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"Optimal Placement of Charging Station in Om Distribution Feeder of New Chabahil Substation Considering Dynamic Nature of Electric Vehicle Load"

by:
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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **" Optimal Placement of Charging Station in Om Distribution Feeder of New Chabahil Substation Considering Dynamic Nature of Electric Vehicle Load "** submitted by **Nandkishor Sah** in partial fulfillment of the requirements for the degree of Master of Science in **Power System Engineering.**

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ABSTRACT

Globally, the main goal of environmentalist is to reduce the problem of global warming and climate change whose one of the major sources is the existing fossil dependent transportation system, has forced many nations to implement pollution free battery-operated electric vehicle (EV) system which requires electrically operated charging station (CS). Due to this, the number of charging station integrated in the existing distribution system is increasing day by day and the increase in number is further motivated by the research being carried out for development of enhanced battery with cost optimization and subsidies provided by the Government body which is of big concern for the existing electrical distribution system.

Electric vehicle charging stations are connection point between the distribution network and transportation network, so operational behaviour of electric vehicles affects both the network simultaneously. In this work optimal location of charging station is done considering minimization of distribution loss occurring in the electrical network, minimization of travel loss that occurs when an EV travel from their location to CS location point and maximization of utilization factor which shows how efficiently a CS is utilized which help in deciding the number of CS to be placed in a considered network. These three objectives are solved individually using Genetic Algorithm (GA) and solved simultaneously by using non-dominated sorting genetic algorithm- II (NSGA-II) to obtain a set of compromised solution from which best compromised solution is selected by Fuzzy optimization technique. To take into account dynamic behaviour of EVs probabilistic demand modeling of CS is done by Monte Carlo Simulation (MCS) in which queuing theory is used to take into account dynamic serviceability of a charging station. At first the developed concept is implemented on IEEE-33 bus distribution network to confirm accuracy and illustrate how well the methodology works. After confirmation, the same is implement on a real 11kV Om distribution feeder of new Chabahil substation of Maharajgung distribution center (DCS), Nepal Electricity Authority (NEA). Results are obtained by varying the number of CS, number of charging ports and population of electric vehicles. All the results are obtained by using script environment of MATLAB software with coding concept.

Maximum demand of a charging station obtained for Om feeder after MCS method for 8, 4, 2 & 1 number of charging ports are 0.1298 MW, 0.1298 MW, 0.1162 MW & 0.0630 MW respectively and Weibull distribution function best fits on the probability

density function of CS demand. In case of two CSs best compromised solution considering minimization of network and travel loss as objective function is obtained for location 10 & 22 having network loss per phase of 63.9095 kW and travel loss of 0.1872 kW. Om feeder has 80-bus having peak active and reactive load of 3936.00 kW and 1924.50 kVar respectively, per phase network loss of the system is 63.0516 kW with minimum voltage of 0.96871 p.u. Network loss and travel loss are contradictory in nature. Optimal location done in case of two CS considering all the three objective functions produces utilization factor of 9.92% and 17.40% with 8 and 4 no. of charging point respectively. So, it is better to have 4 no. of CP. In case of 2 no. of CP, utilization factor comes to be 27.14% which is better than 4 no. of CP. But due to installation cost of a charging station which is much higher than its charging ports, consideration of a near future EV population and waiting time of EV users in the queue to get charge if we plan to have two CS then it is better to have 4 no. of CP in the system. When the number of CSs is increased from 2 to 3 then utilization factor decreases from 17.40% to 6.22% in case of 4 no. of CP. This shows with less number of CSs, each CS will get utilized properly which is advantageous for policy maker's or the system operator. But from view point of EVs user, more number of CS is better since travel loss gets decreased from 0.3892 kW to 0.1556 kW in case of 4 no. of CP. All the optimal location is done considering voltage limit and during optimal location there was no violation of voltage limit. When the EVs population in the network is doubled then utilization factor of a CS increases from 17.40% to 22.13% but travel loss increases from 0.3829 kW to 0.6314 kW which is obvious. Since, the number of EVs is increasing day by day so, although at present utilization of CS is low in near future it will get utilized properly and benefit to the system operator will get increased. If in near future EV population gets increased to high number then number of CS might have to be increased.

The results shows that the charging station are placed optimally by simultaneously minimizing electrical network loss which benefits the system operator, minimizing travel loss of EVs when traveling to the location of CS benefiting the EVs owner and maximizing the utilization factor which confirms economical utilization of charging station infrastructure thus benefiting the policy maker. Optimal location improves nodal voltage and reduces losses occurring in the network. This work provides guidance to system planner considering their network along with taking customer concern into account.

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The master's thesis on topic "Optimal placement of charging station in Om distribution feeder of New Chabahil substation considering dynamic nature of electric vehicle load" has been completed successfully with excellent guidance, encouragement and the constant source of inspiration from my supervisor, friends and family members. I take this opportunity to extend sincere thanks and indebtedness to all those persons who helped me during the entire period of thesis work.

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LIST OF ABBREVIATIONS USED

M_E Maximum distance a PHEV can travel with battery energy only.

E_M Electrical energy consumed per km by a PHEV.

A_E Function parameter for each vehicle class.

B_E Function parameter for each vehicle class.

K_{EV} Fraction of the total energy supplied through battery.

c The number of charging port in a CS.

ρ Traffic Intensity of the System/Occupation rate per server/CP.

μ_n Effective service rate of the CS per hour.

n_{max} Set of branches of the distribution network.

φ^{dn} Set of buses of the distribution network.

$Z_{i,j}$ Node bus connectivity matrix.

x_i Binary variable denoting CS availability at bus i.

$M_{i,j}^{ev}$ Number of EVs travelling from j^{th} bus to i^{th} bus.

k_{cs} Number of CPs or CS fleet size for r number of CSs.

η_{ev} Number of vehicles connected through CPs of a CS.

I_{max} Maximum Charging current limit of a CP in the CS.

EV Electric Vehicle

BEV Battery Electric Vehicle

PEV Plug-in Electric Vehicle

PHEV Plug-in Hybrid Electric Vehicle

CS Charging Station

E_{ICE} Energy delivered by ICE of the PHEV.

C_{Bat} Energy delivered by the battery.

D_E Daily recharge energy requirement of a PHEV.

V Charging voltage.

t_μ Average service time of a CP in a CS.

t_{min} Minimum charging time limit.

t_{max} Maximum charging time limit.

C_{Bat} Battery capacity of a PHEV.

M_d Daily driven distance of a PHEV

CHAPTER 1: INTRODUCTION

1.1 Background

In the power and energy sector, recent research has primarily focused on using zero-emission technologies to reduce the rate of global warming and the effects of climate change. The world's consumption of crude oil increased by 3% between 2021 and 2022, from 4.26 billion metric tons to 4.39 billion metric tons, according to the BP statistical review of world energy 2023. Consequently, carbon emissions increased by 0.9% in 2022 is the highest growth in the last many years. In the energy market, petroleum products are the most widely utilized fuel. The transportation sector consumes the majority of petroleum. The world is in danger due to carbon emissions and global warming, which are caused by fossil fuels. The transportation sector is responsible for 23% Of the GHG emissions in the world [1]. International agreements like the Kyoto Protocol and the Paris Agreements have been brought by global environmental issues. All of these emphasize moving toward zero-emission or renewable energy sources. Therefore, without a major contribution from the transportation sector, the goal of limiting global warming cannot be achieved. Utilizing low- or emissions-free electric vehicles (EVs) is the only way to electrify vehicles and reduce greenhouse gas emissions in the transportation sector. The economy and environment will benefit greatly from the switch to electric vehicles from conventional Internal Combustion Engines (ICE) vehicles.

Electric vehicles have become incredibly popular in recent years, and it appears that this trend will continue until the transportation sector adopts a maximum of EVs, in accordance with new policies implemented by several governments across the globe. The selection of EVs is growing due to advancements in power electronics and battery technologies. Electricity is a more affordable option than petroleum oil for the transportation sector, lowering greenhouse gas emissions and a country's reliance on foreign fuel imports. Plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and battery electric vehicles (BEVs) are the various types of electric vehicles (EVs). Major electric vehicle manufacturers such as Tesla, Nissan, GMW, Hyundai, Toyota, BMW, Mercedes, BYD, MG, TATA, and others have released their plug-in hybrid cars into the market. 1.1 million of public transportation electric vehicles marketed globally in 2017, and more than 3 million plug-in hybrid electric vehicles

(PHEVs) and EVs were on the road worldwide in that same year. By 2030, many countries have stated that their entire transportation system will be electrified [2]. The Nepal government also intends to increase the percentage of electric vehicles driven to 25% by 2025 and to 90% by 2030. In Nepal, electric vehicles have become quite popular in recent times. Some electric vehicles are available in Nepalese market in 2022/23 is listed in table 1.1.

Table 1.1:Eelectric Vehicles are available in Nepalese market in 2022/23

Electric Vehicles	**Battery Capacity (KWh)**	**All-Electric Range (Km)**	**Charging Standards**
NEXON PRIME	30.2	312	CCS
NEXON MAX	40.5	413	CCS
NEXON TIGOR/E-PRES-T	26	315	CCS
BYD ATTO 3	60.48	420	CCS
BYD E6	71.7	415	CCS
GMW ORA	47.788	400	CCS
MZ ZS LUX	44.5	320	CCS
MG SHORT RANGE	51	320	CCS
MG LONG RANGE	72	440	CCS
HYUNDAI KONA	39.2	452	CCS
HYUNDAI IONIQ5	58.9	375	CCS
CITROEN	29.2	320	CCS
NETA	38.5	380	CCS
NISSAN LEAF	40	311	CHAdemo

For the electrical system operator, integrating electric vehicles (EVs) can have both positive and negative effects. The unfortunate thing is that an increase in the number of electric vehicles on the road can lead to problems such as reduced voltage, overloaded power transformers, overloaded low voltage lines, increased energy loss, and harmonic currents [3]. The current system might not be able to handle. Electric cars represent a new class of electricity user, and the electrical system of the future must be prepared for them. Uncontrolled car charging has the potential to disrupt the electrical grid making it more difficult to maintain proper operation. Uncontrolled electric car charging can rapidly increase demand for electricity. However, scheduling car charging, for example, for midnight or another time when few others are using electricity, can help minimize grid-related issues. The power distribution system will have to work harder as more and more electric cars use the system, which could lead to problems like voltage deviation, unbalanced electricity, overloaded transformers, and increased energy loss in the system. In order to prevent these issues, grid managers and electric vehicle users must collaborate and develop a plan for energy-efficient use of electricity.

The presence of a robust public charging infrastructure plays a pivotal role in promoting the widespread use of EVs, as EVs have limited electric range and cannot manage long-distance journeys without reliable charging options. Consequently, establishing a public charging service as a supplementary resource to home charging becomes imperative. While Electrical Fast Charging Stations (FCSs) are expected to proliferate throughout the network, a lack of thoughtful planning in deploying charging infrastructure could hinder the acceleration of EV adoption. Therefore, careful consideration and strategic placement of charging stations are essential to maximize the efficient utilization of FCSs.

The planning strategy for implementing charging infrastructure should prioritize meeting the needs of both users and suppliers. EV users require convenient access to Electrical Fast Charging Stations (FCSs) whenever they require them, accompanied by a high level of service quality. Consequently, the improper or absent placement of FCSs can adversely affect driver convenience. The planning model should also optimize the selection of charging points from a pool of candidate sites to enhance EV drivers' accessibility throughout the planning network. Furthermore, investing in emerging technology carries inherent risks. Investors seek profitable ventures that offer maximum returns and a secure investment environment, so the establishment of a public charging service should undergo a thorough evaluation that considers all uncertainties and potential impacts on the business. Accurate forecasting of future EV demand can enhance investment security, enabling decision-makers and investors to assess their long-term investments effectively. Additionally, it provides electrical utilities with data on projected EV demand, which must be factored into their infrastructure upgrade plans.

Here, 11kV Om distribution feeder of 66/11 kV New Chabahil Substation in Kathmandu's Chabahil area is selected because the availability of numerous business facilities, many numbers of industries, VIP colonies, highly populated residency in the area. So, it is highly probable that EV users will find it convenient to charge their vehicles there, without experiencing any boredom as they wait. Therefore, this feeder seems most likely to have EV charging penetration in near future. Considering this analysis can provide a realistic overview of the potential scenario in this context.

1.2 Problem Statement

The escalating cost of fossil fuels and the growing environmental concerns associated with Internal Combustion Vehicles (ICVs) are steadily rendering them outdated. Various countries have established targets to phase out traditional ICE vehicles in favor of electric vehicles (EVs). Consequently, EVs are poised to play an increasingly dominant role in future transportation. To support this shift, the transportation network will require robust charging infrastructure similar to traditional refueling stations.

Likewise, the proximity between the EV customer's location and the charging station should be minimized to eliminate any additional energy expenditure during the charging journey. Therefore, an optimal location should be chosen based on traffic conditions, favoring areas with a high concentration of EV ownership or usage. This approach helps reduce daily travel costs for EV customers.

Improperly located and sized fast-charging stations can lead to various adverse effects, including increased power loss, voltage drop, power transformer overload, overload of low-voltage lines, and the introduction of harmonic currents. Consequently, the time-varying nature of EV charging can potentially degrade the quality of the electrical supply.

Within the Nepalese distribution system, electric vehicles are currently in an emerging phase, with government policies actively encouraging the adoption of EVs for transportation. It becomes imperative to investigate the impact of the rising penetration of electric vehicles on the electrical distribution network and assess the necessary adjustments in charging infrastructure. This study will enable the distribution system operator to determine whether the current infrastructure can accommodate a significant influx of PEVs or if system reinforcement is required.

1.3 Specific Objectives

The first aim of this thesis is to develop an algorithm for the optimal placement of charging stations in 11kV Om distribution feeder of 66/11 kV New Chabahil Substation in Kathmandu's Chabahil area by minimizing the network losses as well as travel losses of EVs and maximizing the minimum infrastructure usage of a CS considering the dynamic behaviour of EVs load.

The other objectives are as follows:

1. To model stochastic load demand of PHEV and CS operation to considers all essential parameters and variables for its characteristic behaviour.
2. To perform the load flow of IEEE-33 bus radial distribution system in MATLAB.
3. To analyse base case load flow of Om feeder without PEVs.
4. To minimize the network losses as well as travel losses of EVs and maximize the minimum infrastructure usage of a CS.
5. To analyse the influence on voltage profile after optimal placement of CS in distribution Network as compare to voltage profile of the network without any CSs integration.

1.4 Scope and limitations of study

Electric vehicles (EVs) are becoming more and more common because they are environmentally friendly. But setting up an efficient infrastructure for charging stations is essential to meeting the increasing demand for regular battery replacements. Therefore, in order to sufficiently accommodate the growing number of EVs, the widespread installation of electric vehicle charging stations becomes necessary.

1. This research provides a complete structure for thoughtful placement of EV charging stations in the distribution network.
2. Moreover, this research provides prospective investors with a comprehensive understanding of the different costs related to charging stations, encouraging them to make accurate decisions that maximize profits.
3. This study also shows correlations between different expenses related to charging station capacity and planning, enabling planners to make accurate decisions about the location and size of these infrastructures.

The following are the limitations of this study which are referred for further study:

1. The study only looks at cars with small battery capacities up to 71.7 kWh and is limited to an urban area, so it does not cover charging stations located along highways or transportation corridors.
2. The assumption that vehicles remain fixed at node points will change with time. Consequently, it is essential to forecast the presence of EVs in the study area.
3. The study treats Electric Vehicles (EVs) solely as a system's positive load, neglecting the possibility of them contributing to negative load scenarios.
4. The research work is not done on how EV drivers charge or how the electric network will need to be expanded to accommodate EV penetration.

1.5 Outline of Thesis

This thesis has been organized into five chapters:

Chapter One gives a brief introduction for necessity of electric vehicle charging stations placement strategies study for IEEE 33 bus system and Om distribution feeder, objective, scope and limitations of thesis and outline.

Chapter Two provides the overview of literature review done for this thesis. Optimal placement of electric vehicle charging station in IEEE 33 bus system and Om distribution feeder using MATLAB are discussed.

Chapter Three presents the methodology used in this thesis. It also discusses the methodology for electric vehicle charging station load modelling.

Chapter Four discusses the results of this thesis. Outputs are analyzed and discussed in this chapter.

Chapter Five summarizes the thesis and highlights the contribution of thesis.

Finally, the thesis ends with the bibliography referred and appendices included.

CHAPTER 2: LITERATURE REVIEW

2.1 Electrical Vehicle (EVs)

The environment is directly impacted by internal combustion engines, which also contribute to cars' low efficiency and rising fossil fuel costs. For the purpose of developing EV technology, the EV battery is an essential part of energy storage for use as driving fuel. In order to convert an electrical vehicle for long-distance use, charging stations are necessary. In this case, EV must take into account the specific electricity supplier that supplies EV users. The utility needs to assess how the addition of the EV charging station will affect the current distribution network while considering potential future network congestion [4].

An electrical vehicle is one that is propelled by an electrical motor. Electric vehicles include electric cars, electric trains, and electric boats. For the purposes of this study, an electric vehicle is any car or vehicle with an electric motor that is either entirely or partially powered by electricity. The market share of electric vehicles has increased due to recent advancements in battery technology. Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are the two main technologies that have the potential to control the electric vehicle market in the near future. The use of electric vehicles has been encouraged by many government tax exemptions and incentive programs. Norway's tax exemptions combined with no parking fees for electric vehicles have resulted in a 37% market share for EVs [5]. The Nepal government also plans to increase the percentage of electric vehicles driven to 25% by 2025 and to 90% by 2030. In Nepal, electric vehicles have become quite popular in recent times.

2.1.1 Battery Electric Vehicle (BEV)

Vehicles with electric motors that are solely powered by chemical energy stored in battery packs, typically lithium-ion batteries, are referred to as battery-electric vehicles. This means that the only energy source for BEVs is electrical energy, which is kept in the battery packs as chemical energy. The basic idea behind a BEV is that it is propelled by electric motors and controllers. Rechargeable batteries serve as a fuel source for electric motors, and the controller modifies the power delivered to the motor to control the vehicle's speed. BEVs are limited in their driving range compared to conventional cars (ICE) because they are entirely dependent on a finite amount of battery capacity.

BEVs have no internal combustion engine and emit no emissions from their exhaust [6].

2.1.2 Plug-in Hybrid Electric Vehicles (PHEV)

A vehicle classified as PHEV uses both electricity and gas or diesel. Internal combustion engines (ICEs) are combined with electric motors and rechargeable batteries to develop the very basic concept of PHEV. Their batteries can be charged externally by plugging-in them, but when the battery runs low, they can still go farther because of the gasoline or diesel engine. PHEVs provide the convenience of using conventional fuels along with the ability to drive entirely on electricity. PHEVs have a high level of energy resilience because they have two separate power sources [6].

Only PHEVs with direct access to the electrical grid will be taken into consideration for reference paper work in order to examine the effects of charging electric vehicles as a new load on the distribution system. The electric vehicles available in Nepal are battery-powered vehicle. For the purpose of probabilistic load modeling of electric vehicle charging stations in the event of a real system, only BEVs with direct access to the electrical grid will be taken into account. These EVs will need charging stations in the distribution; however, the implementation of FCS may have different technical effects, so it is important to give more attention to planning the distribution as well as handling these additional loads. Battery sizes, charging time and the movable nature of these loads should be considered in the planning process for these new types of loads. This kind of load is primarily battery-based, so an overview of battery technologies is related to a summary of their various characteristics.

2.2 Battery Technology and Energy storage system

Different components of electric vehicles have an impact on their operation. These components include electric motors, controllers, power converters, battery packs, and battery chargers. These components differ between various electric vehicles can affect how well they operate and charge.

Certain electric vehicles are set up differently. For instance, there are two different types of plug-in hybrid electric vehicles (PHEVs): parallel and series. Some PHEVs use transmissions that allow them to operate in either parallel or series configurations, switching between the two based on the drive profile. Parallel hybrid operation connects the engine and the electric motor to the wheels through mechanical coupling. Each kind has its own benefits and drawbacks.

Different types of batteries are also used in electric vehicles. these batteries must have a large capacity for energy storage to power the car, The battery, which serves as the main energy source in fully electric vehicles (BEVs), can be costly and heavy. Because PHEVs have a fuel source and a battery, the battery must be light weight in order to increase the vehicle's efficiency.

Because car batteries must store a lot of electrical energy and provide power for acceleration using batteries can be difficult. For instance, a normal family car would require a battery capacity of 50kWh to travel 350 km in one direction. Conventional lead acid batteries are not as suitable for use in electric vehicles due to their low energy density and heigh weight.

Batteries for electric cars are available in various types. Regardless of being inexpensive, lead acid batteries have a short lifespan. Despite having a large energy capacity of Ni-MH batteries, its self-discharge rate is high when the vehicle is not being in used. Li-Ion batteries are expected to be the batteries of the future for electric vehicles because of their strength and efficiency. Though, it is difficult to scale up the size of Li-Ion batteries while lowering costs.

A battery or energy storage system is another vital component of a plug-in electric car. The energy contained in the battery packs is used by the electric car. The size and cost of batteries have decreased due to recent advancements in technology. Over the past 20 years, there have been numerous advancements in battery technology that have led to the creation of batteries with high energy density, durability, affordability, and compact size. Lithium-ion (Li-Ion) and nickel-metal hybrid (Ni-MH) batteries are the two most types of batteries used in electric vehicles (EVs). High-power and range electric vehicles have advanced with the development of lithium-ion batteries. Lithium-Ion batteries are currently used in the majority of electric vehicles (EVs) due to their higher energy density, longer battery life, lower cost, non-toxicity, and unique fast charge acceptance features [7]. Table 2.1 shows a comparison of Ni-MH and Li-Ion batteries.

Table 2.1: Characteristics of Li-Ion and Ni-MH Battery.

Characteristics	Li-Ion Battery	Ni-MH Battery
Energy Density (Wh/kg)	94	57
Power Density (W/kg)	540	250
Life Cycle at 80% DOD (cycle)	>3500	>3000
Voltage of a single Cell	3.6 V	1.2 V

2.3 Charging Technology and Infrastructure

In their document Surface Vehicle Recommended Practice J1772, the Society of Automotive Engineers (SAE) provides information about electric vehicle charging technology [8]. Three categories of EV charging technology exist: Level 1, Level 2, and Level 3. The battery and converter for level 1 and level 2 charging are found inside the car, and the converter is where the AC to DC conversion takes place. Through the inlet, which is connected to an off-board connector, power and data are delivered. The EV supply equipment (EVSE), which is located off-board, connects PEVs to the power grid. Single phase 120V is used for level 1 charging, with a maximum rated current of 15-20A and a power supply limit of roughly 1.9kW. For usage at home or in the workplace, no extra infrastructure is required [9]. Level 2 charging requires a single phase 240V supply with a 16–32A current rating. The majority of PEV manufacturers recommend Level 2 charging as the primary way for charging PEVs because it speeds up the vehicle's charging process compared to Level 1 charging [9]. AC electricity is typically used to power the on-board charging system for both Level 1 and Level 2 charging. Due to the converter's weight, size, and financial limitations, the PEV charger's on-board conversion of AC power to DC has a power restriction [9].

