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INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

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Impact Analysis of Electric Vehicles on Distribution System
(A Case Study on Patan Feeder, Pulchowk DCS)

by

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A THESIS

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Impact Analysis of Electric Vehicles on Distribution System (A Case Study on Patan Feeder, Pulchowk DCS)**" submitted by Rabin Shrestha in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

With the vision of reducing the dependency on petroleum products for transportation and maximize the consumption of electricity generated, the Government of Nepal GoN and NEA has set up plans to encourage the use of Electric Vehicles (EVs). EVs not only reduces the consumption of petroleum products for transportation but also helps in pollution free transportation. In order to compete with petroleum-based transportation, NEA has plans to set up EV charging station as many as possible. The increased number of charging station will increase EVs in the Distribution System.

In this study of Impact Analysis of Electric Vehicles EVs on Distribution System, the effect of different penetration level of EV battery charging on Distribution System is analyzed. This research presents a methodology for modelling and analyzing load flow and harmonic analysis in a distribution system due to EVs. This study focuses on voltage deviation, line loss and total harmonic distortion caused due to different penetration level of EVs in the Distribution System. Due to ever increasing use of electric vehicle in the world, an electric utility must be able to meet the both energy demand and peak demand caused by charging of EV's. Not only the peak demand and energy demand fulfillment, a utility must be able to maintain its THD within prescribed limit. So, in order to make the system healthy, the supply side of EV battery charging circuit must be harmonic free. For the study purpose ETAP software is used and impacts on Patan feeder, Pulchowk DCS of NEA are studied on different cases of load periods and with and without EV penetration as well. As the selected feeder comprises of two charging stations and transformers capacity of 200 kVA and 1000 kVA, impacts are studied based on the charging stations operating individually and simultaneously. Voltage Deviation and Line Loss are found to be increased at peak demand period with the increased EV penetration while THD is found to be increased at off peak period with the increased EV penetration. This is because at off peak period, with the increased EV penetration, the EV load is very high and the use of converters becomes high. Voltage Deviation and Line Loss goes on increasing with the increase in power demand even without EV Penetration. Maximum Voltage Deviation is 4.82% at Labim Bus at peak demand period. Line Loss is maximum at peak demand period of 102 kW. Maximum Voltage Deviation is 5.83% at Labim Bus at 100% EV Penetration during peak period and Line loss 121 kW, which is also highest at the same period and same penetration level when both Sajha and Labim Mall Charging station are operating simultaneously.

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LIST OF ABBREVIATIONS

A	Ampere
AC	Alternating Current
DC	Direct Current
EV	Electric Vehicle
FFT	Fast Fourier transform
GoN	Government of Nepal
HV	High Voltage
kW	kilo Watt
LPG	Liquid Petroleum Gas
NEA	Nepal Electricity Authority
PEV	Plugin Electric Vehicle
s	Seconds
SOC	State of Charge
THD	Total harmonic Distortion
V2G	Vehicle to Grid
V	Voltage

CHAPTER ONE: INTRODUCTION

1.1. Background

The Government of Nepal (GoN) has to set a long-term vision to replace the use of Liquefied Petroleum Gas (LPG) and substantially reduce the consumption of petroleum products. Betting on the surplus in Nepal Power System after the completion of the 456 Mega Watt Upper Tamakoshi Hydroelectric Project (UTHEP), NEA is taking the initiative to promote electric vehicles for competent management of the surplus power. The power utility Company NEA has planning to install charging stations in different places of major cities to encourage people to shift to Electric Vehicles (EVs).

The Government has also planned to reduce customs tariff on the import of electric vehicles so as to compete with petroleum-based transportations. Customs tariff of big electric vehicles (bus, minibus) normally used as public transportation had been slashed to one per cent (of the total cost) from 30 per cent earlier. Similarly, electric four-wheelers used for individual purpose like jeeps, cars and vans need to pay only 10 per cent customs tariff against 30 per cent in previous years.

With the increase in generation of electricity, NEA has made plans to maximize the consumption of electricity by encouraging the charging of EVs during off peak and medium peak period through the reduction of tariffs in such periods. Charging during peak load period will definitely have impacts on Distribution System impacting Voltage Profile and Line Loss but increased EV penetration during off peak period will also have negative impacts on Distribution System. It will introduce harmonics in the system and eventually reduce the Power Quality of the system.

Power quality is one of the emerging issues to be addressed by a power system engineer. It is desirable that the system voltage and frequency limit not be violated beyond its prescribed limit. Similarly, the harmonics content of the system should be fundamental as can be possible by any means. That is harmonic distortion in the system has various impacts such as heating of cables and wires, overloading of transformer, overloading of the cable, etc. The EV chargers can be either single phase chargers or three phase chargers. The electric vehicle needs to be charged for their daily purpose. This can be either charged at home or can be charged at the charging station which are fed by various feeder. The battery charger acts as the highly nonlinear load due to the use of the semiconductor devices used

in the charger circuit. Hence this semiconductor device will cause the supply to inject harmonics in the charger circuit. This will deviate the voltage and the current waveforms from sine wave and this will create the problem. The total harmonic distortion should be within the acceptable limit. According to the IEEE standard 519-1992 THD should be maintained within 5%. ("IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, 1992). If the THD is not maintained, then this might cause the power quality problems. Due to ever increasing electric vehicle it is important to study the impacts of EVs and their chargers have on the electric grid. Basically, it depends on the configuration of the electric chargers for different types of harmonic distortion. For this different EV chargers needs to be simulated.

In this research, a methodology for modelling and analyzing load flow and harmonic analysis in a distribution system due to EVs. This study focuses on voltage deviation, line loss and total harmonic distortion caused due to different penetration level of EVs in the Distribution System. With the brief introduction to the common types of EV batteries and their charging characteristics, an analytical solution for predicting the EV charging load is developed. Due to ever increasing use of electric vehicle in the world, an electric utility must be able to meet the both energy demand and peak demand caused by charging of EV's. Not only the peak demand and energy demand fulfillment, a utility must be able to maintain its THD within prescribed limit. So, in order to make the system healthy, the supply side of EV battery charging circuit must be harmonic free. For the study purpose ETAP software is used and impacts on Patan feeder, Pulchowk DCS of NEA are studied on different cases of load periods and with and without EV penetration as well. As the selected feeder comprises of two charging stations and transformers capacity of 200 kVA and 1000 kVA, impacts are studied based on the charging stations operating individually and simultaneously. Voltage Deviation and Line Loss are found to be increased at peak demand period with the increased EV penetration while THD is found to be increased at off peak period with the increased EV penetration. This is because at off peak period, with the increased EV penetration, the EV load is very high and the use of converters(rectifiers) becomes high.

1.2. Problem Statement

With the increase in the number of electric vehicles demand for electricity will rise and profile of peak daily load curve is bound to change, which does not always have positive impact on the distribution network

The demand for the electricity will increase significantly with the rise in EV based transportation, which can be considered as a major challenge to the power systems. Power systems are designed to handle predicted load with specific characteristics depending on the standard and grid code. The utility company knows the load profile of any area and it supply the needed electricity all the time for the consumers. The balance between generation and consumption of electric power is controlled and monitored all the time. Therefore, when new modern technology is introduced to the power grid, it should be compatible with the grid in order to improve its operation, ensure stability and reliability.

The impact of charging on the power system depends on where it is on the grid and how it is charged. They do not pose a problem if they are charged slowly at low voltage system. However, during the fast and uncontrolled charging the different power quality parameters like voltage unbalances, harmonic distortions, frequency variations, voltage drop and line loss are quantified and their rise or fall are restricted by a number of relevant standards. An excessive flow of currents may cause circuits of overload, which may deteriorate cable insulation, which results in reduced lifespan and increase the need of maintenance. (Trovão *et al.*, 2011)

1.3. Research Gap

EV chargers are a new and a typical load that power distribution systems must accommodate. In various developing countries like Nepal, efforts are being made to have adopt as many electrical vehicles as possible. Since it is the cleanest form of energy used on transportation and regarding the electricity generation potential of Nepal, it will not be difficult to predict the increasing number of EVs in Nepal. As Government of Nepal is also focusing on adapting electrical vehicle-based transportation through different policies and schemes, there will soon be sudden rise in the number of EVs. With the increase in number of EVs, the issues like power quality in the distribution feeders will arise. Power Quality (PQ) is of concern because it shows deviations in voltage magnitude, issues with service continuity from the utility, or transient voltages and currents, DC offset, harmonics and phase imbalance etc. (Bass and Zimmerman, 2013).

Distribution engineers need models that represent the multi-state, unbalanced, and distorted nature of these loads in order to predict the impacts that EV chargers may have on distribution assets.

1.4. Objectives

1.4.1. Main objective

To study the impact of Electric Vehicle (EV) charging station on the urban radial distribution network at different penetration level of charging.

1.4.2. Specific objectives

- To carry out the simulation of distribution network in the ETAP
- To perform the impact study for voltage variation, line loss and harmonics of the distribution network.

1.5. Limitation

- 1) The smart charging of EV has not been considered owing to the unavailability of the same in Nepal.
- 2) The contribution of renewable resources like wind and solar power in the network is not considered.
- 3) EV charging is only considered in Low Voltage system only but not in medium voltages.
- 4) Different charger level and different power factor are not considered.
- 5) Charging duration is not considered.

CHAPTER TWO: LITERATURE REVIEW

2.1. Harmonics

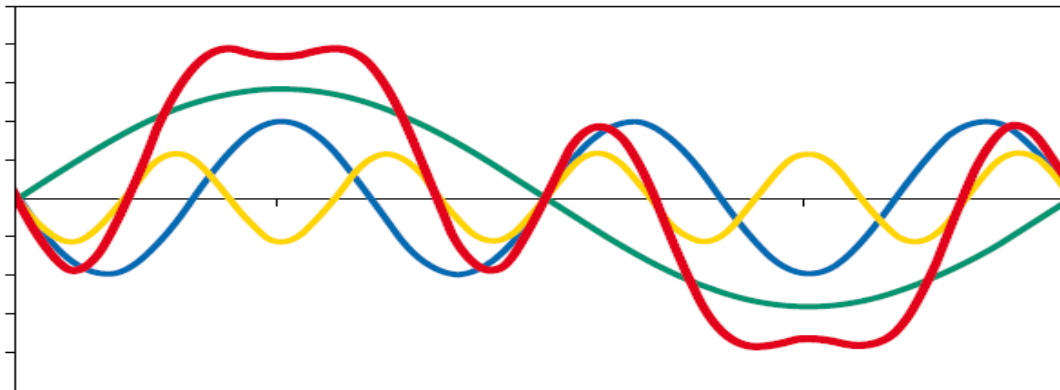
The distortion on the normal waveform of the electric current and voltages caused due to nonlinear loads is considered as harmonics like variable speed motors and drives, computers, printers, photocopy and fax machines, battery chargers and UPS etc. Nonlinear loads can be either or single phase or three phase, single phase being available in modern buildings while three phase in industries and factories. On electrical distribution networks, most non electrical loads are converters that convert grid AC to DC required for internal electronics. These nonlinear loads draw current in high amplitude and short pulses which causes significant distortion in the waveform of current and voltage. This distortion is referred as harmonic distortion and is measured as total harmonic distortion (THD) The distortion travels back into the electrical source and can have negative impacts on other equipment connected to the same source. Most electrical power systems can tolerate a certain level of harmonic distortion but will cause serious problems when THD becomes significantly high. As percentage THD becomes high, they can cause several problems such as:

- Overheating of electrical distribution components like overhead lines, cables, transformers, standby generators, etc.
- High voltages and high circulating currents due to harmonic resonance.
- Malfunctioning of equipment caused due to excessive voltage distortion.
- Increase in energy losses in connected equipment, which causes failure in components and shortened life span
- False tripping of branch circuit breakers and generator failures
- Metering errors
- Fires in wiring and distribution systems
- System power factor degradation, which results in penalties on utility bills

2.1.1. Technical Overview of Harmonics

The currents or voltages having frequencies which are integer multiples of the fundamental frequency. If the fundamental frequency is 50 Hz, then the 2nd harmonic is 100 Hz, the 3rd is 150 Hz, etc When harmonic frequencies are existing in the system, power panels and

electrical transformers become mechanically resonant to magnetic fields caused due to higher frequency harmonics. As this happens, power panel or transformer vibrates and produces a buzzing sound for the different harmonic frequencies. Harmonic frequencies from the 3rd to the 25th are the most common range of frequencies measured in electrical distribution systems.



Caption:
■ nonsinusoidal waveform
■ first harmonic (fundamental)
■ third harmonic
■ fifth harmonic

Figure 2-1: Fundamental frequency and harmonics (source: electricaltoolbox.com)

For example, 3rd harmonics (150Hz) is shown in Figure 2-1 The third harmonics is the third multiple of the fundamental frequency.

In order to lessen these adverse effects, IEEE established standards 519-1992, with the objective of developing recommended practices and requirements for harmonic control in electrical power system. The standard describes the problems that are caused due to unmitigated harmonic current distortion within the electrical system as well as the degree to which harmonics can be tolerated by a given standard (“IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, 1992).

2.1.2. Total Harmonic Distortion

The Total Harmonic Distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. In power systems, lower THD implies lower

peak currents, less heating, lower electromagnetic emissions, and less core loss in motors. The measure of additional signal content that is not present in the input signal is THD.

According to IEEE the standard limit of THD is 5%. Non sinusoidal input current can be resolved into Fourier series as under:

$$i(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \quad \text{Equation 2-1}$$

$$a_0 = \left(\frac{2}{T}\right) \int_0^T i(t) dt \quad \text{Equation 2-2}$$

$$a_n = \left(\frac{2}{T}\right) \int_0^T i(t) \cos n\omega t dt \quad \text{Equation 2-3}$$

$$b_n = \left(\frac{2}{T}\right) \int_0^T i(t) \sin n\omega t dt \quad \text{Equation 2-4}$$

Evaluation of each of these coefficients will give the complete solution of current.

2.2. Electric Vehicles

In past times vehicles were powered by steam engine. Steam engine was great achievement at that time but these engines were not efficient and were slow. Slowly, from steam engine, petrol and diesel engines were developed. These engines were more powerful and efficient. Vehicles were fast too. But those engines emit harmful gases to the environment which is the global problem of 21st century. Thus, to reduce those emission of those gases electric vehicles was developed.

In past also there was attempt to develop electric motors but with the lack of instrument and technology it was not successful. With petrol and diesel engine another problem was nonrenewable sources. To reduce consumption of those sources electric vehicles were developed. Electric vehicles are environment friendly. They are quite vehicles with powerful engines. Development of electric vehicle is a great achievement.

An Electric Vehicle (EV) uses one or more electric motors or traction motors for propulsion. EV may be powered by electricity from off-vehicle sources, or may be self-contained system with a battery, solar panels, fuel cells etc. In the 21st century, EVs have been reviving due to technological evolution, and an increased focus on renewable energy so as to reduce impacts of petroleum-based transportation on climate change and other environmental issues. A pre-COVID 2019 analysis, projected that Electric Vehicle are expected to increase from 2% of global share in 2016 to 22% in 2030. Much of this market growth is expected in markets like North America and Europe; a 2020 literature review, suggested that growth

in use of electric vehicles, especially electric personal vehicles, currently appears economically unlikely in developing economies (Giordano, 2018).

As of March 2018, there are some 45 series production highway-capable all-electric cars available in various countries. As of early December 2015, the Leaf, with 200,000 units sold worldwide, was the world's top-selling highway-capable all-electric car of all time, followed by the Tesla Model S with global deliveries of about 100,000 units (*Car Reviews: New Car Prices and Used Cars Classifieds*, 2015).

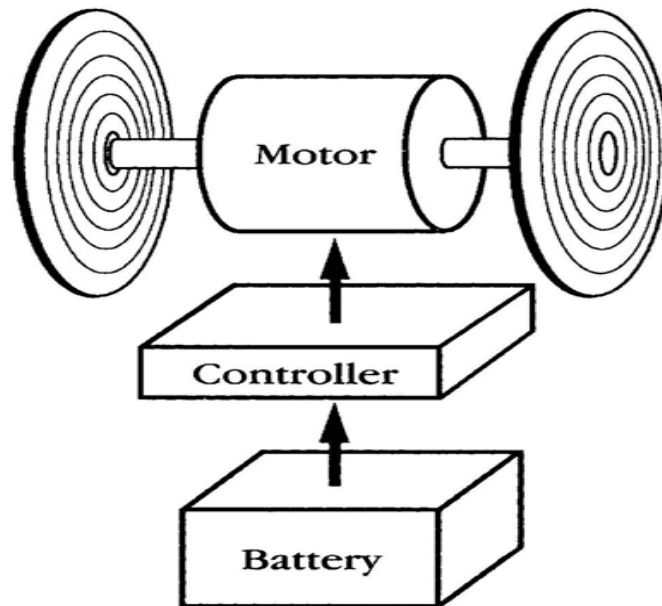


Figure 2-2: Electric Vehicle Component (source:electricalengineeringtoolbox.com)

2.3. Battery Chargers

Electric vehicle (EV) chargers are highly nonlinear electrical power system load. They introduce excessive harmonics in the system and create potential problems to the system as well as lower pf. Thus, it is very necessary to analyze the impacts of EV chargers on power system harmonics and then to take some measures to improve the loading factor of power systems and acquire better power quality.

The general battery charging circuit is as shown in the Figure 2-3. At first the input AC supply is rectified into DC with the help of Rectifier circuit. The rectifier used can be either controlled or uncontrolled one. The rectifier itself can be either half wave or bridge type rectifier. This rectifier is then connected to filter circuit and then to the DC-DC converter. Finally, battery is connected to the system.

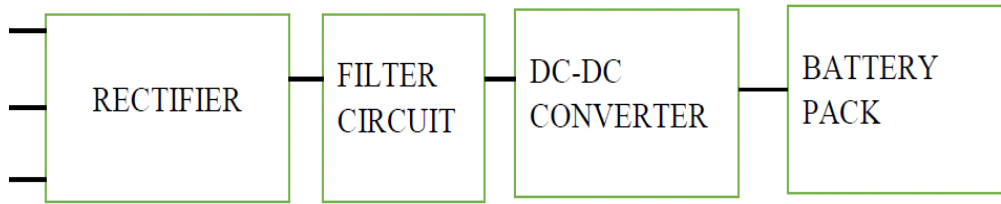


Figure 2-3: Battery charging circuitry diagram

However, in this simulation study we have not taken the DC-DC converter and simply made the charger circuit and simulation was done.(Kutt *et al.*, 2014)

EV Charging requires a transformer which converts higher feeder voltage to lower voltage as required by the chargers. The AC to DC Power Electronics Converter converts AC to intermediate DC voltage and DC to DC Converter converts this intermediate voltage to the required voltage for the vehicle battery. The connection pattern of charging stations in the Distribution systems is shown in

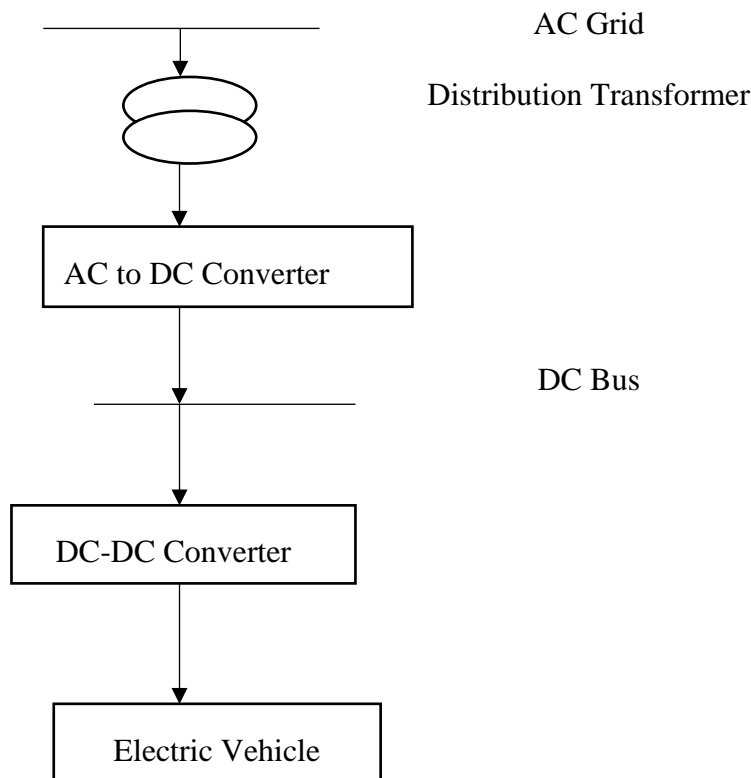


Figure 2-4 EV Charging Connection Block diagram

2.4. EV Charging Methods

There are basically 3 types of EV charging methods and they are briefly described below:

2.4.1. Battery Swap Station (BSS)

This is based on paying monthly rent for the battery to the BSS owners. This method adopts slow charging technologies which helps to extend the battery life. (Ahmad *et al.*, 2018) It is much easier to integrate locally generated Renewable Energy Sources (REs) like Solar and Wind with the BSS system. This system allows the drivers to stay inside the vehicle and the discharged battery can be replaced quickly. Moreover, the battery kept at the BSS can be used in the V2G initiative. (Gschwendtner, Sinsel and Stephan, 2021)

2.4.2. Wireless Power Transfer (WPT)

This method is based on Electromagnetic Induction (EMI) and consists of two coils; primary coil and secondary coil. Primary coil is placed on the road's surface and secondary coil is placed inside the vehicle. This technique is gaining popularity recently due to its ability to enable the EV to recharge conveniently and safely. It has also advantage of charging while the vehicles in motion. (Sanguesa *et al.*, 2021)

2.4.3. Conductive Charging (CC)

This technology requires electric connection between the vehicle and charging inlet and has high efficiency in charging due to its direct connection.

Different types of charging facilities used under this technology are as follows:

- Level 1 charger
- Level 2 charger
- Level 3 charger

Level 2 and Level 3 are employed for a public charging station.

2.4.3.1. Level 1 Charger

Level 1 Charger operates through a 120V single phase AC and expected power level ranges from 1.44 kW and 1.92 kW. This charger is generally used for EV Charging at home and offices

Level 1 charger takes about 8 to 12 hours to completely charge.

