after the integration of PEVs at the charging station. The total energy loss increased from 0.23 MWh to 0.47 MWh after 60% penetration of PEV. The total daily energy loss at a different level of PEVs is shown in Figure 4.37.

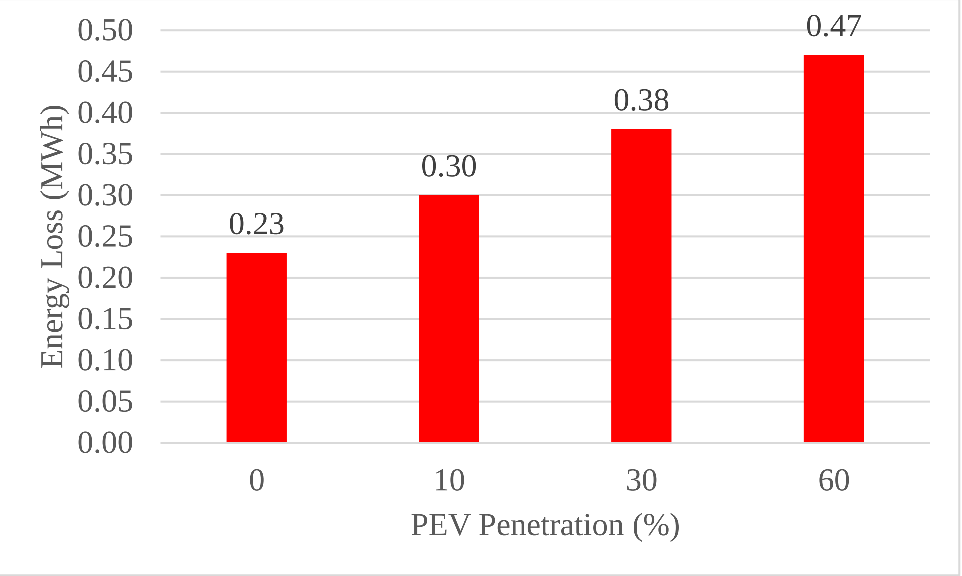

Figure 4.37: Daily Energy Loss with PEVs (Public Charging Winter Peak)

f) Load Factor

The load factor indicates the smoothness of the load curve. As the winter peak is at mid-day so, up to 10% of PEV shows the improvement in load factor. But after that increment of PEV will further increase the peak in the evening and the load factor again starts to decrease. The load factor of the feeder at a different level of penetration is shown in Table 4.29.

Table 4.29: Load Factor with PEVs (Public Charging Winter Peak)

Penetration Percentage (%)	Load Factor
0	0.58
10	0.64
30	0.56
60	0.48

4.5 Discussion on Results

The real case study of Bageshwori feeder after the integration of PEV shows an increment in feeder peak and power loss with the overloading of the different transformers. Under residential charging scenarios, line loading is violated with 80% of PEV (1678 numbers of PEV) whereas voltage is under the limit, whereas for public charging scenarios line was overloaded with 60% of PEV (1221 numbers of PEV). The overloading is observed in the summer peak only. A similar Result of feeder overloading and poor voltage was observed in the Hungarian Distribution system with 60% of PEV under uncoordinated charging (Ramadan, et al., 2018). In real case study of Gothenburg, overloading of line and transformer at simultaneous charging of vehicle at peak load time but there was no problem with voltage drop (Babaei, et al., 2010).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

The research work in this thesis focused on the assessment of the distribution system of Bageshwori feeder with the stochastic load profile of PEVs. The distribution system is analyzed in terms of feeder peak load, total line losses, voltage profile, and transformer loading, line loading, and energy loss after the penetration of PEVs. Following conclusions are made after the analysis.