Highway stop areas and city recharging stations can be equipped with Level 3 commercial fast charging station. A battery management system (BMS) regulates the off-board charging system to supply the vehicle with DC power. The charger type has a maximum fast-charging rate of 250kW and is supplied with a voltage range of 3-phase 230V AC to 600V AC [10]. PEVs can take several hours to few minutes to fully charge due to variations in battery size and charging power level. Table 2.2 shows the expected power level according to the Electric Power Research Institute (EPRI) and Society of Automotive Engineers (SAEJ1772).

Table 2.2: EPRI and SAEJ1772 Charging Power Level Standards

Power Charging Level	**Converter Location**	**Usage**	**Expected Power Level**
Level 1 120V AC	Onboard Single-Phase	Home and office	1.44 kW (15A)
			1.92 kW (20A)
Level 2 120V AC 240V AC	Onboard Single-Phase	Residential Outlet	3 kW (16A)
			6 kW (32A)
		Commercial Outlet	15.5 kW (80A)
Level 3 480V AC 600V AC	Onboard Single-Phase	Commercial Fast Charging Station (FCS)	50 kW
			100 kW
			250 kW

A three-phase transformer that lowers the level of medium AC voltage which is necessary for the FCS. An intermediate DC voltage is produced from AC by the AC-DC power electronic converter. Ultimately, the intermediate DC voltage is transformed into the voltage needed for the vehicle's battery by the DC-DC power electronic step.

The connection pattern of charging stations in the distribution is shown in figure 2.1. Transformers are used to link the electric vehicle's quick charger to the distribution system so that the voltage can be adjusted to the proper level for charging. Subsequently, a converter supports in converting voltage from alternating current (AC) to direct current (DC). It's possible that installing a charger pattern may differ from installing a basic connection pattern. In order for the charging station to accommodate the number of EVs, it can install multiple EV chargers. On the other hand, adding EV charging stations immediately increases the transformer load.

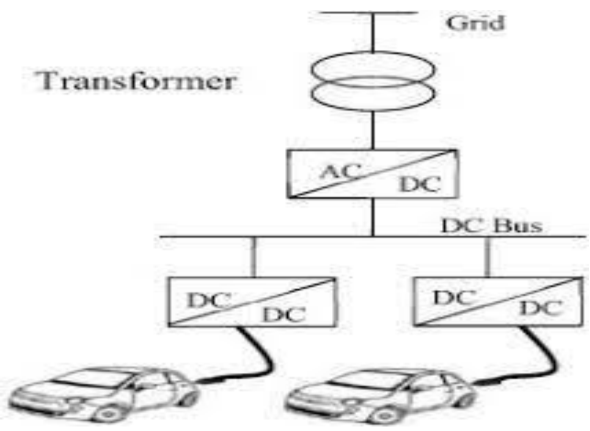

Figure 2.1: Charging Station Connection to Distribution Network

2.4 PEV Load Modelling

PEV load directly depends upon the driving behaviour and driving distance of the vehicles. Different research uses deterministic and probabilistic approaches to model PEVs loads.

G. Li and X.P. Zhang [11] modeling of PHEV charging demand considering the daily driven distance pattern, arrival time and service time, energy consumption per mile, total battery capacity and daily recharge energy by employing M/M/c queuing theory to describe the different uncertain behaviour of PHEV for analyzing the impact of PHEVs charging on the distribution network.

Wang, D. et.al. [12] modeling of PEV load considering driving pattern and energy consumption in a stochastic framework considering the random charging start time, initial state of charge of battery.

Hafez and Bhattacharya [13] PEV charging load was modeled by considering arrival time of PEVs as non-homogeneous Poisson process where arrival rates vary with time including two scenarios, one with customer convenience and other depending upon charging price.

S. Shojaabadi et.al. [14] modelling of Charging stations' output/input power considering charge/discharge schedule of electric vehicles, type of electric vehicle and battery capacity of electric vehicles and presence percentage of electric vehicles in the CS.

Ni, X., & Lo, K. L. [15] modeling of EV load considering charging power, initial SOC of the EV batteries, charging start time and charging duration period to evaluate the impacts of the integration of charging stations, planning for charging stations in the distribution networks.

Biao Yang, et.al., [16] modeling of EV load considering charging time, initial charge capacity, initial charging time and quantity of different EV types in the future to predict the EV charging curve and analyze the EV charging load impact on the distribution system.

U.N. Bhat [17], in the M/M/c queuing model where the first M denotes the average arrival time of a customer, the second M denotes the average service time for a customer and c denotes the number of servers. According to this approach, all incoming customers create only one line, and the first customer in line or queue gets served immediately as a server becomes available. as long as there are clients to attend to, no server is idle. Both interarrival time and service time are assumed to have an exponential distribution.

The approach used by G. Li and X.P. Zhang [11] is implemented in this thesis with the essential characteristics of PHEVs to obtain probabilistic load profile of PHEVs. The detail modeling of load profile of PHEVs is included in section 3.2.

2.5 Placing EV Charging Stations

Establishing public charging stations presents a problem since it needs integration of two distinct systems: the transportation and electricity system. Each system is different in what it requires and where the charging stations should be placed. There may be issues if we just consider the desires of one system while ignoring the needs of the other.

For example, if we only think about what the electrical system needs and don't consider how people travel and where they need to charge their electric vehicles, we might put charging stations in places that are good for the electrical system but not easy for drivers to reach. This means the solution won't be good for the people who drive electric cars and need to charge them.

On the other hand, if we only think about where people drive and put charging stations in those places, it might be hard for the electrical system to handle all the electric cars charging there. This could lead to power problems in those areas.

So, to find the best places for charging stations, we have to think about both the electrical system and the needs of the people who drive electric cars.

Lately, more attention has been given to figuring out the best spots for electric vehicle charging stations. This has been studied in both electrical and transportation systems.

2.6 Impacts of Electric Vehicle on Distribution System

The distribution network [18] will experience the following issues when an electric vehicle enters the system:

(1) Power Losses

The loss in the distribution system will increase as more and more EVs are charged. The main factors contributing to the increase in power losses are the number of EVs, the charging position, and the charging duration.

(2) Voltage Deviations

An EV's charging may increase the load demand on the electrical network, which could result in a decrease in the voltage. As a result, the voltage differs from what is stated value. Moreover, single-phase EV charging is preferred for home EV chargers. It is therefore probable to result in voltage imbalance.

(3) Distribution Infrastructure Overloading

When the distribution system's EV capacity may be exceeded. In particular, there is going to be a greater distribution of electric power when there is a high demand for load and many EVs charging simultaneously.

(4) Frequency Drop

Since charging an electric vehicle increases load, it has an impact on the electrical system's frequency. When the system is in a state of islanding mode, the issue becomes more severe.

(5) Harmonic Currents

Harmonic current issues may arise when EV batteries are charged using a DC quick charging equipment.

2.7 Optimization Technique

2.7.1 Optimization by Genetic Algorithm (GA)

Natural selection and genetics provide the foundation for optimizing and search methods used by the genetic algorithm (GA). Through the use of specific selection rules, a population made up of numerous individuals can evolve via a genetic algorithm (GA) to a state where "fitness" is maximized, or the cost function is minimized.

Genetic algorithms are especially well-suited to problems involving ill-structured optimization due to their unique features. The GA integrates the process of evolution with functional optimization, using the principles of natural selection and natural genetics. The binary representation of the status of switches in a distribution reconfiguration issue is well suited to the coded discrete information of artificial strings that the GA uses. One intriguing aspect of the GA is that it searches from a population of points rather than a specific search point, which increases the likelihood of finding an optimal solution quickly.

The following are characteristics of GA algorithms:

1. GAs operates using a coding of a number of parameters, not the parameters directly. Hence, discontinuous or integer-based variables are easily handled by GAs.
2. Rather than searching within a single point, GAs search within a population of points. As a result, globally optimal solutions can be offered by GAs.
3. No derivatives or other additional information are used by GAs; only objective function knowledge is used. Hence, non-smooth, intermittent, and non-differentiable functions—all of which are real in real-world optimization problems—can be handled by GAs.
4. Rather than using deterministic transition rules, GAs employs probabilistic ones. We employ GS due to GA's characteristics vary from those of the remaining search strategies in a number of ways, including.
5. The algorithm is a multipath, which lowers the likelihood of nearby minimum capturing by searching numerous peaks concurrently.

In order to help the evolutionary operator, evolve its present state into the next stage with the fewest computations possible, GA uses a coding of variables rather than the actual variable.

2.7.1.1 Advantages of Genetic Algorithm

1. Independent or integer-based parameters can be handled by GAs with ease.
2. Because GAs can escape the trap that is local optimal values, they can offer a solution that is globally optimal.
3. Non-smooth, intermittent, irregular, and non-differentiable functions—all of which are present in real-world optimization problems—can be handled by GAs.

4. Because GAs can concurrently identify solutions across various searching domains, multiple objectives are able to be accomplished in just one run.
5. GAs can quickly converge, create an extensive variety of solutions, and adjust to change.
6. It is simple to code GAs to operate on parallel computing systems.

2.7.1.2 Disadvantages of Genetic Algorithm

1. Since GAs are probabilistic algorithms, the altered solution they offer isn't always the best one.
2. As chromosomal length gets longer, so does the process's length.
3. As the system's size grows, it occasionally converges to impractical solutions.

2.7.1.3 Genetic Algorithms: Natural Selection

Charles Darwin's description of the evolutionary process of things that live is mimicked by Genetic Algorithms (GA), a direct, parallel, stochastic technique for global searching and optimizing. Members of the Evolutionary Algorithms (EA) group include GA. Natural selection, reproduction, and species diversity—maintained by the distinctions between every generation and the previous—are the three fundamental tenets of natural evolution that the algorithms for evolution depend on.

A. Selection

In In the natural world, individuals are chosen based on their ability to survive and reproduce. An individual's opportunities of surviving, procreating, and passing on its genes to another generation increase with degree of environmental adaptation. The best candidates are chosen for EA based on an assessment of their fitness function or functions. The gap between the poles of the closed-loop structure and what is needed poles, the sum of the square errors between the needed and actual system responses, etc., are instances of this type of function of fitness. In the event that the optimization issue involves minimizing, individuals with lower fitness function values will be more likely to recombine and, consequently, produce children (offspring).

B. Recombination

Recombination, or crossover, is the first stage of reproduction. In it, a completely new chromosome is formed using the genes of its parents. Although schemes involving several parents are also possible, the GA typically requires two parents for recombination. Traditional (Distributed) Crossover and Combining (Intermediate) Crossover are two of the most popular algorithms.

C. Mutation

It is possible to apply the recently formed population through crossover and selection to change in the future. A mutation is an alteration to certain DNA sequences. These alterations are mostly the result of errors made when the parent's genes are copied. In genetics, mutation refers to the haphazard alteration of a gene's value within a population.

2.7.2 Optimization by Non-Dominated Sorting Genetic Algorithm (NSGA-II)

NSGA-II is a multi-objective optimization algorithm based on the principles of genetic algorithms. It is used to find solutions that optimize multiple conflicting objectives [19]. This algorithm is particularly useful in problems where you want to find a set of solutions, known as a Pareto front, that represents the trade-off between different objectives. NSGA-II is an improved version of the original NSGA algorithm.

Overview of NSGA-II working Steps:

1. Initialization: Start with a population of random candidate solutions, often referred to as individuals or chromosomes.
2. Fitness Evaluation: Evaluate the fitness of each individual with respect to the multiple objectives. In multi-objective optimization, a solution's quality is measured by a vector of objective functions. Each objective function represents a different aspect of the problem that you want to optimize.
3. Non-Dominated Sorting: Sort the individuals into different non-dominated fronts. A solution is said to dominate another if it is at least as good in all objectives and better in at least one. The first front contains non-dominated solutions (Pareto-optimal solutions), and the second front contains solutions that are dominated by those in the first front, and so on.
4. Crowding Distance Assignment: Calculate the crowding distance for each individual in the current front. The crowding distance measures how close an individual is to its neighbors in the objective space. This helps maintain diversity in the population.

5. Selection: Create a new population for the next generation by selecting individuals from the current population. Solutions from less crowded fronts are preferred. If two solutions are from the same front, the one with the greater crowding distance is selected.
6. Crossover and Mutation: Apply genetic operators, such as crossover and mutation, to create new individuals in the population.
7. Termination Criteria: Repeat the above steps for a certain number of generations or until a termination criterion is met.
8. Final Output: The final output of NSGA-II is a set of Pareto-optimal solutions, which represents the trade-off between the conflicting objectives. These solutions are not dominated by any other solutions in the population.

NSGA-II is widely used in various fields, including engineering, economics, and other domains where multiple, often conflicting objectives need to be optimized. It's known for its ability to find diverse and well-distributed Pareto fronts, making it a powerful tool for multi-objective optimization problems.

CHAPTER 3: METHODOLOGY

Figure 3.1 shows the fundamental methodological strategy for this research. The research work begins with the modeling of an electric vehicle's stochastic charging profile, load flow, validation of an IEEE-33-bus radial distribution test system, and implementation in the actual Nepalese distribution system.

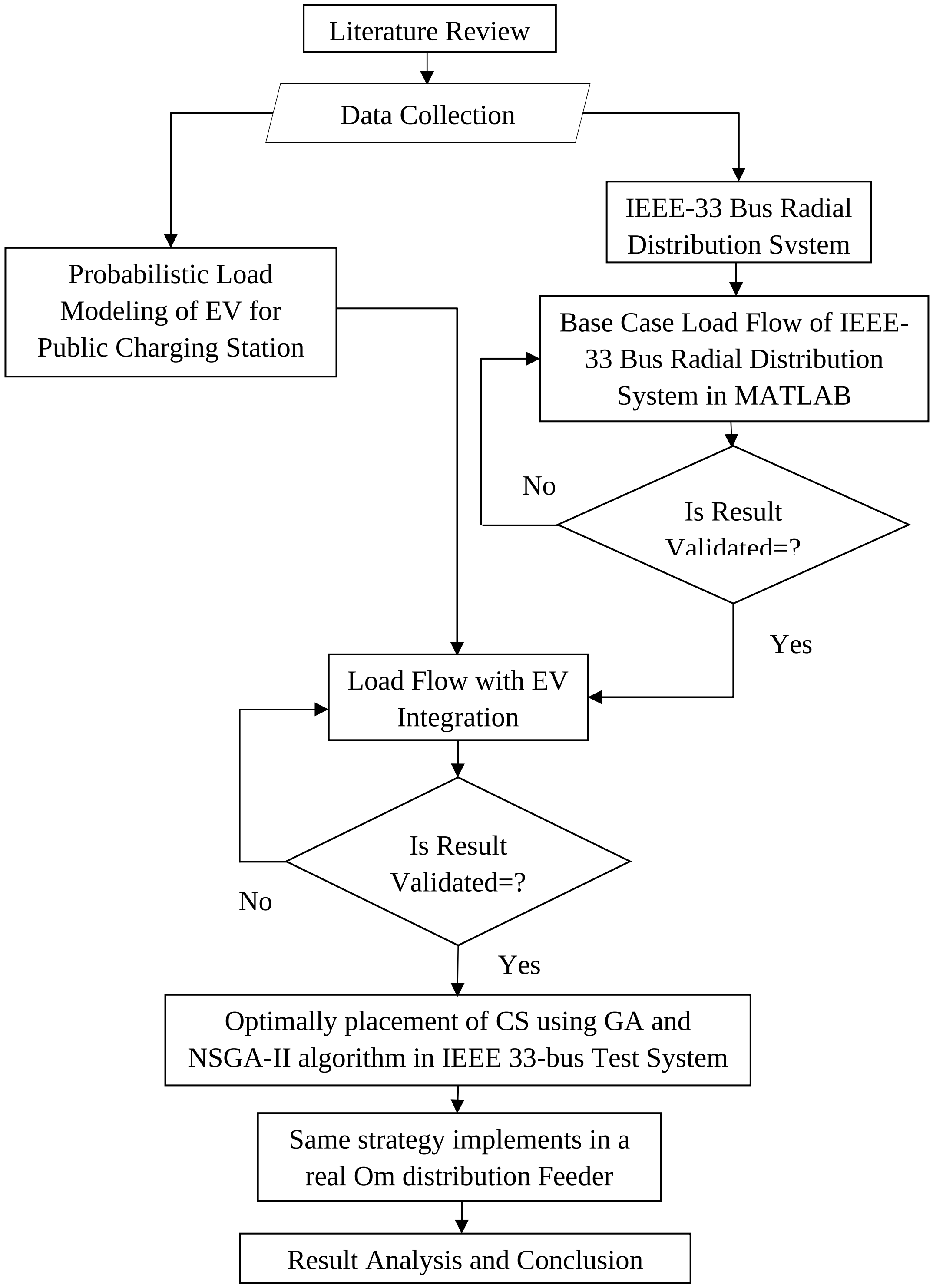

Figure 3.1: Flow Chart of fundamental methodological strategy for this research.

3.1 Data Collection

3.1.1 Daily Driving Distance

An essential component for modeling an EV is driving behavior. The average daily driving distance of a vehicle can be derived from the Nepal Electricity Authority, Head Office Ratnapark, Kathmandu, Nepal, charging station software during a six-month period and from the survey of Ratnapark EVCS. After that the average daily driving distance is determined. Arc Geographic Information System (GIS) software is used to trace the trip route of the OM distribution feeder for the research work's case study. The Department of Transportation Management (DoTM), located in Ekantakuna, Lalitpur, Nepal, is the source of information regarding the number of electric vehicles registered in the Bagmati Province.

3.1.2 Distribution System

For EV impact research, the OM feeder of the New Chabahil Substation in Kathmandu, Nepal has been chosen as the distribution system. Different datas of distribution network such as type of conductors, consumer number, line length, distribution transformer capacity is collected from NEA, Maharajgunj Distribution Centre, Ratnapark Distribution Centre, Kathmandu, Nepal and Kathmandu Valley Central and Northen Distribution System Enhancement Project, Kharipati, Bhaktapur.

The OM distribution feeder mostly uses DOG, Rabbit, Weasel conductors and XLPE 120, XLPE 70, XLPE 50 cables. Using Arch map software, the line length and the distribution transformer's location are taken from GIS route map. The feeder has a radial length of 2.52 km and total length of 10.58 km. There are 21 private transformers and 35 NEA transformers in this feeder. Table 3.1 shows specification of conductors.

Table 3.1: Specifications of Different Conductor and Cable

S.N.	Conductor Name	Resistance (R) (Ω/km)	Reactance (R) (Ω/km)	Ampacity (A)	Line Voltage (KV)
1	DOG	0.2733	0.321878	300	11
2	RABBIT	0.5419	0.343371	193	11
3	WEASEL	0.9065	0.35954	139	11
4	XLPE 300	0.129	0.075	367	11
5	XLPE 120	0.315	0.074	223	11
6	XLPE 70	0.125	0.0751	164	11
7	XLPE 50	0.796	0.0779	133	11

The travelling route of EVs alongside the OM distribution feeder route and location of different distribution transformers is traced on Arc Geographic Information System (GIS) software which is shown in figure 3.2.

Figure 3.2: Route Map for PEV Travel, OM Distribution Feeder Route and Location of Different Distribution Transformers

3.2 Modelling of PHEV Charging Station demand Profile

3.2.1 Parameters for Single PHEV Modeling

Plug-in Hybrid Electric vehicles (PHEVs) behave differently from regular loads in the power system when they are integrated into the distribution network for the purpose of charging. Various attributes and the actions of the vehicle's owner determine the load pattern of PHEVs [22]. These consist of Vehicle Model

a) Vehicle Model

b) Daily Driven Distance

c) Operating status of a PHEV

d) Total Battery Capacity

e) Energy consumption per mile

f) Daily recharge energy of a PHEV.

1.1.1.1 Vehicle Model

Various vehicle models with varying battery capacities, all-electric ranges, and specific consumption of energy are in the market at the time of this study. For each type of vehicle, there is a different minimum state of charge. The car's battery is charged at home using a 230V/16A slow on-board charger. According to NEA 2023, the public charging charger is rated at 60 kW.

3.2.1.1 Daily Driven Distance

When modeling PHEVs and their load profiles, the daily driven distance (M_d) of these vehicles is essential [20]. PHEVs' daily driven range varies from car to car, day to day, and greatly depends on the owner of the vehicle. The minimum and longest distance that the owner of the vehicle can travel is used to determine the daily driven distance for PHEVs. After analyzing the acquired data, the distribution of probability is discovered. To find the lognormal distribution daily driven distance, use the best curve fit tools in MATLAB.

$$M_d = e^{\mu_m + \sigma_m * N} \quad (1)$$

Where, μ_m and σ_m are mean and standard deviation of M_d.

$$\mu_m = \text{in}\left(\frac{\mu_{M_d}^2}{\sqrt{\mu_{M_d}^2 + \sigma_{M_d}^2}}\right) \quad (2)$$

$$\sigma_m = \sqrt{\text{in}\left(1 + \frac{\sigma_{M_d}^2}{\mu_{M_d}^2}\right)} \quad (3)$$

And N is a standard normal variate which is calculated from U_1 and U_2. The lognormal random variable N is generated using the Box-Muller method.

$$N = \sqrt{-2.\,\text{in}(U_1)} * \cos(2\pi U_2) \quad (4)$$

3.2.1.2 Operating status of a PHEV

The K_{EV} is the percentage of the total amount of energy supplied to the engine and the electrical drive controller which is used up by the electrical drive controller of a predetermined driving schedule, K_{EV} plays an important role in the operation of a plug-in hybrid electric vehicle [11]. Hence, we have

$$K_{EV} = \frac{E_{Bat}}{E_{Bat} + E_{Eng}} \quad (5)$$

Since no battery energy is used when the internal combustion engine (ICE) powers the vehicle, K_{EV} = 0. On the other hand, for an electric vehicle that runs solely on battery power and emits no emissions, $K_{EV} = 1$. For a PHEV, K_{EV} ranges from 0 to 1, $K_{EV} \in$ [0, 1] and for BEV, K_{EV} = 1.