2.4.3.2. Level 2 Charger

Level 2 Charger operates through a 240V single phase AC plug and expected power level ranges from 3 kW and 6 kW. This charger is generally used for EV Charging at residential and commercial outlet.

Level 2 charger has a cord that plugs directly into the vehicle in the same connector location used for level 1 equipment.

Level 2 charger takes about 4 to 6 hours to completely charge.

2.4.3.3. Level 3 Charger

Level 3 charger is also known as DC fast charging, charges through a 480V three phase AC and 600V DC and expected power level ranges from 50 kW, 100kW and 250 kW. This charger is generally used for EV Charging at Commercial Fast Charging Stations

Level 3 Charger takes about 1 to 2 hours to completely charge

Table 2-1 Charging Power Level (Yilmaz and Krein, 2013)

Power Level Types	Converter Location	Usage	Expected Power Level
Level 1 120V AC	On Board Single Phase	Home and Office	1.44 kW 1.92 kW
Level 2 208V AC 240V AC	On Board Single Phase	Residential Outlet	3 kW 6 kW
		Commercial Outlet	15.5 kW
Level 3 480V AC 600V DC	Off Board Three Phase	Commercial Fast Charging Station (FCS)	50 kW 100 kW 250 kW

Due to the increasing number of EVs, Society of Automobile Engineers (SAE) has proposed AC and DC charging standards for the US and EU considering the voltage and current levels as shown in Table 2

Table 2-2 SAE Standards Current and Voltage Level for AC and DC Charging

Standards	Phase	Level	Voltage(V)	Current(A)	Source
SAEJ1772	Single	1	120	16	AC
	Single	2	240	32-80	AC
	DC	1	200-450	80	DC
	DC	2	200-450	200	DC

2.5. Rectifier

A rectifier is an electrical device which converts AC to DC and the process is known as rectification. While the inverter converts DC to AC. Rectifiers are frequently used as components of DC power supplies and HVDC power transmission systems. Depending on the arrangement of rectifier circuit and AC supply, additional smoothing may be required so as to produce a uniform steady voltage. A steady constant DC voltage (as produced by a battery) as required by many applications like radio, television, computer, etc. is provided by rectifiers. In these applications the output of the rectifier is smoothed by an electronic filter, like a capacitor, choke, or combinations of choke, capacitor and resistor, and then with a voltage regulator to produce a steady voltage.

2.5.1. Rectifier Circuit

Rectifier circuits may be single or three-phase. Single phase rectifiers are used for domestic equipment with low power applications, while three phase rectifiers are used for industrial applications and for high voltage DC transmission (HVDC)

2.5.2. Single Phase Rectifiers

2.5.2.1. Half Wave Rectification

In single phase half wave rectification, either only positive or negative half of the AC wave is passed, while the other half of the signal is blocked. Since only half of the input waveform reaches the output, average voltage is lower. Half-wave rectification requires a single diode.

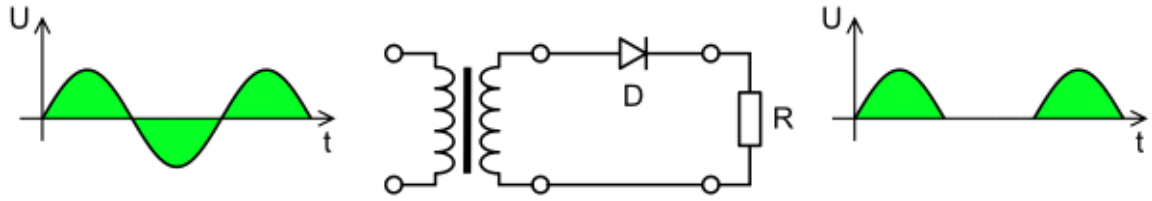


Figure 2-5: Half wave rectifier waveform

The no-load output DC voltage of an ideal half-wave rectifier for a sinusoidal input voltage is:

$$V_{DC} = \left(\frac{1}{\pi}\right) \int_0^{\pi} V_{peak} \sin t dt = (V_{peak}/\pi) \quad \text{Equation 2-5}$$

$$V_{peak} = \sqrt{2} V_{rms} \quad \text{Equation 2-6}$$

Where:

V_{DC} : DC or average output voltage,

V_{peak} : the peak value of the phase input voltages,

V_{rms} : the root mean square (RMS) value of output voltage.

2.5.2.2. Full Wave Rectification

A full-wave rectifier is used to convert whole of the input waveform to one of constant polarity either positive or negative at its output. In full-wave rectification both polarities of the input waveform is converted to pulsating DC and thus results in a higher average output voltage..

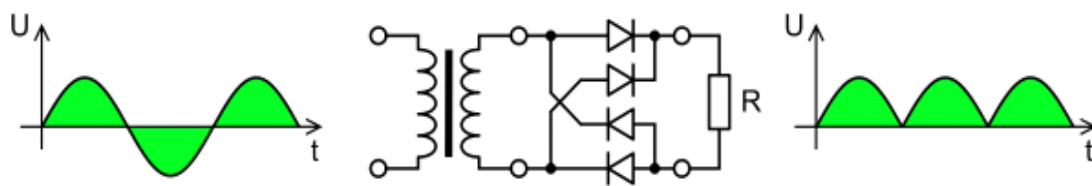


Figure 2-6: Full wave rectifier wave form

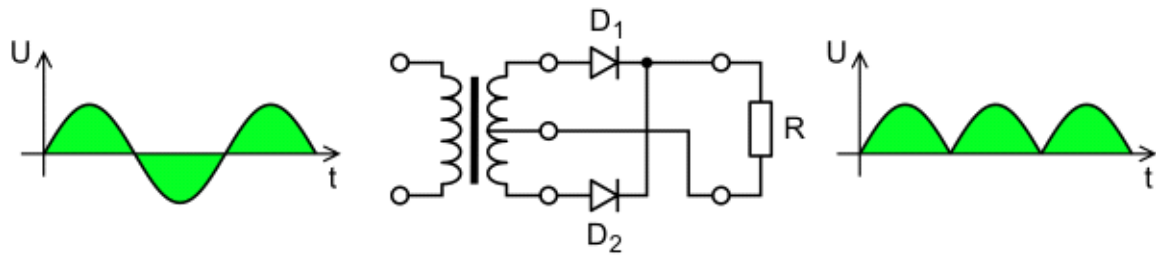


Figure 2-7: Full wave rectifier using center tap transformer

2.5.3. Three Phase Rectifiers

. Single phase rectifiers are used for domestic equipment with low power applications, while three phase rectifiers are used for industrial applications and for high voltage DC transmission (HVDC). Like single-phase rectifiers, three-phase rectifiers can also take the form of a half-wave circuit, a full-wave circuit using a center-tapped transformer, or a full-wave bridge circuit.

2.5.3.1. Three Phase, Half Wave Rectifier Circuit

For an uncontrolled three-phase, three diodes, one connected to each phase is required. This is the simplest three phase rectifier but has disadvantages of relatively high harmonic distortion.:

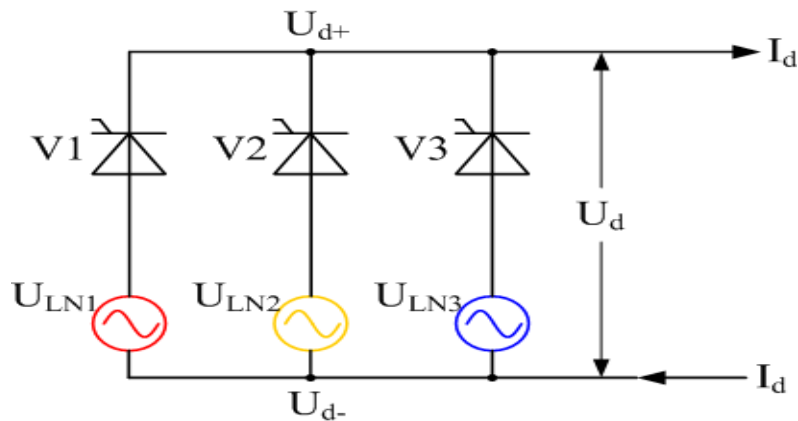


Figure 2-8: Three phase half wave rectification circuit

2.5.3.2. Three Phase, Full Wave Circuit using Centre-Tapped Transformer

A rectifier circuit with center tapped transformer can be used to obtain improved harmonic performance.

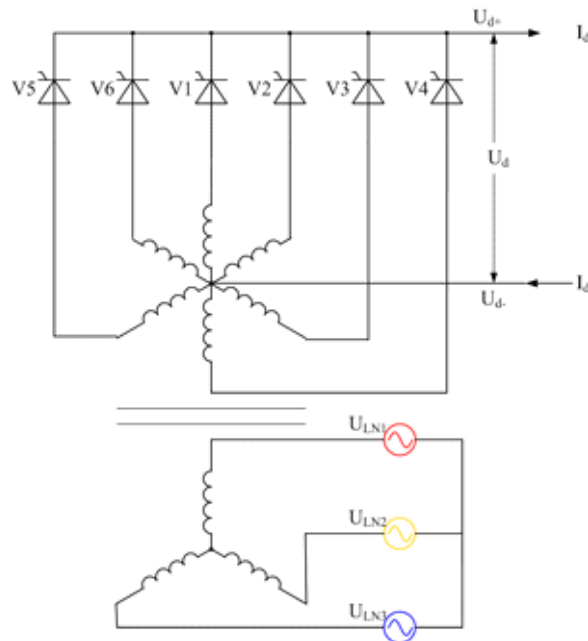


Figure 2-9: Three phase full wave rectifier circuit using center tap transformer

2.6. Battery

A simple device consisting of one or more electrochemical cells with the facility of external connection for powering electrical devices like mobile phones, flashlights, and electric cars. is battery. While supplying positive power, cathode is the positive terminal and negative terminal is the anode.

There are two types of battery

- Primary battery: Battery which cannot be recharged such as dry cell, alkaline batteries.
- Secondary battery: Battery which can be recharged such as lead acid, lithium ion etc.

Here we will mainly discuss about secondary battery as they are used in electrical vehicle charging station. The different types of secondary battery are as follows:

2.6.1. Lead Acid Battery

Electricity is generated with the help a double sulphate chemical reaction. Such batteries are mostly used in photovoltaic systems battery applications. Although they have disadvantages of a low energy density, moderate efficiency and high maintenance requirements, they also have advantages of a long life and low costs as compared to other

battery types. They are the most commonly used for most rechargeable battery applications and therefore have a well-established established, mature technology base.

- Nominal cell voltage: 2.1 V
- Charge/discharge efficiency: 50–95%
- Charge temperature interval: Min. $-35\text{ }^{\circ}\text{C}$, max. $45\text{ }^{\circ}\text{C}$
- Self-discharge rate: 3–20%/month
- Energy density: 80–90 Wh/L
- Specific energy: 35–40 Wh/kg
- Specific power: 180 W/k

2.6.2. **Lithium-Ion Battery**

They are rechargeable battery and are commonly used for portable electronics and electric devices. Such batteries are used for electric vehicles and charging stations. They have a higher energy density as compared to lead acid batteries and nickel cadmium batteries.

- Nominal cell voltage: 3.6 / 3.7 / 3.8 / 3.85 V, LiFePO₄ 3.2 V
- Energy density: 250–693 W·h/L (0.90–2.43 MJ/L)
- Specific energy: 100–265 W·h/kg (0.36–0.875 MJ/kg)
- Charge/discharge efficiency: 80–90%
- Specific power: ~250 – ~340 W/kg
- Self-discharge rate: 0.35% to 2.5% per month

2.6.3. **Nickel-Cadmium Battery**

It is one of the various types of rechargeable battery which uses nickel oxide hydroxide and metallic cadmium as electrodes. NiCd use electrodes made of nickel oxide hydroxide, metallic cadmium and an alkaline electrolyte of potassium hydroxide. They are used in computers, drills, cam coder etc.

- Nominal cell voltage: 1.2 V
- Charge/discharge efficiency: 70–90%
- Self-discharge rate: 10%/month

- Specific energy: 40–60 Wh/kg
- Specific power: 150 W/kg
- Cycle durability: 2,000 cycles
- Energy density: 50–150 Wh/L

2.6.4. Nickel-Metal-Hydride Battery

It is one of the rechargeable batteries in which chemical reaction at the positive electrode is similar to that of the nickel–cadmium cell, both using nickel oxide hydroxide. However, it is different as the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. They are used in digital cameras, cellular phones etc.

- Charge/discharge efficiency: 66%–92%
- Nominal cell voltage: 1.2 V
- Cycle durability: 180–2000 cycles
- Specific energy: 60–120 W·h/kg
- Energy density: 140–300 W·h/L
- Specific power: 250–1,000 W/kg

Impacts of EVs on the grid

An electric power system grid consists of generation, transmission, and distribution systems. The generation system is composed of power plants like hydropower, wind, solar, diesel etc. where electrical energy is generated.

The transmission system is composed of transmission lines to transfer electricity from generating stations to distribution systems, and it is composed of transformers where lower generation voltage is stepped up to higher transmission voltage. The distribution system mainly is composed of substations, and transformers which step down the higher transmission voltage to a level used by end-use customers; usually 230/400 V for customers. The impact of EV charging on the electric grid as a whole is mainly influenced by two aspects; (1) the level of EV penetration, and (2) the point in time and the duration of EV charging. (Bunga, Eltom and Sisworahardjo, 2014)

When EVs are introduced to the Distribution System, following impacts can be seen in the system: (Papadopoulos *et al.*, 2012)

1. Voltage Drop

EV Charging will add the load demand in the Distribution System, thereby causing Voltage Drop in the system.

2. Power Transformer Overload

In the current scenario, power transformers are designed to serve the power consumption up to 80 percent of maximum demand. But with the advancement of EVs, transformer loading needs to be improved, although transformers in the distribution system can load up to 200 percent if designed accordingly.

3. Line Loss

EV charging station will increase the line loss in the Distribution System. Increased number of EVs, charging time and location of charging station will play important roles in increasing the line loss in the system.

4. Voltage Imbalance

EV chargers in household are mainly charged in the single phase, therefore Voltage Imbalance is very likely.

5. Harmonics

EV chargers use rectifiers which introduce harmonics in the system.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. General

The outline of this work begins from the literature review, in which the electric vehicle charger and its impact on voltage profile of the distribution network, when integrated to the existing network is studied. The distribution system is modelled in ETAP and simulation, Load Flow and Harmonic Analysis is performed.

3.2. Research Framework

The study was carried out by following the frame work as shown in Figure 3-1.

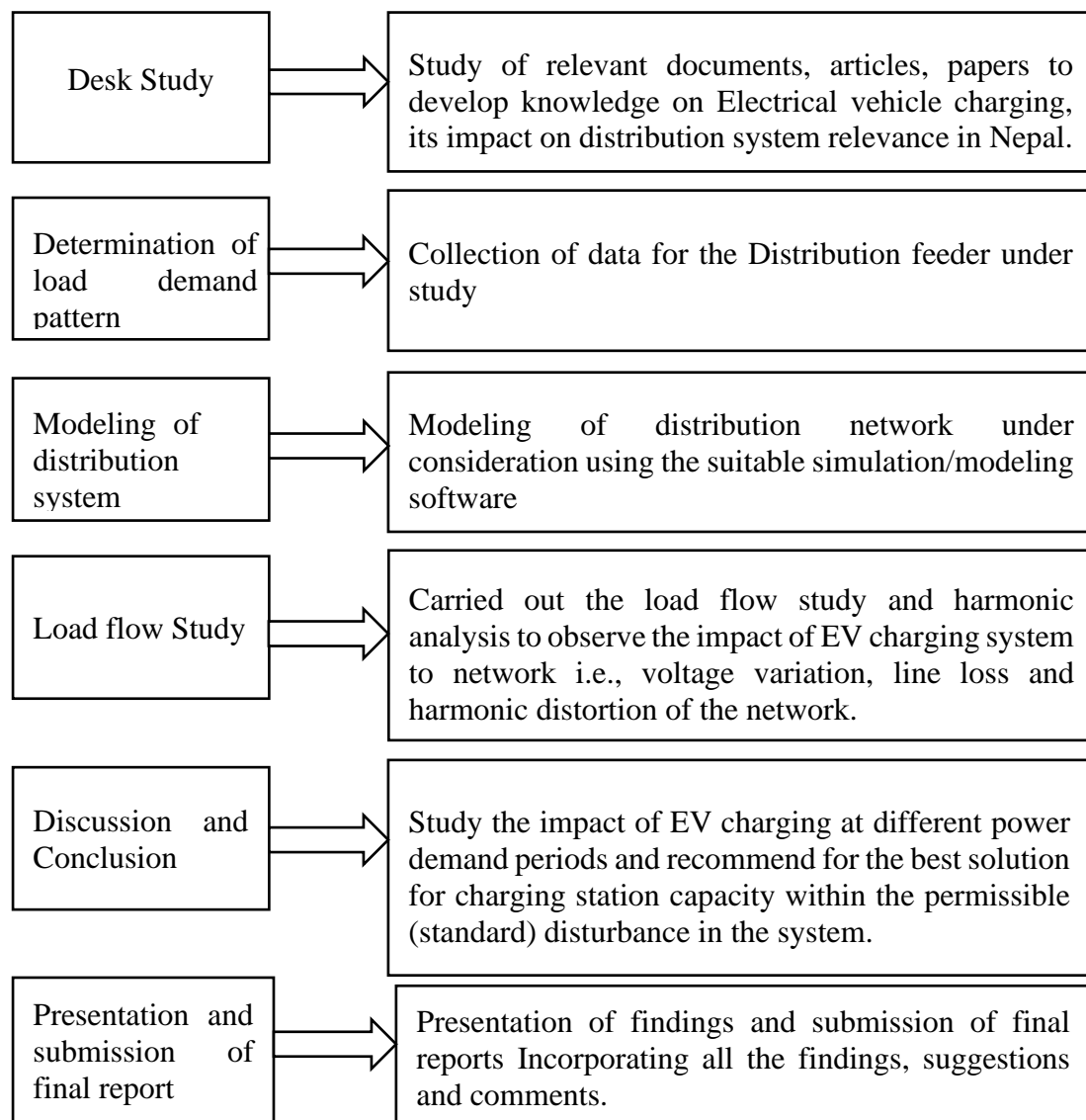


Figure 3-1: Research Framework

3.3. Electrical Transient Analyzer Program

Electrical Transient Analyzer Program (ETAP), software is the main tool used for the simulation of test system in our case. ETAP is the most comprehensive analysis platform for the design, simulation, operation, control, optimization, and automation of generation, transmission, distribution, and industrial power systems.

Inside the ETAP simulation, there are different simulators like Load Flow Analysis, Transient Stability Analysis, Optimal Power Flow, Optimal Capacitor Placement, and Reliability Analysis & Short Circuit Analysis and also Harmonic Load Flow Analysis.

Among the above, the Load Flow Analysis is used for primary purpose on the constructed Test System, which is run to find the bus Voltage Profile, Line Losses, Reactive and Active Power Flow through the lines and also THD.

3.4. Required Data

3.4.1. Branch Data

The branch data is entered into the branch editors (Transformer, Transmission Line and Impedance editors). Data for a branch must include:

- Branch Z, R, X, or X/R values and units, tolerance, and temperature, if applicable
- Transmission line, length, and unit.
- Transformer rated kV and kVA/MVA, tap, and LTC settings.
- Impedance base kV and base kVA/MVA

3.4.2. Lumped Load Data

The data required for load flow for lumped load includes:

- Rated kV, MVA, power factor, and % motor load
- % Loading

3.4.3. Electrical Vehicle Load

The data required for electrical vehicle load includes:

- kW and Voltage rating for Chargers
- Ah and Voltage rating for Batteries

3.5. Steady State Simulation

ETAP provides four load flow calculation methods: Adaptive Newton-Raphson, Newton-Raphson, Fast-Decoupled, and Accelerated Gauss-Seidel. They possess different convergent characteristics, and sometimes one is more favorable in terms of achieving the best performance. We can select any one of them depending on our system configuration, generation, loading condition, and the initial bus voltages.

3.6. Modelling of Distribution System using ETAP

The modelled Distribution System is a radial system, receiving power from a three-phase source at 11 kV. The selected feeder is Patan Feeder under Pulchowk DCS of NEA as it comprises of two charging stations located at Sajha Charging Station and Labim Mall Charging Station. There are altogether 18 transformers connected to this feeder. Transformers of rating 200 kVA and 1000 kVA are installed at Sajha and Labim Mall Charging Station respectively. Patan Feeder of Pulchowk DCS, as represented by GIS map as shown in Figure 3-2 was selected for the study



Figure 3-2 GIS map of Patan Feeder, Pulchowk DCS (source: Pulchowk DCS)

3.6.1. Overhead Lines and Underground Cables:

The modelled Distribution System is comprised of both overhead lines and underground cables. The size, conductor type and materials and line length are used as provided by the power distributor. Since distribution length being shorter than 80 km and feeder voltage being 11 kV, the OH lines and UG cables are represented as short transmission lines.

Table 3-1: Properties and type of conductors considered under the study

Conductor_Type_Size	Materials	Resistance/km (R/km)	Reactance/km (X/km)
Rabbit_50	Al	0.5426	0.006459
Dog_100	Al	0.2792	0.003292
ABC_150	Al	0.256	0.0082
XLPE_150	Al	0.259	0.0745
XLPE_185	Al	0.206	0.0742
XLPE_240	Al	0.159	0.0752

The conductor details and length used are shown in details in APPENDIX II

3.6.2. Distribution Transformers

In the modelled system, Distribution Transformers are of three phase transformers with primary being connected to 11 kV and the secondary side of the transformer consists of 400 V. Each service transformer parameters are manually entered on the transformer parameter block. The modelled Distribution Transformers parameters as provided by the power distributor are listed by their ratings as:

Table 3-2: Details of distribution transformers considered under the study

Ratings(kVA)	%Impedance(%Z)	X/R Ratio	No Load Loss (W)	Full Load Loss (W)
100	4	4	220	1210
200	4	4	365	2100
250	4	4	455	2550
400	4	4	745	4025
1000	5	10	1500	13000

3.6.3. Distribution System Load Data Analysis:

As the enough load data were not provided by the power distributor, some assumptions have been made as per the charging time slots characterized by NEA. As per NEA, the charging time slots and rate are as follows:

Table 3-3: Charging slots as per power demand under the study

Charging Slots	Time	Energy Rate (Rs)
Off Peak Hours	11 PM – 5 AM	3.70
Medium Peak Hours	5 AM – 5 PM	5.50
Peak Hours	5 PM – 11 PM	7.00

Keeping this table in mind, the load data for Off Peak Hours, Medium Peak Hours and Peak Hours are assumed to be 25%, 50% and 75% loading of Distribution Transformers as per their kVA ratings. The system power factor is assumed to be 0.85.