- Stochastic charging profile of PEV is modeled and demand profile of PEV fleet is obtained for different penetration level.
- Load flow of IEEE-33 bus radial distribution system is performed using DigSILENT software and total power loss of 210 kW and minimum voltage of 0.90400 pu is obtained. This is done to verify the DigSILENT software setup for distribution system modeling.
- Bageshwori Feeder of Nepalgunj substation is modeled in DigSILENT software and load flow is performed successfully for the base case of both summer and winter peak. The peak load for summer is found to be 4.325 MVA at 17:00 hours with a peak power loss of 0.0478 MW. The minimum voltage of 0.98182 pu is found at bus 46 (Senthomas School) at 17:00 which is the lateral ends. Similarly, the peak load of winter is found at 3.163 MVA at noon with a peak power loss of 0.0254 MW. The minimum voltage of 0.98673 pu is obtained at bus 19 (Gulariya Buspark) at noon. The winter peak is during midday because of the dominant commercial load.
- Considering residential charging, for summer case feeder peak increase by 29.82 % with 80% of PEV resulting in the violation of line loading and overloading of 10 transformers. At the same time, feeder peak power loss increased by 72.38% whereas daily energy loss increases by 30.67% without violating the voltage drop limit. In winter case too, the feeder peak increases by 19.06% for 80% penetration of PEVs with an increase in peak power loss by 45.66% and daily energy loss by 60.86%. There is no violation of line loading and voltage drop limit in winter peak, but seven transformer gets overloaded. Hence considering the worst-case scenario of summer, as the feeder gets overloaded at 80% of PEV (1678 numbers of PEV), so only up to 60% of PEV (1221 numbers of PEV) can be penetrated without violating any distribution system parameters in existing infrastructure.

- Observing the public charging scenario, in the summer peak case, feeder peak load increases by 32.39% with only 60% penetration of PEV leading to 106.24% loading of the line thus exceeding the limit. At the same time, feeder peak power loss increases by 97.28% whereas daily energy loss increased by 36.00% without violation of voltage drop. Similarly, for the winter peak case, feeder peak load increases by 52.26% at 60% penetration of PEV but there is no overloading of line and hence no violation of distribution system parameter at all. But the feeder peak power loss increases by 207.08 % with 60% of PEV along with a 104.34% increment in daily energy loss. Hence considering the summer peak case with public charging scenario, feeder loading is violated at 60% of PEV (1221 numbers of PEV), so only 30% of PEV (646 number of PEV) can be penetrated without overloading of line in existing scenario.

Following recommendation are made after the conclusion of this thesis

- Coordinated charging should be emphasized for both residential and public charging to for peak clipping and valley filling of load curve.
- Time of use tariff must be implemented for residential charging for promoting the off-peak charging.
- Unbalance load flow should be performed to determine the voltage unbalance effect of PEVs.
- Similar study should be conducted on major city of Nepal so that vehicles load in near future can be forecasted which helps utility to reinforce their distribution system.

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APPENDIX A: Load Profile of Distribution Transformer (Summer Peak, Ashad)

Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Transformer Load	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA
AG Bank NEA	130	133	126	117	114	103	108	117	136	155	164	157	161	177	151	169	199	178	199	173	175	191	173	162
Aman Krishi Farm Pvt	5	7	7	7	5	24	5	4	9	13	14	8	13	8	8	9	11	9	9	10	9	9	20	5
Angel School PVT	4	2	4	4	3	0	7	9	12	8	9	8	12	7	8	5	5	5	5	6	4	4	4	2
Bageshwori Mandir vitra NEA	89	88	84	78	76	68	72	78	91	103	110	105	107	118	101	113	133	119	133	115	117	128	115	108
Civil Plastic PVT	31	72	60	88	85	56	62	143	215	270	259	256	246	247	307	256	225	143	194	227	242	81	80	140
Cygnett Hotel PVT	54	42	43	44	38	37	43	45	115	94	67	96	87	85	46	51	54	64	50	80	52	56	35	43
DK Food PVT	18	20	19	19	11	27	19	20	3	6	8	29	6	21	19	17	13	17	11	14	20	19	20	21
Dailekhi Tol NEA	38	38	36	33	33	29	31	33	39	44	47	45	46	51	43	48	57	51	57	49	50	55	49	46
Dewa Fulbari NEA	56	56	53	49	48	43	46	49	58	65	69	66	68	75	64	71	84	75	84	73	74	81	73	68
Dhomboji Chowk 1 NEA	80	79	75	70	68	62	65	70	82	93	98	94	96	106	90	101	119	107	119	104	105	115	104	97
Dhomboji Chowk 2 NEA	194	194	183	170	167	150	158	171	199	226	240	229	235	259	220	247	291	260	291	253	255	279	252	237
East Gumba NEA	50	50	47	44	43	38	41	44	51	58	61	59	60	66	56	63	75	67	75	65	65	72	65	61
East Puja Dal Mill NEA	57	56	53	50	49	44	46	50	58	66	70	67	68	75	64	72	85	76	85	74	74	81	74	69
Everest Bank PVT	1	1	1	1	1	1	1	1	6	9	9	10	10	10	14	12	13	9	4	4	1	1	1	1
Front AG Bank NEA	77	76	72	67	66	59	62	67	78	89	94	90	93	102	87	97	115	103	115	100	100	110	99	93
Ganesh Pur Chowk NEA	50	50	47	44	43	39	41	44	52	58	62	59	61	67	57	64	75	67	75	65	66	72	65	61
Gharbari Tol NEA	96	96	91	84	82	74	78	85	98	112	119	113	116	128	109	122	144	129	144	125	126	138	125	117
Gokul Mill Front NEA	41	41	38	36	35	31	33	36	42	47	50	48	49	54	46	52	61	55	61	53	53	59	53	50
Gulariya Buspark NEA	67	66	63	58	57	51	54	59	68	77	82	78	81	89	75	85	100	89	100	87	87	96	87	81
Gumba NEA	25	25	24	22	22	20	21	22	26	29	31	30	31	34	29	32	38	34	38	33	33	36	33	31
Gumba Nera NEA	107	107	101	94	92	83	87	94	110	125	132	126	130	143	122	136	161	144	161	140	141	154	139	131
Hello Satellite PVT	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Transformer Load	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA
Hitesh Khadye Ind PVT	5	6	6	5	4	5	6	6	186	202	247	7	209	218	185	38	9	6	5	4	5	5	5	6
Hotel City Palace PVT	42	41	37	40	32	66	36	51	53	54	56	66	63	60	69	50	50	37	56	54	47	60	41	41
Hotel Shrinet NEA	51	51	48	44	44	39	41	45	52	59	63	60	61	68	57	64	76	68	76	66	67	73	66	62
Jilla Police Office NEA	42	42	40	37	36	33	34	37	43	49	52	50	51	56	48	53	63	56	63	55	55	61	55	51
Jumli Tole Jane Bato NEA	53	53	50	46	46	41	43	47	54	62	65	62	64	71	60	67	79	71	79	69	70	76	69	65
Jumli Tole NEA	56	56	53	49	48	43	46	49	58	65	69	66	68	75	64	71	84	75	84	73	74	81	73	68
Jyoti Bikas Bank NEA	29	29	27	25	25	22	24	26	30	34	36	34	35	39	33	37	43	39	43	38	38	42	38	35
Kalopatro Hotel Pvt	51	47	49	48	49	57	48	57	55	64	61	71	74	81	81	78	70	75	76	77	90	94	78	49
Khanal Complex PVT	27	27	22	16	17	15	24	35	24	26	20	29	24	30	30	32	30	30	35	38	38	36	30	26
Maruti Nandan PVT	37	42	38	33	32	34	33	23	22	28	23	21	21	34	27	27	16	24	33	36	46	50	42	40
North Ganeshpur Chowk NEA	84	84	79	73	72	65	68	74	86	97	103	99	101	112	95	106	125	112	125	109	110	120	109	102
North seto BK Chowk NEA	96	96	91	84	82	74	78	85	98	112	119	113	116	128	109	122	144	129	144	125	126	138	125	117
OM Plywood PVT	0	0	0	0	0	2	0	0	0	4	2	3	2	2	2	2	2	2	0	0	2	0	0	0
Om Cottage NEA	100	99	94	87	86	77	81	88	102	116	123	117	121	133	113	126	149	134	149	130	131	143	129	121
Plywood Industries NEA	51	51	48	45	44	39	42	45	52	60	63	60	62	68	58	65	77	69	77	67	67	74	67	62
Puja Dal Mill NEA	51	51	48	45	44	39	42	45	52	60	63	60	62	68	58	65	77	69	77	67	67	74	67	62
QFX Cinemas PVT	16	17	16	12	10	8	18	9	8	14	3	47	39	40	37	46	27	36	37	39	29	9	10	11
RNAC NEA	47	46	44	41	40	36	38	41	48	54	58	55	56	62	53	59	70	63	70	61	61	67	61	57
RNAC PVT	0	0	0	0	0	0	0	1	4	4	3	4	4	3	4	4	4	3	3	1	1	1	0	0
Rai Mart PVT	4	4	4	4	5	5	5	5	10	13	13	14	16	14	90	73	65	63	64	64	4	4	4	4
Regional West NEA	48	48	45	42	41	37	39	42	49	56	59	57	58	64	54	61	72	64	72	62	63	69	62	58
SOS NEA	63	63	59	55	54	49	51	55	65	73	78	74	76	84	71	80	94	84	94	82	83	91	82	77
Sanima Bank PVT	12	13	13	13	12	14	14	14	13	16	16	15	15	16	15	15	16	17	11	11	10	11	11	12
Senthomas School NEA	52	51	49	45	44	40	42	45	53	60	64	61	62	69	58	66	77	69	77	67	68	74	67	63

Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Transformer Load	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA
Seto BK Chowk NEA	90	89	85	79	77	69	73	79	92	104	111	106	108	120	102	114	134	120	134	117	118	129	117	109
Seto BK Chowk New NEA	96	96	91	84	82	74	78	85	98	112	119	113	116	128	109	122	144	129	144	125	126	138	125	117
Shiva Mandir 1 NEA	25	25	24	22	22	20	21	22	26	29	31	30	31	34	29	32	38	34	38	33	33	36	33	31
Shiva Mandir NEA	34	34	32	30	29	26	28	30	35	40	42	40	41	45	38	43	51	46	51	44	45	49	44	41
Siddhartha Cottage PVT	10	10	8	9	6	6	6	8	13	10	12	9	7	9	7	8	4	11	10	8	5	5	8	11
Subodh Sir Ghar NEA	61	60	57	53	52	47	49	53	62	71	75	71	73	81	69	77	91	81	91	79	80	87	79	74
Triveni Mode NEA	190	190	180	167	163	147	155	167	195	221	235	224	230	254	215	241	285	255	285	247	250	274	247	232
Western Business PVT	0	0	0	0	0	0	0	0	8	39	44	46	43	43	38	0	0	33	12	10	10	10	11	0

APPENDIX B: Load Profile of Distribution Transformer (Winter Peak, Poush)

Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Transformer Load	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA
AG Bank NEA	42	36	34	35	34	48	64	46	70	79	117	147	109	91	83	81	99	97	91	94	89	73	55	48
Aman Krishi Farm Pvt	3	3	3	3	3	3	3	5	4	4	6	2	3	3	3	4	7	13	10	11	16	8	12	3
Angel School PVT	1	1	0	0	13	8	0	5	4	4	5	2	4	2	7	5	2	3	3	2	2	0	0	0
Bageshwori Mandir vitra NEA	28	24	23	24	23	32	43	31	46	53	78	98	73	60	55	54	66	64	61	62	60	49	37	32
Civil Plastic PVT	138	145	164	136	127	147	119	176	177	175	138	160	175	184	154	173	110	182	148	150	126	133	128	129
Cygnett Hotel PVT	19	19	19	19	19	18	18	24	22	28	24	24	19	52	49	49	16	24	23	32	32	18	19	25
DK Food PVT	19	12	13	13	12	11	15	28	14	22	15	30	26	14	15	16	16	20	20	16	16	16	12	12
Dailekhi Tol NEA	12	10	10	10	10	14	18	13	20	23	33	42	31	26	24	23	28	28	26	27	26	21	16	14
Dewa Fulbari NEA	18	15	14	15	14	20	27	19	29	33	49	62	46	38	35	34	42	41	38	39	38	31	23	20
Dhomboji Chowk 1 NEA	25	22	20	21	20	29	38	28	42	47	70	88	65	54	50	48	59	58	54	56	53	44	33	28
Dhomboji Chowk 2 NEA	61	53	50	51	50	71	93	67	101	116	171	214	159	132	121	118	145	141	133	136	130	106	81	69
East Gumba NEA	16	13	13	13	13	18	24	17	26	30	44	55	41	34	31	30	37	36	34	35	33	27	21	18
East Puja Dal Mill NEA	18	15	14	15	14	21	27	20	30	34	50	62	46	39	35	34	42	41	39	40	38	31	24	20
Everest Bank PVT	1	1	1	1	1	1	1	1	6	14	5	4	5	8	3	4	5	3	3	2	2	1	1	1
Front AG Bank NEA	24	21	20	20	20	28	37	27	40	46	67	84	63	52	48	46	57	56	52	54	51	42	32	27
Ganesh Pur Chowk NEA	16	14	13	13	13	18	24	17	26	30	44	55	41	34	31	31	37	37	34	35	34	27	21	18
Gharbari Tol NEA	30	26	25	25	24	35	46	33	50	57	84	106	79	65	60	58	72	70	66	67	64	52	40	34
Gokul Mill Front NEA	13	11	10	11	10	15	20	14	21	24	36	45	33	28	25	25	30	30	28	29	27	22	17	15
Gulariya Buspark NEA	21	18	17	18	17	24	32	23	35	40	59	73	55	45	42	40	50	48	45	47	45	36	28	24
Gumba NEA	8	7	6	7	6	9	12	9	13	15	22	28	21	17	16	15	19	18	17	18	17	14	11	9
Gumba Nera NEA	34	29	27	28	27	39	52	37	56	64	94	118	88	73	67	65	80	78	73	75	72	59	45	38
Hello Satellite PVT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time (Hours)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Transformer Load	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**	**KVA**