3.2.1.3 Total Battery Capacity

It is assumed that a PHEV's control strategy will modify K_{EV} in accordance with its battery capacity, C_{Bat} [21]. Therefore, bivariate normal distribution can be used to model K_{EV} and C_{Bat} and assume that they are correlated.

$$\begin{bmatrix} K_{EV} \\ C_{Bat} \end{bmatrix} = \begin{bmatrix} \mu_{K_{EV}} \\ \mu_{C_{Bat}} \end{bmatrix} + L \begin{bmatrix} N_1 \\ N_2 \end{bmatrix} \quad (6)$$

Where,

$$\mu_{K_{EV}} = \frac{(\text{Min } K_{EV} + \text{Max } K_{EV})}{2} \quad (7)$$

$$\mu_{C_{Bat}} = \frac{(\text{Min } C_{Bat} + \text{Max}C_{Bat})}{2} \quad (8)$$

$$\sigma_{K_{EV}} = \frac{(\text{Max } K_{EV} - \text{Min } K_{EV})}{4} \quad (9)$$

$$\sigma_{C_{Bat}} = \frac{(\text{Max } C_{Bat} - \text{Min} C_{Bat})}{4} \quad (10)$$

And L is the Cholesky decomposition of their covariance matrix $\sum$. i.e., $\sum = L.L^T$

$$\sum = \begin{bmatrix} \sigma^2_{K_{EV}} & \rho\Sigma\ \sigma_{K_{EV}}\sigma_{C_{Bat}} \\ \rho\Sigma\ \sigma_{K_{EV}}\sigma_{C_{Bat}} & \sigma^2_{C_{Bat}} \end{bmatrix} \quad (11)$$

And N_1 and N_2 are two independent standard normal variates.

3.2.1.4 Energy consumption per km

A PHEV's consumption of energy per km driven E_M, can be used to evaluate its performance. This can be roughly expressed to be a function of K_{EV} [22].

$$E_M = (0.6214).A_E.(K_{EV})^{B_E} \quad (12)$$

Where the PHEV type affects both the constant parameters A_E and B_E. When considering a pure BEV, B_E is taken to have a value of zero. Therefore, K_{EV} becomes one.

3.2.1.5 Daily recharge energy of a PHEV.

This value is dependent upon M_d and M_E. The needed grid energy is C_{Bat} if M_d is higher than or equal to equal to M_E. If not, D_E is the result of multiplying M_d by E_M [11]. The definition of each day recharge energy D_E is

$$D_E = \begin{cases} C_{Bat} & M_d \geq M_E \\ E_M.M_d & M_d < M_E \end{cases} \quad (13)$$

Where static M_E, which can be determined as the maximum distance that a plug-in hybrid electric vehicle can travel when its battery is fully charged.

$$M_E = \frac{C_{Bat}}{E_M} = \frac{C_{Bat}}{A_E.(K_{EV})^{B_E}} \quad (14)$$

3.2.2 Parameters for Multiple PHEV Modeling

The waiting line model, also known as the queuing model, can be used to illustrate how well a charging station functions [17]. Vehicles arrive, wait in line for a while, get served or charged, and then exit the CS in the typical queue ahead of any CS. The CS's servers are called CPs. Generally speaking, the arrival distribution is Poisson, and the service distribution is exponential [17]. The average hourly arrival rate is denoted by λ. The service center's hourly average service rate is represented by μ, and c represent the total number of customers that can be charged simultaneously. A model with an infinite length of queues requires that μ is rigorously greater in compare to λ. If not, the waiting line for services won't end.

$$\text{Traffic Intensity of the System } (\rho) = \frac{\text{inter arrival rate of a customer}}{\text{inter service rate of a customer}}; \quad \rho < 1$$

This indicates the inter-arrival rate of the charging station is lower compared to the charging station's the inter service rate. There will therefore be a guarantee that each EV that joins the line will be served before leaving. Because of their power limitation, there are also very few charging ports in a particular charging station. The electric vehicles in charging stations get charged by an entire number of charging ports in a moment. EVs arrive at commercial EV charging stations in an unpredictable fashion. The charging duration is determined after its SOC was measured. Every CP in the CS has an average charging rate for serving all EVs, and the CS has a set number of CPs. Since it's a commercial EVCS, there is no limit to the length of the line and the number of vehicles in the network area is sufficiently large. Here, employing the concept of queuing, all charging energy demand for both battery electric vehicles and plug-in hybrid electric vehicles is determined. The EVCS uses the M/M/C queuing theory. The first M indicates the interval arrival time of electric vehicle customer when that customer follows an exponential distribution with a mean time of T_λ. The second M indicates the customer's service time for an electric vehicle with a mean time of T_μ and c represent the total number of customers that can be charged simultaneously. The total number of PHEVs in the waiting line is indicated by n in an M/M/c queue model, and the probability that any arriving vehicle in the line will be served is calculated as

$$p_n = \begin{cases} \dfrac{\rho^n}{n\,!}\, p_0 & n = 1,2,3, \dots \dots \dots \dots \dots \dots \dots \dots \dots c \\ \dfrac{\rho^n}{c\,!\; c^{n-c}}\, p_0 & n = c+1, c+2, \dots \dots . \dots \text{infinity} \end{cases}$$

Where, $$p_0 = \frac{1}{\left(\sum_{i=0}^{c-1} \frac{(c\rho)^i}{i!} + \frac{(c\rho)^c}{c!} \cdot \frac{1}{1-\rho}\right)}$$

$$\mu_n = \begin{cases} \mu . n & n < c \\ \mu . c & n \geq c, \end{cases} \qquad \alpha = \frac{\lambda}{\mu_n} \qquad (15)$$

Where, $$\lambda = \frac{1}{T_\lambda}, \quad \mu = \frac{1}{T_\mu}$$

$$\{T_\lambda, T_\mu\} > 1, c \geq 1$$

when the number of electric vehicles n in line to be charged is less than the number of charging ports c in the charging station. Obviously, the inter arrival rate λ remains constant regardless of the number of electric vehicle customers in the system. However, the charging station's service rate will increase proportionally when the number of entries in the system increases. Hence the service rate at that time is $\mu.n$. Consequently, there is an extremely high probability that any arriving vehicle into a queue will be charged. This is determined by:

$$p_n = \frac{\rho^n}{n!} p_0 \ \text{ for } \mu_n = \mu.n$$

When there are more cars n in line than there are charging ports c at the EVCS. Hence the service rate at that time is $\mu.c$. The $\mu.c$ is the maximum service rate of EVCS and indicates that every server in the charging station is currently in use. On the other hand, the maximum service rate ($\mu.c$) of EVCS won't change as n in the queue increases. As a result, the chance that any arriving vehicle in the waiting line will be served will become

$$p_n = \frac{\rho^n}{c!\,c^{n-c}} p_0 \ \text{ for } \mu_n = c.\mu$$

Although, every car in the waiting line will receive service, $\rho < 1$.

In the above queue model, the service time t_{toc} for charging a plug-in hybrid electric vehicle (PHEV) is assumed to follow an exponential distribution with mean t_μ [11].

$$t_{toc} = -t_\mu.\,\text{In}(U) \qquad (16)$$

Where, U is a uniformly distributed variate in (0,1).

Although, t_{toc} is truncated inside a certain range [t_{min}, t_{max}] because it is not reasonable to charge a plug-in hybrid electric vehicle (PHEV) for a very short period of time, and the charging time has an upper limit because of the capacity of the battery or service restrictions.

$$t_{toc} = \begin{cases} t_{min} & t_{toc} \le t_{min} \\ t_\mu.\,\text{In}(U) & t_{min} < t_{toc} < t_{max} \\ t_{max} & t_{toc} \ge t_{max} \end{cases} \qquad (17)$$

However, it makes sense that an EV charging station would prefer to operate at a higher charging power level in order to shorten the service time required to charge a plug-in hybrid electric vehicle.

Once the charging power level is known, calculating maximum charging current I_{max} and the charging voltage V is calculated. Therefore, it is possible to determine the average charging current of a PHEV as follows:

$$I = \min\left(\frac{D_E * 1000}{V.(t_{toc}/60)}, I_{max}\right) \quad (18)$$

Finally, the total charging demand P of all the n PHEVs that are charged at a charging station is calculated as follows:

$$P = \sum_{i=1}^{n} V.I_i \quad (19)$$

where, I_i is the i^{th} PHEV's charging current, which comes from equation (18).

3.3 Modelling of Distribution Loss

The present distribution network must accommodate the total charging demand of EVs created by the addition of a CS to the electric network, and charging power must be transferred to the charging station. The distribution loss will increase in such a scenario as the distance between the distribution transformer bus and the charging station increases. It is important for correctly evaluating the network loss as a result.

$$P_{Loss} = \sum_{b=1}^{n_{max}} (I_b)^2.R_b \quad \forall b \in n_{max} \quad (20)$$

Where, n_{max} is the number of branches in the network, R_b is the branch resistance and I_b is the branch current.

3.4 Modelling of Travelling Loss

Since an EV's battery will provide both the power needed for mobility and the need to charge, it is necessary for it to travel via the network's transportation path from its current location to a candidate CS location and back again [23]. For EVs, this is a power loss. The user will pay more to refill the lost power as a result of this power loss. An extra cost will result from an increase in the loss experienced by EV users as the distance to the candidate CS increases. The travel loss will be impacted by placing CSs close to the users' residential area. The shortest distance to travel will use a minimum of power as it reaches the CS. The initial step in travelling loss calculation is to calculate the minimum travelling distance L_{min} from currently situated spot at j^{th} bus number up to the candidate charging station spot at i^{th} bus number [23]. The following method is used to get this distance:

$$L_{i,j} = Z_{i,j}.x_i \; ; \;\; \forall i, j \;\; i \neq j$$

$$L_{i,j}^{min} = \min (L_{i,j})$$

$$\text{Subject to: } \; x_i \in \{0,1\}, \;\; \forall\{i, j\} \in \varphi^{dn} \qquad (21)$$

Node bus connectivity matrix $Z_{i,j}$ shows the geographic route from any i^{th} bus number to j^{th} bus number linked by path. The elements of this matrix have numerical values that are determined by the road network's bus-to-bus distance. The power network of the distribution system is coordinated with the dispersed road transportation network. Both the distributed road transportation network and the distribution network are the same for those who use electric vehicles as well as those who live within them. As a result, the geographical path distance and distribution line length coexist. In actuality, electrification via the road network is accomplished through the distribution line. The road connectivity is designed using a node bus connectivity matrix [23]. The power required for an EV to travel $L_{i,j}^{min}$ is determined as,

$$E_{i,j} = \sum_{s=1}^{M_{i,j}^{ev}} E_{m,s} \, . \, L_{i,j}^{min} \qquad (22)$$

$$L_{Travel} = \sum_{i=2}^{\varphi^{dn}} . \sum_{j=2}^{\varphi^{dn}} E_{i,j} \;\; ; \quad \forall i, j, \{i, j\} \in \varphi^{dn} \qquad (23)$$

The power consumption per kilometer, E_m, for a given travel distance of $L_{i,j}^{min}$ km is taken into account when calculating the power loss $E_{i,j}$ of an EV. The total power loss incurred by all EVs traveling from their current location to a specific charging station location is the cumulative total of those losses. Subsequently, each bus location is evaluated separately as a CS location within the distribution network for this loss.

3.5 Modelling of Utilization Factor of Charging Station

The utility of the CS is evaluated by the utilization factor. Its definition is the percentage between the total number of charging ports and the number of charging ports that are active [23] & [24].

$$\text{Utilization Factor} = \frac{\text{Total amount of energy Traded}}{\text{CS's Power capacity} * \text{CS's total working time } (T_w)}$$

$$UF_r = \frac{\sum_{t_{unit}} P_r}{\sum_{t_{unit}} P_{CS}^r}; \quad \forall t_{unit} \in T_w; \; \forall r \in N_{CS}$$

$$P_{CS}^r = P_{CP}^q . k_{cp}$$

The charging station's individual server is referred to as each CP in the definition given above.

$$UF = \frac{\sum_{t_{unit}} \sum_q P_q^{cp}}{\sum_{t_{unit}} \sum_q P_{cp}^q}, \quad \forall q \in k_{cp}$$

$$k_{cp} = \frac{c}{N_{CS}} \qquad (24)$$

where T_w is a CS's total working time, N_{CS} indicates the quantity of charging stations within the distribution system, the charging station r's capacity is represented by P_{CS}^r and t_{unit} is the time discrimination.

3.6 Objective Function

A network's best place for CS depends on the various design priorities listed in equations (20), (23), and (24). As a result, the problem is stated as follows in the form of a multi-objective optimization problem.

3.6.1 Minimization of Distribution Loss

It is carried out for minimizing the distribution loss in the electrical system that results from the extra charging stations' load, as stated in equation (20).

$$f_{obj1} = \min\{P_{Loss}\} \qquad (25)$$

3.6.2 Minimization of Travelling Loss

It is carried out for minimizing the travelling loss by minimizing the additional distance, a vehicle needs to travel to get to a charging station, as stated in equation (23).

$$f_{obj2} = \min\{L_{Travel}\} \qquad (26)$$

3.6.3 Utilization Factor Maximization

By the optimization of the utilization factor stated in equation (24), taking into account the number of vehicles within the charging station, the goal is of maximizing the minimum infrastructure utilization of an electric vehicle charging station.

$$f_{obj3} = \max\{\min\{UF\}\} \qquad (27)$$

The objective here is to optimize a CS's utilization factor, as found in equation (24), while taking the number of cars plugged into the charging station into account. This will maximize the minimum infrastructure utilization of the CS.

3.7 Constraints

a) Charging Station Location Restriction:

Multiple charging station should not be in one location in the system. Placing two or more than one charging stations in a single bus location is equivalent of placing one charging station with fleets size sum of two charging stations. In that scenario, it would not be beneficial to place them together, as installation cost of EV charging station is much higher than their charging ports. Placing two or more than one charging stations in one location will result in reduce the service area and wasted investment in EV charging stations. Total number of EVs in the system must move towards the same direction because every CS will be in the same location, not able to select nearby CS.

$$-\left|l_i^{CS} - l_j^{CS}\right| + 1 \leq 0 \qquad (28)$$

Subject to

$$i \neq j$$

where, l_i^{CS}, l_j^{CS} is the bus location of the i^{th}, j^{th} bus in the electrical distribution system.

b) Charging Power Limit:

An i^{th} bus CS's charging power requirements must stay within its limits (P_i^{min} & P_i^{max}).

$$P_i^{min} \leq P_i \leq P_i^{max};\ \forall i \epsilon \varphi^{dn} \qquad (29)$$

where P_i represents the CS's load demand at the i^{th} bus location. The associated distributed system's supply capacity limitations are reflected in this constraint.

$$P_i = \sum_{q=1}^{k_{cp}} P_q^{CP} \quad \forall i \in \varphi^{dn} \tag{30}$$

Subject to: $c = k_{cp}.N_{CS}; \; k_{cp} \geq \eta_{ev}; \; \forall q \in k_{cp}$

c) Voltage Limit:

Each bus's voltage should be kept between its maximum and minimum limits (i.e., V_i^{Min} and V_i^{Max}) in order to maintain a high-quality power supply.

$$V_i^{Min} \leq V_i \leq V_i^{Max} \qquad (i = 1, 2, 3, \ldots\ldots\ldots, N_{Bus}) \tag{31}$$

3.8 Algorithm for EV Charging Load Demand

Following the establishment of correlations and relationships between the various parameters & variables that dictate the charging behavior of electric vehicle models, the overall charging demand samples of an EVCS [11] can be calculated as shown in figure 3.3.

Step 1: The number of plug-in hybrid electric vehicles and battery electric vehicles n being charged at the same instant is randomly generated using equation (15) for a charging station.

Step 2: Randomly select the class of an PHEV.

Step 3: Randomly generate PHEV parameters for selected market shares.

Step 4: Calculate electrical energy consumed per km by a PHEV, E_M.

Step 5: Calculate daily recharge energy requirement of a PHEV, D_E.

Step 6: Charging time, t_{toc} generated randomly using equation (17).

Step 7: Charging current I is calculated using equation (18).

Step 8: Overall charging demand P of a CS for charging n EV is calculated using equation (19).

For every EV, the aforementioned steps must be performed.

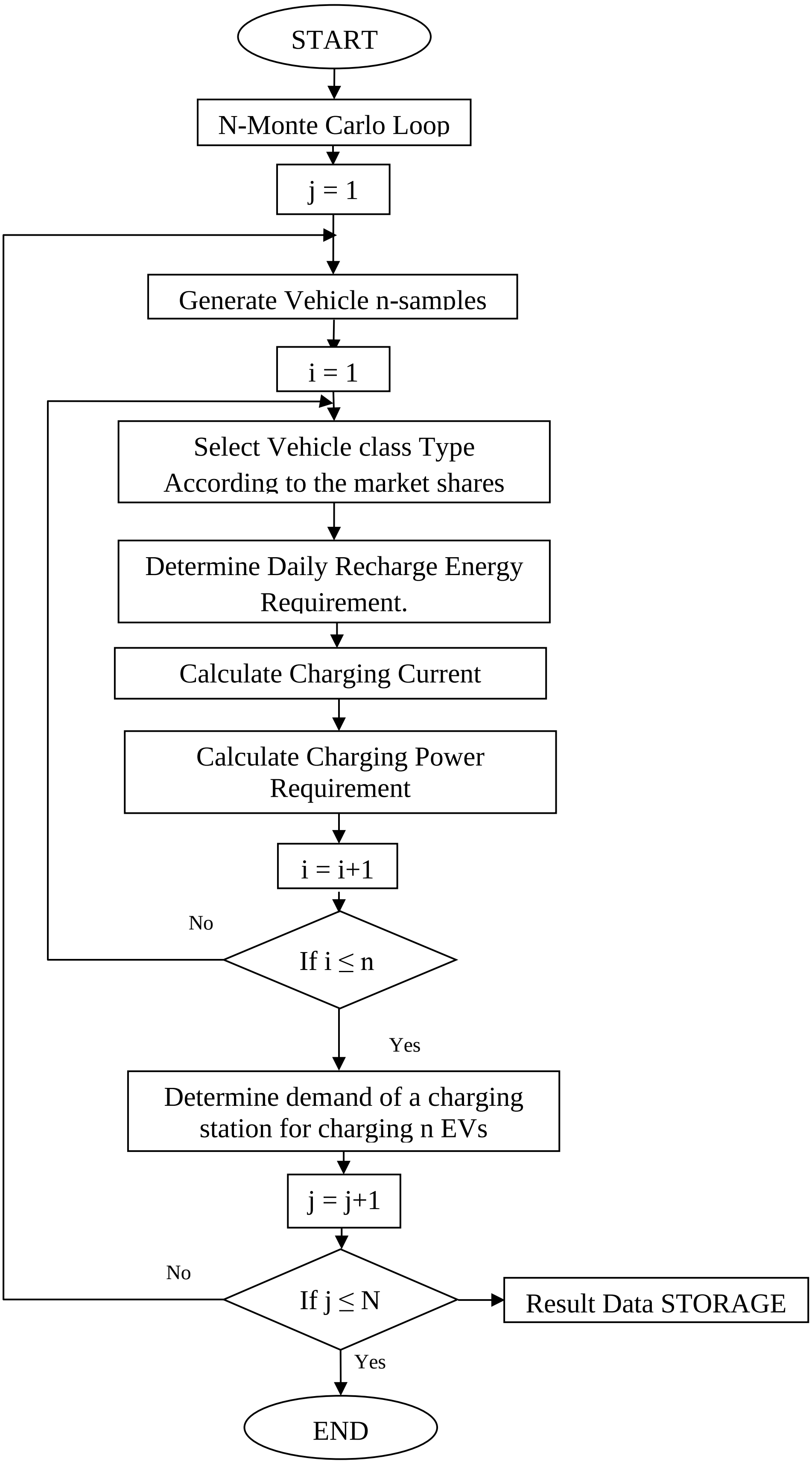

Figure 3.3: Flowchart of EV Charging station demand load modeling

3.9 Algorithm for Backward/Forward Sweep Distribution Load Flow

Step 1: Initially set all the branch Real and Reactive power losses to zero for all j and assume Voltage magnitude as 1p.u and phase angle *zero*.

Step 2: Obtain the nodes fed by a particular node.

Step 3: Estimate Pm_2 and Qm_2 as the sum of the loads of all nodes beyond node m_2 plus the load of node m_2 itself.

Step 4: Find $|V(m_2)|$ by expression $|V(m_2)| = |B(j) - A(j)|^{1/2}$

Where, $A(j) = P(m_2) \times R(j) + Q(m_2) \times X(j) - 0.5|V(m_1)|^2$

$B(j) = \{A(j) - [R^2(j) + X^2(j)] \times [P^2(m_2) + Q^2(m_2)]\}^{½}$

Step 5: Find δm_2 by expression

$$\delta_{m2} = \delta_{m1} - \tan^{-1}\frac{P(m2)X(j) - Q(m2)R(j)}{P(m2)R(j) + Q(m2)X(j) + V^2(m2)}$$

$$LP[j] = \frac{R(j)[P^2(m2) + Q^2(m2)]}{|V(m2)|^2}$$

$$LQ[j] = \frac{X(j)[P^2(m2) + Q^2(m2)]}{|V(m2)|^2}$$

Step 6: Find new $P(m_2)$ and $Q(m_2)$ taking into account LP(j) and LQ(j).

Step 7: Increase iteration number by 1 and go to step 4.

Step 8: Repeat steps 4 to 7 until convergence is reached.

3.10 Algorithm and Flow Chart for Optimal Location

In order to determine the best location for a charging station, GA and NSGA-II are used to solve these objectives for distribution loss, travelling loss and utilization factor of charging station separately and concurrently.

3.10.1 Genetic Algorithm

The computational procedure of the GA for handling the target problem primarily includes the following steps as shown in figure 3.4.

Step 1: Initially, a set of chromosomes is created in a random fashion.

Step 2: The fitness of each chromosome is evaluated based on the objective function defined.

Step 3: Based on the fitness value of each chromosome, different genetic operators including reproduction, crossover and mutation are applied in the entire population in order to produce the next generation of chromosomes.

Step 4: Repeat step 2 and 3 until any stopping criterion is satisfied. The chromosome with the highest fitness value is the final solution to the target problem.