Table 3-4: Load demand of different transformers at different % loadings

Transformers	kVA ratings	Off peak demand		Medium Peak Demand		Peak Demand	
		P(kW)	Q (kVAR)	P(kW)	Q(kVAR)	P(kW)	Q (kVAR)
Hanumansthan	200	42.5	26.5	85	53	127.5	79.5
Kupondole	250	53.125	33.125	106.25	66.25	159.375	99.375
Jwagal	100	21.25	13.25	42.5	26.5	63.75	39.75
Himalayan	1000	212.5	132.5	425	265	637.5	397.5
Nabil	100	21.25	13.25	42.5	26.5	63.75	39.75
PulchowkClg	100	21.25	13.25	42.5	26.5	63.75	39.75
PulchowkWal	100	21.25	13.25	42.5	26.5	63.75	39.75
Telecom	200	42.5	26.5	85	53	127.5	79.5
Sajha	200	42.5	26.5	85	53	127.5	79.5
Infrastructure	100	21.25	13.25	42.5	26.5	63.75	39.75
Nidhan	100	21.25	13.25	42.5	26.5	63.75	39.75
PoliceBeat	200	42.5	26.5	85	53	127.5	79.5
Labim	1000	212.5	132.5	425	265	637.5	397.5
UN	100	21.25	13.25	42.5	26.5	63.75	39.75
Sanchayakosh	400	85	53	170	106	255	159
HighCourt	100	21.25	13.25	42.5	26.5	63.75	39.75
FP	200	42.5	26.5	85	53	127.5	79.5
Kardata	200	42.5	26.5	85	53	127.5	79.5
Total							

The transformers details are shown in APENDIX III

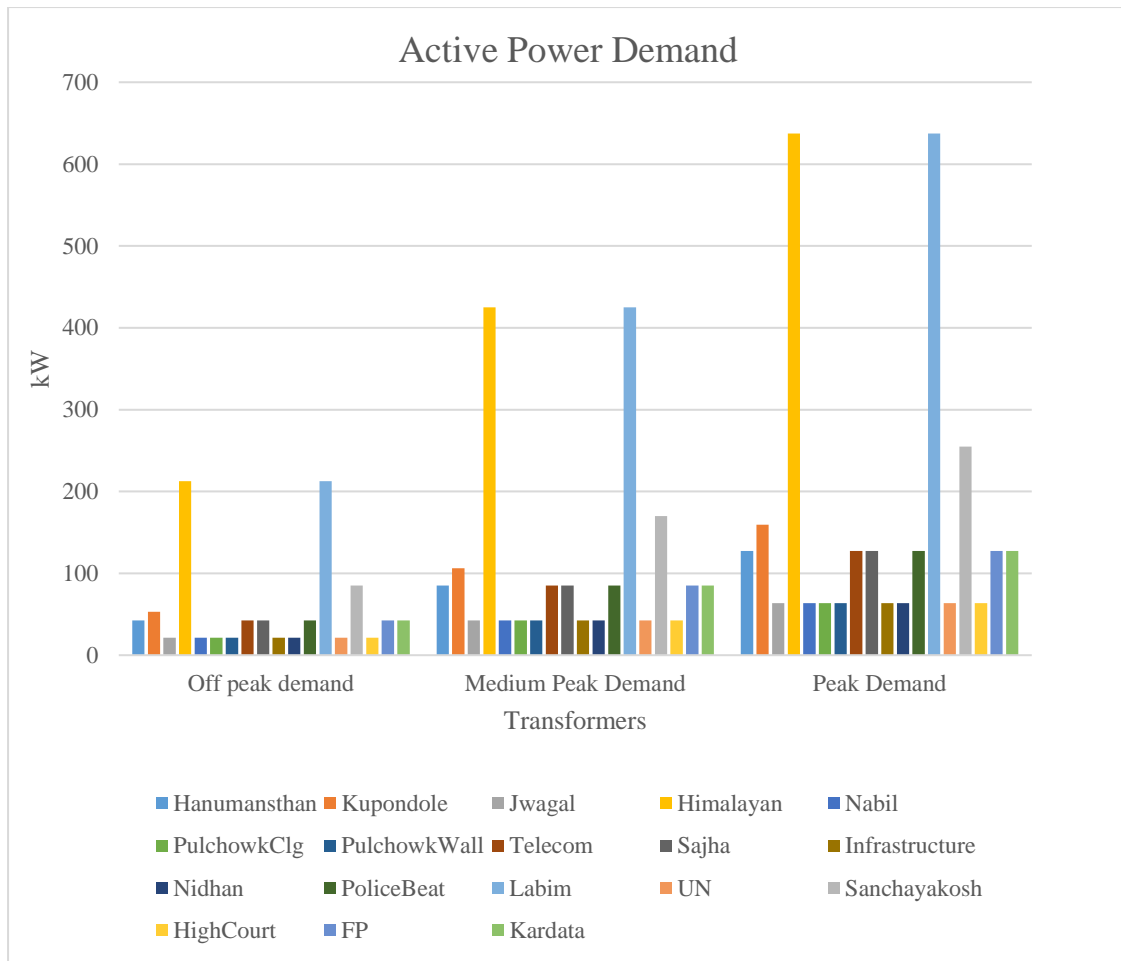


Figure 3-3: Active power demand at different period without EV

From Figure 3-3 it is clear that power demand is higher at peak demand than off peak demand. So more number of loads or electrical vehicles can be added to the transformers without overloading the transformers at off peak demand than peak demand.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Load Flow Analysis

As the basic step of impact analysis, load flow analysis is performed in the distribution network with step increase in the EV size. Main purpose of the load flow is to test whether the steady state operating constraints are violated with increment of EV interconnection. The steady state constraints considered in the study are as follows.

- Voltage Profile
- Line flow
- Line losses

4.2. Harmonic Analysis

Harmonic analysis is performed in the modelled distribution system with step increase in the EV size. The main purpose of the Harmonic Analysis is to test whether Total Harmonic Distortion is within limit or not as prescribed by IEEE 519-2014.

4.3. Model Testing without EV Penetration

4.3.1. Voltage Profile without EV Penetration

The base voltage of feeder is 11 kV so voltage deviation is in percentage of base kV.

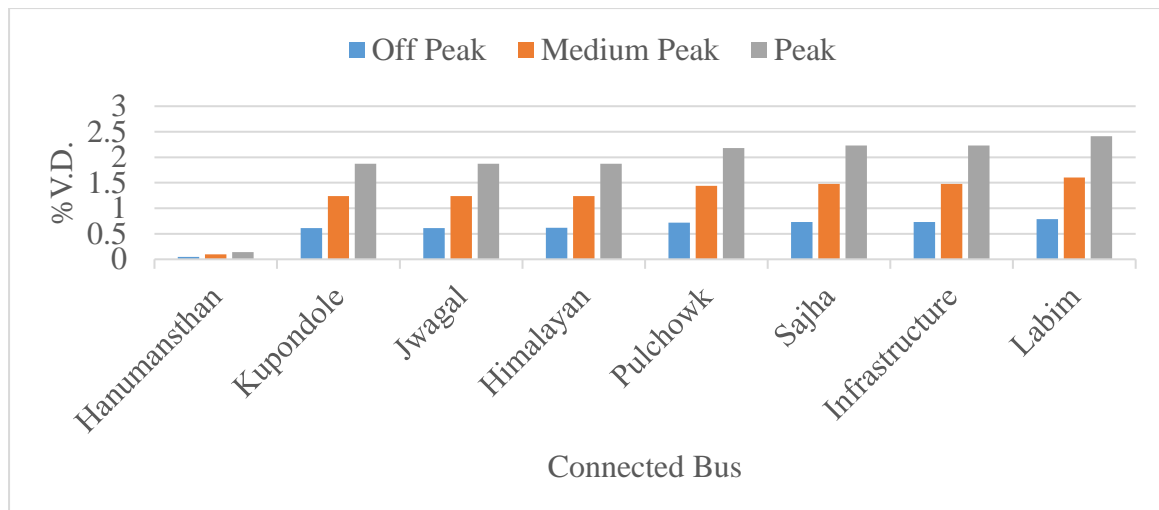


Figure 4-1 Voltage Deviation at different bus at different power demand without EV penetration

4.3.2. Line Loss

Table 4-1: Line loss without electrical vehicle

Power Demand	Line Loss	
	P(kW)	Q(kVAR)
Off Peak Demand	10.9	13.6
Medium Peak Demand	44.4	55.4
Peak Demand	102	127

4.4. Model Testing with EV Penetration

Different Levels of EV Penetration are studied on different load periods. In this study different load periods are classified on the basis of transformer loading. EV Penetration on different load periods is calculated as the remaining portion of the transformer load that are to be loaded.

4.4.1. EV Penetration at Sajha Charging Station

Table 4-2: Size of EVs at Sajha station at different penetration level for different demand

Sajha	kVA Rating	Off Peak		Medium Peak		Peak	
		P(kW)	Q(kVAR)	P(kW)	Q(kVAR)	P(kW)	Q(kVAR)
10%	200	12.75	7.95	8.5	5.3	4.25	2.65
20%	200	25.5	15.9	17	10.6	8.5	5.3
30%	200	38.25	23.85	25.5	15.9	12.75	7.95
40%	200	51	31.8	34	21.2	17	10.6
50%	200	63.75	39.75	42.5	26.5	21.25	13.25
60%	200	76.5	47.7	51	31.8	25.5	15.9
70%	200	89.25	55.65	59.5	37.1	29.75	18.55
80%	200	102	63.6	68	42.4	34	21.2
90%	200	114.75	71.55	76.5	47.7	38.25	23.85
100%	200	127.5	79.5	85	53	42.5	26.5

This table shows active and reactive power consumed by Sajha Charging Station at different penetration level of EVs and at different power demand.

4.4.2. EV Penetration at Labim Mall Charging Station

Table 4-3: Size of EVs at Labim Mall charging station at different penetration level for different demand

Labim Mall	kVA Rating	Off Peak		Medium Peak		Peak	
		P(kW)	Q(kVAR)	P(kW)	Q(kVAR)	P(kW)	Q(kVAR)
10%	1000	63.75	39.75	42.5	26.5	21.25	13.25
20%	1000	127.5	79.5	85	53	42.5	26.5
30%	1000	191.25	119.25	127.5	79.5	63.75	39.75
40%	1000	255	159	170	106	85	53
50%	1000	318.75	198.75	212.5	132.5	106.25	66.25
60%	1000	382.5	238.5	255	159	127.5	79.5
70%	1000	446.25	278.25	297.5	185.5	148.75	92.75
80%	1000	510	318	340	212	170	106
90%	1000	573.75	357.75	382.5	238.5	191.25	119.25
100%	1000	637.5	397.5	425	265	212.5	132.5

This table shows active and reactive power consumed by Labim Mall Charging Station at different penetration level of EVs and at different power demand.

4.4.3. EV Penetration when both Sajha and Labim operating at the same time

Table 4-4: EV Penetration when both Sajha and Labim operating at the same time

Sajha & Labim Mall	kVA Rating	Off Peak		Medium Peak		Peak	
		P(kW)	Q(kVAR)	P(kW)	Q(kVAR)	P(kW)	Q(kVAR)
10%	1200	76.5	47.7	51	31.8	25.5	15.9
20%	1200	153	95.4	102	63.6	51	31.8
30%	1200	229.5	143.1	153	95.4	76.5	47.7
40%	1200	306	190.8	204	127.2	102	63.6
50%	1200	382.5	238.5	255	159	127.5	79.5
60%	1200	459	286.2	306	190.8	153	95.4
70%	1200	535.5	333.9	357	222.6	178.5	111.3
80%	1200	612	381.6	408	254.4	204	127.2
90%	1200	688.5	429.3	459	286.2	229.5	143.1
100%	1200	765	477	510	318	255	159

This table shows active and reactive power consumed by Sajha and Labim Mall Charging Stations operating simultaneously at different penetration level of EVs and at different power demand.

4.5. Total Harmonic Distortion

4.5.1. Charging Station at Sajha

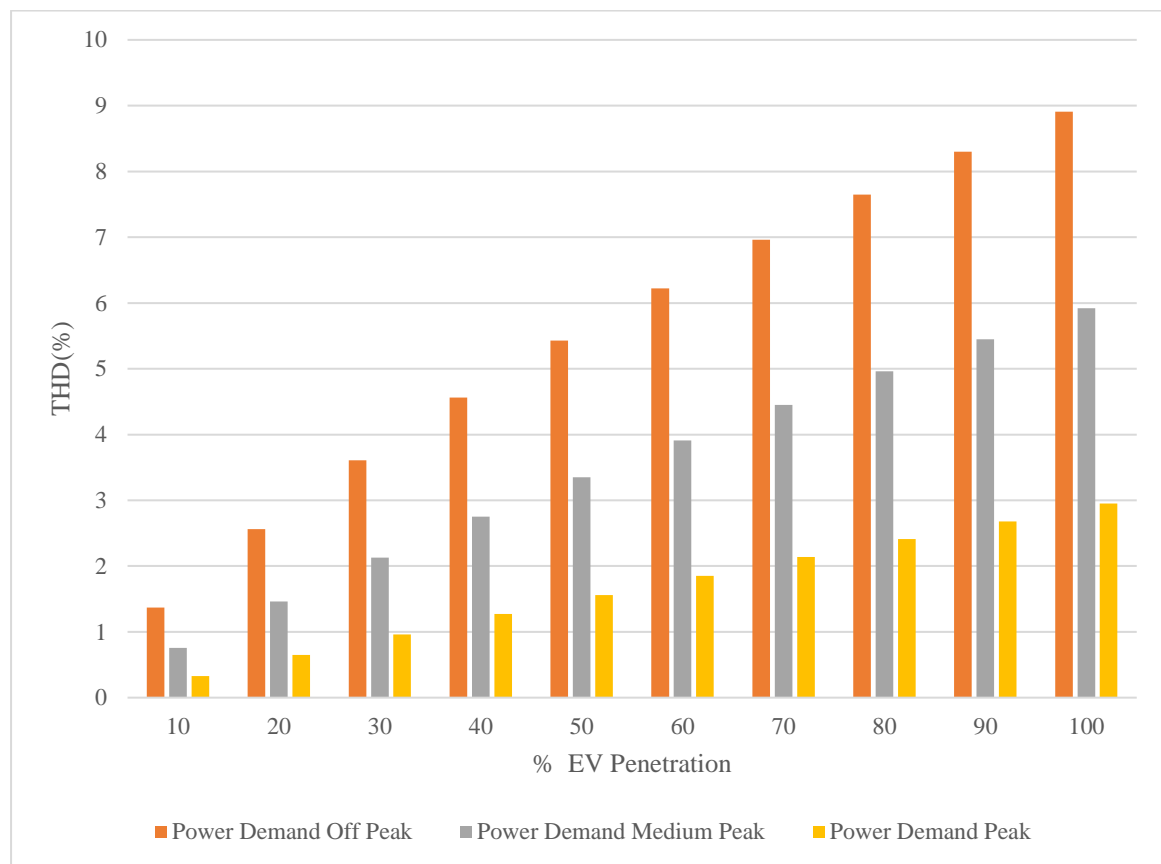


Figure 4-2 (%) THD at different penetration level at different power demand at Sajha

From the Figure 4-2, it is clear that when EV are being charged at Sajha Charging Station only, then THD limitation is violated at 50% (63.75 kW) EV Penetration Level at Off Peak Demand and 90% (76.5 kW) EV Penetration Level at Medium Peak Demand. At Peak Demand 100% (42.5 kW) EV Penetration Level can be charged without overloading the transformer.

4.5.2. Charging Station at Labim Mal

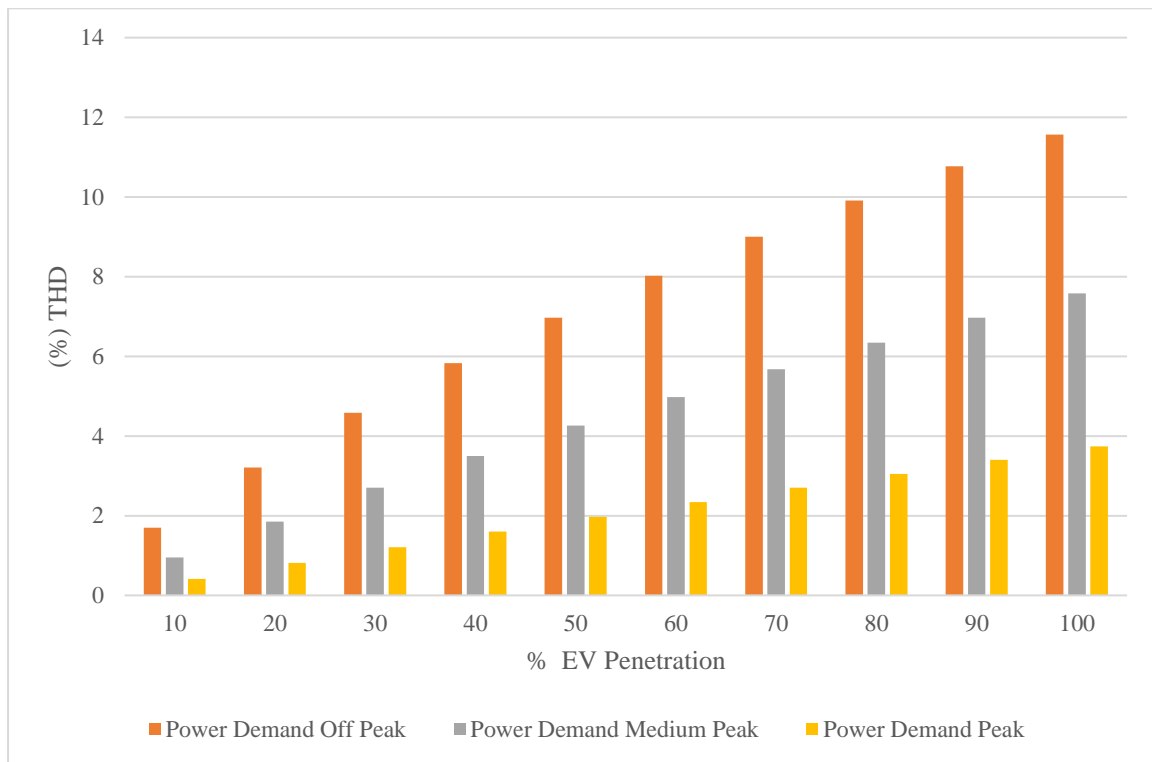


Figure 4-3 (% THD) at different penetration level at different power demand at Labim Mall

From the Figure 4-3, it is clear that when EV are being charged at Labim Mall Charging Station only, then THD limitation is violated at 40% (255 kW) EV Penetration Level at Off Peak Demand and 70% (297.5 kW) EV Penetration Level at Medium Peak Demand. At Peak Demand 100% (212.5 kW) EV Penetration Level can be charged without overloading the transformer.

4.5.3. Charging Station at Sajha and Labim Mall operating at the same time

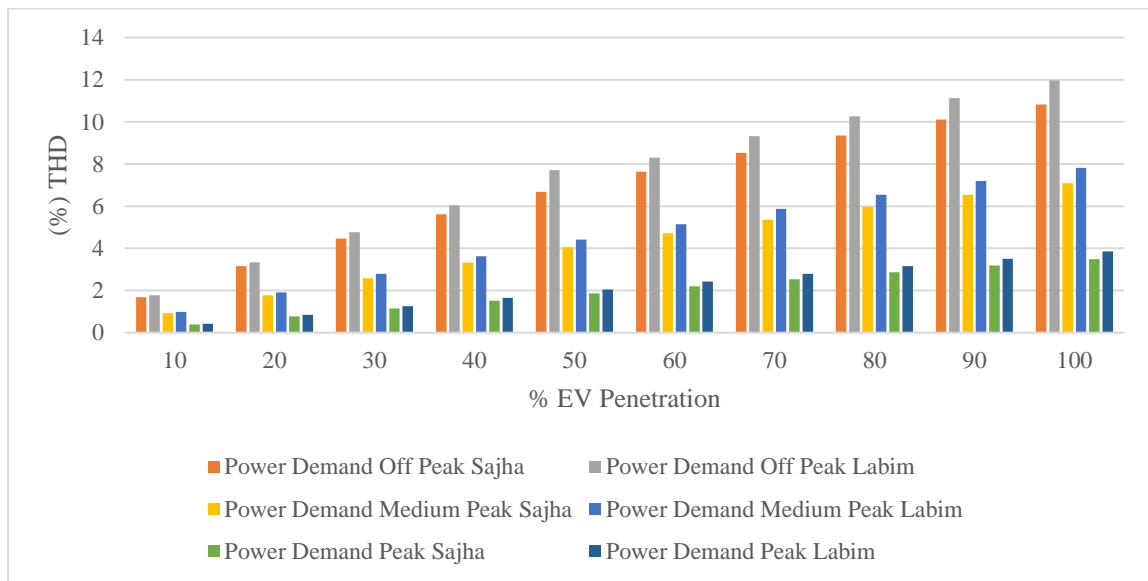


Figure 4-4 (% THD) at different penetration level at different power demand at Sajha and Labim simultaneous operation

From the Figure 4-4, it is clear that when EV are being charged at Labim Mall Charging Station only, then THD limitation is violated at 40% (306 kW) EV Penetration Level at Off Peak Demand and 60% (357 kW) EV Penetration Level at Medium Peak Demand. At Peak Demand 100% (255 kW) EV Penetration Level can be charged without overloading the transformer.

4.6. Voltage Profile at different cases of EV Penetration Level

Voltage Profile at different penetration level from 10 to 100 percent with the increase in 10 percent for all the connected buses are shown in APPENDIX. In this section, the results for the penetration level where THD limit is crossed and just before and after the penetration level where THD limit is crossed are shown.