Hitesh Khadye Ind PVT	4	4	5	4	5	5	4	209	209	214	250	4	249	244	244	245	12	25	4	3	3	4	4	4
Hotel City Palace PVT	37	37	29	34	36	45	48	52	46	46	30	32	28	29	26	19	23	39	39	42	48	34	32	37
Hotel Shrinet NEA	16	14	13	13	13	18	24	18	26	30	45	56	42	35	32	31	38	37	35	36	34	28	21	18
Jilla Police Office NEA	13	11	11	11	11	15	20	15	22	25	37	46	35	29	26	26	31	31	29	30	28	23	18	15
Jumli Tole Jane Bato NEA	17	14	14	14	14	19	25	18	28	32	47	58	43	36	33	32	40	38	36	37	36	29	22	19
Jumli Tole NEA	18	15	14	15	14	20	27	19	29	33	49	62	46	38	35	34	42	41	38	39	38	31	23	20
Jyoti Bikas Bank NEA	9	8	7	8	7	11	14	10	15	17	25	32	24	20	18	18	22	21	20	20	19	16	12	10
Kalopatro Hotel Pvt	54	54	56	53	43	53	64	45	58	57	57	58	51	52	37	37	3	78	67	66	60	68	59	51
Khanal Complex PVT	23	17	16	23	12	21	26	12	14	15	22	17	16	16	22	21	23	33	36	30	29	24	28	22
Maruti Nandan PVT	8	9	13	10	14	13	20	14	8	10	9	9	10	19	12	11	0	10	10	14	14	15	11	10
North Ganeshpur Chowk NEA	26	23	21	22	21	30	40	29	44	50	74	92	69	57	52	51	62	61	57	59	56	46	35	30
North seto BK Chowk NEA	30	26	25	25	24	35	46	33	50	57	84	106	79	65	60	58	72	70	66	67	64	52	40	34
OM Plywood PVT	0	0	0	0	0	0	0	2	3	3	0	2	0	2	0	2	1	1	0	0	0	0	0	0
Om Cottage NEA	31	27	26	26	25	36	48	35	52	59	88	110	82	68	62	60	74	72	68	70	67	54	41	36
Plywood Industries NEA	16	14	13	14	13	19	25	18	27	30	45	56	42	35	32	31	38	37	35	36	34	28	21	18
Puja Dal Mill NEA	16	14	13	14	13	19	25	18	27	30	45	56	42	35	32	31	38	37	35	36	34	28	21	18
QFX Cinemas PVT	8	7	8	8	7	7	7	7	10	12	20	18	26	33	30	34	0	36	35	31	15	8	7	8
RNAC NEA	15	13	12	12	12	17	22	16	24	28	41	51	38	32	29	28	35	34	32	33	31	26	19	17
RNAC PVT	0	0	0	0	0	0	0	1	2	1	1	1	1	1	1	2	2	2	1	1	0	0	0	0
Rai Mart PVT	3	3	4	3	3	3	3	5	9	11	10	11	11	11	9	10	0	13	11	10	4	4	3	3
Regional West NEA	15	13	12	13	12	17	23	17	25	29	42	53	39	33	30	29	36	35	33	34	32	26	20	17
SOS NEA	20	17	16	17	16	23	30	22	33	37	55	69	52	43	39	38	47	46	43	44	42	34	26	22
Sanima Bank PVT	14	14	14	14	13	11	12	12	11	11	11	14	13	12	12	12	13	13	13	13	13	13	13	14
Senthomas School NEA	16	14	13	14	13	19	25	18	27	31	45	57	42	35	32	31	39	38	35	36	35	28	21	18

Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Transformer Load	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA
Seto BK Chowk NEA	28	24	23	24	23	33	43	31	47	53	79	99	73	61	56	54	67	65	61	63	60	49	37	32
Seto BK Chowk New NEA	30	26	25	25	24	35	46	33	50	57	84	106	79	65	60	58	72	70	66	67	64	52	40	34
Shiva Mandir 1 NEA	8	7	6	7	6	9	12	9	13	15	22	28	21	17	16	15	19	18	17	18	17	14	11	9
Shiva Mandir NEA	11	9	9	9	9	12	16	12	18	20	30	37	28	23	21	21	25	25	23	24	23	19	14	12
Siddhartha Cottage PVT	9	11	11	12	10	9	11	12	16	15	40	24	22	15	17	22	13	30	27	26	15	12	9	12
Subodh Sir Ghar NEA	19	16	16	16	15	22	29	21	32	36	53	67	50	41	38	37	45	44	41	43	41	33	25	22
Triveni Mode NEA	60	52	49	50	48	69	92	66	99	113	167	210	156	129	119	115	142	138	130	134	128	104	79	68
Western Business PVT	0	0	0	0	0	0	0	0	18	18	18	17	17	17	22	20	21	18	11	0	0	0	0	0

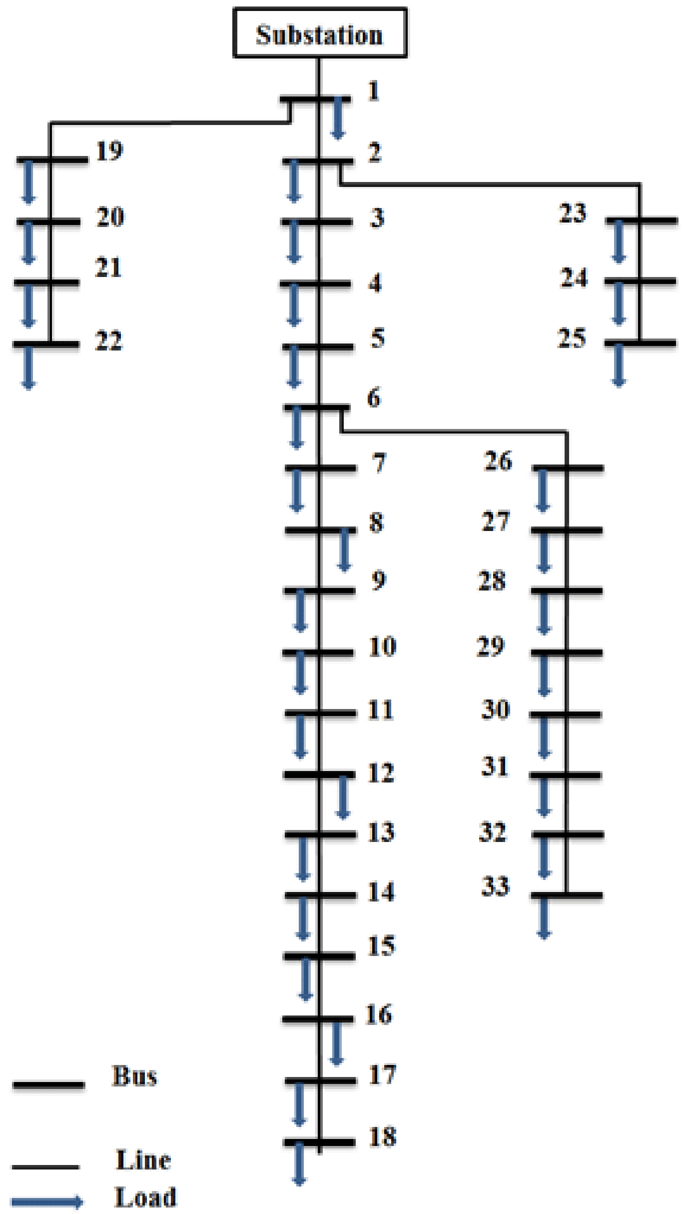
APPENDIX C: Load Profile of Bageshwori Feeder

Time (Hours)	Summer Peak (MVA)	Winter Peak (MVA)
1	2.801	1.124
2	2.820	1.010
3	2.667	0.991
4	2.515	0.991
5	2.439	0.953
6	2.267	1.257
7	2.343	1.543
8	2.610	1.467
9	3.296	1.924
10	3.753	2.134
11	3.925	2.839
12	3.658	3.163
13	3.887	2.705
14	4.230	2.401
15	3.791	2.210
16	3.868	2.191
17	4.325	2.115
18	3.906	2.343
19	4.325	2.153
20	3.906	2.191
21	3.868	2.058
22	4.020	1.715
23	3.620	1.372
24	3.429	1.219