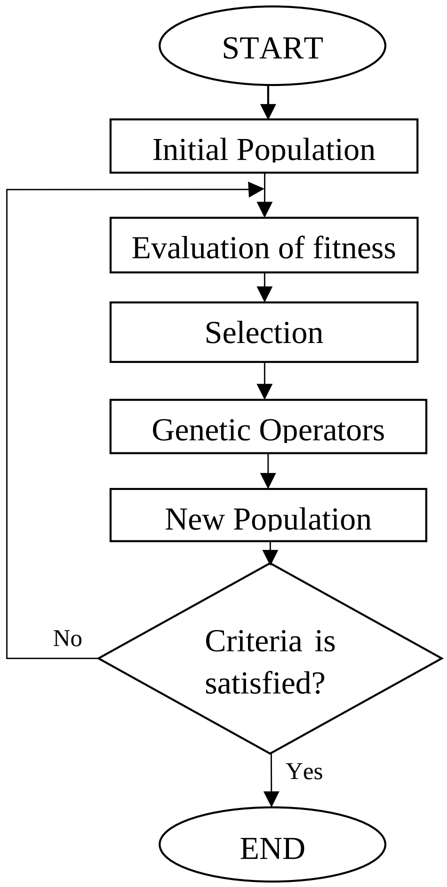

Figure 3.4: Steps of Genetic Algorithm

3.10.2 Non-Dominated Sorting Genetic Algorithm-II (NSGA-II)

The computational procedure of the NSGA-II for handling the target problem primarily includes the following steps [19] as shown in figure 3.5.

Step 1: Solution representation, t= 0 (Generation counter), Maximum allowed generation = t;

Step 2: Initialize random population [p(t)]; %Referring as parent population.

Step 3: Evaluate [p(t)] and assign rank using dominance depth method and diversity using crowding distance operator to p(t).

Step 4: While t < T do; % standard loop of the number of generations.

Step 5: M(t) = Selection [p(t)]; %Crowded Binary Tournament Selection is used.

Step 6: Q(t) = Variation [M(t)];

Step 7: Evaluate Q(t); % Evaluate the offspring population

Step 8: Merge population $\hat{p}(t)$ = [p(t) U Q(t)]; %merge the p(t) and Q(t).

Step 9: Thereafter, assigning rank (the fitness) using dominance depth method and diversity using crowding distance operator to $\hat{p}(t)$.

Step 10: p(t+1) = Survival [$\hat{p}(t)$]; % Survival of the fittest.

Step 11: t = t+1; % Counter increased by 1.

Step 12: End while; % While loop follows till the termination condition get satisfied.

3.10.2.1 Algorithm for Fast Non-Dominated Sorting(P)

Step 1: Stage-1

Step 2: For Each p ∈ P do; % member p belongs to population P.

Step 3: $S_p = \emptyset, n_p = 0$

Step 4: For each q ∈ P do;

Step 5: If ($p \propto q$) then; % comparing these two solutions if p dominates q.

Step 6: $S_p = S_p U q$; % adding solution q to the set of solutions dominated by p.

Step 7: Else if ($q \propto p$) then; % q dominates p.

Step 8: $n_p = n_p + 1$; % domination counter of p will be increased by 1.

Step 9: End if

Step 10: End for

Step 11: If $n_p = 0$ then % looking for the non-dominated solutions.

Step 12: $p_{rank} = 1$ % p belongs to the first front.

Step 13: $F_1 = F_1 U \{p\}$

Step 14: End if

Step 15: End for

3.10.2.2 Algorithm for Fast Non-Dominated Sorting(P)

Step 1: Stage-2

Step 2: i = 1 %assign i equals to 1.

Step 3: While $F_1 \neq \emptyset$ do %if F_1 is not equal to zero then it will go inside the while loop.

Step 4: $Q = \emptyset$ %currently, set Q is empty and used to store members of the next front.

Step 5: For each $p \in F_i$ do %taking all the solutions that belongs to F_i.

Step 6: For each $q \in S_p$ do % making q belongs to S_p.

Step 7: $n_q = n_q - 1$; %subtracting those solutions which are lying in S_p.

Step 8: If $n_q = 0$ then % looking for any solutions having n_q equals to 0.

Step 9: $q_{rank} = i + 1$ % assign rank i plus 1.

Step 10: $Q = QU\{q\}$ %coping the solutions into the Q.

Step 11: End if

Step 12: End for

Step 13: End for

Step 14: $i = i + 1$ %looking for front 2 after taking all the q belongs to the S_p in step 6.

Step 15: $F_i = Q$ %saving all the components of Q into F_i if i equals to 2.

Step 16: End While

3.10.2.3 Algorithm for Crowding Distance(F)

Step 1: $r = |F|$ % number of solutions belongs to F.

Step 2: For each $i \in F$, set $d_i = 0$ %initialize distance equals to zero.

Step 3: For each objectives m do %taking one objective at a time.

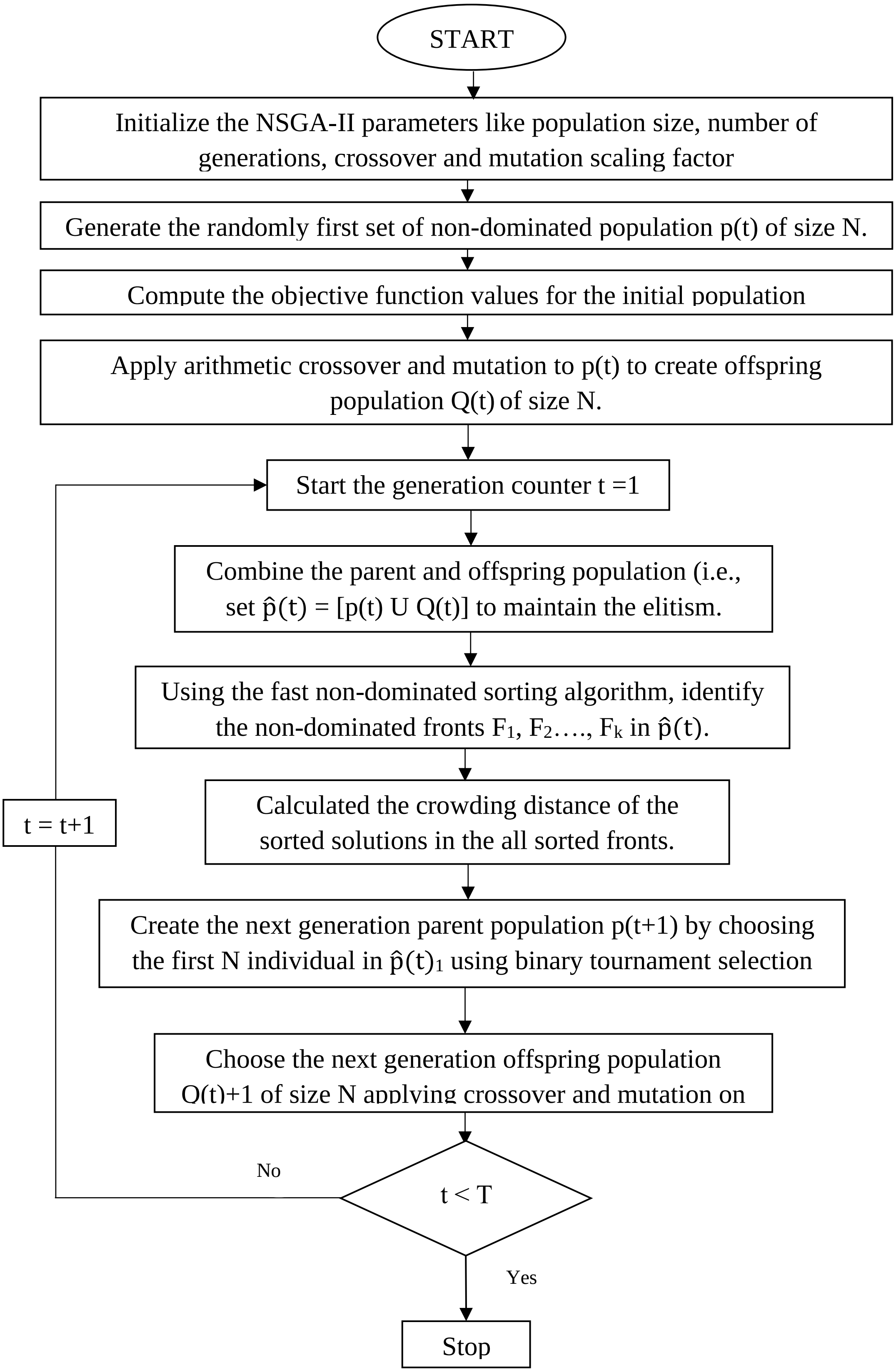

Figure 3.5: Steps of Non-dominated Sorting Genetic Algorithm-II (NSGA-II)

Step 4: F = sort (F, m)   %sorting the solutions based on objective value

Step 5: $d_1 = d_r = \infty$ %assigning a very large value to first and last solutions.

Step 6: For i = 2 to (r-1) do   %starting from solutions 2 to r-1 for all other solutions.

Step 7: $d_i = d_i + \frac{|f_m(i+1) - f_m(i-1)|}{f_m^{max} - f_m^{min}}$ %finding the crowding distance of solution i.

Step 8: End for

Step 9: End for

3.11 Fuzzy Optimization Technique

This method can be used to choose the best compromise non-dominated solution from the set of N_D for a multi-objective problem. The best compromised solution is selected from the set by normalizing the solution values & modeling them using a membership function [25]. Here is an explanation of the fuzzy optimization function:

$$\mu_r = \begin{cases} 1 & \text{if } F_r(x) \le F_r^{Min} \\ \dfrac{F_r^{Max} - F_r(x)}{F_r^{Max} - F_r^{Min}} & \text{if } F_r^{Min} < F_r(x) < F_r^{Max} \\ 0 & \text{if } F_r(x) \ge F_r^{Max} \end{cases} \qquad (20)$$

F_r^{Max} is the maximum and F_r^{Min} is the minimum value of the rth objective function $F_r(x)$, and its membership value is μ_r.

$$N_{\mu_q} = \frac{\sum_{r=1}^{N_{obj}} \mu_r(q)}{\sum_{q=1}^{N_{nd}} \sum_{r=1}^{N_{obj}} \mu_r(q)} \qquad (21)$$

The normalized value of the membership function for the qth non-dominated solution is denoted by N_{μ_q}. The number of objective functions is denoted by N_{obj}, and the number of non-dominated solutions is represented by N_{nd}. The maximum N_{μ_q} value of all is used to select the best solution from N_{nd} compromised non-dominated solutions of the multi-objective problem.

3.12 Tools and Software

The abbreviation MATLAB, which stands for matrix laboratory, is a powerful tool for optimizing software. MATLAB is an efficient language for technical computing that combines programming, visualization, and computation in a user-friendly environment. This enables problems to be expressed in well-known forms of mathematics. Numerous tasks, including mathematical computations, algorithm development, modeling, simulation, and prototyping, as well as data analysis, exploration, and visualization, are covered by its various applications. MATLAB is a high-level matrix/array language capable of producing scientific and engineering graphics, functions, structures of data, input/output mechanisms, and programming with object-oriented features. It can also be used to develop applications, including graphical user interfaces. It is noteworthy that it makes it easier to do large-scale programming for the development of difficult, comprehensive application programs as well as small-scale programming for the quick creation of temporary programs. A programmer can take advantage of an extensive collection of tools and resources designed specifically for managing workspace parameters, importing data, and creating, debugging, and profiling M-files—MATLAB's applications.

CHAPTER 4: RESULTS AND DISCUSSION

In this thesis, for optimal placement of EV charging stations considering loss minimization of the electrical grid, as well as EV's power loss during travel towards charging station, a novel method is developed and tested on IEEE-33 bus distribution network. Further in order to analyze how the proposed technique can be used in case of Nepal, a real 11kV distribution feeder i.e., Om feeder of New Chabahil Substation of Maharajgunj Distribution Center (DCS), Nepal Electricity Authority (NEA) is taken. Queuing theory is used for considering the dynamic behavior of a charging station serviceability and a probabilistic load modeling is employed to capture the uncertainty in electrical demand & EV behavior. For probabilistic modeling Monte Carlo Simulation (MCS) technique is employed. Backward/Forward sweep method is employed for carrying load flow of distribution network. Genetic algorithm is employed in case of single objective function while non-dominated sorting genetic algorithm-II (NSGA-II) is considered in case of multi-objective function. A population size of 200 and a number of iterations of 200 are employed for both optimization techniques (algorithms). All the work is carried out in MATLAB script environment.

4.1 IEEE-33 Bus Distribution Network

Figure 4.1 shows a single line diagram of the 12.66 kV, IEEE-33 bus radial distribution system. It has one feeder with four different laterals, 32 branches and 32 normally closed switches. The total active and reactive peak load of the system is 3715 kW and 2300 kVAr respectively. The detail of load data and line parameters for the considered system [26] is shown in Appendix I. Alongside the 33-bus distribution system, the length of the road transportation network is estimated to be 100 km.

With the coded backward/forward sweep method taking base power 100 MVA, the total loss for base configuration is 210.998 kW with minimum voltage of 0.9038 p.u. at bus number 18 and are validated with result present in literature paper.

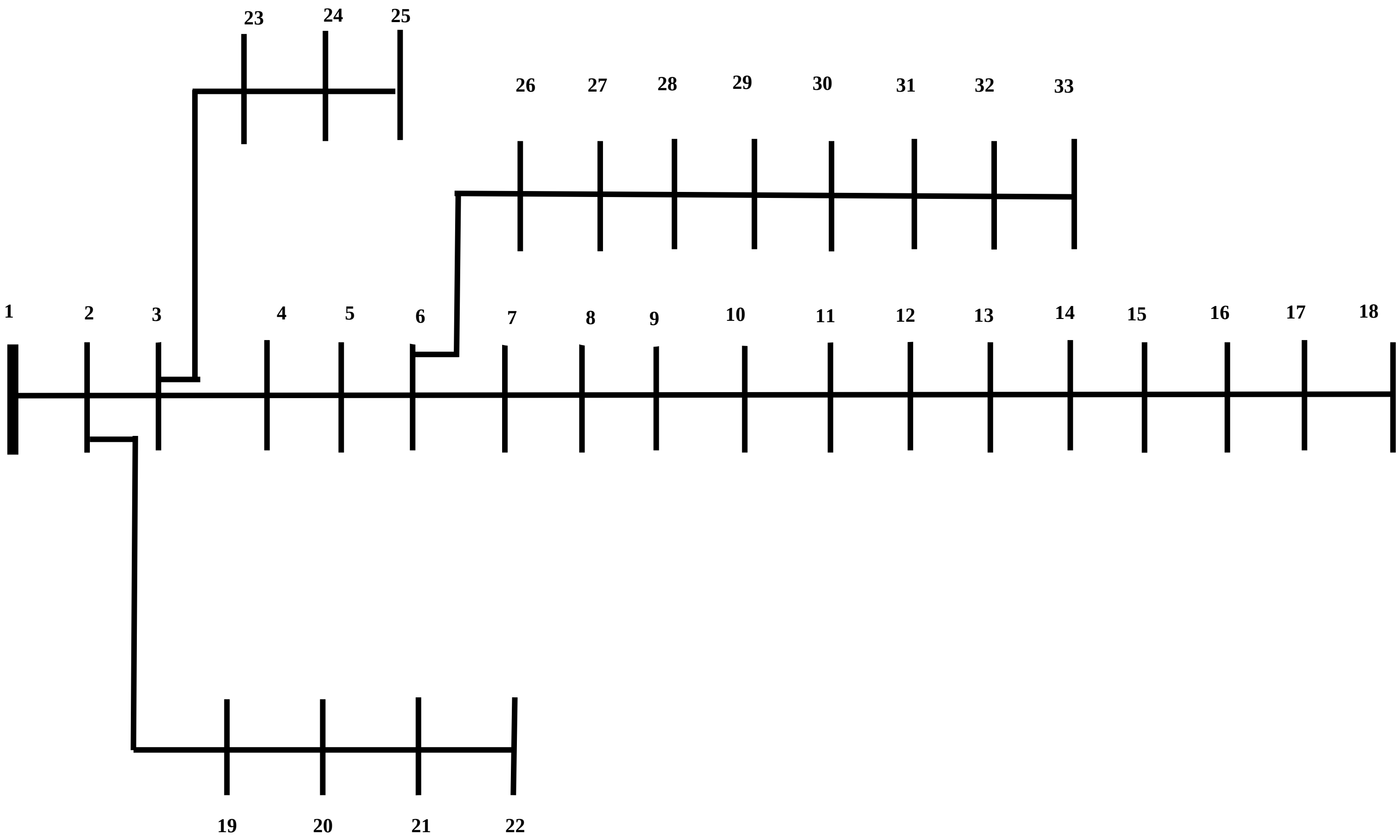

Figure 4.1: IEEE 33-Bus Test Bus System

4.1.1 Simulation of CS Load Demand

As per the mathematical modeling, algorithm and flowchart explained in previous chapter data required for obtaining charging station load demand is shown in table 4.1. In order to consider the differences in PHEV parameters, such as k_{EV}, C_{Bat}, E_m and M_E, PHEVs are divided into four classes in this work, according to their possible k_{EV} and C_{Bat}. Since, the market share can be viewed as a discrete distribution, the class of a PHEV is randomly selected according to the defined market shares. Four classes of PHEV are Micro car, Economy car, Mid-size car & Light truck/SUV having market share of 20%, 30%, 30% & 20% respectively. It is assumed that M_d has a mean μ_{Md} = 40 miles and a deviation σ_{Md} = 20 miles [11], in order to approximate the statistical data on EV driving distance. Because M_E of different PHEV classes could range widely it is selected to be μ_{Md} for simplicity. Using Min. C_{Bat}, Max. C_{Bat} and μ_{Md} the possible range of k_{EV} is obtained and shown in table 4.1.

Table 4.1: Different parameters of EV Class

Class	**MinC_{Bat} (KWh)**	**Max C_{Bat} (KWh)**	**A_E (KWh/mile)**	**B_E**	**Min K_{EV}**	**Max K_{EV}**
Micro Car	8	12	0.379	0.4541	0.2447	0.5976
Economy Car	10	14	0.4288	0.4179	0.275	0.6151
Mid-size Car	14	18	0.574	0.404	0.2939	0.5475
Light truck/SUV	19	23	0.818	0.4802	0.3224	0.48

Mean and standard deviation of k_{EV} and C_{Bat} are obtained considering bivariate normal distribution and the values are as show in table 4.2.

Table 4.2: Parameters of k_{EV} and C_{Bat} of EV classes.

Class	**Mean K_{EV}**	**Standard Deviation K_{EV}**	**Mean C_{Bat}**	**Standard Deviation C_{Bat}**
Micro Car	0.42118	0.08823	10	1
Economy Car	0.44506	0.08504	12	1
Mid-size Car	0.42069	0.06339	16	1
Light truck/SUV	0.40119	0.03939	21	1

The EV charging power requirement and CS load distribution are generated using correlation coefficient ρ_Σ = 0.8 in Cholesky decomposition. The number of PHEVs in any CS is generated using M/M/c queuing model with parameters: T_λ = 10 minute, T_μ = 60 minute, & c = 30. Charging time is generated using T_{min} = 10 minute, & T_{max} =

120 minute. The charging power level is obtained considering V=400 volt, & I_{max} = 63 Amp [11]. Charging station load demand is obtained by Monte Carol simulation method considering 10000 iterations.

Probability value with increase in number of PHEV by considering the above parameters and probability of CS demand with obtained number of PHEV is as shown in figure 4.2.

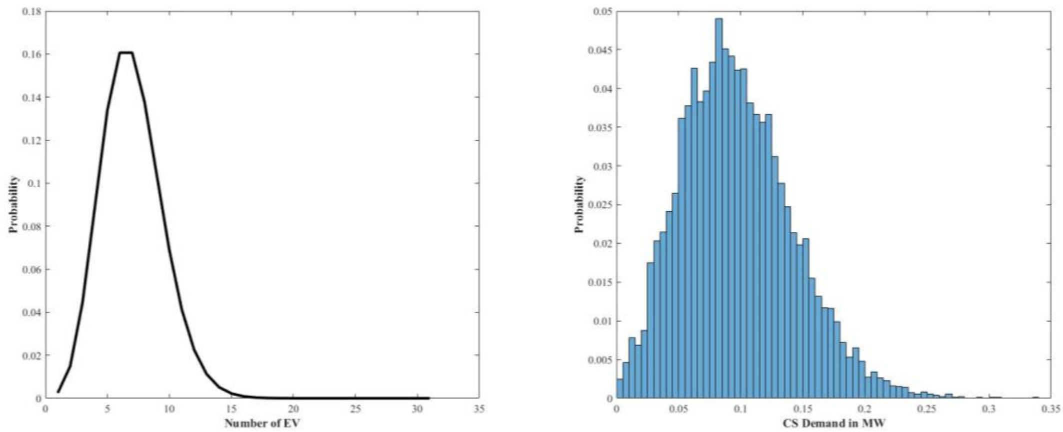

Figure 4.2: Probability values for no. of EV & CS demand

The histogram PDF and CDF curve of the generated samples for the total demand of an EV charging station with the above-mentioned parameter is shown in figure 4.3. The sample capacity is 10,000 which is adequate because the shape of this histogram changes a little when increases further.

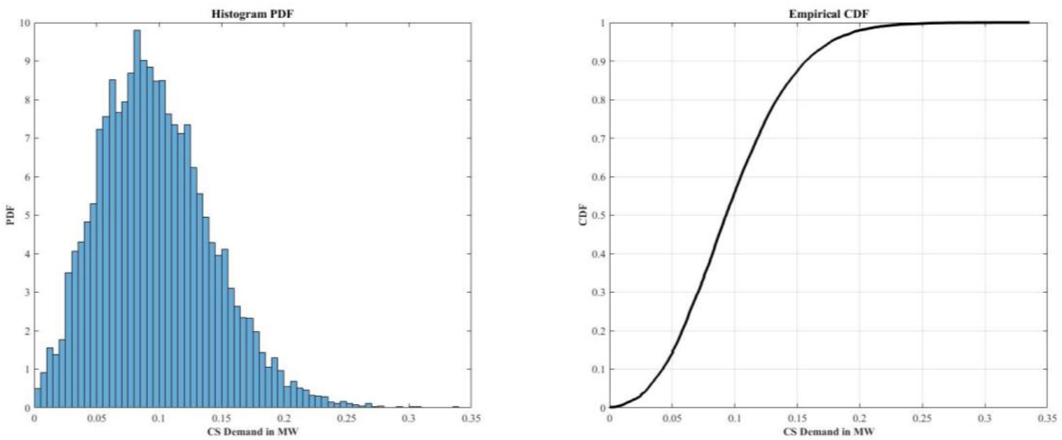

Figure 4.3: PDF & CDF of CS load demand

From the above curve, it can be seen that CS demand varies from 0 to 0.35 MW. After simulation maximum number of PHEV selected is 19, maximum demand of CS is 0.3356 MW, average demand of CS is 0.0971 MW and standard deviation of CS demand is 0.0449 MW. Probability of empty system is 0.0025, probability that the customer has to wait is 2.582e-12 (i.e., 0), and expected number of customers in the system is 6.00. For the considered system, among 30 charging port at most 19 will be busy at a time and remaining 11 will be idle. With the given parameters for varying number of CS various parameters obtained are as shown in table 4.3.