4.6.1. Voltage Profile at Sajha Charging Station Only

4.6.1.1. At Off Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha Charging Station only at Off Peak Demand, at 40% (51 kW), 50% (63.75 kW) and 60% (76.5 kW) EV Penetration Level. This means that if harmonics can be controlled using suitable

Harmonic Filter, then EV Penetration Level can still be increased without overloading the transformer.

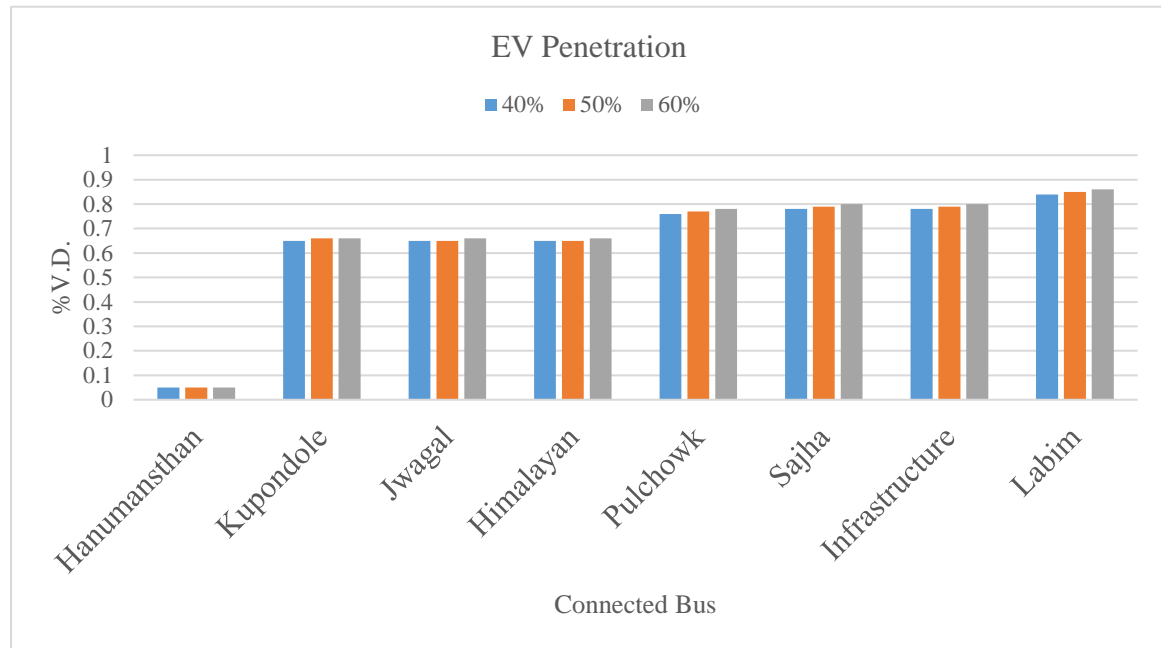


Figure 4-5 Voltage Profile at Sajha Charging Station at Off Peak Demand at 40%, 50% and 60% EV Penetration Level

Here Voltage deviation goes on increasing with the in EV penetration level.

4.6.1.2. At Medium Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha Charging Station only at Medium Peak Demand, at 80% (68 kW), 90% (76.5 kW) and 100% (85 kW) EV Penetration Level.

Table 4-5 Voltage Profile at Sajha Charging Station at Medium Peak Demand at 80%, 90% and 100% EV Penetration Level

BUS ID	%V.D. at EV Penetration		
	80%	90%	100%
Hanumansthan	0.1	0.1	0.1
Kupondole	1.28	1.28	1.29
Jwagal	1.28	1.28	1.29
Himalayan	1.28	1.29	1.29
Pulchowk	1.49	1.5	1.51
Sajha	1.53	1.54	1.55
Infrastructure	1.53	1.54	1.55
Labim	1.65	1.66	1.67

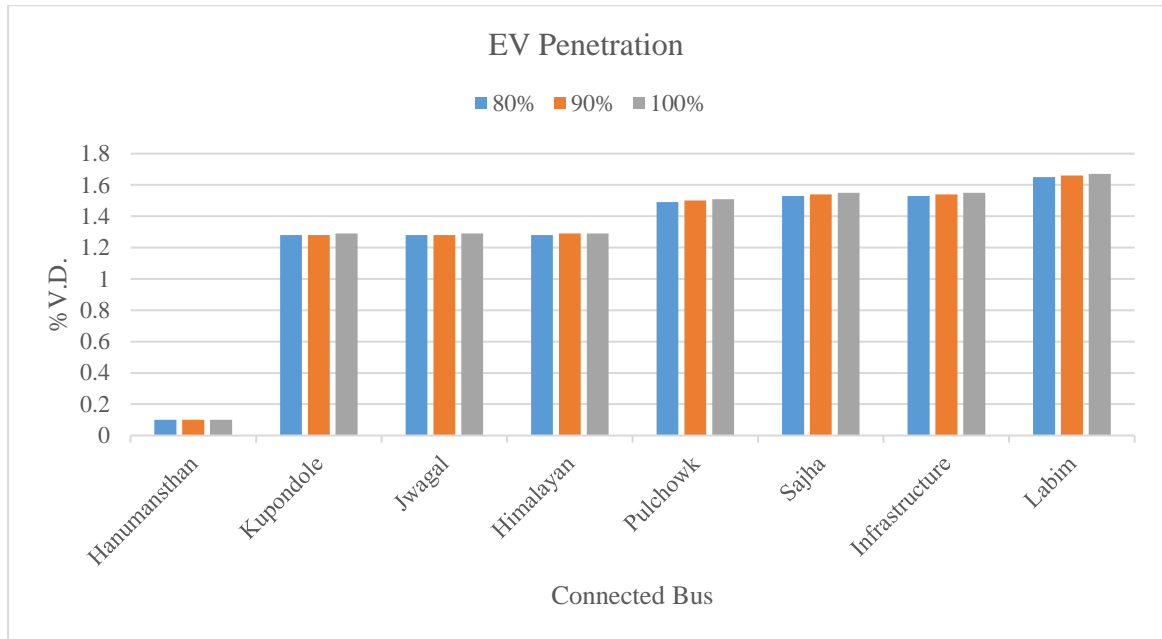


Figure 4-6 Voltage Profile at Sajha Charging Station at Medium Peak Demand at 80%, 90% and 100% EV Penetration Level

Here Voltage deviation goes on increasing with the in EV penetration level.

4.6.1.3. At Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha Charging Station only at Peak Demand, at 100% (42.5 kW) EV Penetration Level. This means that up to 42.5 kW EV Penetration can be done at Sajha Charging Station when operating alone without overloading the transformer during peak load hours.

Table 4-6 Voltage Profile at Sajha Charging Station at Peak Demand at 100% EV Penetration Level

BUS ID	%V.D. at 100% EV Penetration
Hanumansthan	0.15
Kupondole	1.89
Jwagal	1.89
Himalayan	1.9
Pulchowk	2.21
Sajha	2.26
Infrastructure	2.27
Labim	2.45

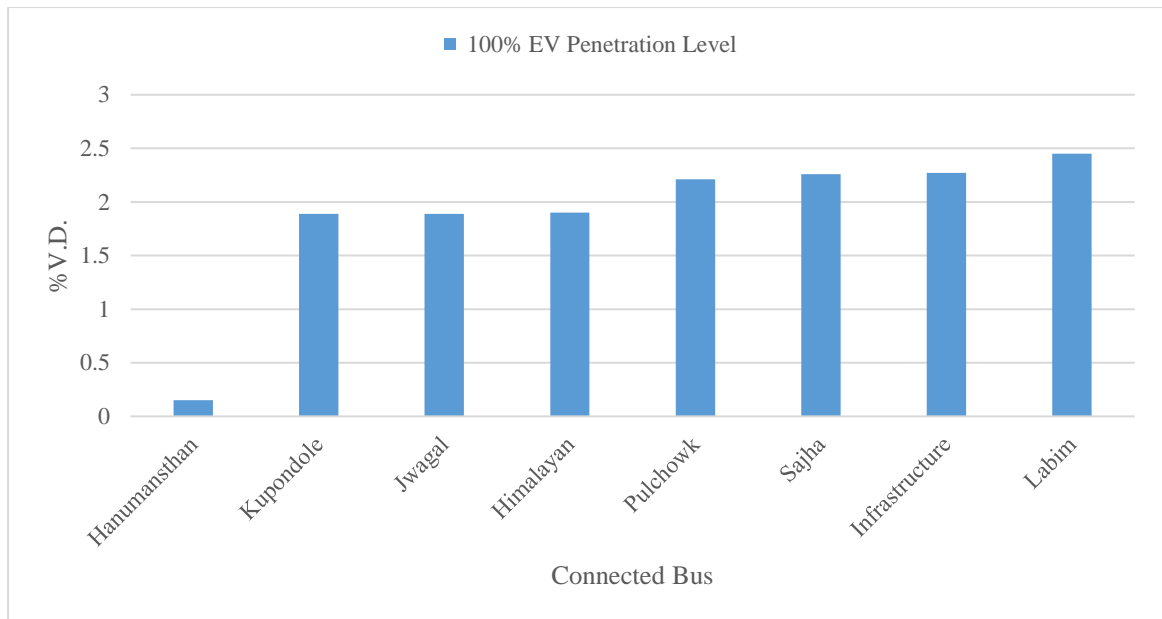


Figure 4-7 Voltage Profile at Sajha Charging Station at Peak Demand at 100% EV Penetration Level

Here, Voltage deviation goes on increasing with the increase in distance level from starting point of feeder that is Hanumansthan and deviation being highest at the end point of the feeder that is Labim Mall.

4.6.2. Voltage Profile at Labim Mall Charging Station Only

4.6.2.1. At Off Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Labim Mall Charging Station only at Off Peak Demand, at 30% (191.25 kW), 40% (255 kW) and 50% (318.75 kW) EV Penetration Level are analyzed. This means that if harmonics can be controlled using suitable Harmonic Filter, then EV Penetration Level can still be increased without overloading the transformer.

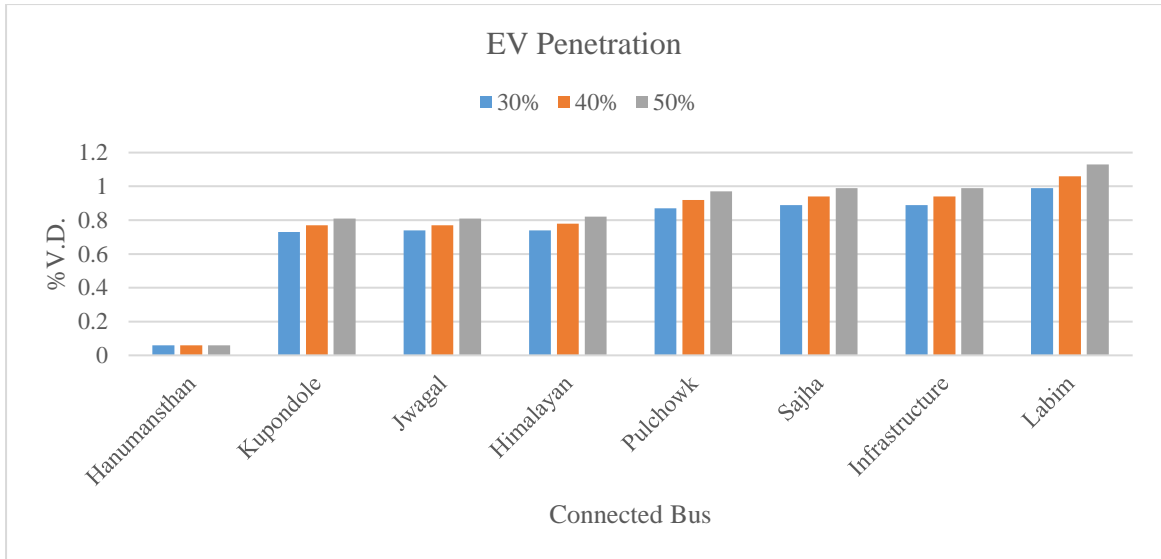


Figure 4-8 Voltage Profile at Labim Mall Charging Station at Off Peak Demand at 30%, 40% and 50% EV Penetration Level

Here Voltage deviation goes on increasing with the in EV penetration level.

4.6.2.2. At Medium Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Labim Mall Charging Station only at Medium Peak Demand, at 60% (255 kW), 70% (297.5 kW) and 80% (340 kW) EV Penetration Level are analyzed.

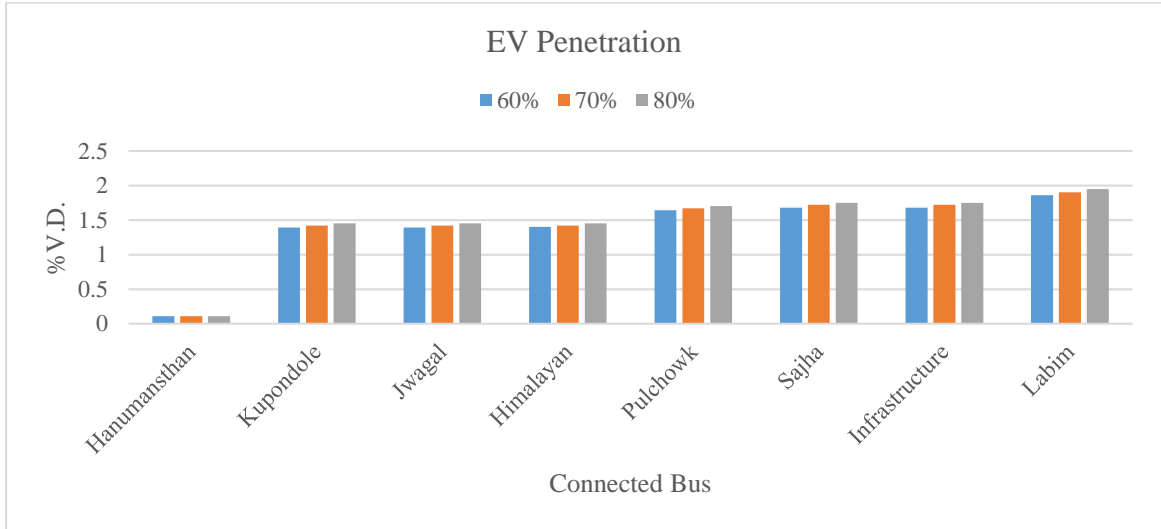


Figure 4-9 Voltage Profile at Labim Mall Charging Station at Medium Peak Demand at 60%, 70% and 80% EV Penetration Level

Here Voltage deviation goes on increasing with the in EV penetration level.

4.6.2.3. At Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Labim Mall Charging Station only at Peak Demand, at 100% (212.5 kW) EV Penetration Level. This means that up to 212.5 kW EV Penetration can be done at Labim Mall Charging Station when operating alone without overloading the transformer.

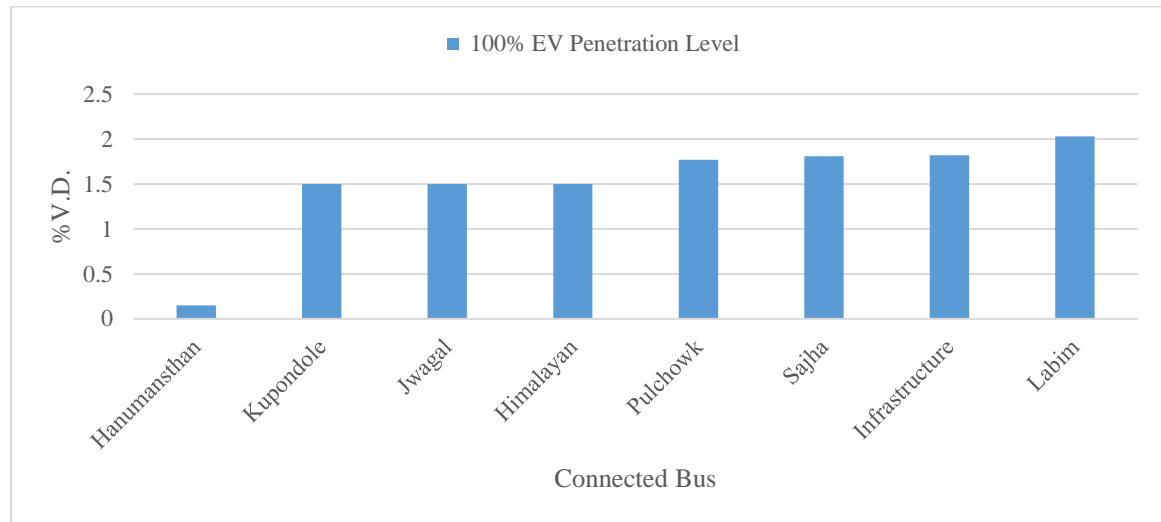


Figure 4-10 Voltage Profile at Labim Mall Charging Station at Peak Demand at 100% EV Penetration Level

Here, Voltage deviation goes on increasing with the increase in distance level from starting point of feeder that is Hanumansthan and deviation being highest at the end point of the feeder that is Labim Mall.

4.6.3. Voltage Profile at Sajha and Labim Mall Charging Station operating simultaneously

4.6.3.1. At Off Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha and Labim Mall Charging Station operating simultaneously at Off Peak Demand, at 30% (229.25 kW), 40% (306 kW) and 50% (382.5 kW) EV Penetration Level. This means that if harmonics can be controlled using suitable Harmonic Filter, then EV Penetration Level can still be increased without overloading the transformer.

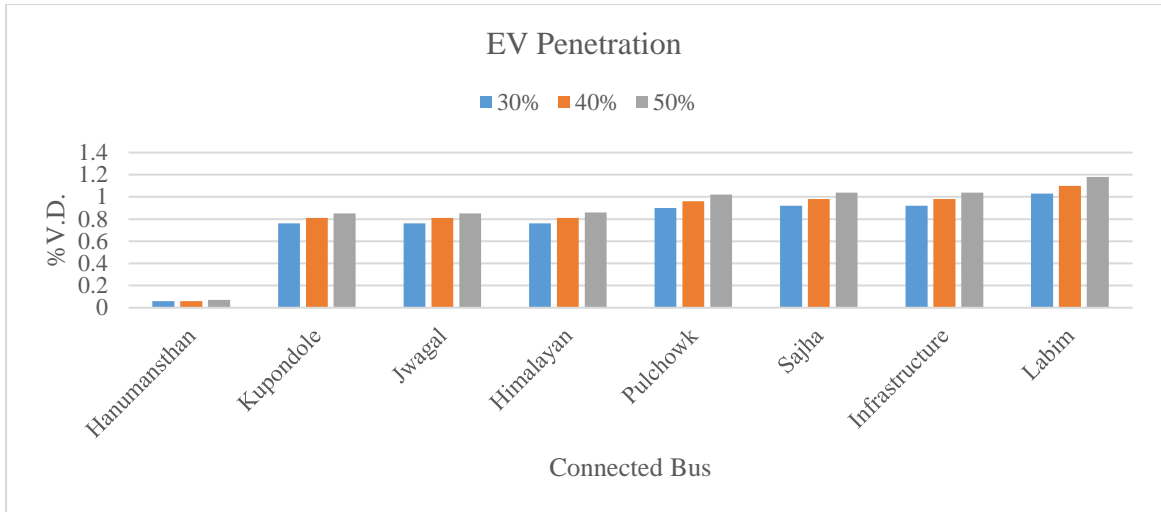


Figure 4-11 Voltage Profile at Sajha and Labim Mall Charging Station when operating simultaneously at Off Peak Demand at 30%, 40% and 50% EV Penetration Level

Here, Voltage deviation goes on increasing with the increase in EV Penetration Level.

4.6.3.2. At Medium Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha and Labim Mall Charging Station operating simultaneously at Medium Peak Demand, at 50% (255 kW), 60% (306 kW) and 70% (357 kW) EV Penetration Level.

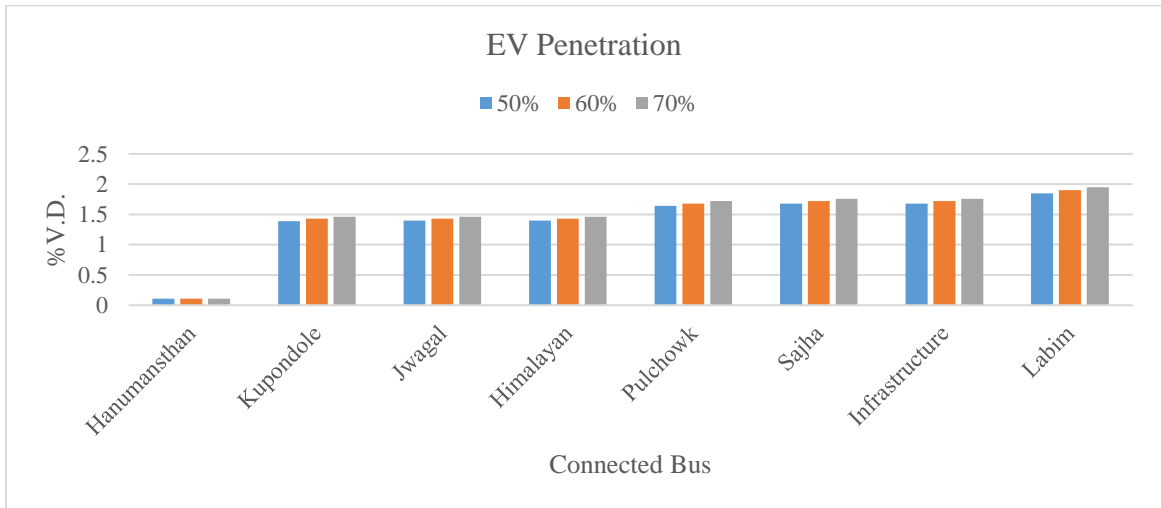


Figure 4-12 Voltage Profile at Sajha and Labim Mall Charging Station when operating simultaneously at Medium Peak Demand at 50%, 60% and 70% EV Penetration Level

Here, Voltage deviation goes on increasing with the increase in EV Penetration Level.

4.6.3.3. At Peak Demand

At this section, impacts on voltage profile, when EV are being charged at Sajha and Labim Mall Charging Station operating simultaneously at Peak Demand, at 100% (255 kW) EV Penetration Level are analyzed. This means that up to 255 kW EV Penetration can be done at Sajha and Labim Mall Charging Station when operating simultaneously without overloading the transformer.