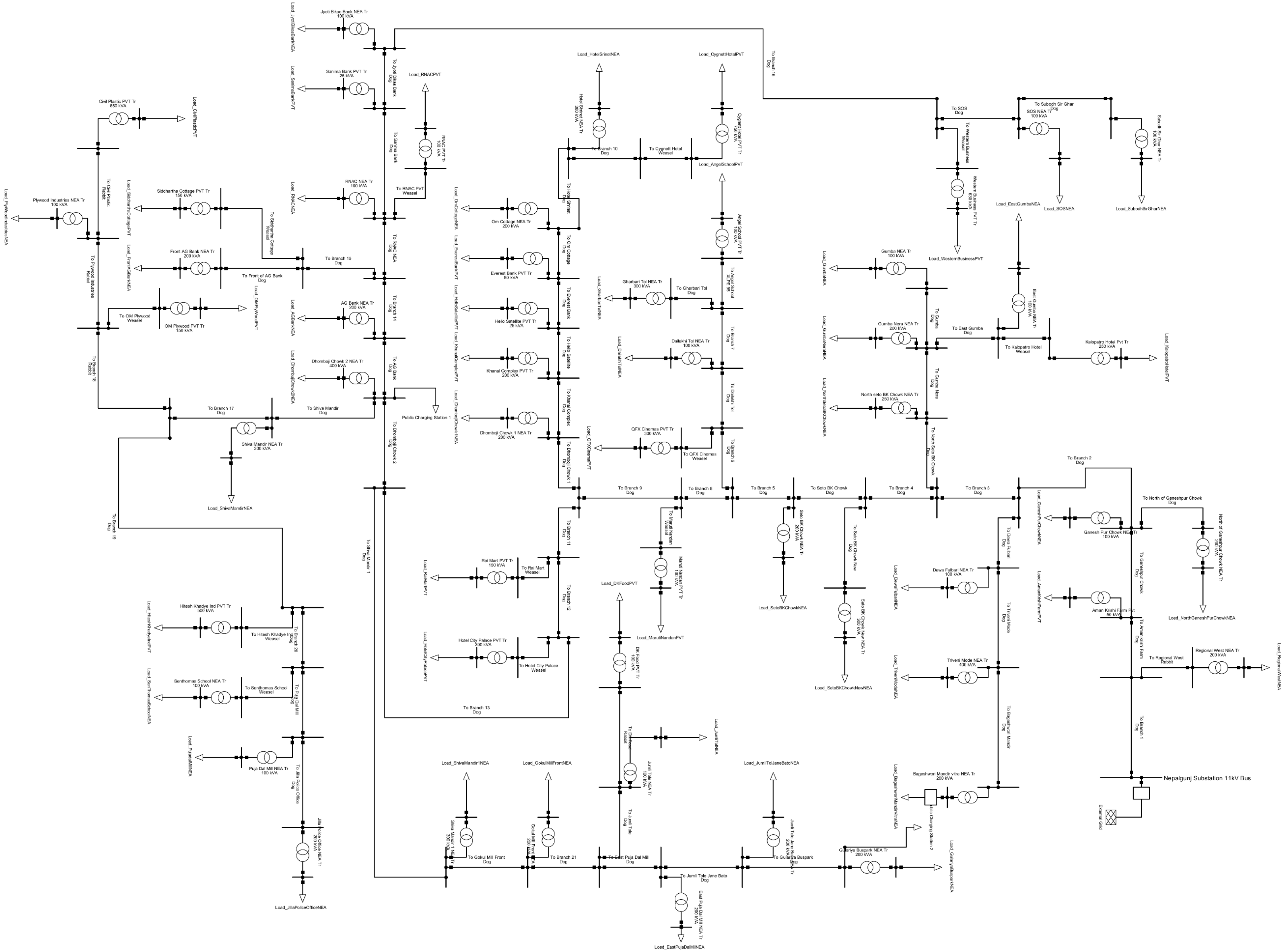
APPENDIX D: Line Data and Load of IEEE-33 Bus RDS

Line Number	Sending Bus No.	Receiving Bus No.	Resistance (Ω)	Reactance (Ω)	Load At Receiving End Bus	
					Real power (kW)	Reactive power (kVAR)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	1.7114	1.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.04	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

APPENDIX E: Single Line Diagram of IEEE-33 Bus RDS



APPENDIX F: Single Line Diagram of Bageshwori Feeder in DigSILENT Powerfactory



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