Table 4.3: Parameters for varying number of CP

No. CP	Max. Capacity of a CS in MW	Demand in MW of a CS			Max. Number of EV in the system
		Maximum	Average	Standard deviation	
30	0.7560	0.3356	0.0971	0.0449	19
15	0.3780	0.3038	0.0970	0.0448	18
10	0.2520	0.2501	0.0979	0.0432	24
7	0.1764	0.1764	0.0970	0.0323	80
6	Occupation rate per CP becomes equal to 1. The queue will explode				

From table 4.3, it can be observed that with same number of charging station when number of CP is decreased then total demand of CS in the system also decreases. It can be also observed that maximum number of EV coming to a CS increases with decrease in number of CP. In case of only six charging ports, occupation rater per charging port becomes equal to 1, so the queue will explode. This means that all customer will never get served. Hence, with considered parameters minimum number of CP in the system should be at least seven and it is better to have more than six CP in the considered system.

4.1.2 Minimization of Distribution Loss

Considering objective function as minimization of distribution network loss optimal placement of charging station is done with the help of Genetic algorithm optimization technique. Maximum CS demand obtained after MCS is taken as input for size of CS and location is obtained with GA taking constraint that more than one CS is not allowed to be located at same bus. In case of more than one CS, demand of each CS is taken equal. The summary of result obtained is as shown in table 4.4.

From the table 4.4, it can be observed that with increase in number of CS, the distribution loss increases as total capacity of charging station and total EV population in the distribution network are kept constant. Increase in distribution loss is by 1 or 2 kW. Distribution of charging station seems to be not good idea from the distribution system's operator perspectives.

Table 4.4: Result for minimization of distribution loss

No. of CSs	Location	Distribution Loss in kW	Travelling Loss in kW	Min. Voltage in p.u.
1	2	212.6796	454.705	0.90356
2	2 & 19	212.8352	445.904	0.90356
3	2, 19 & 20	213.6053	441.135	0.90356
4	2, 19, 20 & 21	214.1839	439.770	0.90356

4.1.3 Minimization of Travelling Loss

With the help of GA optimal placement of charging station considering minimization of travelling loss is done and results obtained are shown in table 4.5. Travelling loss is obtained by calculation distance to be traveled from the bus where a vehicle is located to the bus where CS is placed. More than one CS is not allowed to be placed at same bus.

Table 4.5: Result for minimization of travelling loss

No. of CSs	Location	Travelling Loss in kW	Distribution Loss in kW	Min. Voltage in p.u.
1	13	261.266	270.862	0.88286
2	6 & 16	114.462	255.967	0.88837
3	6, 14 & 17	82.299	261.766	0.88498
4	6, 10, 15 & 17	57.980	261.914	0.88544

From the result, it can be said that in reference to consideration of only travelling loss as minimization function it is better to have as many CS as possible. But, on consideration of distribution loss and voltage profile there will be limitation on number of CS. Time taken for algorithm to converge is similar in various number of CS.

4.1.4 Minimization of Distribution Loss and Travelling Loss

In this case, optimal placement of CS is done by simultaneously minimizing both distribution loss as well as travelling loss with the help of NSGA-II optimization algorithm. Two objective functions are contradictory, so best compromised solution is obtained with the help of fuzzy optimization technique [25]. Best solution obtained are shown in table 4.6.

Table 4.6: Result considering distribution loss and travelling loss simultaneously.

No. of CSs	Location	Distribution Loss in kW	Travelling Loss in kW	Min. Voltage in p.u.
1	7	241.4123	275.615	0.89798
2	2 & 15	240.9491	121.054	0.89189
3	2, 15 & 19	231.0231	122.378	0.89583
4	2, 16, 19 & 21	227.2058	111.868	0.89731

In case of one CS, values of distribution loss and travelling loss obtained in pareto front-1 of NSGA-II algorithm are shown in table 4.7.

Table 4.7: Distribution loss and Travelling loss in case of one charging station.

Pareto Set Number	Bus No.	Distribution Loss in kW	Travelling Loss in kW
1	2	212.680	377.107
2	3	220.866	360.537
3	4	225.366	343.616
4	5	229.924	334.337
5	6	239.943	292.144
6	7	241.412	275.615
7	8	251.825	261.991
8	9	257.144	242.663
9	10	262.307	219.752
10	12	264.800	216.539
11	13	270.862	215.474

From table 4.7, it can be observed that when location of CS is moved away from substation (i.e., bus number 1) then value of distribution loss increases whole travelling loss decreases. So, the two objective functions are contradictory. Table 4.7 shows a list of compromising solutions for various bus places, based on the values of distribution loss and travelling loss. By using fuzzy optimization technique as explained in previous chapter, best compromised solution is obtained from the list of compromising solutions. The best compromised values for distribution loss and travelling loss are 241.412 kW and 275.615 kW respectively at the bus location 7. The pareto optimal front for one CS is show in figure 4.4.

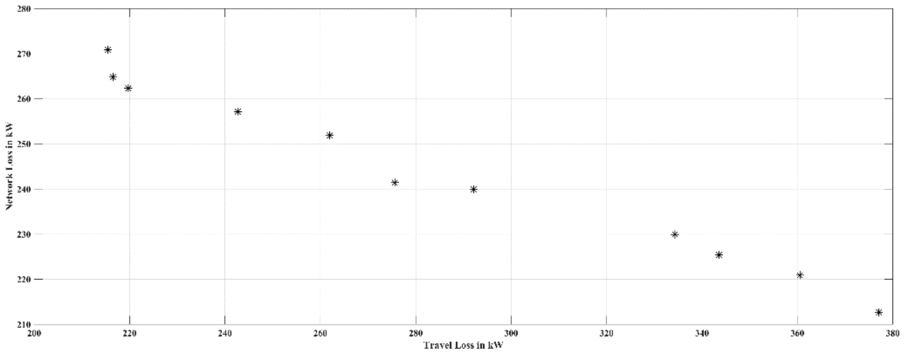

Figure 4.4: Distribution loss vs. travelling loss in case of one charging station.

Table 4.8, shows pareto set and corresponding distribution loss and travelling loss in case of two charging station. The results are of first pareto set.

Table 4.8: Distribution loss and travelling loss in case of two charging station.

Pareto Set Number	Bus No.	Bus No.	Distribution Loss in kW	Travelling Loss in kW
1	19	2	212.835	380.258
2	2	21	214.221	374.645
3	3	2	216.678	368.997
4	3	19	216.833	356.602
5	4	2	218.850	339.561
6	5	2	221.042	332.667
7	19	5	221.197	327.369
8	6	2	225.834	285.056
9	7	2	226.513	268.542
10	8	2	231.235	247.899
11	9	2	233.577	224.203
12	19	9	233.732	223.130
13	10	2	235.815	190.305
14	11	2	236.195	179.692
15	2	12	236.873	174.400
16	2	13	239.384	139.858
17	2	14	240.254	129.669
18	2	15	240.949	121.054
19	3	15	245.199	114.603
20	15	4	247.564	110.804
21	16	5	250.695	108.361
22	15	6	255.2318	108.1414
23	16	6	255.9672	104.1469

From the table 4.8, it can be observed that distribution loss changes between the

212.835 kilowatts and 255.9672 kilowatts while the travelling loss changes between 104.1469 kilowatts and 380.258 kilowatts.

Table 4.8 shows set of compromised solution obtained from NSGA-II algorithm, where each value has an equal level of significance. Among the set of compromised solution, best compromised solution obtained with the help of fuzzy optimization technique is for bus number 2 & 15, where distribution loss is 240.949 kW and travelling loss are 121.054 kW. Figure 4.5 shows the Pareto-optimal front for the case of two charging station placement.

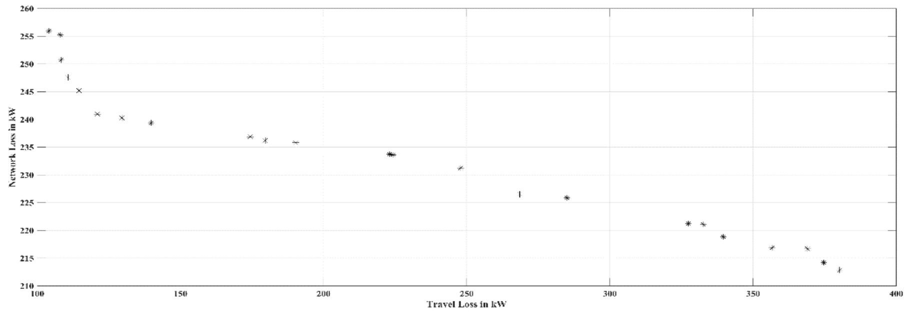

Figure 4.5: Distribution loss vs. travelling loss in case of two charging station.

Distribution loss and travelling loss obtained in case of two charging station when plotted against Pareto set number then the result is as shown in figure 4.6.

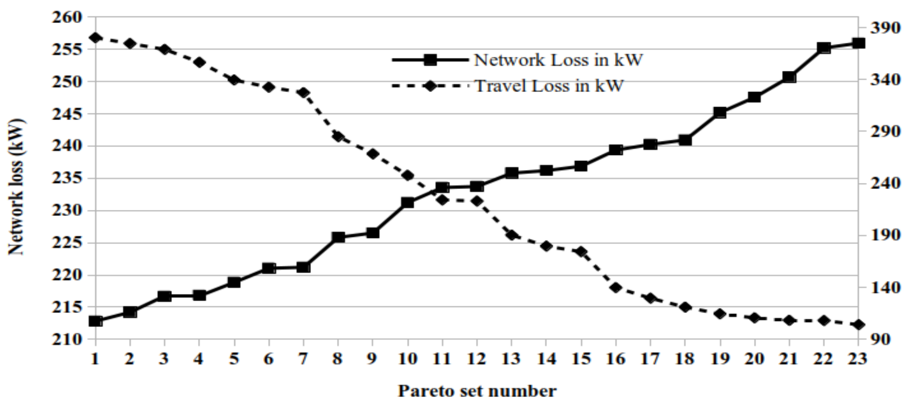

Figure 4.6: Distribution loss and travelling loss in case of two charging station.

From this figure, it can be observed that both the objectives are contradictory in nature. Similarly optimal placement of three and four number of charging station is carried and Pareto-optimal front along with distribution loss and travelling loss are show in

4.1.5 Minimization of Distribution Loss and Travelling Loss with Maximization of Charging Station Utilization Factor.

When using more than one charging station, utilization factor should consider. Due to the significant infrastructure costs associated with electric vehicle charging station, which must be covered by the network manager, it checks how charging stations are used effectively. When the facility is fully used, it benefits owners who have more charging stations.

In this case optimal placement of more than one CS is done by simultaneously minimizing both distribution loss as well as travelling loss with maximizing the minimum infrastructure usage with the help of NSGA-II optimization algorithm. Three objective functions are contradictory, so best compromised solution is obtained with the help of fuzzy optimization technique [25]. Best solution obtained for different number of charging stations placement are shown in table 4.9.

Table 4.9: Result considering distribution loss, travelling loss and utilization factor simultaneously

No. of CSs	**Location**	**Min. Distribution Loss in kW**	**Min. Travelling Loss in kW**	**Max. Utilization Factor in %**	**Min. Voltage in p.u.**
2	7 & 22	228.324	280.591	40.69	0.900778
3	2, 13 & 17	251.388	94.446	20.52	0.887202
4	3, 9, 15 & 18	255.582	68.089	18.94	0.886674

From the table 4.9, it is observed that distribution power loss decreases but travelling loss increases as a result of the search of improved utilization. It also shows the very low utilization levels in case of the three and four charging station in the distribution network. In case of the two charging station operations, a highest utilization of 40.69% has been found. While comparing, the maximum possible utilization is found 20.52% and 18.94%, in case of the three and four charging station respectively. CS owners are forced to consider their significant capital even though the optimum use of CS is incredibly low, despite the extremely low travel loss. It would not be beneficial to place more than two charging stations in the distribution network, as installation cost of EV charging station is much higher than their charging ports. Hence, investing in more than two CSs in the same distribution system is not profitable and seems wasting of money. When network loss and utilization factor are plotted against pareto number then the graph as shown in figure 4.7 is obtained.

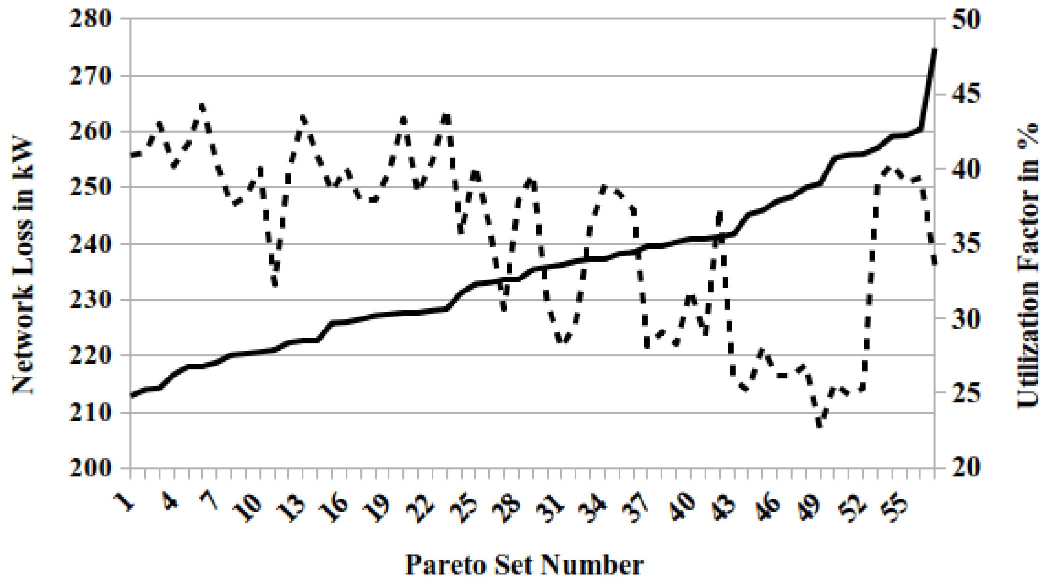

Figure 4.7: Network loss and utilization factor for each pareto set number

When the travelling loss is plotted against distribution loss obtained in compromised solution of pareto front-1 then the graph as shown in figure 4.8 is obtained.

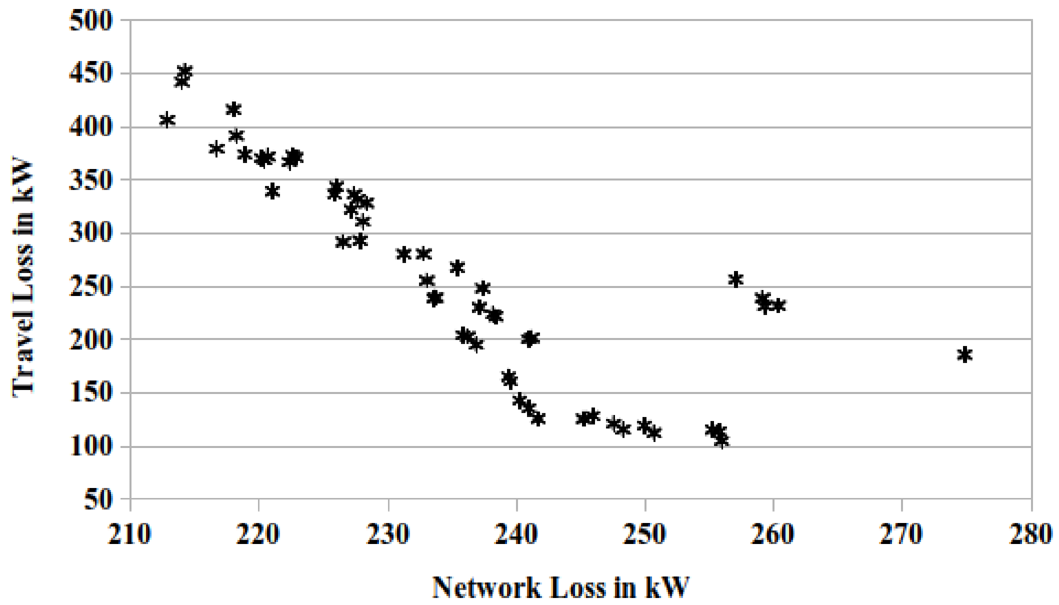

Figure 4.8: Travel loss versus network loss in case of three objective function

Similarly optimal placement of two number of charging station is carried and Pareto-optimal front along with distribution loss, travelling loss and utilization factor are shown in Appendix II.

Figure 4.9 shows the voltage profile is analysed for all bus when placing multiple CS considering minimization of distribution loss and travelling loss with maximizing the utilization factor. Complete numerical value of voltage magnitude at each bus is given in Appendix III.

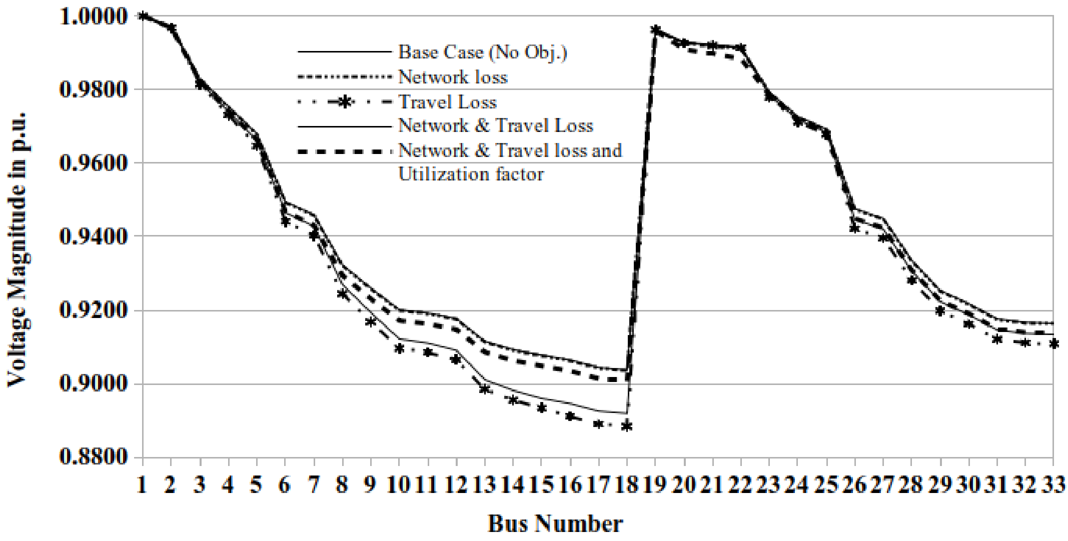

Figure 4.9: Voltage profile for multiple charging station placement.

From the figure 4.9 it can be observed that when considering only minimization of distribution loss, the voltage profile of the network matches up to the voltage profile of the distribution network before any charging station penetration. There is significant drop in the voltage profile as considering only minimization of travelling loss. In case of minimizing both distribution loss and travelling loss simultaneously, the voltage profile slightly improved in comparison to considering only minimizing the travelling loss. Unexpectedly, the voltage profile improves to a level which is nearly identical to the voltage profile of the network with zero charging station load. It demonstrates that when the utilization factor is involved in the problem to enhance the network's voltage profile as well as the charging infrastructure's usefulness. Network operators, charging station operators, and electric vehicle customers can all benefit from this behavior.

4.2 Om Feeder Distribution Network

A real 11kV distribution feeder namely Om feeder of New Chabahil Substation of Maharajgunj Distribution Center (DCS), Nepal Electricity Authority (NEA) is considered for implementing the considered concept in context of Nepal and single line diagram of the considered network is as shown in figure 4.10. It has one feeder with 16 different laterals, 80 buses including substation and 79 branches. The network for this thesis work is considered to be balanced system and it's per phase total active and reactive peak load of the system considering total installed capacity of transformer is 3936.00 kW and 1924.50 kVAr respectively. The detail of load data including number of vehicles present at each bus obtained by considering transformer capacity and total consumer present in that feeder, and line parameters including length of each branch for the selected Om feeder radial distribution network is shown in Appendix I. Alongside the 80-bus distribution system, the selected distribution network's road transportation network spans is 10.581 km.

With the coded backward/forward sweep method taking base power 100 MVA, and base voltage 12.00 kV, the total per phase power loss for base configuration obtained is 63.0516 kW with minimum voltage of 0.96871 p.u. at bus number 58 and current in branch-1 is 371.773 Amp.

4.2.1 Simulation of CS load demand

To obtain CS load demand, data of all the electric vehicles currently available and running in Nepal is obtained to categorize them into different classes similar to the case of IEEE-33 bus distribution network. Here, all the vehicles considered are purely electric only i.e., there is no any hybrid electric vehicle as in case of IEEE-33 bus.

In the below table 4.10 vehicles are grouped into different classes as their battery capacity. Number of registered vehicles from Department of Transportation & Management (DoTM) is taken from fiscal year 2077/078 to 2079/080 and their number from respective showroom is taken till to this date. With these number market share of each EV and then their average is taken to obtain class-wise market share. Battery capacity of each EV of a class is averaged to obtain class-wise capacity and 90% of total kWh is considered here because battery won't be fully discharged before going to charging station. Energy consumption per km is obtained from traveling range and battery capacity of vehicle.