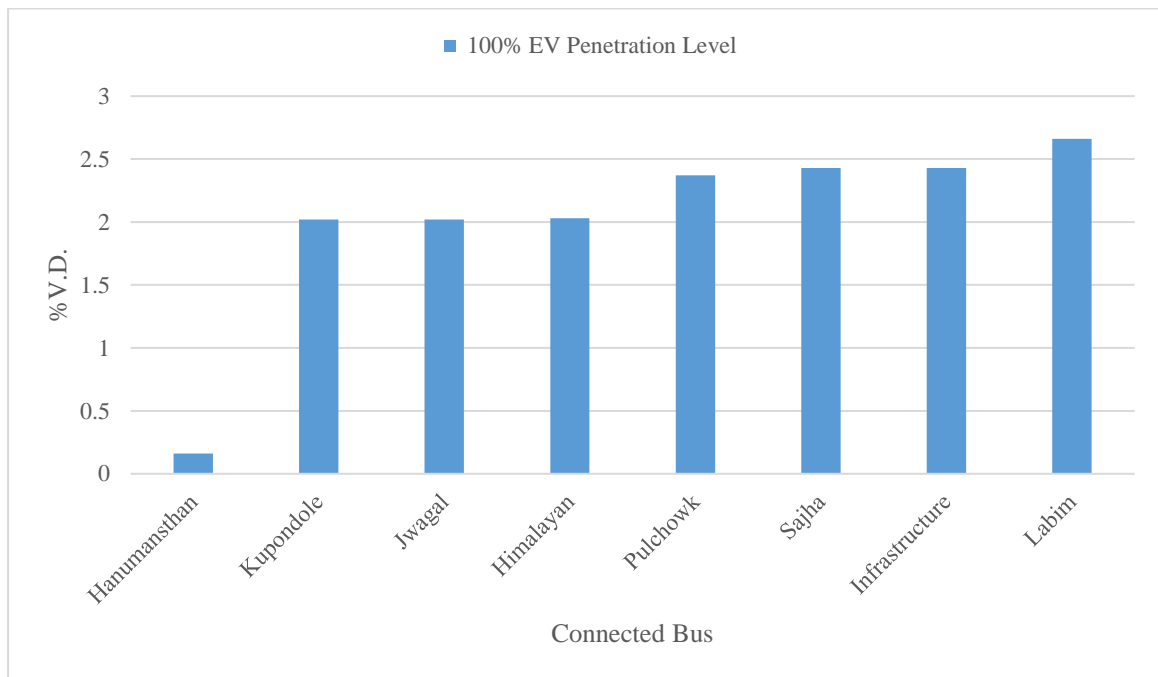


Figure 4-13 Voltage Profile at Sajha and Labim Mall Charging Station when operating simultaneously at Peak Demand at 100% EV Penetration Level

Here, Voltage deviation goes on increasing with the increase in distance level from starting point of feeder that is Hanumansthan and deviation being highest at the end point of the feeder that is Labim Mall.

4.7. Line Loss

4.7.1. Sajha Charging Station

4.7.1.1. At Off Peak Demand

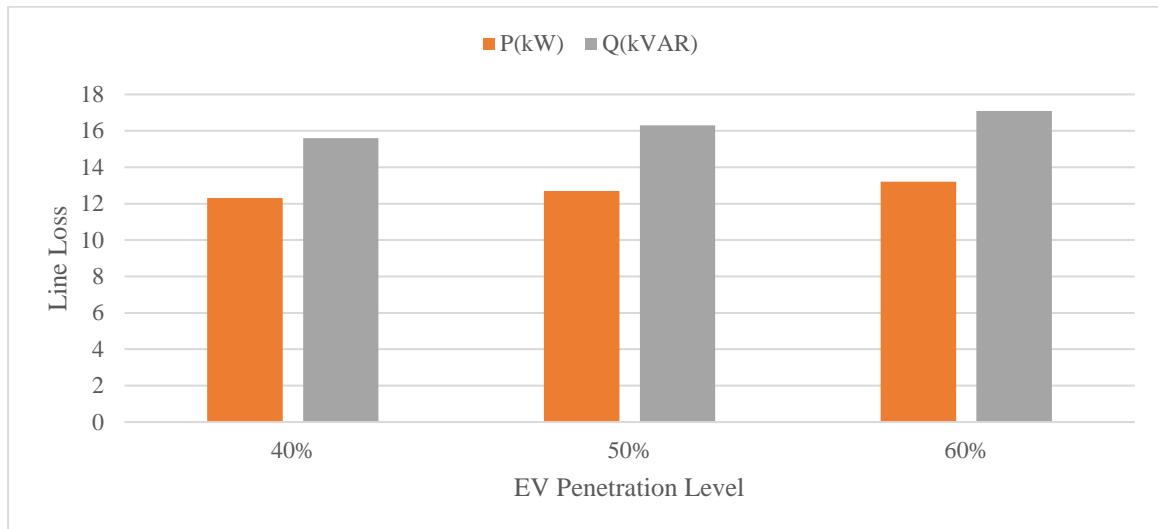


Figure 4-14 Active and Reactive Power Loss at Sajha Charging Station when operating alone at Off Peak Demand at 40%, 50% and 60% EV Penetration Level

Here Line Loss goes on increasing with the increase in EV Penetration Level.

4.7.1.2. At Medium Peak Demand

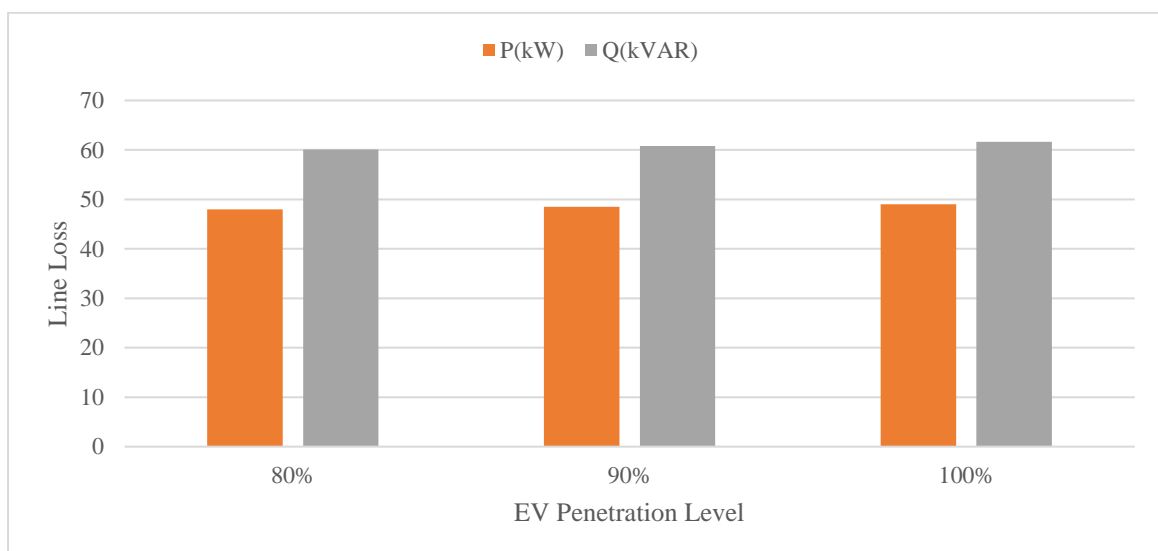


Figure 4-15 Active and Reactive Power Loss at Sajha Charging Station when operating alone at Medium Peak Demand at 80%, 90% and 100% EV Penetration Level

Line Loss goes on increasing with the increase in EV Penetration Level.

4.7.1.3. At Peak Demand

Table 4-7 Active and Reactive Power Loss at Sajha Charging Station when operating alone at Peak Demand at 100% EV Penetration Level

EV Penetration Level	Peak Demand	
	P(kW)	Q(kVAR)
100	105	131

From this table it is clear that Line Loss is maximum at peak demand at 100% EV Penetration Level.

4.7.2. Labim Mall Charging Station

4.7.2.1. At Off Peak Demand

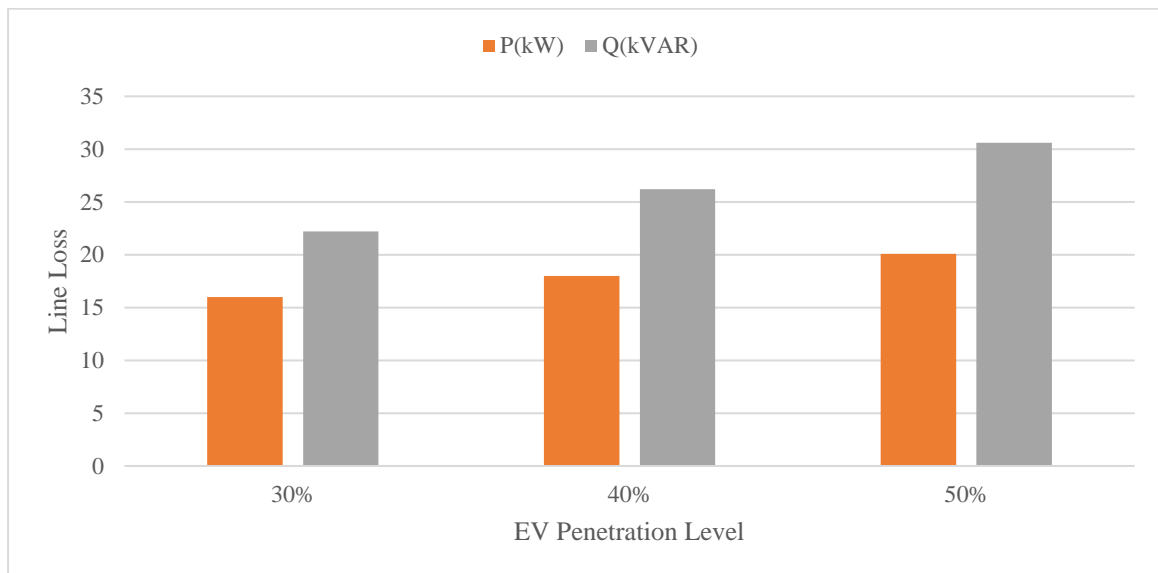


Figure 4-16 Active and Reactive Power Loss at Labim Mall Charging Station when operating alone at Off Peak Demand at 30%, 40% and 50% EV Penetration Level

Here Line loss goes on increasing with the increase in EV Penetration Level

4.7.2.2. At Medium Peak Demand

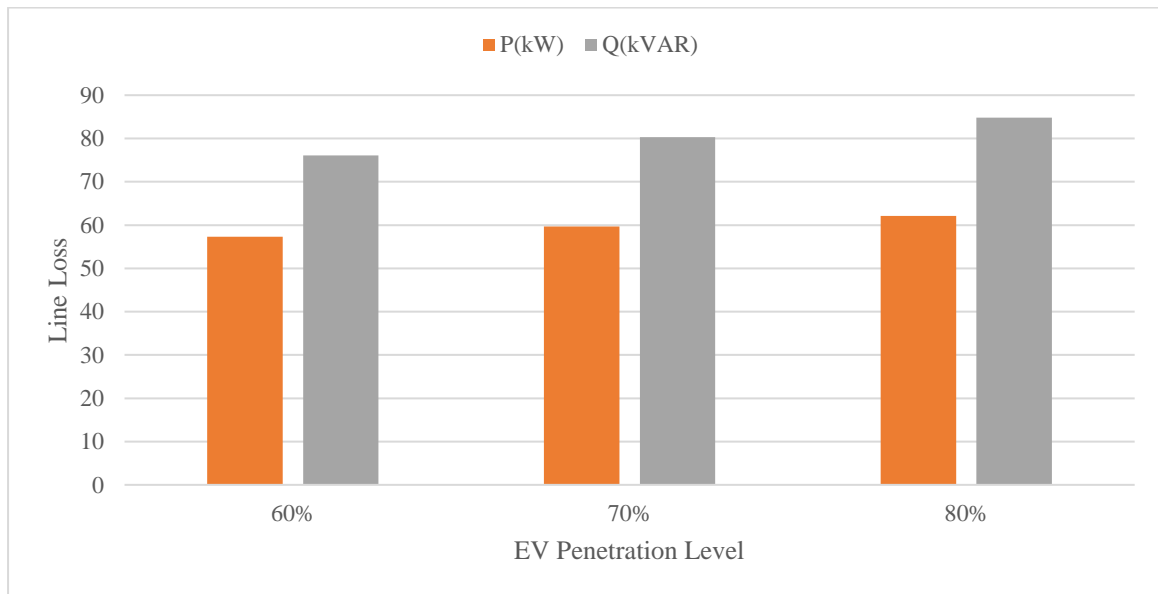


Figure 4-17 Active and Reactive Power Loss at Labim Mall Charging Station when operating alone at Medium Peak Demand at 60%, 70% and 80% EV Penetration Level

From this graph it is clear that Line Loss increases with the increase in EV Penetration Level.

4.7.2.3. At Peak Demand

Table 4-8 Active and Reactive Power Loss at Labim Mall Charging Station when operating alone at Peak Demand at 100% EV Penetration Level

EV Penetration Level	Peak Demand	
	P(kW)	Q(kVAR)
100	117	151

4.7.3. Sajha and Labim Mall Charging Station operating simultaneously

4.7.3.1. At Off Peak Demand

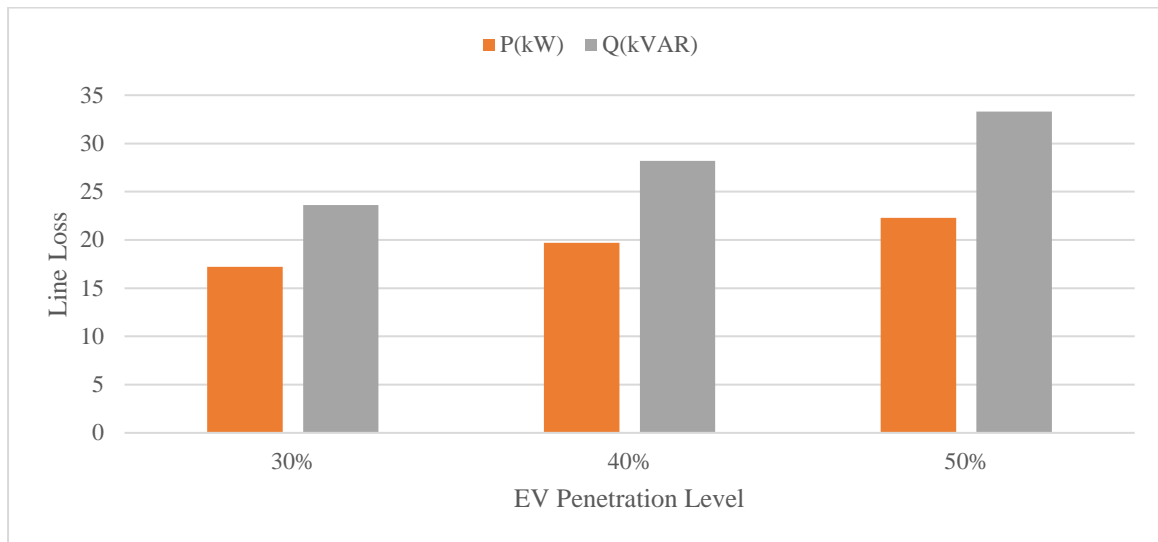


Figure 4-18 Active and Reactive Power Loss at Sajha and Labim Mall Charging Station when operating simultaneously at Off Peak Demand at 30%, 40% and 50% EV Penetration Level

Line Loss goes on increasing with the increase in EV Penetration Level.

4.7.3.2. t Medium Peak Demand

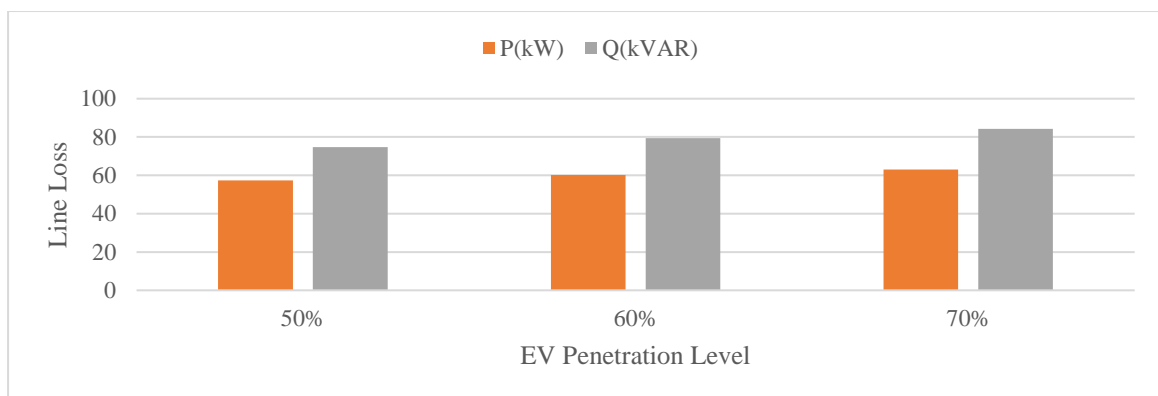


Figure 4-19 Active and Reactive Power Loss at Sajha and Labim Mall Charging Station when operating simultaneously at Medium Peak Demand at 50%, 60% and 70% EV Penetration Level

Line Loss goes on increasing with the increase in EV Penetration Level.

4.7.3.3. At Peak Demand

Table 4-9 Active and Reactive Power Loss at Sajha and Labim Mall Charging Station when operating simultaneously at Peak Demand at 100% EV Penetration Level

EV Penetration Level	Peak Demand	
	P(kW)	Q(kVAR)
100	121	155

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This paper presents following conclusions based on the results obtained and specific objectives of the study:

Voltage Deviation and Line Loss goes on increasing with the increase in power demand even without EV Penetration. Maximum Voltage Deviation is 4.82% at Labim Bus at peak demand period. Line Loss is maximum at peak demand period and is 102 kW.

The impacts of EVs in Distribution has been realized by increasing the Penetration Level of EV in the system. For same percentage EV Penetration but for different demand period, kW and kVAR Penetration of EV is different. For example: at Off peak period, Medium Peak and Peak period, 10% EV Penetration is equal to 12.75 kW, 8.5 kW and 4.25 kW respectively at Sajha Charging Station, while corresponding values are 63.75 kW, 42.5kW and 21.25 kW respectively for Labim Mall Charging Station and when both stations are operating simultaneously, corresponding values are 76.5 kW, 51 kW and 25.5 kW respectively. With the increase in EV Penetration level at different periods, Voltage Deviation and Line loss increases. Maximum Voltage Deviation is 5.83% at Labim Bus at 100% EV Penetration (255 kW EV load) during peak period and Line loss is equal to 121 kW, which is also highest at the same period and same penetration level when both Sajha and Labim Mall Charging station are operating simultaneously.

THD also goes on increasing with the increase in EV Penetration Level, but the major difference is that THD is greater at Off Peak demand than that in Peak demand because power consumed by EV load is greater in Off Peak Period at the same penetration level as explained above. When Sajha Charging Station is operating alone, then THD limit (5%) is crossed at 50% EV Penetration (i.e., 63.75 kW EV Load) during Off Peak Period while THD limit is crossed at 90% EV Penetration (i.e., 76.5 kW EV Load) during Medium Peak Period. When Labim Mall Charging Station is operating alone, then THD limit (5%) is crossed at 40% EV Penetration (i.e., 255 kW EV Load) during Off Peak Period while THD limit is crossed at 70% EV Penetration (i.e., 297.5 kW EV Load) during Medium Peak Period. When Sajha and Labim Mall Charging Station are operating simultaneously, then THD limit (5%) is crossed at 40% EV Penetration (i.e., 306 kW EV Load) during Off Peak Period while THD limit is crossed at 60% EV Penetration (i.e., 306 kW EV Load) during Medium Peak Period.

5.2. Recommendations

EVs are estimated to become a means of electrifying road transportation through technological advances and need for eco-friendly solutions. With the adoption of EVs, a challenge to the existing infrastructure of the electrical grid in terms of generation, transmission and mainly distribution will arise; as higher EV penetration may introduce new peaks into the system, which may cause overloading in electrical distribution components and cause power quality problems. Also with the higher EV penetration, there will be increase in the use of converters; which causes rise in THD and finally reducing power quality.

Since these challenges will be inevitable with the increased adoption of EVs, smart or coordinated charging, optimization of grid, use of harmonic filters will be indispensable to meet the new energy requirements without straining the infrastructure.