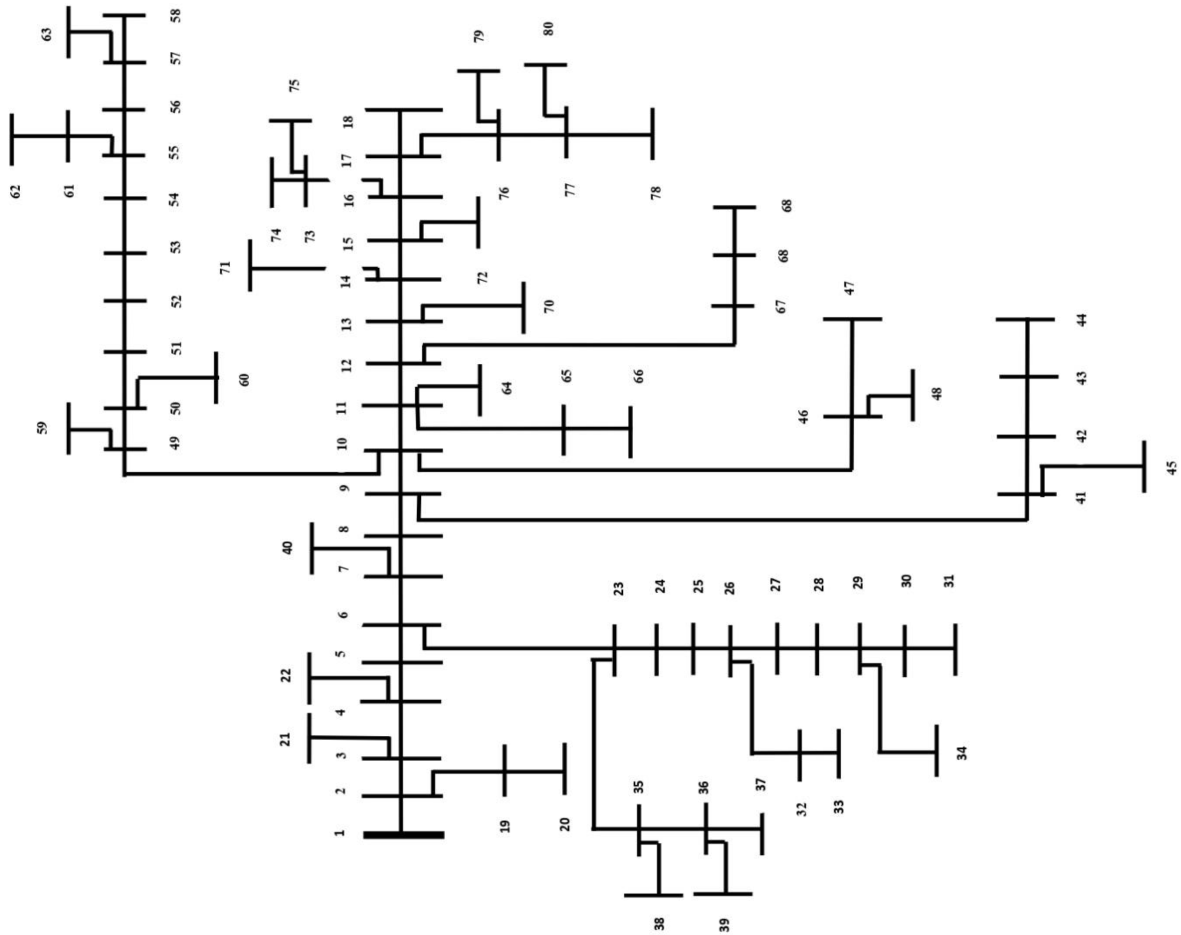

Figure 4.10: Om feeder 80-bus radial distribution network single line diagram.

Table 4.10: Detail of various vehicles in context of Nepal

All car support CCS-2 charger type										
Description	**Class 1**			**Class 2**			**Class 3**		**Class 4**	**Total**
	Tigor / E-pres-t	**CITROEN**	**NEXON Prime**	**NETA**	**KONA**	**NEXON Max**	**ORA**	**MG ZS**	**BYD**	
Calculation of Market Share of EV as per Class										
No. as per Showroom	600	60	1200	300	400	1500	50	2180	1065	7355
Unit Percentage of total	8.16%	0.82%	16.32%	4.08%	5.44%	20.39%	0.68%	29.64%	14.48%	100%
No. of units as per DoTM	460	46	919	230	306	1,149	38	1,670	816	5634
Market share as per Class	**25.29%**			**29.91%**			**30.32%**		**14.48%**	100%
Calculation of Battery Capacity in kWh										
Battery Capacity from Catalog (kWh)	26	29.2	30.2	38.5	39.2	40.5	47.79	51	71.7	
Considered Battery Capacity (90%) (kWh)	23.4	26.28	27.18	34.65	35.28	36.45	43.01	45.9	64.53	
Average Battery Capacity as per Class (kWh)	**25.620**			**35.460**			**44.4546**		**64.530**	
Energy Consumption kWh per km										
Motor Capacity (kW)	55	57	100	70	100	110	99	99	70	
Estimated Charging – SOC in %	0-80	10-80	10-80	30-80	10-80	0-80	0-80	0-80	0-80	
Estimated Charging – Time in Min.	65	57	60	20	47	56	46	30	30	
Traveling Range (km)	315	320	312	380	452	413	400	320	415	
Energy Consumption – Vehicle Type	0.0825	0.0913	0.0968	0.1013	0.0867	0.0981	0.1195	0.1594	0.1728	
Energy Consumption – Class-wise	**0.0902**			**0.0954**			**0.1395**		**0.1728**	

Table 4.11: Data for obtaining arrival and service time

S. No.	Chargin g Time	No. of Vehicle	S. No.	Chargin g Time	No. of Vehicle	S. No.	Chargin g Time	No. of Vehicl e
1	0:10	2	32	0:41	4	63	1:12	3
2	0:11	1	33	0:42	3	64	1:13	8
3	0:12	3	34	0:43	5	65	1:14	5
4	0:13	4	35	0:44	7	66	1:15	2
5	0:14	4	36	0:45	5	67	1:16	6
6	0:15	7	37	0:46	8	68	1:17	1
7	0:16	2	38	0:47	3	69	1:18	1
8	0:17	8	39	0:48	6	70	1:19	7
9	0:18	7	40	0:49	8	71	1:20	4
10	0:19	5	41	0:50	9	72	1:21	1
11	0:20	5	42	0:51	3	73	1:22	1
12	0:21	3	43	0:52	6	74	1:23	2
13	0:22	7	44	0:53	7	75	1:24	2
14	0:23	4	45	0:54	7	76	1:25	5
15	0:24	2	46	0:55	4	77	1:26	1
16	0:25	5	47	0:56	6	78	1:28	2
17	0:26	5	48	0:57	13	79	1:29	1
18	0:27	9	49	0:58	4	80	1:31	1
19	0:28	5	50	0:59	6	81	1:32	2
20	0:29	7	51	1:00	7	82	1:33	1
21	0:30	6	52	1:01	6	83	1:35	1
22	0:31	12	53	1:02	10	84	1:38	2
23	0:32	3	54	1:03	4	85	1:43	1
24	0:33	4	55	1:04	6	86	1:45	1
25	0:34	5	56	1:05	6	87	1:48	2
26	0:35	10	57	1:06	5	88	1:50	1
27	0:36	4	58	1:07	9	89	1:53	1
28	0:37	13	59	1:08	4	90	1:58	1
29	0:38	11	60	1:09	2	91	2:00	2
30	0:39	4	61	1:10	4	**Total**	**13:19**	**419**
31	0:40	4	62	1:11	3			
Average Arrival time of a Vehicle (the above data of 22 days) in minute							**75.61**	
Average Service time of a Vehicle in minute							**56.25**	

Data obtained from existing charging station of Nepal is show in the table 4.11 in order to calculate the arrival and service time of a vehicle in a charging station. For this study, arrival time and service time of a vehicle is taken as 75 minute and 56 minutes respectively.

Table 4.12 shows current, voltage and power drawn by different vehicle during different state of charge of battery. Current and power drawn during different state of charge varies a lot but variation in voltage is very small. The plot of voltage and current for different state of charge is shown in figure 4.11.

Table 4.12: Output voltage and current of a charging station

SOC	Output Current	Output Voltage	Charging Power	Demand Current	Demand Voltage
%	**Ampere**	**Voltage**	**kW**	**Ampere**	**Voltage**
10	133.04	411.00	54.00	133.04	425.92
14	121.07	430.50	52.00	121.07	446.13
20	137.47	412.60	56.00	137.60	422.50
22	49.99	426.30	21.00	50.00	443.30
27	121.10	440.50	53.00	121.00	456.60
30	61.40	345.10	21.00	61.40	357.63
50	119.27	417.70	49.00	119.10	427.70
57	109.18	422.40	46.00	109.10	432.30
70	136.01	446.00	60.00	136.00	461.90
73	120.91	446.00	53.00	121.00	461.90
75	136.87	447.30	61.00	137.00	463.10
76	121.98	371.30	45.00	122.00	387.20
79	100.05	480.00	58.00	100.00	499.00
82	39.34	382.40	15.00	39.30	412.10
88	36.14	445.10	16.00	36.10	455.00
89	51.12	377.80	19.00	51.10	389.10
95	38.02	438.50	16.00	38.00	455.80
95	13.32	448.50	5.00	13.30	458.40
97	33.46	421.80	14.00	33.40	431.80
Average	**88.41**	**421.62**	**37.58**	**88.40**	**436.18**
Maximum	**137.47**	**480.00**	**61.00**	**137.60**	**499.00**
Minimum	**13.32**	**345.10**	**5.00**	**13.30**	**357.63**

From the figure and graph 4.11 obtained from charging station it can be concluded that voltage remains almost constant. So, in this study voltage of charging station is taken as 420V and maximum charging current limit of a charging port is taken as 150 A. Limiting value of charging time is taken as 10 minute and 120 minutes. To obtain mean and standard deviation of daily driven distance of each vehicle, data of distance traveled were obtained from logbook of 125 number of different vehicle and then are converted to per day.

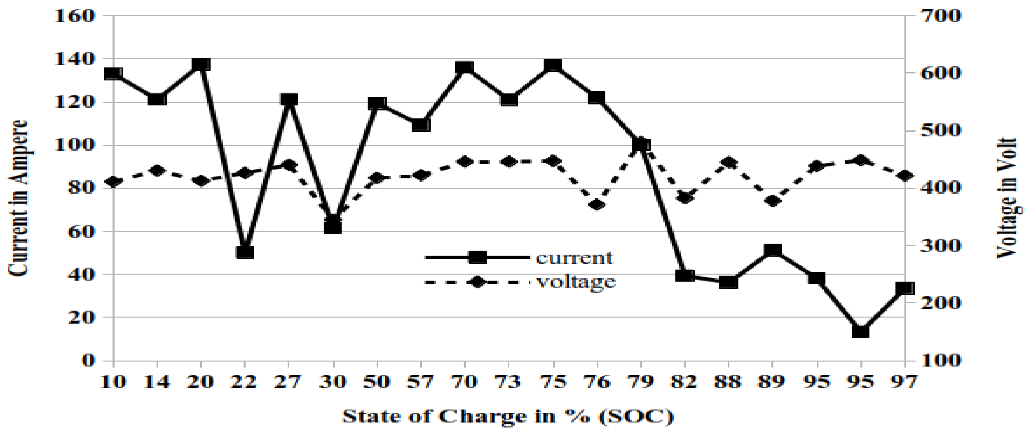

Figure 4.11: Current and Voltage variation with variation in state of charge of battery

After calculation mean and standard deviation of daily driven distance of a vehicle inside Kathmandu value are found to be equal to 40.26 km and 19.45 km respectively. Monte Carlo Simulation technique is employed to obtain demand of EVCS and simulation is done for 25000 number of iterations. The result obtained for different number of charging station is as shown in table 4.13.

Table 4.13: Result of charging station demand modeling in case of Kathmandu valley

No. CP	Max. Capacity of a CS in MW	Demand in MW of a CS			Max. Number of EV in the system
		Maximum	Average	Standard deviation	
16	1.0080	0.1298	0.0163	0.0165	6
8	0.5040	0.1298	0.0163	0.0165	6
4	0.2520	0.1298	0.0163	0.0164	7
2	0.1260	0.1162	0.0157	0.0151	10
1	0.0630	0.0630	0.0114	0.0121	28

From table 4.13, it can be observed that when the number of charging port is increased then maximum demand of charging station for charging port more than 4 is same but when the number of charging port is decreased below 4 them maximum demand of CS decreases. Maximum number of EV generated by M/M/c queuing theory in case of CP more than 4 is almost same while the number increases when the number of CP is decreased below 4. So, with the selected parameters for CS demand modeling it is economical to have total number of CP equal to 4 or less than 4. Different statistical distribution functions are fitted over the empirical distribution of charging station load demand as shown in figure 4.12.

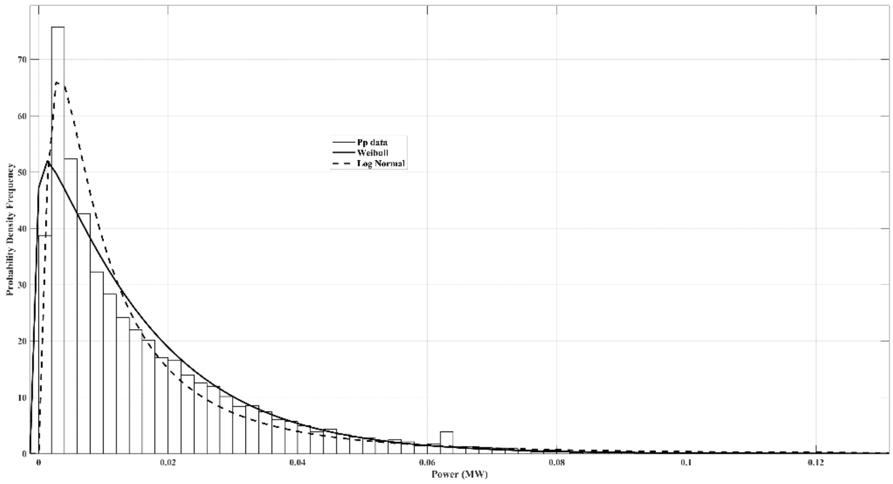

Figure 4.12: Probability density function fitting on various distribution functions

From the figure 4.12 it can be observed that Weibull distribution fits the best on the sample of charging station demand in case of single CS with 4 number of ports. Weibull distribution parameters are A= 0.0166289, B = 1.04722 and Log-likelihood of 41060.5. Mean and variance of fitting are 0.0163257 and 0.000243179 respectively with error in parameter A and B of 0.0146463% and 0.694882% respectively.

Parameters of the fitted distribution function can be used in case of probabilistic load flow for real time placement of charging station and continuous demand of charging station can be obtained as per the requirement of study.

4.2.2 Minimization of Distribution Loss and Travelling Loss

From the study of IEEE network, it was concluded that it is better to consider both distribution loss and travelling loss simultaneously. So, individual objective function case is not considered here and if required can be done similar to IEEE network case. Optimal placement of charging station by simultaneously minimizing both distribution loss and travelling loss is carried with help of NSGA-II optimization algorithm. Since, both the objective functions are contradictory in nature, so best compromised solution among the set of compromised solution is obtained with the help of fuzzy optimization technique [25]. Here, 8 number of CP is considered as maximum demand of CS in case of both 4 and 8 number of CP is same. Number of CP does not affect distribution loss and travelling loss as far as demand is same. Best solution of optimal location obtained for different number of charging station keeping total demand of CS in system constant is shown in table 4.14. In this table demand and distribution loss values are of one phase of the considered network.

Table 4.14: Optimized result considering both distribution and travelling loss objective function

No. of CSs	Location	Distribution Loss in kW	Travelling Loss in kW	Min. Voltage in p.u.
1	7	63.7658	0.2982	0.9686
2	10 & 22	63.7095	0.1872	0.9686
3	2, 4 & 10	63.6783	0.1807	0.9686
4	2, 4, 19 & 46	63.5645	0.1810	0.9686

From the table 4.14, it can be observed that when number of CS is increased from one then distribution and travelling loss decreases but for four number of CS travelling loss increases. So, distribution of charging station is better.

In case of two charging station, values of distribution loss and travelling loss obtained in pareto front-1 of NSGA-II algorithm are shown in table 4.15.

Table 4.15: Pareto set considering distribution and travelling loss in case of two CS

Pareto Set Number	Bus No.	Bus No.	Distribution Loss in kW	Travelling Loss in kW
1	2	19	63.222	0.473
2	2	20	63.222	0.470
3	21	2	63.317	0.448
4	3	19	63.317	0.386
5	22	2	63.361	0.362
6	4	19	63.362	0.356
7	5	19	63.394	0.339
8	6	19	63.423	0.316
9	2	40	63.492	0.288
10	7	19	63.494	0.287
11	8	20	63.501	0.286
12	9	19	63.528	0.264
13	9	21	63.624	0.260
14	8	22	63.640	0.258
15	9	22	63.668	0.234
16	46	2	63.768	0.215
17	3	46	63.864	0.199
18	46	4	63.909	0.193
19	10	22	63.910	0.187

20	54	9	64.482	0.187
21	57	8	64.498	0.186
22	9	55	64.506	0.184
23	55	10	64.750	0.179
24	57	11	64.772	0.178

From the table 4.15, it can be observed that distribution loss value per phase varies from 63.222 kW to 64.772 kW while travelling loss varies from 0.473 kW to 0.178 kW. When the obtained results are plotted against pareto set number then the result is as shown in figure 4.13 and from this figure it can be observed that both distribution (network) loss and travelling (travel) loss are contradictory in nature.

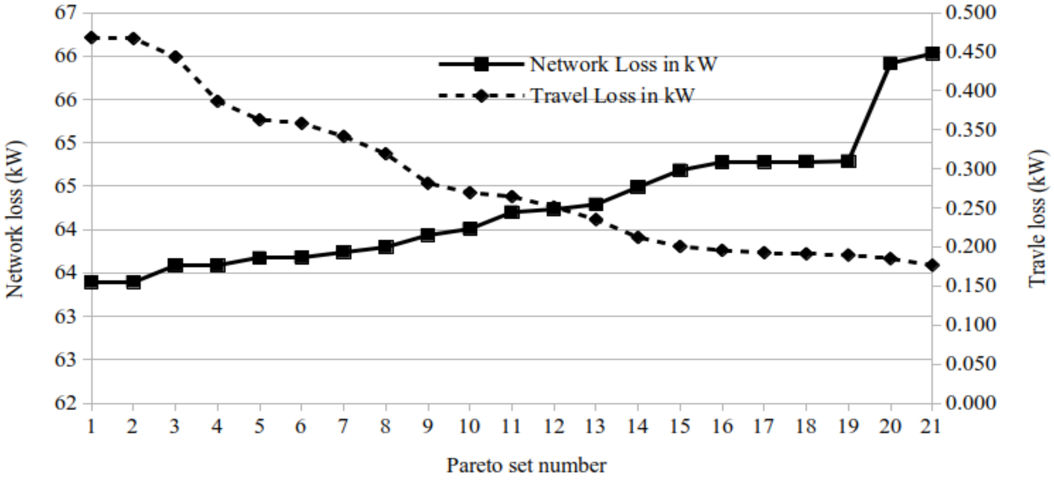

Figure 4.13: Network loss and travel loss for pareto set number for two CSs.

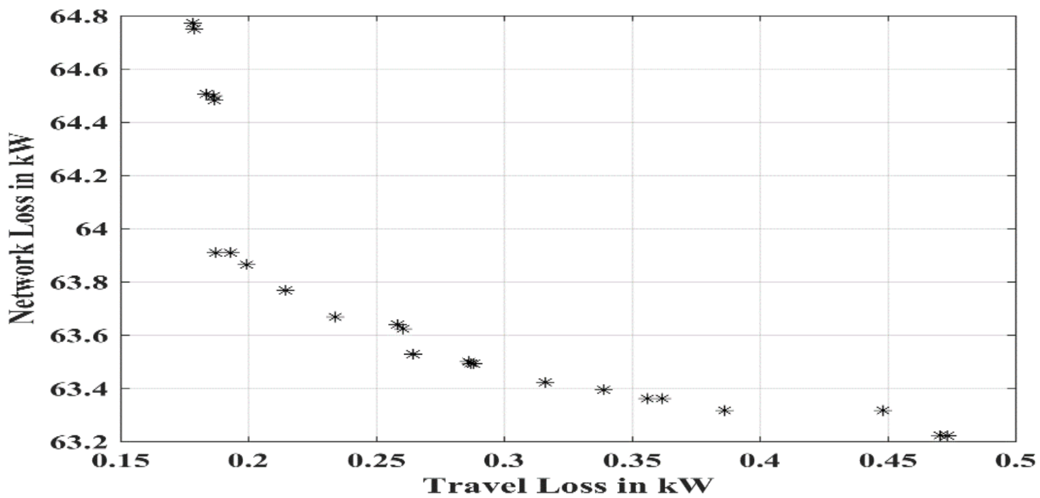

Figure 4.14: Network loss and travel loss of pareto set in case of two CS

For different pareto set present in pareto front-1, if network loss and travel loss are plotted then the result is as shown in figure 4.14. Similarly optimal placement of one, three and four number of charging station is carried out and the result obtained after optimal placement consisting of distribution loss and travelling loss of different pareto set of pareto-optimal front-1 are shown in Appendix II.

Voltage magnitude of different bus for different number of charging station when plotted then the graph obtained is as shown in figure 4.15.

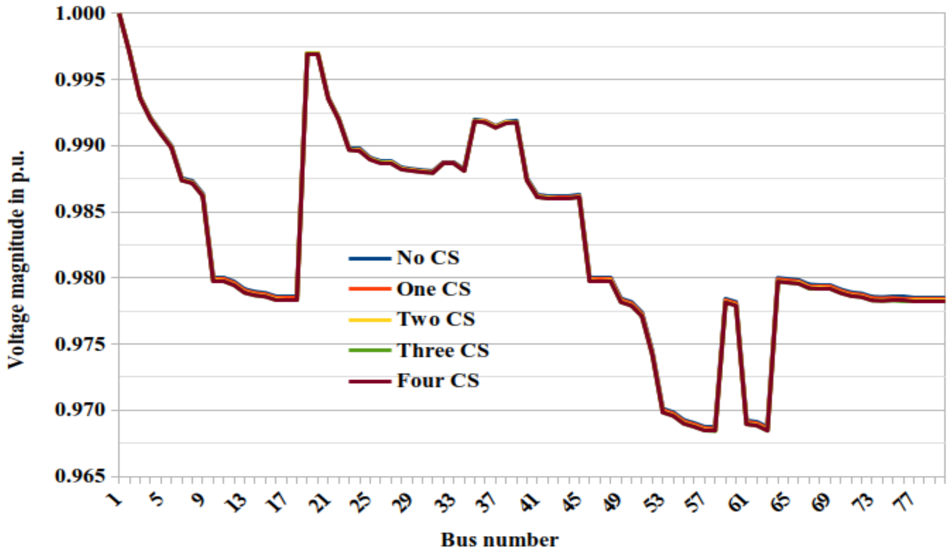

Figure 4.15: Voltage magnitude for different number of CS

From figure 4.15, it can be observed that variation in voltage at each bus for different number of charging station is minor and there is no violation of voltage limit also. Complete numerical value of voltage magnitude at each bus is given in Appendix III. Minimum value of voltage magnitude of the system for different number of charging station is almost same which can be seen in table 4.14.