As already mentioned in limitations, this thesis doesn't consider the contribution of other renewable resources like wind and solar power in the system. Further study can be done to study the impacts of EV combined with the contribution of solar and wind power. Bidirectional EV charging is not also considered so future studies can be done regarding bidirectional charging also. Charging duration, different charging level and different pf can also be taken into consideration for future research Last but not the least, the design of Harmonics Filter to tackle harmonics introduced by EV Penetration in the system, can be of good research material

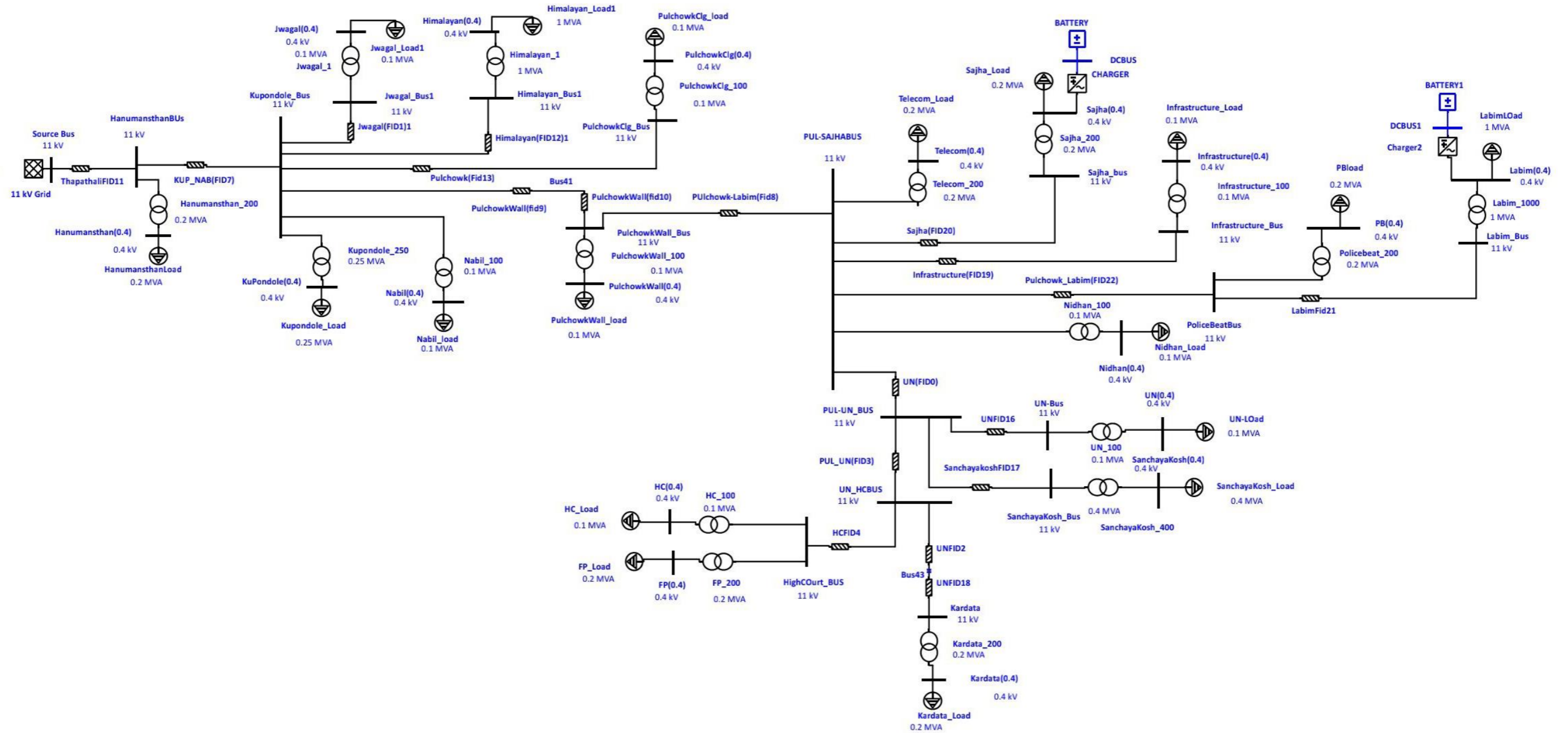
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APPENDIX I: ETAP MODEL



APPENDIX II: FEEDER DATA

FEEDER NAME	FEEDER_NUM	CON_TYP_SIZE	LENGTH (km)
Thapathali	FID11	XLPE_240	0.292525
Hanumansthan	FID7	DOG_100	0.774138
Jwagal	FID1	DOG_100	0.008902
Himalayan	FID12	XLPE_185	0.039533
PulchowkClg	FID13	XLPE_185	0.01824
PulchowkWall	FID9	XLPE_240	0.091129
PulchowkWall	FID10	ABC_150	0.582926
P_UN	FID0	DOG_100	0.19034
Sajha	FID20	XLPE_185	0.027621
Infrastructre	FID19	RABBIT_50	0.018439
labim	FID8	DOG_100	0.038631
labim	FID22	DOG_100	0.303394
Labim	FID21	XLPE_185	0.017446
UN	FID16	XLPE_150	0.016724
SanchayaKosh	FID17	XLPE_185	0.043634
HighCourt	FID4	DOG_100	0.140803
UN-Kardata	FID3	DOG_100	0.036486
UN-Kardata	FID2	DOG_100	0.397134
UN-Kardata	FID18	DOG_100	0.074059

APPENDIX III: TRANSFORMER DATA

Transformer Rating	kVA Rating (kVA)	% Impedance (%Z)	No Load Loss (W)	Full Load Loss (W)	X/R ratio
Hanumansthan	200	4	365	2100	4
Kupondole BusStop	250	4	455	2550	4
Jwagal Chowk	100	4	220	1210	4
Himalaya	1000	5	1500	13000	10
Nabil Bank	100	4	220	1210	4
Pulchowk Eng College	100	4	220	1210	4
Pulchowk Eng Col. Wall	100	4	220	1210	4
Telecom Office	200	4	365	2100	4
United Nations	100	4	220	1210	4
Sanchaya Kosh	400	4	745	4025	4
High Court	100	4	220	1210	4
Family Planning	200	4	365	2100	4
Thhulo Kardata	200	4	365	2100	4
Sajha Petrol	200	4	365	2100	4
Infrastructure	100	4	220	1210	4
Nidhan Hospital	100	4	220	1210	4
Police Beat	200	4	365	2100	4
Labim Mall	1000	5	1500	13000	10

APPENDIX IV: VOLTAGE PROFILE AT SAJHA AT DIFFERENT EV
PENETRATION LEVEL

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
10%	HanumansthanBUs	0.05	0.1	0.14
	HighCOurt_BUS	0.79	1.57	2.36
	Himalayan_Bus1	0.62	1.25	1.88
	Infrastructure_Bus	0.74	1.48	2.24
	Jwagal_Bus1	0.62	1.24	1.87
	Kardata	0.79	1.58	2.38
	Kupondole_Bus	0.62	1.24	1.87
	Labim_Bus	0.8	1.61	2.42
	PoliceBeatBus	0.8	1.6	2.41
	PUL-SAJHABUS	0.74	1.48	2.23
	PUL-UN_BUS	0.78	1.55	2.33
	PulchowkClg_Bus	0.62	1.24	1.87
	PulchowkWall_Bus	0.73	1.45	2.18
	Sajha	0.74	1.48	2.23
	SanchayaKosh_Bus	0.78	1.55	2.33
	Source Bus	0	0	0
	UN-Bus	0.78	1.55	2.33
	UN_HCBUS	0.78	1.55	2.34
	FP(0.4)	1.51	3.04	4.6
	HC(0.4)	1.51	3.04	4.6
	Himalayan(0.4)	1.4	2.81	4.27
	Infrastructure(0.4)	1.47	2.96	4.47
	Jwagal(0.4)	1.35	2.71	4.1
	Kardata(0.4)	1.52	3.06	4.62
	KuPondole(0.4)	1.35	2.71	4.1
	Labim(0.4)	1.58	3.18	4.82
	Nabil(0.4)	1.35	2.71	4.1
	Nidhan(0.4)	1.47	2.95	4.47
	PB(0.4)	1.53	3.08	4.65
	PulchowkClg(0.4)	1.35	2.71	4.1
	PulchowkWall(0.4)	1.45	2.92	4.41
	Sajha(0.4)	1.68	3.1	4.54
SanchayaKosh(0.4)	1.5	3.02	4.57	
Telecom(0.4)	1.47	2.95	4.47	
UN(0.4)	1.5	3.02	4.57	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
20%	HanumansthanBUs	0.05	0.1	0.14
	HighCOurt_BUS	0.8	1.57	2.36
	Himalayan_Bus1	0.63	1.25	1.88
	Infrastructure_Bus	0.76	1.49	2.24
	Jwagal_Bus1	0.63	1.25	1.87
	Kardata	0.8	1.59	2.39
	Kupondole_Bus	0.63	1.25	1.87
	Labim_Bus	0.82	1.61	2.42
	PoliceBeatBus	0.81	1.61	2.42
	PUL-SAJHABUS	0.75	1.49	2.24
	PUL-UN_BUS	0.79	1.55	2.33
	PulchowkClg_Bus	0.63	1.25	1.87
	PulchowkWall_Bus	0.74	1.45	2.18
	Sajha	0.76	1.49	2.24
	SanchayaKosh_Bus	0.79	1.56	2.33
	Source Bus	0	0	0
	UN-Bus	0.79	1.55	2.33
	UN_HCBUS	0.79	1.56	2.34
	FP(0.4)	1.52	3.05	4.6
	HC(0.4)	1.52	3.05	4.6
	Himalayan(0.4)	1.4	2.82	4.27
	Infrastructure(0.4)	1.48	2.96	4.48
	Jwagal(0.4)	1.36	2.72	4.1
	Kardata(0.4)	0.8	3.06	4.63
	KuPondole(0.4)	1.53	2.72	4.1
	Labim(0.4)	1.36	3.19	4.82
	Nabil(0.4)	1.59	2.72	4.1
	Nidhan(0.4)	1.36	2.96	4.47
	PB(0.4)	1.48	3.08	4.66
	PulchowkClg(0.4)	1.54	2.72	4.1
	PulchowkWall(0.4)	1.36	2.93	4.42
	Sajha(0.4)	1.46	3.25	4.62
SanchayaKosh(0.4)	1.91	3.03	4.57	
Telecom(0.4)	1.51	2.96	4.47	
UN(0.4)	1.91	3.03	4.57	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
30%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.81	1.58	2.37
	Himalayan_Bus1	0.64	1.26	1.88
	Infrastructure_Bus	0.77	1.5	2.24
	Jwagal_Bus1	0.64	1.25	1.88
	Kardata	0.81	1.6	2.39
	Kupondole_Bus	0.64	1.25	1.88
	Labim_Bus	0.83	1.62	2.42
	PoliceBeatBus	0.82	1.62	2.42
	PUL-SAJHABUS	0.77	1.5	2.24
	PUL-UN_BUS	0.8	1.56	2.34
	PulchowkClg_Bus	0.64	1.25	1.88
	PulchowkWall_Bus	0.75	1.46	2.19
	Sajha	0.77	1.5	2.24
	SanchayaKosh_Bus	0.8	1.56	2.34
	Source Bus	0	0	0
	UN-Bus	0.8	1.56	2.34
	UN_HCBUS	0.8	1.57	2.34
	FP(0.4)	1.53	3.05	4.6
	HC(0.4)	1.53	3.05	4.6
	Himalayan(0.4)	1.41	2.83	4.27
	Infrastructure(0.4)	1.49	2.97	4.48
	Jwagal(0.4)	1.36	2.72	4.11
	Kardata(0.4)	1.54	3.07	4.63
	KuPondole(0.4)	1.36	2.72	4.11
	Labim(0.4)	1.6	3.19	4.83
	Nabil(0.4)	1.36	2.72	4.11
	Nidhan(0.4)	1.49	2.97	4.48
	PB(0.4)	1.55	3.09	4.66
	PulchowkClg(0.4)	1.36	2.72	4.11
	PulchowkWall(0.4)	1.47	2.93	4.42
	Sajha(0.4)	2.13	3.4	4.69
SanchayaKosh(0.4)	1.52	3.03	4.58	
Telecom(0.4)	1.49	2.97	4.48	
UN(0.4)	1.52	3.03	4.57	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
40%	HanumansthanBUS	0.05	0.1	0.15
	HighCOurt_BUS	0.82	1.59	2.37
	Himalayan_Bus1	0.65	1.26	1.88
	Infrastructure_Bus	0.78	1.51	2.25
	Jwagal_Bus1	0.65	1.26	1.88
	Kardata	0.83	1.6	2.39
	Kupondole_Bus	0.65	1.26	1.88
	Labim_Bus	0.84	1.63	2.43
	PoliceBeatBus	0.84	1.62	2.43
	PUL-SAJHABUS	0.78	1.5	2.24
	PUL-UN_BUS	0.81	1.57	2.34
	PulchowkClg_Bus	0.65	1.26	1.88
	PulchowkWall_Bus	0.76	1.47	2.19
	Sajha	0.78	1.5	2.24
	SanchayaKosh_Bus	0.81	1.57	2.34
	Source Bus	0	0	0
	UN-Bus	0.81	1.57	2.34
	UN_HCBUS	0.81	1.57	2.35
	FP(0.4)	1.54	3.06	4.61
	HC(0.4)	1.54	3.06	4.61
	Himalayan(0.4)	1.42	2.83	4.28
	Infrastructure(0.4)	1.5	2.98	4.48
	Jwagal(0.4)	1.37	2.73	4.11
	Kardata(0.4)	1.55	3.08	4.63
	KuPondole(0.4)	1.37	2.73	4.11
	Labim(0.4)	1.61	3.2	4.83
	Nabil(0.4)	1.37	2.73	4.11
	Nidhan(0.4)	1.5	2.98	4.48
	PB(0.4)	1.56	3.1	4.66
	PulchowkClg(0.4)	1.37	2.73	4.11
	PulchowkWall(0.4)	1.48	2.94	4.43
	Sajha(0.4)	2.36	3.54	4.76
SanchayaKosh(0.4)	1.53	3.04	4.58	
Telecom(0.4)	1.5	2.98	4.48	
UN(0.4)	1.53	3.04	4.58	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
50%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.83	1.59	2.37
	Himalayan_Bus1	0.66	1.27	1.89
	Infrastructure_Bus	0.79	1.51	2.25
	Jwagal_Bus1	0.65	1.26	1.88
	Kardata	0.84	1.61	2.4
	Kupondole_Bus	0.65	1.26	1.88
	Labim_Bus	0.85	1.63	2.43
	PoliceBeatBus	0.85	1.63	2.43
	PUL-SAJHABUS	0.79	1.51	2.25
	PUL-UN_BUS	0.82	1.57	2.34
	PulchowkClg_Bus	0.65	1.26	1.88
	PulchowkWall_Bus	0.77	1.47	2.19
	Sajha	0.79	1.51	2.25
	SanchayaKosh_Bus	0.82	1.58	2.34
	Source Bus	0	0	0
	UN-Bus	0.82	1.57	2.34
	UN_HCBUS	0.82	1.58	2.35
	FP(0.4)	1.55	3.07	4.61
	HC(0.4)	1.55	3.07	4.61
	Himalayan(0.4)	1.43	2.84	4.28
	Infrastructure(0.4)	1.51	2.98	4.49
	Jwagal(0.4)	1.38	2.73	4.11
	Kardata(0.4)	1.56	3.08	4.64
	KuPondole(0.4)	1.38	2.73	4.11
	Labim(0.4)	1.62	3.21	4.83
	Nabil(0.4)	1.38	2.73	4.11
	Nidhan(0.4)	1.51	2.98	4.48
	PB(0.4)	1.57	3.1	4.67
	PulchowkClg(0.4)	1.38	2.73	4.11
	PulchowkWall(0.4)	2.58	2.95	4.43
	Sajha(0.4)	1.54	3.69	4.84
	SanchayaKosh(0.4)	1.51	3.05	4.58
Telecom(0.4)	1.54	2.98	4.48	
UN(0.4)	1.51	3.05	4.58	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
60%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.84	1.6	2.38
	Himalayan_Bus1	0.66	1.27	1.89
	Infrastructure_Bus	0.8	1.52	2.25
	Jwagal_Bus1	0.66	1.27	1.88
	Kardata	0.85	1.62	2.4
	Kupondole_Bus	0.66	1.27	1.88
	Labim_Bus	0.86	1.64	2.43
	PoliceBeatBus	0.86	1.64	2.43
	PUL-SAJHABUS	0.8	1.52	2.25
	PUL-UN_BUS	0.83	1.58	2.35
	PulchowkClg_Bus	0.66	1.27	1.88
	PulchowkWall_Bus	0.78	1.48	2.2
	Sajha	0.8	1.52	2.25
	SanchayaKosh_Bus	0.83	1.58	2.35
	Source Bus	0	0	0
	UN-Bus	0.83	1.58	2.35
	UN_HCBUS	0.83	1.59	2.35
	FP(0.4)	1.56	3.07	4.61
	HC(0.4)	1.56	3.07	4.61
	Himalayan(0.4)	1.44	2.84	4.28
	Infrastructure(0.4)	1.52	2.99	4.49
	Jwagal(0.4)	1.39	2.74	4.11
	Kardata(0.4)	1.57	3.09	4.64
	KuPondole(0.4)	1.39	2.74	4.11
	Labim(0.4)	1.63	3.21	4.84
	Nabil(0.4)	1.39	2.74	4.11
	Nidhan(0.4)	1.52	2.99	4.49
	PB(0.4)	1.58	3.11	4.67
	PulchowkClg(0.4)	1.39	2.74	4.11
	PulchowkWall(0.4)	1.5	2.95	4.43
	Sajha(0.4)	2.8	3.84	4.91
SanchayaKosh(0.4)	1.55	3.05	4.59	
Telecom(0.4)	1.52	2.99	4.49	
UN(0.4)	1.55	3.05	4.58	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
70%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.85	1.61	2.38
	Himalayan_Bus1	0.67	1.28	1.89
	Infrastructure_Bus	0.81	1.53	2.26
	Jwagal_Bus1	0.67	1.27	1.89
	Kardata	0.86	1.63	2.41
	Kupondole_Bus	0.67	1.27	1.89
	Labim_Bus	0.87	1.65	2.44
	PoliceBeatBus	0.87	1.65	2.44
	PUL-SAJHABUS	0.81	1.52	2.25
	PUL-UN_BUS	0.84	1.59	2.35
	PulchowkClg_Bus	0.67	1.27	1.89
	PulchowkWall_Bus	0.79	1.49	2.2
	Sajha	0.81	1.53	2.25
	SanchayaKosh_Bus	0.84	1.59	2.35
	Source Bus	0	0	0
	UN-Bus	0.84	1.59	2.35
	UN_HCBUS	0.84	1.59	2.36
	FP(0.4)	1.57	3.08	4.62
	HC(0.4)	1.57	3.08	4.62
	Himalayan(0.4)	1.44	2.85	4.28
	Infrastructure(0.4)	1.53	3	4.49
	Jwagal(0.4)	1.4	2.74	4.12
	Kardata(0.4)	1.58	3.1	4.64
	KuPondole(0.4)	1.4	2.74	4.12
	Labim(0.4)	1.64	3.22	4.84
	Nabil(0.4)	1.4	2.74	4.12
	Nidhan(0.4)	1.53	3	4.49
	PB(0.4)	1.59	3.12	4.68
	PulchowkClg(0.4)	1.4	2.74	4.12
	PulchowkWall(0.4)	1.51	2.96	4.44
	Sajha(0.4)	3.02	3.99	4.99
SanchayaKosh(0.4)	1.56	3.06	4.59	
Telecom(0.4)	1.53	3	4.49	
UN(0.4)	1.56	3.06	4.59	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
80%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.86	1.61	2.38
	Himalayan_Bus1	0.68	1.28	1.89
	Infrastructure_Bus	0.82	1.53	2.26
	Jwagal_Bus1	0.68	1.28	1.89
	Kardata	0.87	1.63	2.41
	Kupondole_Bus	0.68	1.28	1.89
	Labim_Bus	0.88	1.65	2.44
	PoliceBeatBus	0.88	1.65	2.44
	PUL-SAJHABUS	0.82	1.53	2.26
	PUL-UN_BUS	0.85	1.59	2.35
	PulchowkClg_Bus	0.68	1.28	1.89
	PulchowkWall_Bus	0.8	1.49	2.2
	Sajha	0.82	1.53	2.26
	SanchayaKosh_Bus	0.85	1.6	2.35
	Source Bus	0	0	0
	UN-Bus	0.85	1.59	2.35
	UN_HCBUS	0.85	1.6	2.36
	FP(0.4)	1.58	3.09	4.62
	HC(0.4)	1.58	3.09	4.62
	Himalayan(0.4)	1.45	2.85	4.29
	Infrastructure(0.4)	1.54	3	4.5
	Jwagal(0.4)	1.4	2.75	4.12
	Kardata(0.4)	1.59	3.1	4.65
	KuPondole(0.4)	1.4	2.75	4.12
	Labim(0.4)	1.65	3.23	4.84
	Nabil(0.4)	1.4	2.75	4.12
	Nidhan(0.4)	1.54	3	4.49
	PB(0.4)	1.6	3.12	4.68
	PulchowkClg(0.4)	1.4	2.75	4.12
	PulchowkWall(0.4)	1.52	2.97	4.44
	Sajha(0.4)	3.24	4.14	5.06
SanchayaKosh(0.4)	1.57	3.07	4.59	
Telecom(0.4)	1.54	3	4.49	
UN(0.4)	1.57	3.07	4.59	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
90%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.87	1.62	2.39
	Himalayan_Bus1	0.69	1.29	1.9
	Infrastructure_Bus	0.83	1.54	2.26
	Jwagal_Bus1	0.69	1.28	1.89
	Kardata	0.88	1.64	2.41
	Kupondole_Bus	0.69	1.28	1.89
	Labim_Bus	0.89	1.66	2.44
	PoliceBeatBus	0.89	1.66	2.44
	PUL-SAJHABUS	0.83	1.54	2.26
	PUL-UN_BUS	0.86	1.6	2.36
	PulchowkClg_Bus	0.69	1.28	1.89
	PulchowkWall_Bus	0.81	1.5	2.21
	Sajha	0.83	1.54	2.26
	SanchayaKosh_Bus	0.86	1.6	2.36
	Source Bus	0	0	0
	UN-Bus	0.86	1.6	2.36
	UN_HCBUS	0.86	1.61	2.36
	FP(0.4)	1.59	3.09	4.62
	HC(0.4)	1.59	3.09	4.62
	Himalayan(0.4)	1.46	2.86	4.29
	Infrastructure(0.4)	1.55	3.01	4.5
	Jwagal(0.4)	1.41	2.75	4.12
	Kardata(0.4)	1.6	3.11	4.65
	KuPondole(0.4)	1.41	2.75	4.12
	Labim(0.4)	1.66	3.23	4.85
	Nabil(0.4)	1.41	2.75	4.12
	Nidhan(0.4)	1.55	3.01	4.5
	PB(0.4)	1.61	3.13	4.68
	PulchowkClg(0.4)	1.41	2.75	4.12
	PulchowkWall(0.4)	1.53	2.97	4.44
	Sajha(0.4)	3.46	4.28	5.14
	SanchayaKosh(0.4)	1.58	3.08	4.6
Telecom(0.4)	1.55	3.01	4.5	
UN(0.4)	1.58	3.07	4.59	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
100%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.88	1.63	2.39
	Himalayan_Bus1	0.7	1.29	1.9
	Infrastructure_Bus	0.84	1.55	2.27
	Jwagal_Bus1	0.69	1.29	1.89
	Kardata	0.89	1.65	2.42
	Kupondole_Bus	0.69	1.29	1.89
	Labim_Bus	0.9	1.67	2.45
	PoliceBeatBus	0.9	1.67	2.45
	PUL-SAJHABUS	0.84	1.54	2.26
	PUL-UN_BUS	0.87	1.61	2.36
	PulchowkClg_Bus	0.69	1.29	1.89
	PulchowkWall_Bus	0.81	1.51	2.21
	Sajha	0.84	1.55	2.26
	SanchayaKosh_Bus	0.87	1.61	2.36
	Source Bus	0	0	0
	UN-Bus	0.87	1.61	2.36
	UN_HCBUS	0.87	1.61	2.37
	FP(0.4)	1.6	3.1	4.63
	HC(0.4)	1.6	3.1	4.63
	Himalayan(0.4)	1.47	2.86	4.29
	Infrastructure(0.4)	1.56	3.02	4.5
	Jwagal(0.4)	1.42	2.76	4.13
	Kardata(0.4)	1.61	3.12	4.65
	KuPondole(0.4)	1.42	2.76	4.12
	Labim(0.4)	1.67	3.24	4.85
	Nabil(0.4)	1.42	2.76	4.12
	Nidhan(0.4)	1.56	3.02	4.5
	PB(0.4)	1.62	3.14	4.69
	PulchowkClg(0.4)	1.42	2.76	4.13
	PulchowkWall(0.4)	1.54	2.98	4.45
	Sajha(0.4)	3.68	4.43	5.21
	SanchayaKosh(0.4)	1.59	3.08	4.6
Telecom(0.4)	1.56	3.02	4.5	
UN(0.4)	1.59	3.08	4.6	