4.2.3 Minimization of Distribution Loss and Travelling Loss with Maximization of Charging Station Utilization Factor.

When the number of CS is increased and distributed in the network then EV owners will get benefited but policy makers will enjoy benefit only if the infrastructure is utilized in maximum quantity. When the number of CS is increased then system operator should do investment so, policy makers will always try to decrease the number of CS. To give economical insight to the policy makers regarding increment or decrement in the number of CS, utilization factor is calculated for the CS. Utilization factor measures the number of EVs using charging station. If the utilization factor is maximum then policy makers can do investment in the number of CS. So, in this case not only the distribution loss and travelling loss are minimized but also the utilization factor is maximized when selecting the optimal location of CS. The three objectives are solved simultaneously with NSGA-II algorithm and best optimal solution is obtained by fuzzy optimization technique [25]. For more than one number of CS in the network utilization factor calculation gives proper insight to the policy makers regarding investment option. At first 8 number of charging port is considered keeping total demand and total EV population in the network constant, the best compromised solutions obtained from a set of feasible solution for varying number of CS is shown in table 4.16.

Table 4.16: Results considering three objective function with eight number of CP

No. of CSs	Location	Distribution Loss in kW	Travelling Loss in kW	Utilization Factor in %	Min. Voltage in p.u.
2	2 & 5	63.3916	0.3841	9.92	0.9687
3	9, 35 & 51	63.9569	0.2232	3.15	0.9685
4	3, 13, 23 & 55	64.1488	0.1300	3.38	0.9684

Secondly, keeping all the parameters constant the number of charging port is decreased to four and results obtained are as shown in table 4.17.

Table 4.17: Results considering three objective function with four number of CP

No. of CSs	Location	Distribution Loss in kW	Travelling Loss in kW	Utilization Factor in %	Min. Voltage in p.u.
2	4 & 20	63.3627	0.3829	17.40	0.9687
3	4, 9 & 55	64.1685	0.1556	6.22	0.9684
4	5, 10, 38 & 61	64.1443	0.1137	5.05	0.9684

From table 4.16 and 4.17, it can be observed that when the number of CS is increased from 2 to 3 then utilization factor decreases by around 3 times and when increased from 3 to 4 then utilization factor further decreases. So, in this case we can see that when the number of CS increases then utilization factor decreases. So, it is better to have 2 number of CS instead of 3 and 4 number from policy maker's or system operator perspective. But from EV's owner perspective i.e., considering travelling loss more number of CS in the system is better option. From the above table it is also observed that when the number of charging port is decreased then the utilization factor of a CS is increased. When the number of CP is decreased from 8 to 4 then maximum utilization factor in case of 2 CS is increased from 9.92% to 17.40% respectively. While maximizing utilization factor during optimization, minimum utilization factor among various CS located in the system is considered. So, it is better to have 4 CP in the considered system. Generally, in market a CS has two ports, so in analysis below 4 number of CP is not considered. In case of 2 number of CS with total 4 number of CP, each CS have two number of CP. Since, the utilization factor has reduced by large amount when the number of CS is increased beyond 2, so further data are presented for two number of charging station only. Pareto set for pareto front-1 in case of two CS having 4 CP is as shown in table 4.18.

Table 4.18: Pareto set considering three objective in case of two CS

Pareto Set Number	Bus No.	Bus No.	Distribution Loss in kW	Travelling Loss in kW	Utilization Factor in %
1	19	2	63.222	0.564	16.18
2	20	2	63.222	0.523	14.22
3	2	3	63.315	0.430	15.79
4	19	3	63.317	0.425	13.53
5	2	4	63.360	0.394	15.71
6	19	4	63.362	0.382	13.84
7	20	4	63.363	0.383	17.40
8	2	5	63.392	0.372	14.26
9	19	5	63.394	0.349	13.32
10	2	6	63.421	0.363	15.17
11	19	6	63.423	0.330	8.86
12	20	6	63.424	0.331	9.71
13	2	7	63.492	0.320	14.46
14	19	7	63.494	0.296	11.79
15	20	7	63.495	0.316	14.88
16	2	8	63.498	0.312	14.73
17	19	8	63.500	0.318	15.10
18	2	9	63.526	0.293	12.20
19	19	9	63.528	0.299	15.57
20	3	9	63.622	0.279	12.56
21	4	8	63.639	0.277	11.74
22	4	9	63.667	0.280	12.57
23	22	9	63.668	0.255	11.71
24	9	36	63.676	0.243	6.40
25	9	38	63.678	0.265	12.29

26	25	9	63.762	0.284	12.82
27	2	10	63.768	0.235	12.73
28	19	10	63.770	0.248	14.41
29	3	10	63.864	0.211	11.76
30	3	11	63.865	0.210	10.03
31	4	10	63.909	0.219	13.29
32	22	10	63.910	0.211	11.27
33	4	11	63.911	0.190	7.38
34	6	53	64.366	0.229	15.48
35	8	53	64.443	0.206	13.22
36	7	54	64.448	0.209	14.19
37	8	54	64.454	0.207	13.39
38	9	53	64.471	0.202	14.25
39	8	55	64.477	0.190	11.54
40	7	56	64.481	0.189	5.67
41	8	56	64.487	0.202	11.92
42	8	57	64.498	0.187	9.81
43	9	55	64.506	0.199	12.19
44	9	56	64.515	0.199	13.41
45	9	57	64.526	0.186	12.43
46	10	55	64.750	0.194	12.58

In the set of compromised solution as shown in table 4.18, it can be observed that per phase distribution loss varies from 63.222 kW to 64.750 kW while travelling loss varies from 0.564 kW to 0.194 kW and minimum value of utilization factor varies from 17.40% to 5.67%. Using fuzzy optimization [25], the best compromised solution considering all three-objective function in case of two CS is for charging station located at bus 4 & 20 where the distribution loss, travelling loss and utilization factor are 63.3627kW, 0.3829kW and 17.40% respectively. When distribution loss and utilization factor are plotted against pareto number then the graph as shown in figure 4.16 is obtained. When the travelling loss is plotted against distribution loss obtained in compromised solution of pareto front-1 then the graph as shown in figure 4.17 is obtained.

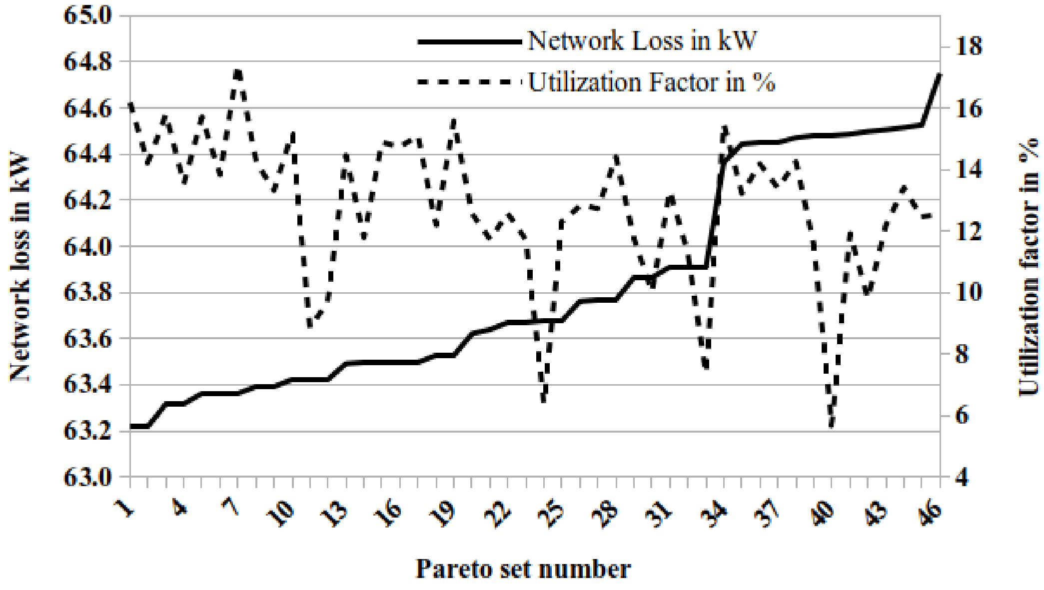

Figure 4.16: Network loss and utilization factor for each pareto set number

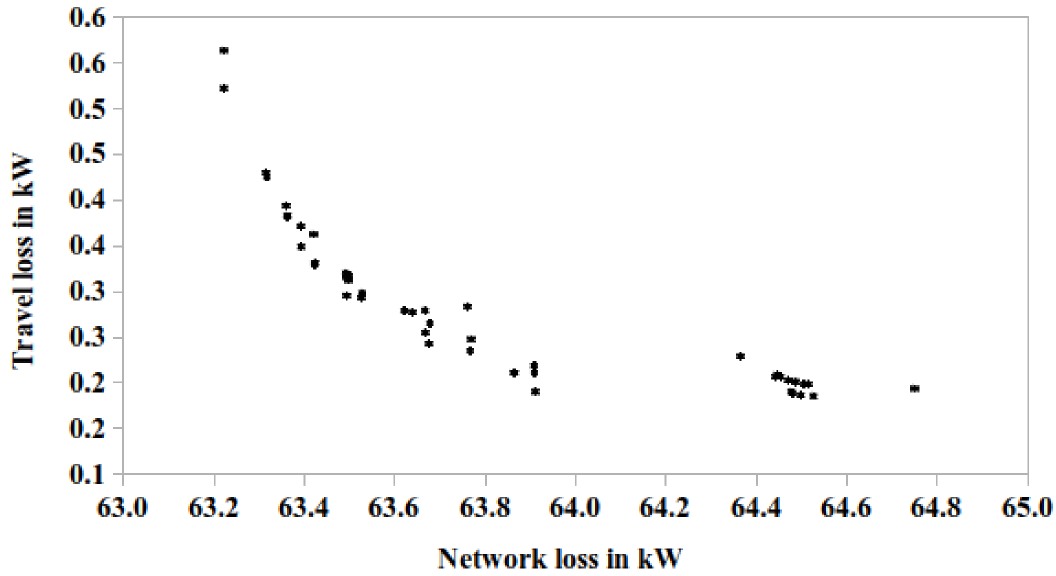

Figure 4.17: Travel loss versus network loss in case of three objective function

Number of charging port is varied considering three objective functions in case of two charging station and the results obtained are as shown in table 4.19. From the table 4.19, it can be seen that with decreasing number of CP, utilization factor increases when all the three objective functions are considered. In case of 2 CP, utilization factor is maximum but due to practical condition it is better to have 4 CP in case of two CS but if only one CS is placed then 2 CP will be better. So, along with this analysis practical constraints and requirement should be considered to decide best number of CS and CP.

Table 4.19: Results for varying number of CP considering three objectives

No. of CS Ports	Location	Total 1 phase Demand of CS in kW	Distribution Loss in kW	Travelling Loss in kW	Utilization Factor in %	Min. Voltage in p.u.
16	2 & 6	43.253	63.4210	0.3590	4.54	0.968658
8	2 & 5	43.253	63.3916	0.3841	9.92	0.968663
4	4 & 20	43.253	63.3627	0.3829	17.40	0.968668
2	4 & 9	38.749	63.6026	0.2549	27.14	0.968629

Further, analysis is done in case of varying EV population of the system. Results obtained after simulation in case of two CS and four CP for varying EV population is as shown in table 4.20.

Table 4.20: Results for varying EVs population

EV Population	Location	Total 1 phase Demand of CS in kW	Distribution Loss in kW	Travelling Loss in kW	Utilization Factor in %	Min. Voltage in p.u.
63	4 & 20	129.759	63.3627	0.3829	17.40	0.96867
126	2 & 7	187.143	63.6877	0.6314	22.13	0.96862
189	9 & 19	175.223	63.6957	0.9199	26.88	0.96861

From the table 4.20, it can be observed that when the EVs population is doubled then utilization factor is increased from 17.40% to 22.13% and when tripled then increased to 26.88%. So, during planning stage near future EVs population can be considered to decide the number of CSs because utilization of CS will get increased in near future and system operator will have more revenue.

When EVs population increases then travelling loss and distribution loss also increases which can be observed in the table also. When the voltage magnitude of each bus obtained in case of no CS, two objective function and three objective function is plotted then graph as shown in above figure 4.18 is obtained.

From the figure 4.16, it can be observed that voltage magnitude for different case of objective function is almost same. Since position of charging station only varies and total capacity is same so there is only slight variation in voltage magnitude. Numerical value of voltage magnitude can be found in appendix III.

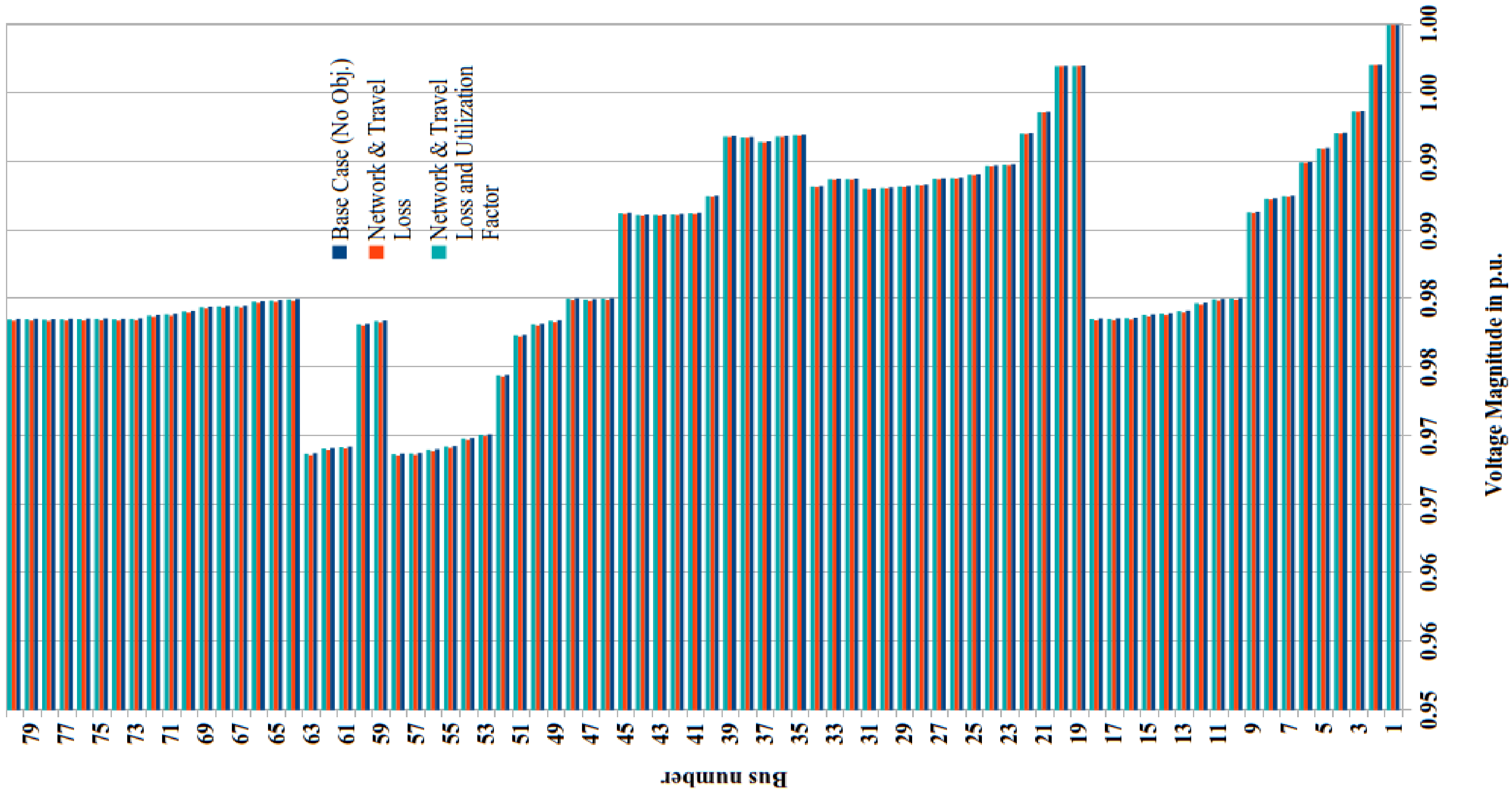

Figure 4.18: Voltage magnitude of Om feeder in case of various objective function

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The global warming and climate changing due to greenhouse gas (GHG) emission, depletion of petroleum and natural gas are the major problems that present generations are facing. Internal combustion engine (ICE) vehicles are the main source of contamination in the globe. Due to various terms and conditions of global community regarding global warming and climate changing problem created by the transport sector has led to use of electric vehicles (EVs) as a favorable alternative solution. Many nations have aim to implement pollution free battery-operated electric vehicle (EV) system which requires electrically operated CS. For instance, Argentina, European Union, Denmark, China, Canada, Brazil, Austria etc. The growing popularity of EVs has led to establishment of number of charging stations (CS), so the placement of CS problems needs to be optimized. To take into account dynamic behaviour of EVs probabilistic demand modeling of CS is done by Monte Carlo Simulation (MCS) in which queuing theory is used to take into account dynamic serviceability of a charging station. The previous studies show that unplanned siting of CS causes increase power loss in the existing distribution network as well as increase travelling loss that occurs when an EV travel from their location to CS location point and decrease utilization of charging station. Hence, these three objectives are solved individually using GA and solved simultaneously by using NSGA-II to obtain a set of compromised solution. The best optimal placement of CS in the existing network is selected by using Fuzzy optimization technique in this work.

GA and NSGA-II algorithm are implemented in IEEE 33-bus test system for optimal placement of CS considering distribution loss, travelling loss and utilization factor. After confirmation, the same is implement in a real 11 kV 80-bus Om distribution feeder of New Chabahil Substation. In case of placing 8, 4, 2 & 1 number of charging ports in a CS for Om feeder after MCS method, the maximum demand obtained are 0.1298 MW, 0.1298 MW, 0.1162 MW & 0.0630 MW respectively and Weibull distribution function best fits on the probability density function of CS demand. Optimal location found in case of two CS considering all the three objective functions produces utilization factor of 9.92%, 17.40% and 27.14% with 8, 4 and 2 no. of CP respectively. So, it is better to have 4 no. of CP due to practical constraint and policy maker perspective. If we consider 4 no. of CP in the system, when the number of CSs is increased from 2 to 3 then utilization factor decreases from 17.40% to 6.22%. In case of less number of CSs, each CS will get utilized properly which is advantageous for policy maker's or the system operator. But from view point of EVs user, more number of CS is better since travel loss gets decreased from 0.3892 kW to 0.1556 kW in case of 4 no. of CP. All the optimal location is done considering voltage limit and during optimal location there was no violation of voltage limit. When the EVs population in the network is doubled then utilization factor of a CS increases from 17.40% to 22.13% but travel loss increases from 0.3829 kW to 0.6314 kW. Similarly, When the EVs population in the network is tripled then utilization factor of a CS increases from 17.40% to 26.88% but travel loss increases from 0.3829 kW to 0.9199 kW.

Thus, it can be concluded that the selected algorithm in this study allocates the optimal location of charging station. The optimal placement of charging station by simultaneously minimizing electrical distribution loss which benefits the system operator, minimizing travelling loss of EVs when traveling to the location of CS benefiting the EVs owner and maximizing the utilization factor which confirms economical utilization of charging station infrastructure thus benefiting the charging station investor considering dynamic behaviour of EVs probabilistic demand modeling of CS and dynamic serviceability of a CS by employing Monte Carlo Simulation (MCS) and M/M/c queuing theory respectively. Optimal location improves nodal voltage and reduces losses occurring in the network. This work will act as a guide for system engineers for placement of CS in existing distribution network considering their network along with taking customer concern into account.

5.2 Recommendation

In this work only, balanced distribution system network is considered so this concept can be extended to unbalanced network. Since, the placement of charging station are considered as positive load so placement of charging station as negative load is also one of the important factors for future work. Deterministic load flow is considered to investigate the impact of the charging station demand integration in the existing distribution network parameters, the real time placement of charging station using probabilistic load flow and obtaining the continuous demand of charging station as per the requirement of study can be considered as future work

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APPENDIX I

Table I.1: Load data and line parameters and number of vehicles at node bus for IEEE 33-Bus Test system

Branch No.	Sending Bus	Receiving Bus	Resistance in Ohm	Reactance in Ohm	Length in km	Load at Receiving Bus		No. of Vehicles at Receiving Bus
						Active in kW	Reactive in kVar	
1	1	2	0.0922	0.0470	0.375	100	60	0
2	2	3	0.4930	0.2511	2.002	90	40	10
3	3	4	0.3660	0.1864	1.486	120	80	20
4	4	5	0.3811	0.1941	1.548	60	30	30
5	5	6	0.8190	0.7070	3.915	60	20	30
6	6	7	0.1872	0.6188	2.339	200	100	40
7	7	8	1.7114	1.2351	2.711	200	100	40
8	8	9	1.0300	0.7400	4.589	60	20	50
9	9	10	1.0440	0.7400	4.630	60	20	50
10	10	11	0.1966	0.0650	0.749	45	30	50
11	11	12	0.3744	0.1238	1.427	60	35	50
12	12	13	1.4680	1.1550	6.759	60	35	60
13	13	14	0.5416	0.7129	3.239	120	80	80
14	14	15	0.5910	0.5260	2.863	60	10	100
15	15	16	0.7463	0.5450	3.344	60	20	120
16	16	17	1.2890	1.7210	7.780	60	20	150
17	17	18	0.7320	0.5740	3.366	90	40	170
18	2	19	0.1640	0.1565	0.820	90	40	200
19	19	20	1.5042	1.3554	7.326	90	40	30
20	20	21	0.4095	0.4784	2.279	90	40	20
21	21	22	0.7089	0.9373	4.252	90	40	20
22	3	23	0.4512	0.3083	1.977	90	50	10
23	23	24	0.8980	0.7091	4.140	420	200	10
24	24	25	0.8960	0.7011	4.117	420	200	10
25	6	26	0.2030	0.1034	0.824	60	25	10
26	26	27	0.2842	0.1447	1.154	60	25	30
27	27	28	1.0590	0.9337	5.108	60	20	30
28	28	29	0.8042	0.7006	3.859	120	70	20
29	29	30	0.5075	0.2585	2.061	200	600	20
30	30	31	0.9744	0.9630	4.957	150	70	20
31	31	32	0.3105	0.3619	1.725	210	100	20
32	32	33	0.3410	0.5302	2.281	60	40	10
Total					**100.00**	**3715**	**2300**	10
Base kV = 12.66kV & Base MVA = 100 MVA							**Total**	**1520**

Table I.2: Load data, line parameters and vehicle data for 80 Bus Om Distribution Feeder.