APPENDIX V: VOLTAGE PROFILE AT LABIM MALL AT DIFFERENT
PENETRATION LEVEL

EV Penetration Level	Bus ID	%V.D.		
		Period		
		Off Peak	Medium Peak	Peak
10%	HanumansthanBUS	0.05	0.1	0.15
	HighCOurt_BUS	0.83	1.59	2.37
	Himalayan_Bus1	0.66	1.27	1.89
	Infrastructure_Bus	0.79	1.51	2.25
	Jwagal_Bus1	0.66	1.26	1.88
	Kardata	0.84	1.61	2.4
	Kupondole_Bus	0.65	1.26	1.88
	Labim_Bus	0.86	1.64	2.44
	PoliceBeatBus	0.86	1.64	2.43
	PUL-SAJHABUS	0.79	1.51	2.25
	PUL-UN_BUS	0.82	1.57	2.34
	PulchowkClg_Bus	0.66	1.26	1.88
	PulchowkWall_Bus	0.77	1.47	2.19
	Sajha	0.79	1.51	2.25
	SanchayaKosh_Bus	0.82	1.58	2.34
	Source Bus	0	0	0
	UN-Bus	0.82	1.57	2.34
	UN_HCBUS	0.82	1.58	2.35
	FP(0.4)	1.55	3.07	4.61
	HC(0.4)	1.55	3.07	4.61
	Himalayan(0.4)	1.43	2.84	4.28
	Infrastructure(0.4)	1.51	2.98	4.49
	Jwagal(0.4)	1.38	2.73	4.11
	Kardata(0.4)	1.56	3.08	4.64
	KuPondole(0.4)	1.38	2.73	4.11
	Labim(0.4)	1.86	3.37	4.91
	Nabil(0.4)	1.38	2.73	4.11
	Nidhan(0.4)	1.51	2.98	4.48
	PB(0.4)	1.59	3.11	4.67
	PulchowkClg(0.4)	1.38	2.73	4.11
	PulchowkWall(0.4)	1.49	2.95	4.43
	Sajha(0.4)	1.51	2.98	4.48
	SanchayaKosh(0.4)	1.54	3.05	4.58
	Telecom(0.4)	1.51	2.98	4.48
UN(0.4)	1.54	3.05	4.58	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
20%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.88	1.63	2.39
	Himalayan_Bus1	0.7	1.29	1.9
	Infrastructure_Bus	0.84	1.55	2.27
	Jwagal_Bus1	0.7	1.29	1.89
	Kardata	0.89	1.65	2.42
	Kupondole_Bus	0.7	1.29	1.89
	Labim_Bus	0.93	1.69	2.46
	PoliceBeatBus	0.93	1.68	2.45
	PUL-SAJHABUS	0.84	1.55	2.26
	PUL-UN_BUS	0.87	1.61	2.36
	PulchowkClg_Bus	0.7	1.29	1.89
	PulchowkWall_Bus	0.82	1.51	2.21
	Sajha	0.84	1.55	2.26
	SanchayaKosh_Bus	0.87	1.61	2.36
	Source Bus	0	0	0
	UN-Bus	0.87	1.61	2.36
	UN_HCBUS	0.87	1.61	2.37
	FP(0.4)	1.61	3.1	4.63
	HC(0.4)	1.61	3.1	4.63
	Himalayan(0.4)	1.47	2.86	4.29
	Infrastructure(0.4)	1.57	3.02	4.5
	Jwagal(0.4)	1.42	2.76	4.13
	Kardata(0.4)	1.61	3.12	4.65
	KuPondole(0.4)	1.42	2.76	4.12
	Labim(0.4)	2.16	3.57	5.01
	Nabil(0.4)	1.42	2.76	4.12
	Nidhan(0.4)	1.56	3.02	4.5
	PB(0.4)	1.65	3.16	4.69
	PulchowkClg(0.4)	1.42	2.76	4.13
	PulchowkWall(0.4)	1.54	2.98	4.45
	Sajha(0.4)	1.57	3.02	4.5
SanchayaKosh(0.4)	1.6	3.08	4.6	
Telecom(0.4)	1.56	3.02	4.5	
UN(0.4)	1.6	3.08	4.6	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
30%	HanumansthanBUs	0.06	0.1	0.15
	HighCOurt_BUS	0.93	1.66	2.41
	Himalayan_Bus1	0.74	1.32	1.91
	Infrastructure_Bus	0.89	1.58	2.28
	Jwagal_Bus1	0.74	1.32	1.91
	Kardata	0.94	1.68	2.43
	Kupondole_Bus	0.73	1.32	1.91
	Labim_Bus	0.99	1.73	2.48
	PoliceBeatBus	0.99	1.73	2.48
	PUL-SAJHABUS	0.89	1.58	2.28
	PUL-UN_BUS	0.92	1.64	2.38
	PulchowkClg_Bus	0.73	1.32	1.91
	PulchowkWall_Bus	0.87	1.54	2.23
	Sajha	0.89	1.58	2.28
	SanchayaKosh_Bus	0.92	1.64	2.38
	Source Bus	0	0	0
	UN-Bus	0.92	1.64	2.38
	UN_HCBUS	0.92	1.65	2.39
	FP(0.4)	1.66	3.14	4.65
	HC(0.4)	1.66	3.14	4.65
	Himalayan(0.4)	1.51	2.89	4.3
	Infrastructure(0.4)	1.62	3.05	4.52
	Jwagal(0.4)	1.46	2.79	4.14
	Kardata(0.4)	1.67	3.15	4.67
	KuPondole(0.4)	1.46	2.79	4.14
	Labim(0.4)	2.45	3.76	5.11
	Nabil(0.4)	1.46	2.79	4.14
	Nidhan(0.4)	1.62	3.05	4.52
	PB(0.4)	1.72	3.2	4.72
	PulchowkClg(0.4)	1.46	2.79	4.14
	PulchowkWall(0.4)	1.59	3.01	4.46
	Sajha(0.4)	1.62	3.05	4.52
	SanchayaKosh(0.4)	1.65	3.12	4.62
Telecom(0.4)	1.62	3.05	4.52	
UN(0.4)	1.65	3.12	4.62	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
40%	HanumansthanBUs	0.06	0.1	0.15
	HighCOurt_BUS	0.98	1.7	2.42
	Himalayan_Bus1	0.78	1.35	1.92
	Infrastructure_Bus	0.94	1.62	2.3
	Jwagal_Bus1	0.77	1.34	1.92
	Kardata	0.99	1.71	2.45
	Kupondole_Bus	0.77	1.34	1.92
	Labim_Bus	1.06	1.77	2.5
	PoliceBeatBus	1.06	1.77	2.5
	PUL-SAJHABUS	0.94	1.61	2.3
	PUL-UN_BUS	0.97	1.68	2.39
	PulchowkClg_Bus	0.77	1.34	1.92
	PulchowkWall_Bus	0.92	1.57	2.24
	Sajha	0.94	1.61	2.3
	SanchayaKosh_Bus	0.97	1.68	2.4
	Source Bus	0	0	0
	UN-Bus	0.97	1.68	2.39
	UN_HCBUS	0.98	1.68	2.4
	FP(0.4)	1.71	3.17	4.66
	HC(0.4)	1.71	3.17	4.66
	Himalayan(0.4)	1.55	2.92	4.32
	Infrastructure(0.4)	1.67	3.09	4.54
	Jwagal(0.4)	1.5	2.81	4.15
	Kardata(0.4)	1.72	3.19	4.69
	KuPondole(0.4)	1.5	2.81	4.15
	Labim(0.4)	2.75	3.96	5.21
	Nabil(0.4)	1.5	2.81	4.15
	Nidhan(0.4)	1.67	3.09	4.54
	PB(0.4)	1.79	3.25	4.74
	PulchowkClg(0.4)	1.5	2.81	4.15
	PulchowkWall(0.4)	1.64	3.05	4.48
	Sajha(0.4)	1.67	3.09	4.54
	SanchayaKosh(0.4)	1.7	3.15	4.63
Telecom(0.4)	1.67	3.09	4.54	
UN(0.4)	1.7	3.15	4.63	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
50%	HanumansthanBUs	0.06	0.11	0.15
	HighCOurt_BUS	1.03	1.73	2.44
	Himalayan_Bus1	0.82	1.37	1.94
	Infrastructure_Bus	0.99	1.65	2.32
	Jwagal_Bus1	0.81	1.37	1.93
	Kardata	1.04	1.75	2.47
	Kupondole_Bus	0.81	1.37	1.93
	Labim_Bus	1.13	1.82	2.52
	PoliceBeatBus	1.12	1.82	2.52
	PUL-SAJHABUS	0.99	1.65	2.31
	PUL-UN_BUS	1.02	1.71	2.41
	PulchowkClg_Bus	0.81	1.37	1.93
	PulchowkWall_Bus	0.97	1.61	2.26
	Sajha	0.99	1.65	2.32
	SanchayaKosh_Bus	1.02	1.71	2.41
	Source Bus	0	0	0
	UN-Bus	1.02	1.71	2.41
	UN_HCBUS	1.03	1.72	2.42
	FP(0.4)	1.76	3.2	4.68
	HC(0.4)	1.76	3.2	4.68
	Himalayan(0.4)	1.59	2.94	4.33
	Infrastructure(0.4)	1.72	3.12	4.55
	Jwagal(0.4)	1.54	2.84	4.16
	Kardata(0.4)	1.77	3.22	4.71
	KuPondole(0.4)	1.54	2.84	4.16
	Labim(0.4)	3.04	4.15	5.31
	Nabil(0.4)	1.54	2.84	4.16
	Nidhan(0.4)	1.72	3.12	4.55
	PB(0.4)	1.85	3.29	4.76
	PulchowkClg(0.4)	1.54	2.84	4.16
	PulchowkWall(0.4)	1.69	3.08	4.49
	Sajha(0.4)	1.72	3.12	4.55
SanchayaKosh(0.4)	1.75	3.19	4.65	
Telecom(0.4)	1.72	3.12	4.55	
UN(0.4)	1.75	3.18	4.65	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
60%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.08	1.76	2.46
	Himalayan_Bus1	0.85	1.4	1.95
	Infrastructure_Bus	1.04	1.68	2.33
	Jwagal_Bus1	0.85	1.39	1.95
	Kardata	1.09	1.78	2.48
	Kupondole_Bus	0.85	1.39	1.95
	Labim_Bus	1.19	1.86	2.54
	PoliceBeatBus	1.19	1.86	2.54
	PUL-SAJHABUS	1.04	1.68	2.33
	PUL-UN_BUS	1.07	1.74	2.43
	PulchowkClg_Bus	0.85	1.39	1.95
	PulchowkWall_Bus	1.01	1.64	2.27
	Sajha	1.04	1.68	2.33
	SanchayaKosh_Bus	1.07	1.75	2.43
	Source Bus	0	0	0
	UN-Bus	1.07	1.74	2.43
	UN_HCBUS	1.08	1.75	2.44
	FP(0.4)	1.81	3.24	4.7
	HC(0.4)	1.81	3.24	4.7
	Himalayan(0.4)	1.63	2.97	4.34
	Infrastructure(0.4)	1.77	3.16	4.57
	Jwagal(0.4)	1.58	2.86	4.18
	Kardata(0.4)	1.82	3.26	4.72
	KuPondole(0.4)	1.58	2.86	4.18
	Labim(0.4)	3.33	4.35	5.41
	Nabil(0.4)	1.58	2.86	4.18
	Nidhan(0.4)	1.77	3.15	4.57
	PB(0.4)	1.92	3.33	4.78
	PulchowkClg(0.4)	1.58	2.86	4.18
	PulchowkWall(0.4)	1.74	3.11	4.51
	Sajha(0.4)	1.77	3.15	4.57
	SanchayaKosh(0.4)	1.8	3.22	4.67
Telecom(0.4)	1.77	3.15	4.57	
UN(0.4)	1.8	3.22	4.67	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
70%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.13	1.8	2.47
	Himalayan_Bus1	0.89	1.42	1.96
	Infrastructure_Bus	1.09	1.72	2.35
	Jwagal_Bus1	0.89	1.42	1.96
	Kardata	1.14	1.82	2.5
	Kupondole_Bus	0.89	1.42	1.96
	Labim_Bus	1.25	1.9	2.57
	PoliceBeatBus	1.25	1.9	2.56
	PUL-SAJHABUS	1.09	1.71	2.35
	PUL-UN_BUS	1.12	1.78	2.44
	PulchowkClg_Bus	0.89	1.42	1.96
	PulchowkWall_Bus	1.06	1.67	2.29
	Sajha	1.09	1.72	2.35
	SanchayaKosh_Bus	1.12	1.78	2.45
	Source Bus	0	0	0
	UN-Bus	1.12	1.78	2.44
	UN_HCBUS	1.13	1.78	2.45
	FP(0.4)	1.86	3.27	4.71
	HC(0.4)	1.86	3.27	4.71
	Himalayan(0.4)	1.67	2.99	4.36
	Infrastructure(0.4)	1.82	3.19	4.59
	Jwagal(0.4)	1.62	2.89	4.19
	Kardata(0.4)	1.87	3.29	4.74
	KuPondole(0.4)	1.62	2.89	4.19
	Labim(0.4)	3.62	4.54	5.5
	Nabil(0.4)	1.62	2.89	4.19
	Nidhan(0.4)	1.82	3.19	4.59
	PB(0.4)	1.98	3.38	4.8
	PulchowkClg(0.4)	1.62	2.89	4.19
	PulchowkWall(0.4)	1.79	3.14	4.53
	Sajha(0.4)	1.82	3.19	4.59
SanchayaKosh(0.4)	1.85	3.25	4.69	
Telecom(0.4)	1.82	3.19	4.59	
UN(0.4)	1.85	3.25	4.68	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
80%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.18	1.83	2.49
	Himalayan_Bus1	0.93	1.45	1.98
	Infrastructure_Bus	1.14	1.75	2.37
	Jwagal_Bus1	0.93	1.45	1.97
	Kardata	1.19	1.85	2.52
	Kupondole_Bus	0.93	1.45	1.97
	Labim_Bus	1.32	1.95	2.59
	PoliceBeatBus	1.31	1.94	2.58
	PUL-SAJHABUS	1.14	1.75	2.37
	PUL-UN_BUS	1.17	1.81	2.46
	PulchowkClg_Bus	0.93	1.45	1.97
	PulchowkWall_Bus	1.11	1.7	2.31
	Sajha	1.14	1.75	2.37
	SanchayaKosh_Bus	1.17	1.81	2.46
	Source Bus	0	0	0
	UN-Bus	1.17	1.81	2.46
	UN_HCBUS	1.18	1.82	2.47
	FP(0.4)	1.91	3.31	4.73
	HC(0.4)	1.91	3.31	4.73
	Himalayan(0.4)	1.7	3.02	4.37
	Infrastructure(0.4)	1.87	3.22	4.61
	Jwagal(0.4)	1.66	2.92	4.2
	Kardata(0.4)	1.92	3.32	4.76
	KuPondole(0.4)	1.66	2.92	4.2
	Labim(0.4)	3.91	4.74	5.6
	Nabil(0.4)	1.66	2.92	4.2
	Nidhan(0.4)	1.87	3.22	4.6
	PB(0.4)	2.04	3.42	4.83
	PulchowkClg(0.4)	1.66	2.92	4.2
	PulchowkWall(0.4)	1.84	3.18	4.54
	Sajha(0.4)	1.87	3.22	4.6
	SanchayaKosh(0.4)	1.9	3.29	4.7
Telecom(0.4)	1.87	3.22	4.6	
UN(0.4)	1.9	3.29	4.7	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
90%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.23	1.86	2.51
	Himalayan_Bus1	0.97	1.47	1.99
	Infrastructure_Bus	1.19	1.78	2.38
	Jwagal_Bus1	0.97	1.47	1.98
	Kardata	1.24	1.88	2.53
	Kupondole_Bus	0.97	1.47	1.98
	Labim_Bus	1.38	1.99	2.61
	PoliceBeatBus	1.38	1.99	2.6
	PUL-SAJHABUS	1.19	1.78	2.38
	PUL-UN_BUS	1.22	1.84	2.48
	PulchowkClg_Bus	0.97	1.47	1.98
	PulchowkWall_Bus	1.16	1.73	2.32
	Sajha	1.19	1.78	2.38
	SanchayaKosh_Bus	1.22	1.85	2.48
	Source Bus	0	0	0
	UN-Bus	1.22	1.84	2.48
	UN_HCBUS	1.23	1.85	2.49
	FP(0.4)	1.96	3.34	4.75
	HC(0.4)	1.96	3.34	4.75
	Himalayan(0.4)	1.74	3.05	4.38
	Infrastructure(0.4)	1.92	3.26	4.62
	Jwagal(0.4)	1.69	2.94	4.22
	Kardata(0.4)	1.97	3.36	4.77
	KuPondole(0.4)	1.69	2.94	4.22
	Labim(0.4)	4.19	4.93	5.7
	Nabil(0.4)	1.69	2.94	4.22
	Nidhan(0.4)	1.92	3.26	4.62
	PB(0.4)	2.11	3.46	4.85
	PulchowkClg(0.4)	1.69	2.94	4.22
	PulchowkWall(0.4)	1.89	3.21	4.56
	Sajha(0.4)	1.92	3.26	4.62
SanchayaKosh(0.4)	1.95	3.32	4.72	
Telecom(0.4)	1.92	3.26	4.62	
UN(0.4)	1.95	3.32	4.72	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
100%	HanumansthanBUs	0.08	0.12	0.15
	HighCOurt_BUS	1.28	1.9	2.52
	Himalayan_Bus1	1.01	1.5	2
	Infrastructure_Bus	1.24	1.82	2.4
	Jwagal_Bus1	1	1.5	2
	Kardata	1.29	1.91	2.55
	Kupondole_Bus	1	1.5	2
	Labim_Bus	1.44	2.03	2.63
	PoliceBeatBus	1.44	2.03	2.63
	PUL-SAJHABUS	1.24	1.81	2.4
	PUL-UN_BUS	1.27	1.88	2.49
	PulchowkClg_Bus	1	1.5	2
	PulchowkWall_Bus	1.2	1.77	2.34
	Sajha	1.24	1.81	2.4
	SanchayaKosh_Bus	1.27	1.88	2.5
	Source Bus	0	0	0
	UN-Bus	1.27	1.88	2.49
	UN_HCBUS	1.27	1.88	2.5
	FP(0.4)	2.01	3.37	4.77
	HC(0.4)	2.01	3.37	4.77
	Himalayan(0.4)	1.78	3.07	4.4
	Infrastructure(0.4)	1.97	3.29	4.64
	Jwagal(0.4)	1.73	2.97	4.23
	Kardata(0.4)	2.02	3.39	4.79
	KuPondole(0.4)	1.73	2.97	4.23
	Labim(0.4)	4.48	5.12	5.8
	Nabil(0.4)	1.73	2.97	4.23
	Nidhan(0.4)	1.97	3.29	4.64
	PB(0.4)	2.17	3.5	4.87
	PulchowkClg(0.4)	1.73	2.97	4.23
	PulchowkWall(0.4)	1.93	3.24	4.58
	Sajha(0.4)	1.97	3.29	4.64
	SanchayaKosh(0.4)	2	3.35	4.74
Telecom(0.4)	1.97	3.29	4.64	
UN(0.4)	2	3.35	4.73	

APPENDIX VI: VOLTAGE PROFILE AT SAJHA AND LABIM OPERATING
SIMULTANEOUSLY

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
10%	HanumansthanBUS	0.05	0.1	0.15
	HighCOurt_BUS	0.84	1.6	2.38
	Himalayan_Bus1	0.66	1.27	1.89
	Infrastructure_Bus	0.8	1.52	2.25
	Jwagal_Bus1	0.66	1.27	1.88
	Kardata	0.85	1.62	2.4
	Kupondole_Bus	0.66	1.27	1.88
	Labim_Bus	0.87	1.65	2.44
	PoliceBeatBus	0.87	1.65	2.44
	PUL-SAJHABUS	0.8	1.52	2.25
	PUL-UN_BUS	0.83	1.58	2.35
	PulchowkClg_Bus	0.66	1.27	1.88
	PulchowkWall_Bus	0.78	1.48	2.2
	Sajha	0.8	1.52	2.25
	SanchayaKosh_Bus	0.83	1.58	2.35
	Source Bus	0	0	0
	UN-Bus	0.83	1.58	2.35
	UN_HCBUS	0.83	1.59	2.35
	FP(0.4)	1.56	3.07	4.61
	HC(0.4)	1.56	3.07	4.61
	Himalayan(0.4)	1.44	2.84	4.28
	Infrastructure(0.4)	1.52	2.99	4.49
	Jwagal(0.4)	1.39	2.74	4.11
	Kardata(0.4)	1.57	3.09	4.64
	KuPondole(0.4)	1.39	2.74	4.11
	Labim(0.4)	1.87	3.38	4.92
	Nabil(0.4)	1.39	2.74	4.11
	Nidhan(0.4)	1.52	2.99	4.49
	PB(0.4)	1.6	3.12	4.68
	PulchowkClg(0.4)	1.39	2.74	4.11
	PulchowkWall(0.4)	1.5	2.95	4.43
	Sajha(0.4)	1.74	3.13	4.56
SanchayaKosh(0.4)	1.56	3.05	4.59	
Telecom(0.4)	1.52	2.99	4.49	
UN(0.4)	1.55	3.05	4.58	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
20%	HanumansthanBUs	0.05	0.1	0.15
	HighCOurt_BUS	0.9	1.64	2.4
	Himalayan_Bus1	0.71	1.3	1.9
	Infrastructure_Bus	0.86	1.56	2.27
	Jwagal_Bus1	0.71	1.3	1.9
	Kardata	0.91	1.66	2.42
	Kupondole_Bus	0.71	1.3	1.9
	Labim_Bus	0.95	1.7	2.46
	PoliceBeatBus	0.95	1.7	2.46
	PUL-SAJHABUS	0.86	1.56	2.27
	PUL-UN_BUS	0.89	1.62	2.37
	PulchowkClg_Bus	0.71	1.3	1.9
	PulchowkWall_Bus	0.84	1.52	2.22
	Sajha	0.86	1.56	2.27
	SanchayaKosh_Bus	0.89	1.62	2.37
	Source Bus	0	0	0
	UN-Bus	0.89	1.62	2.37
	UN_HCBUS	0.89	1.63	2.38
	FP(0.4)	1.63	3.12	4.64
	HC(0.4)	1.63	3.12	4.64
	Himalayan(0.4)	1.49	2.87	4.3
	Infrastructure(0.4)	1.59	3.03	4.51
	Jwagal(0.4)	1.44	2.77	4.13
	Kardata(0.4)	1.64	3.13	4.66
	KuPondole(0.4)	1.44	2.77	4.13
	Labim(0.4)	2.18	3.58	5.02
	Nabil(0.4)	1.44	2.77	4.13
	Nidhan(0.4)	1.59	3.03	4.51
	PB(0.4)	1.68	3.17	4.7
	PulchowkClg(0.4)	1.44	2.77	4.13
	PulchowkWall(0.4)	1.56	2.99	4.45
	Sajha(0.4)	2.01	3.32	4.65
SanchayaKosh(0.4)	1.62	3.1	4.61	
Telecom(0.4)	1.59	3.03	4.51	
UN(0.4)	1.62	3.1	4.6	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
30%	HanumansthanBUS	0.06	0.1	0.15
	HighCOurt_BUS	0.96	1.68	2.42
	Himalayan_Bus1	0.76	1.34	1.92
	Infrastructure_Bus	0.92	1.6	2.29
	Jwagal_Bus1	0.76	1.33	1.91
	Kardata	0.97	1.7	2.44
	Kupondole_Bus	0.76	1.33	1.91
	Labim_Bus	1.03	1.75	2.49
	PoliceBeatBus	1.02	1.75	2.49
	PUL-SAJHABUS	0.92	1.6	2.29
	PUL-UN_BUS	0.95	1.66	2.39
	PulchowkClg_Bus	0.76	1.33	1.91
	PulchowkWall_Bus	0.9	1.56	2.24
	Sajha	0.92	1.6	2.29
	SanchayaKosh_Bus	0.95	1.67	2.39
	Source Bus	0	0	0
	UN-Bus	0.95	1.66	2.39
	UN_HCBUS	0.96	1.67	2.4
	FP(0.4)	1.69	3.16	4.66
	HC(0.4)	1.69	3.16	4.66
	Himalayan(0.4)	1.53	2.91	4.31
	Infrastructure(0.4)	1.65	3.07	4.53
	Jwagal(0.4)	1.49	2.8	4.15
	Kardata(0.4)	1.7	3.17	4.68
	KuPondole(0.4)	1.49	2.8	4.15
	Labim(0.4)	2.48	3.78	5.12
	Nabil(0.4)	1.49	2.8	4.15
	Nidhan(0.4)	1.65	3.07	4.53
	PB(0.4)	1.75	3.22	4.73
	PulchowkClg(0.4)	1.49	2.8	4.15
	PulchowkWall(0.4)	1.62	3.03	4.47
	Sajha(0.4)	2.29	3.5	4.74
	SanchayaKosh(0.4)	1.68	3.14	4.63
Telecom(0.4)	1.65	3.07	4.53	
UN(0.4)	1.68	3.14	4.63	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
40%	HanumansthanBUs	0.06	0.11	0.15
	HighCOurt_BUS	1.02	1.72	2.44
	Himalayan_Bus1	0.81	1.37	1.94
	Infrastructure_Bus	0.98	1.64	2.31
	Jwagal_Bus1	0.81	1.36	1.93
	Kardata	1.03	1.74	2.46
	Kupondole_Bus	0.81	1.36	1.93
	Labim_Bus	1.1	1.8	2.51
	PoliceBeatBus	1.1	1.8	2.51
	PUL-SAJHABUS	0.98	1.64	2.31
	PUL-UN_BUS	1.01	1.7	2.41
	PulchowkClg_Bus	0.81	1.36	1.93
	PulchowkWall_Bus	0.96	1.6	2.25
	Sajha	0.98	1.64	2.31
	SanchayaKosh_Bus	1.01	1.71	2.41
	Source Bus	0	0	0
	UN-Bus	1.01	1.7	2.41
	UN_HCBUS	1.02	1.71	2.42
	FP(0.4)	1.75	3.2	4.68
	HC(0.4)	1.75	3.2	4.68
	Himalayan(0.4)	1.58	2.94	4.33
	Infrastructure(0.4)	1.71	3.12	4.55
	Jwagal(0.4)	1.53	2.83	4.16
	Kardata(0.4)	1.76	3.22	4.7
	KuPondole(0.4)	1.53	2.83	4.16
	Labim(0.4)	2.79	3.99	5.22
	Nabil(0.4)	1.53	2.83	4.16
	Nidhan(0.4)	1.71	3.11	4.55
	PB(0.4)	1.83	3.27	4.75
	PulchowkClg(0.4)	1.53	2.83	4.16
	PulchowkWall(0.4)	1.68	3.07	4.49
	Sajha(0.4)	2.56	3.68	4.83
SanchayaKosh(0.4)	1.74	3.18	4.65	
Telecom(0.4)	1.71	3.11	4.55	
UN(0.4)	1.74	3.18	4.65	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
50%	HanumansthanBUS	0.07	0.11	0.15
	HighCOurt_BUS	1.09	1.77	2.46
	Himalayan_Bus1	0.86	1.4	1.95
	Infrastructure_Bus	1.04	1.68	2.33
	Jwagal_Bus1	0.85	1.4	1.95
	Kardata	1.09	1.78	2.48
	Kupondole_Bus	0.85	1.39	1.95
	Labim_Bus	1.18	1.85	2.54
	PoliceBeatBus	1.18	1.85	2.54
	PUL-SAJHABUS	1.04	1.68	2.33
	PUL-UN_BUS	1.08	1.75	2.43
	PulchowkClg_Bus	0.85	1.39	1.95
	PulchowkWall_Bus	1.02	1.64	2.27
	Sajha	1.04	1.68	2.33
	SanchayaKosh_Bus	1.08	1.75	2.43
	Source Bus	0	0	0
	UN-Bus	1.08	1.75	2.43
	UN_HCBUS	1.08	1.75	2.44
	FP(0.4)	1.81	3.24	4.7
	HC(0.4)	1.81	3.24	4.7
	Himalayan(0.4)	1.63	2.97	4.34
	Infrastructure(0.4)	1.77	3.16	4.57
	Jwagal(0.4)	1.58	2.87	4.18
	Kardata(0.4)	1.82	3.26	4.72
	KuPondole(0.4)	1.58	2.87	4.18
	Labim(0.4)	3.09	4.19	5.33
	Nabil(0.4)	1.58	2.87	4.18
	Nidhan(0.4)	1.77	3.16	4.57
	PB(0.4)	1.9	3.32	4.78
	PulchowkClg(0.4)	1.58	2.87	4.18
	PulchowkWall(0.4)	1.74	3.11	4.51
	Sajha(0.4)	2.83	3.86	4.93
SanchayaKosh(0.4)	1.8	3.22	4.67	
Telecom(0.4)	1.77	3.16	4.57	
UN(0.4)	1.8	3.22	4.67	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
60%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.15	1.81	2.48
	Himalayan_Bus1	0.9	1.43	1.97
	Infrastructure_Bus	1.1	1.72	2.35
	Jwagal_Bus1	0.9	1.43	1.96
	Kardata	1.15	1.82	2.5
	Kupondole_Bus	0.9	1.43	1.96
	Labim_Bus	1.25	1.9	2.56
	PoliceBeatBus	1.25	1.9	2.56
	PUL-SAJHABUS	1.1	1.72	2.35
	PUL-UN_BUS	1.14	1.79	2.45
	PulchowkClg_Bus	0.9	1.43	1.96
	PulchowkWall_Bus	1.07	1.68	2.29
	Sajha	1.1	1.72	2.35
	SanchayaKosh_Bus	1.14	1.79	2.45
	Source Bus	0	0	0
	UN-Bus	1.14	1.79	2.45
	UN_HCBUS	1.14	1.79	2.46
	FP(0.4)	1.87	3.28	4.72
	HC(0.4)	1.87	3.28	4.72
	Himalayan(0.4)	1.68	3	4.36
	Infrastructure(0.4)	1.83	3.2	4.59
	Jwagal(0.4)	1.63	2.9	4.19
	Kardata(0.4)	1.88	3.3	4.74
	KuPondole(0.4)	1.63	2.9	4.19
	Labim(0.4)	3.39	4.39	5.43
	Nabil(0.4)	1.63	2.9	4.19
	Nidhan(0.4)	1.83	3.2	4.59
	PB(0.4)	1.98	3.37	4.8
	PulchowkClg(0.4)	1.63	2.9	4.19
	PulchowkWall(0.4)	1.8	3.15	4.53
	Sajha(0.4)	3.11	4.05	5.02
SanchayaKosh(0.4)	1.86	3.26	4.69	
Telecom(0.4)	1.83	3.2	4.59	
UN(0.4)	1.86	3.26	4.69	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
70%	HanumansthanBUs	0.07	0.11	0.15
	HighCOurt_BUS	1.21	1.85	2.5
	Himalayan_Bus1	0.95	1.46	1.98
	Infrastructure_Bus	1.16	1.76	2.37
	Jwagal_Bus1	0.95	1.46	1.98
	Kardata	1.21	1.86	2.52
	Kupondole_Bus	0.95	1.46	1.98
	Labim_Bus	1.33	1.95	2.59
	PoliceBeatBus	1.32	1.95	2.59
	PUL-SAJHABUS	1.16	1.76	2.37
	PUL-UN_BUS	1.2	1.83	2.47
	PulchowkClg_Bus	0.95	1.46	1.98
	PulchowkWall_Bus	1.13	1.72	2.31
	Sajha	1.17	1.76	2.37
	SanchayaKosh_Bus	1.2	1.83	2.47
	Source Bus	0	0	0
	UN-Bus	1.2	1.83	2.47
	UN_HCBUS	1.2	1.83	2.48
	FP(0.4)	1.93	3.32	4.74
	HC(0.4)	1.93	3.32	4.74
	Himalayan(0.4)	1.72	3.03	4.38
	Infrastructure(0.4)	1.89	3.24	4.61
	Jwagal(0.4)	1.67	2.93	4.21
	Kardata(0.4)	1.94	3.34	4.76
	KuPondole(0.4)	1.67	2.93	4.21
	Labim(0.4)	3.69	4.59	5.53
	Nabil(0.4)	1.67	2.93	4.21
	Nidhan(0.4)	1.89	3.24	4.61
	PB(0.4)	2.05	3.42	4.83
	PulchowkClg(0.4)	1.67	2.93	4.21
	PulchowkWall(0.4)	1.86	3.19	4.55
	Sajha(0.4)	3.38	4.23	5.11
SanchayaKosh(0.4)	1.92	3.3	4.71	
Telecom(0.4)	1.89	3.24	4.61	
UN(0.4)	1.92	3.3	4.71	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
80%	HanumansthanBUs	0.08	0.12	0.15
	HighCOurt_BUS	1.27	1.89	2.52
	Himalayan_Bus1	0.99	1.49	2
	Infrastructure_Bus	1.22	1.8	2.39
	Jwagal_Bus1	0.99	1.49	1.99
	Kardata	1.27	1.9	2.54
	Kupondole_Bus	0.99	1.49	1.99
	Labim_Bus	1.4	2	2.61
	PoliceBeatBus	1.4	2	2.61
	PUL-SAJHABUS	1.22	1.8	2.39
	PUL-UN_BUS	1.26	1.87	2.49
	PulchowkClg_Bus	0.99	1.49	1.99
	PulchowkWall_Bus	1.19	1.76	2.33
	Sajha	1.22	1.8	2.39
	SanchayaKosh_Bus	1.26	1.87	2.49
	Source Bus	0	0	0
	UN-Bus	1.26	1.87	2.49
	UN_HCBUS	1.26	1.87	2.5
	FP(0.4)	1.99	3.36	4.76
	HC(0.4)	1.99	3.36	4.76
	Himalayan(0.4)	1.77	3.06	4.39
	Infrastructure(0.4)	1.95	3.28	4.63
	Jwagal(0.4)	1.72	2.96	4.23
	Kardata(0.4)	2	3.38	4.79
	KuPondole(0.4)	1.72	2.96	4.23
	Labim(0.4)	3.99	4.79	5.63
	Nabil(0.4)	1.72	2.96	4.23
	Nidhan(0.4)	1.95	3.28	4.63
	PB(0.4)	2.13	3.47	4.85
	PulchowkClg(0.4)	1.72	2.96	4.23
	PulchowkWall(0.4)	1.92	3.23	4.57
	Sajha(0.4)	3.64	4.41	5.2
SanchayaKosh(0.4)	1.98	3.34	4.73	
Telecom(0.4)	1.95	3.28	4.63	
UN(0.4)	1.98	3.34	4.73	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
90%	HanumansthanBUs	0.08	0.12	0.16
	HighCOurt_BUS	1.32	1.93	2.54
	Himalayan_Bus1	1.04	1.52	2.01
	Infrastructure_Bus	1.28	1.84	2.41
	Jwagal_Bus1	1.04	1.52	2.01
	Kardata	1.33	1.94	2.56
	Kupondole_Bus	1.04	1.52	2.01
	Labim_Bus	1.47	2.05	2.64
	PoliceBeatBus	1.47	2.05	2.64
	PUL-SAJHABUS	1.28	1.84	2.41
	PUL-UN_BUS	1.31	1.91	2.51
	PulchowkClg_Bus	1.04	1.52	2.01
	PulchowkWall_Bus	1.25	1.79	2.35
	Sajha	1.28	1.84	2.41
	SanchayaKosh_Bus	1.32	1.91	2.51
	Source Bus	0	0	0
	UN-Bus	1.31	1.91	2.51
	UN_HCBUS	1.32	1.91	2.52
	FP(0.4)	2.05	3.4	4.78
	HC(0.4)	2.05	3.4	4.78
	Himalayan(0.4)	1.81	3.09	4.41
	Infrastructure(0.4)	2.01	3.32	4.65
	Jwagal(0.4)	1.76	2.99	4.24
	Kardata(0.4)	2.06	3.42	4.81
	KuPondole(0.4)	1.76	2.99	4.24
	Labim(0.4)	4.28	4.99	5.73
	Nabil(0.4)	1.76	2.99	4.24
	Nidhan(0.4)	2.01	3.32	4.65
	PB(0.4)	2.2	3.52	4.88
	PulchowkClg(0.4)	1.76	2.99	4.24
	PulchowkWall(0.4)	1.97	3.27	4.59
	Sajha(0.4)	3.91	4.59	5.29
SanchayaKosh(0.4)	2.04	3.38	4.75	
Telecom(0.4)	2.01	3.32	4.65	
UN(0.4)	2.04	3.38	4.75	

EV Penetration Level	Bus ID	% V.D.		
		Period		
		Off Peak	Medium Peak	Peak
100%	HanumansthanBUs	0.08	0.12	0.16
	HighCOurt_BUS	1.38	1.97	2.56
	Himalayan_Bus1	1.08	1.55	2.03
	Infrastructure_Bus	1.34	1.88	2.43
	Jwagal_Bus1	1.08	1.55	2.02
	Kardata	1.39	1.98	2.58
	Kupondole_Bus	1.08	1.55	2.02
	Labim_Bus	1.54	2.1	2.66
	PoliceBeatBus	1.54	2.09	2.66
	PUL-SAJHABUS	1.34	1.88	2.43
	PUL-UN_BUS	1.37	1.95	2.53
	PulchowkClg_Bus	1.08	1.55	2.02
	PulchowkWall_Bus	1.3	1.83	2.37
	Sajha	1.34	1.88	2.43
	SanchayaKosh_Bus	1.37	1.95	2.53
	Source Bus	0	0	0
	UN-Bus	1.37	1.95	2.53
	UN_HCBUS	1.38	1.95	2.54
	FP(0.4)	2.11	3.44	4.8
	HC(0.4)	2.11	3.44	4.8
	Himalayan(0.4)	1.86	3.12	4.42
	Infrastructure(0.4)	2.07	3.36	4.67
	Jwagal(0.4)	1.81	3.02	4.26
	Kardata(0.4)	2.12	3.46	4.83
	KuPondole(0.4)	1.81	3.02	4.26
	Labim(0.4)	4.58	5.19	5.83
	Nabil(0.4)	1.81	3.02	4.26
	Nidhan(0.4)	2.07	3.36	4.67
	PB(0.4)	2.27	3.57	4.9
	PulchowkClg(0.4)	1.81	3.02	4.26
	PulchowkWall(0.4)	2.03	3.31	4.61
	Sajha(0.4)	4.18	4.77	5.38
	SanchayaKosh(0.4)	2.1	3.42	4.77
Telecom(0.4)	2.07	3.36	4.67	
UN(0.4)	2.1	3.42	4.77	

APPENDIX VII: VOLTAGE PROFILE WITHOUT EV PENETRATION

Bus ID	%V.D.		
	Off Peak	Medium Peak	Peak
HanumansthanBUs	0.05	0.1	0.14
HighCOurt_BUS	0.77	1.56	2.36
Himalayan_Bus1	0.62	1.24	1.87
Infrastructure_Bus	0.73	1.48	2.23
Jwagal_Bus1	0.61	1.24	1.87
Kardata	0.78	1.58	2.38
Kupondole_Bus	0.61	1.24	1.87
Labim_Bus	0.79	1.6	2.41
PoliceBeatBus	0.79	1.6	2.41
PUL-SAJHABUS	0.73	1.48	2.23
PUL-UN_BUS	0.76	1.54	2.32
PulchowkClg_Bus	0.61	1.24	1.87
PulchowkWall_Bus	0.72	1.44	2.18
Sajha_bus	0.73	1.48	2.23
SanchayaKosh_Bus	0.77	1.54	2.33
UN-Bus	0.77	0	0
UN_HCBUS	0.77	1.54	2.33
FP(0.4)	1.5	1.55	2.33
HC(0.4)	1.5	3.03	4.59
Himalayan(0.4)	1.39	3.03	4.59
Infrastructure(0.4)	1.46	2.81	4.26
Jwagal(0.4)	1.34	2.95	4.47
Kardata	0.78	2.71	4.1
Kardata(0.4)	1.51	3.05	4.62
KuPondole(0.4)	1.34	2.71	4.1
Labim(0.4)	1.57	3.17	4.82
Nidhan(0.4)	1.46	2.71	4.1
PB(0.4)	1.52	2.95	4.47
PulchowkClg(0.4)	1.34	3.07	4.65
PulchowkWall(0.4)	1.44	2.71	4.1
Sajha(0.4)	1.46	2.91	4.41
SanchayaKosh(0.4)	1.49	2.95	4.47
Telecom(0.4)	1.46	3.01	4.57
UN(0.4)	1.49	2.95	4.47

APPENDIX VIII: LINE LOSS AT SAJHA WITH EV PENETRATION

EV Penetration Level(%)	Power Demand					
	Off Peak		Medium Peak		Peak	
	P(kW)	Q(kVar)	P(kW)	Q(kVar)	P(kW)	Q(kVar)
10	11.2	14	44.8	55.9	102	128
20	11.6	14.4	45.2	56.4	102	128
30	11.9	15	45.7	56.9	103	128
40	12.3	15.6	46.1	57.5	103	129
50	12.7	16.3	46.6	58.1	103	129
60	13.2	17.1	47	58.7	104	129
70	13.6	17.9	47.5	59.4	104	130
80	14.1	18.8	48	60.1	104	130
90	14.6	19.8	48.5	60.8	105	131
100	15.1	20.9	49	61.6	105	131

APPENDIX IX: LINE LOSS AT LABIM MALL WITH EV PENETRATION

EV Penetration Level(%)	Power Demand					
	Off Peak		Medium Peak		Peak	
	P(kW)	Q(kVar)	P(kW)	Q(kVar)	P(kW)	Q(kVar)
10	12.4	15.9	46.4	58.3	103	129
20	14.1	18.8	48.4	61.4	105	132
30	16	22.2	50.6	64.8	106	134
40	18	26.2	52.7	68.3	108	136
50	20.1	30.6	55	72.1	109	138
60	22.4	35.5	57.3	76.1	111	141
70	24.8	41	59.7	80.3	113	143
80	27.4	46.9	62.1	84.8	114	146
90	30.1	53.3	64.6	89.4	116	148
100	32.9	60.2	67.1	94.3	117	151

**APPENDIX X: LINE LOSS AT SAJHA AND LABIM MALL CHARGING STATION
OPERATING SIMULTANEOUSLY WITH EV PENETRATION**

EV Penetration Level(%)	Power Demand					
	Off Peak		Medium Peak		Peak	
	P(kW)	Q(kVar)	P(kW)	Q(kVar)	P(kW)	Q(kVar)
10	12.8	16.3	46.8	58.8	104	130
20	14.9	19.6	49.3	62.4	105	132
30	17.2	23.6	51.9	66.2	107	135
40	19.7	28.2	54.6	70.4	109	137
50	22.3	33.3	57.3	74.8	111	140
60	25.2	39.1	60.2	79.4	113	143
70	28.3	45.4	63.1	84.3	115	146
80	31.6	52.3	66.1	89.5	117	149
90	35	59.7	69.2	94.9	119	152
100	38.6	67.7	72.4	101	121	155

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