Branch Number	Sending Bus	Receiving Bus	Resistance in Ohm	Reactance in Ohm	Ampacity in Ampere	Length in km	Load at Receiving Bus		No. of Vehicles at Receiving Bus
							Active in kW	Reactive in kVar	
1	1	2	0.0682	0.0732	300.000	0.2985	0.00	0.00	0
2	2	3	0.0808	0.0952	300.000	0.2957	0.00	0.00	0
3	3	4	0.0386	0.0455	300.000	0.1413	0.00	0.00	0
4	4	5	0.0329	0.0387	300.000	0.1202	30.00	14.67	1
5	5	6	0.0309	0.0363	300.000	0.1129	0.00	0.00	0
6	6	7	0.0826	0.0973	300.000	0.3023	0.00	0.00	0
7	7	8	0.0070	0.0083	300.000	0.0257	30.00	14.67	1
8	8	9	0.0329	0.0387	300.000	0.1203	60.00	29.33	1
9	9	10	0.3163	0.1254	139.000	0.3489	0.00	0.00	0
10	10	11	0.0040	0.0048	300.000	0.0148	0.00	0.00	0
11	11	12	0.0496	0.0314	193.000	0.0915	30.00	14.67	1
12	12	13	0.1368	0.0867	193.000	0.2525	0.00	0.00	0
13	13	14	0.0494	0.0313	193.000	0.0911	0.00	0.00	0
14	14	15	0.0274	0.0173	193.000	0.0505	0.00	0.00	0
15	15	16	0.0837	0.0530	193.000	0.1544	0.00	0.00	0
16	16	17	0.0241	0.0153	193.000	0.0444	60.00	29.33	1
17	17	18	0.0279	0.0177	193.000	0.0514	30.00	14.67	1
18	2	19	0.0340	0.0401	300.000	0.1245	94.50	46.20	2
19	19	20	0.0221	0.0052	223.000	0.0700	90.00	44.00	1
20	3	21	0.0556	0.0654	300.000	0.2033	90.00	44.00	1
21	4	22	0.0037	0.0044	300.000	0.0137	90.00	44.00	1
22	6	23	0.0509	0.0600	300.000	0.1864	0.00	0.00	0
23	23	24	0.0279	0.0111	139.000	0.0308	48.00	23.47	1

24	24	25	0.2865	0.1137	139.000	0.3161	15.00	7.33	0
25	25	26	0.1120	0.0444	139.000	0.1235	0.00	0.00	0
26	26	27	0.0285	0.0113	139.000	0.0314	60.00	29.33	1
27	27	28	0.3611	0.1447	139.000	0.4507	60.00	29.33	1
28	28	29	0.1460	0.0579	139.000	0.1611	0.00	0.00	0
29	29	30	0.1473	0.0584	139.000	0.1625	15.00	7.33	0
30	30	31	0.1239	0.0492	139.000	0.1367	60.00	29.33	1
31	26	32	0.1896	0.0752	139.000	0.2092	30.00	14.67	1
32	32	33	0.0726	0.0099	164.000	0.1320	15.00	7.33	0
33	29	34	0.0528	0.0209	139.000	0.0582	15.00	7.33	0
34	22	35	0.0251	0.0100	139.000	0.0277	60.00	29.33	1
35	35	36	0.0372	0.0147	139.000	0.0410	0.00	0.00	0
36	36	37	0.2130	0.0845	139.000	0.2350	225.00	110.00	4
37	35	38	0.0810	0.0321	139.000	0.0893	225.00	110.00	4
38	36	39	0.0055	0.0008	164.000	0.0100	60.00	29.33	1
39	7	40	0.0055	0.0064	300.000	0.0200	7.50	3.67	0
40	9	41	0.0330	0.0389	300.000	0.1208	0.00	0.00	0
41	41	42	0.0409	0.0482	300.000	0.1498	60.00	29.33	1
42	42	43	0.0313	0.0369	300.000	0.1145	60.00	29.33	1
43	43	44	0.0330	0.0045	164.000	0.0600	60.00	29.33	1
44	41	45	0.0030	0.0035	300.000	0.0108	30.00	14.67	1
45	10	46	0.0141	0.0056	139.000	0.0155	0.00	0.00	0
46	46	47	0.2737	0.1086	139.000	0.3019	30.00	14.67	0
47	46	48	0.0108	0.0043	139.000	0.0119	30.00	14.67	1
48	10	49	0.1960	0.0777	139.000	0.2162	0.00	0.00	0
49	49	50	0.0363	0.0144	139.000	0.0400	30.00	14.67	0
50	50	51	0.1199	0.0476	139.000	0.1323	30.00	14.67	0
51	51	52	0.4555	0.1807	139.000	0.5025	90.00	44.00	1
52	52	53	0.7708	0.3057	139.000	0.8503	60.00	29.33	1

53	53	54	0.0510	0.0202	139.000	0.0563	45.00	22.00	1
54	54	55	0.1245	0.0494	139.000	0.1373	0.00	0.00	0
55	55	56	0.0571	0.0227	139.000	0.0630	60.00	29.33	1
56	56	57	0.0768	0.0305	139.000	0.0847	0.00	0.00	0
57	57	58	0.1881	0.0746	139.000	0.2075	30.00	14.67	1
58	49	59	0.0136	0.0054	139.000	0.0150	150.00	73.33	2
59	50	60	0.0054	0.0022	139.000	0.0060	15.00	7.33	0
60	55	61	0.0694	0.0275	139.000	0.0766	15.00	7.33	0
61	61	62	0.1970	0.0781	139.000	0.2173	60.00	29.33	1
62	57	63	0.0059	0.0023	139.000	0.0065	390.00	190.67	6
63	11	64	0.0312	0.0368	300.000	0.1143	30.00	14.67	0
64	11	65	0.0126	0.0149	300.000	0.0462	600.00	293.33	10
65	65	66	0.1090	0.1283	300.000	0.3987	60.00	29.33	1
66	12	67	0.1762	0.0998	193.000	0.3121	48.00	23.47	1
67	67	68	0.0150	0.0095	193.000	0.0277	30.00	14.67	0
68	68	69	0.1025	0.0649	193.000	0.1891	60.00	29.33	1
69	13	70	0.0600	0.0149	193.000	0.0853	30.00	14.67	0
70	14	71	0.0864	0.0343	139.000	0.0953	60.00	29.33	1
71	15	72	0.0782	0.0077	133.000	0.0982	60.00	29.33	1
72	16	73	0.0644	0.0255	139.000	0.0710	0.00	0.00	0
73	73	74	0.1374	0.0545	139.000	0.1516	30.00	14.67	0
74	73	75	0.0056	0.0022	139.000	0.0062	60.00	29.33	1
75	17	76	0.0174	0.0110	193.000	0.0321	0.00	0.00	0
76	76	77	0.0121	0.0077	193.000	0.0223	0.00	0.00	0
77	77	78	0.0756	0.0074	133.000	0.0950	48.00	23.47	1
78	76	79	0.0318	0.0031	133.000	0.0400	30.00	14.67	0
79	77	80	0.0394	0.0039	133.000	0.0495	45.00	22.00	1
Total			**7.0366**	**3.4520**		**10.581**	**3,936.00**	**1924.250**	**63**

APPENDIX II

Table II.1: Pareto set and corresponding distribution loss and travelling loss in case of three charging station for IEEE 33-Bus Test system

Pareto Set Number	Bus No.	Bus No.	Bus No.	Distribution Loss in kW	Travelling Loss in kW
1	20	19	2	213.6053	366.962
2	3	2	19	215.421	355.715
3	20	19	3	216.250	350.747
4	4	2	19	216.852	349.868
5	4	2	21	217.697	347.147
6	5	2	19	218.294	336.444
7	5	2	21	219.139	318.694
8	6	2	19	221.441	284.400
9	7	2	19	221.881	275.141
10	8	2	19	224.924	246.059
11	9	2	19	226.417	223.186
12	9	2	20	227.122	216.402
13	19	2	10	227.836	192.437
14	11	2	19	228.076	186.994
15	19	2	12	228.502	172.447
16	19	2	13	230.066	140.127
17	19	2	14	230.604	131.377
18	15	19	2	231.023	122.378
19	15	2	21	231.868	119.865
20	16	2	20	232.158	117.725
21	15	19	3	233.778	117.572
22	16	2	3	234.112	113.418
23	15	21	3	234.623	106.894
24	16	21	4	236.571	106.010
25	15	5	20	237.531	103.924
26	16	5	20	237.963	103.626
27	16	21	5	238.104	99.256
28	2	15	6	240.085	96.396
29	2	16	6	240.518	93.900
30	3	7	16	243.864	89.842
31	17	2	13	251.389	85.194
32	17	11	4	253.349	82.892
33	17	4	13	255.862	80.497
34	17	5	13	257.489	76.724
35	17	6	13	261.062	73.512
36	26	14	17	262.139	70.237

Table II.2: Pareto set and corresponding distribution loss and travelling loss in case of Four charging station for IEEE 33-Bus Test system

Pareto Set Number	**Bus No.**	**Bus No.**	**Bus No.**	**Bus No.**	**Distribution Loss in kW**	**Travelling Loss in kW**
1	2	19	20	3	215.3164	356.449
2	19	4	2	20	216.383	347.082
3	2	19	20	5	217.457	325.297
4	2	19	20	6	219.800	276.679
5	2	19	22	6	220.001	275.475
6	2	19	20	7	220.125	275.297
7	2	19	21	7	220.224	266.735
8	20	7	19	21	220.968	263.990
9	2	19	20	8	222.369	253.184
10	2	19	21	8	222.468	250.695
11	2	19	22	8	222.570	249.139
12	20	8	19	21	223.211	247.502
13	2	19	20	9	223.463	220.740
14	2	19	21	9	223.562	219.902
15	2	19	20	10	224.500	189.761
16	2	19	20	11	224.675	177.346
17	20	19	12	2	224.985	174.584
18	20	19	13	2	226.118	142.513
19	21	19	13	2	226.217	139.070
20	20	19	14	2	226.506	128.828
21	21	19	14	2	226.604	128.197
22	20	19	15	2	226.804	120.371
23	2	16	19	20	227.107	116.255
24	2	16	19	21	227.206	111.868
25	15	4	21	2	229.969	104.814
26	24	19	15	3	231.779	103.795
27	19	15	6	2	232.948	96.526
28	19	16	6	2	233.253	92.326
29	20	16	6	2	233.758	92.314
30	21	16	6	2	233.857	89.801
31	20	16	7	2	234.114	88.152
32	20	16	7	3	236.205	86.770
33	21	16	9	3	240.044	86.102
34	20	16	10	3	241.141	84.402
35	2	20	13	17	241.403	84.171
36	3	20	12	17	242.141	81.658
37	4	20	12	17	243.302	80.265
38	3	20	13	17	243.504	77.695
39	3	20	14	17	243.981	77.152
40	4	20	14	17	245.144	73.386
41	4	20	14	18	245.307	72.117
42	12	17	2	6	246.477	71.493
43	5	22	14	17	246.523	71.273

44	5	22	14	18	246.686	68.861
45	13	17	2	6	247.847	62.128
46	14	18	2	6	248.489	61.940
47	18	15	7	2	249.268	61.861
48	10	18	14	3	256.546	61.368
49	11	18	14	3	256.780	60.438
50	10	18	15	3	256.944	57.338
51	10	18	15	4	258.155	55.670
52	10	18	15	5	259.383	55.343
53	10	18	14	6	261.681	54.633
54	11	18	14	6	261.917	53.480
55	10	18	15	6	262.081	52.729
56	11	18	15	6	262.318	51.642

Table II.3: Pareto set and corresponding distribution loss, travelling loss and utilization factor in case of Two charging station for IEEE 33-Bus Test system.

Pareto Set Number	**Bus No.**	**Bus No.**	**Distribution Loss in kW**	**Travelling Loss in kW**	**Utilization Factor in %**
1	19	2	212.835	406.259	40.90
2	20	2	213.984	442.044	41.10
3	21	2	214.221	452.266	43.00
4	2	3	216.678	379.257	40.19
5	20	3	217.983	416.179	41.76
6	3	21	218.219	391.599	44.23
7	2	4	218.850	373.796	40.36
8	4	20	220.155	370.610	37.57
9	4	21	220.391	368.420	38.11
10	4	22	220.662	371.938	40.01
11	2	5	221.042	339.223	32.27
12	5	20	222.346	366.954	39.79
13	5	21	222.582	372.909	43.46
14	5	22	222.853	371.065	40.89
15	6	2	225.834	336.597	38.50
16	6	19	225.989	343.906	40.03
17	7	2	226.513	291.660	37.84
18	6	20	227.139	322.130	37.89
19	6	21	227.375	336.457	39.82
20	6	22	227.645	331.884	43.36
21	7	20	227.817	293.008	38.38
22	7	21	228.054	310.949	40.49
23	22	7	228.324	328.302	44.03

24	8	2	231.235	280.473	35.60
25	8	21	232.776	280.572	40.23
26	8	22	233.047	255.506	36.03
27	9	2	233.577	238.791	30.62
28	9	19	233.732	239.405	37.90
29	9	22	235.389	267.805	39.63
30	10	2	235.815	203.870	31.10
31	2	11	236.195	202.824	28.04
32	2	12	236.873	194.928	29.70
33	10	20	237.120	230.169	36.09
34	10	21	237.356	248.248	38.94
35	12	20	238.178	223.889	38.37
36	12	21	238.414	221.752	37.23
37	2	13	239.384	165.022	28.16
38	13	19	239.539	160.606	29.10
39	14	2	240.254	142.901	28.28
40	21	13	240.925	200.236	31.90
41	2	15	240.949	135.349	28.80
42	22	13	241.196	201.662	37.40
43	16	2	241.676	125.614	25.91
44	3	15	245.199	125.377	25.21
45	3	16	245.928	128.452	28.08
46	4	15	247.564	120.921	26.15
47	4	16	248.295	115.332	26.11
48	5	15	249.963	119.249	26.93
49	16	5	250.695	112.267	22.64
50	15	6	255.232	115.207	25.66
51	26	15	255.805	113.599	24.90
52	16	6	255.967	104.943	25.32
53	9	33	257.032	256.437	39.18
54	32	10	259.133	239.037	40.33
55	33	10	259.299	231.324	39.06
56	33	12	260.371	231.853	39.42
57	13	18	274.839	185.682	33.59

Table II.4: Pareto set and corresponding distribution loss and travelling loss in case of Single charging station for 80 Bus Om Distribution Feeder.

Pareto Set Number	**Bus No.**	**Distribution Loss in kW**	**Travelling Loss in kW**
1	2	63.220	0.470
2	3	63.411	0.397
3	4	63.501	0.360
4	5	63.565	0.345
5	6	63.624	0.331
6	7	63.766	0.298
7	9	63.834	0.292
8	10	64.320	0.273
9	11	64.323	0.272

Table II.5: Pareto set and corresponding distribution loss and travelling loss in case of Three charging station for 80 Bus Om Distribution Feeder.

Pareto Set Number	**Bus No.**	**Bus No.**	**Bus No.**	**Network Loss in kW**	**Travel Loss in kW**
1	4	3	2	63.377	0.356
2	5	3	2	63.398	0.332
3	6	2	3	63.418	0.310
4	7	2	3	63.465	0.264
5	3	2	9	63.487	0.240
6	4	2	9	63.517	0.226
7	2	3	10	63.648	0.189
8	2	3	11	63.650	0.189
9	4	2	10	63.678	0.181
10	10	24	22	63.819	0.179
11	10	25	22	63.836	0.175
12	10	26	22	63.842	0.171
13	2	40	55	64.052	0.171
14	2	40	56	64.058	0.170
15	2	40	57	64.065	0.169
16	57	2	45	64.090	0.167
17	3	40	54	64.100	0.165
18	3	40	55	64.116	0.159
19	3	41	53	64.117	0.155
20	54	35	8	64.138	0.153
21	3	41	55	64.140	0.149

22	4	41	53	64.147	0.149
23	53	35	9	64.149	0.141
24	36	53	9	64.151	0.141
25	54	35	9	64.156	0.138
26	35	55	9	64.172	0.129
27	55	2	46	64.236	0.128
28	57	2	46	64.250	0.123
29	53	3	46	64.278	0.119
30	54	3	46	64.285	0.117
31	55	3	46	64.301	0.108
32	57	3	46	64.314	0.106
33	55	4	46	64.331	0.104
34	35	55	10	64.334	0.102
35	55	35	11	64.335	0.100
36	35	57	11	64.349	0.098
37	36	57	10	64.350	0.097

Table II.6: Pareto set and corresponding distribution loss and travelling loss in case of Four charging station for 80 Bus Om Distribution Feeder.

Pareto Set Number	**Bus No.**	**Bus No.**	**Bus No.**	**Bus No.**	**Network Loss in kW**	**Travel Loss in kW**
1	2	3	19	35	63.341	0.377
2	2	3	19	39	63.343	0.376
3	2	3	20	39	63.343	0.375
4	2	4	19	35	63.364	0.370
5	2	4	19	36	63.365	0.359
6	2	5	19	36	63.381	0.346
7	2	5	19	39	63.381	0.328
8	2	6	19	35	63.394	0.314
9	2	6	19	36	63.396	0.310
10	2	3	19	40	63.404	0.277
11	2	3	19	41	63.422	0.264
12	2	3	19	45	63.422	0.259
13	2	4	19	45	63.445	0.252
14	3	5	19	45	63.509	0.250
15	2	3	19	46	63.542	0.192
16	2	4	19	46	63.565	0.181
17	4	2	23	46	63.667	0.176
18	23	2	39	46	63.672	0.175
19	35	11	24	2	63.672	0.171
20	36	10	25	2	63.685	0.170
21	36	11	25	2	63.686	0.164
22	3	2	40	55	63.891	0.152
23	53	19	7	35	63.900	0.147

24	53	20	7	35	63.900	0.147
25	53	19	8	36	63.904	0.142
26	53	19	9	35	63.917	0.131
27	54	19	9	35	63.922	0.130
28	54	20	9	35	63.922	0.129
29	55	19	9	35	63.934	0.124
30	56	19	9	35	63.938	0.120
31	53	19	10	35	64.038	0.102
32	53	19	10	36	64.040	0.101
33	54	19	10	35	64.043	0.096
34	10	2	35	61	64.055	0.094
35	55	19	10	35	64.055	0.092
36	57	19	10	35	64.065	0.091
37	11	2	35	63	64.065	0.090
38	26	55	10	3	64.151	0.087
39	26	56	11	3	64.157	0.087
40	26	57	10	3	64.161	0.086
41	26	57	11	3	64.162	0.084
42	26	56	10	4	64.178	0.083
43	26	56	11	4	64.179	0.081

Table II.7: Pareto set and corresponding distribution loss, travelling loss and utilization factor in case of Three charging station for 80 Bus Om Distribution Feeder.

Pareto Set Number	Bus No.	Bus No.	Bus No.	Network Loss in kW	Travel Loss in kW	Utilization Factor
1	20	2	19	63.2229	0.4668	0
2	19	2	3	63.2846	0.3988	0
3	19	2	4	63.3145	0.3686	0
4	20	2	4	63.3149	0.354	0
5	19	2	5	63.3355	0.3438	0
6	19	2	6	63.3551	0.3309	0
7	20	2	6	63.3555	0.3303	0
8	19	2	7	63.4022	0.2846	0
9	20	2	8	63.4067	0.2828	0
10	19	2	9	63.4248	0.2613	0
11	19	3	9	63.4887	0.241	0
12	19	4	9	63.5187	0.2261	0
13	19	2	10	63.5858	0.2137	0
14	4	40	22	63.5895	0.3018	1.96
15	4	41	22	63.6136	0.2689	1.53
16	21	2	10	63.6494	0.2019	0
17	19	3	10	63.6496	0.1998	0

18	19	3	11	63.6508	0.1972	0
19	22	2	10	63.6788	0.1847	0
20	24	2	12	63.7324	0.234	0.60
21	24	2	13	63.7461	0.2371	3.39
22	2	46	40	63.7667	0.233	3.86
23	22	4	10	63.773	0.2056	0.66
24	22	4	11	63.7742	0.2007	1.96
25	2	46	9	63.7894	0.2433	5.02
26	2	46	41	63.791	0.2088	2.7904
27	2	47	41	63.7932	0.2959	6.27
28	5	46	39	63.7997	0.1946	0.13
29	5	46	38	63.8012	0.2228	4.01
30	27	11	35	63.8473	0.1714	0
31	7	46	39	63.8668	0.2166	3.43
32	7	46	38	63.8683	0.2172	4.44
33	9	51	35	63.9569	0.1995	1.82
34	2	49	10	63.9936	0.2266	4.46
35	3	52	9	64.0001	0.1957	4.82
36	2	53	7	64.0287	0.1878	2.43
37	2	40	53	64.0287	0.1762	0.21
38	4	52	9	64.0302	0.1871	3.41
39	52	22	9	64.0307	0.1827	2.10
40	9	52	35	64.0337	0.1773	2.04
41	2	54	7	64.0357	0.1737	1.25
42	2	40	54	64.0357	0.1841	2.17
43	2	53	9	64.0514	0.1684	5.77
44	2	54	9	64.0584	0.1647	2.50
45	2	55	9	64.0742	0.1638	4.15
46	2	56	9	64.0805	0.1655	4.40
47	2	57	9	64.0879	0.1519	3.39
48	3	53	9	64.1155	0.1657	4.53
49	3	54	9	64.1225	0.1497	2.14
50	3	55	9	64.1384	0.1528	3.97
51	3	56	9	64.1446	0.1462	2.79
52	4	55	8	64.1498	0.1551	4.07
53	4	54	9	64.1527	0.1592	5.64
54	35	9	54	64.1562	0.1376	0.22
55	4	55	9	64.1685	0.1556	6.22
56	35	9	55	64.172	0.1514	4.39
57	4	56	9	64.1748	0.1497	4.15
58	4	57	9	64.1822	0.15	4.86
59	2	55	10	64.2362	0.1382	3.88

60	2	56	10	64.2425	0.1384	5.98
61	2	57	10	64.2499	0.1359	3.75
62	3	53	10	64.2775	0.1359	4.43
63	3	53	11	64.2787	0.1306	3.75
64	3	54	10	64.2845	0.124	4.45
65	3	54	11	64.2857	0.1136	5.22
66	3	55	10	64.3003	0.1133	2.18
67	3	55	11	64.3015	0.1125	4.25
68	3	56	10	64.3066	0.1096	0.38
69	4	53	10	64.3077	0.1022	0.16
70	3	57	10	64.3141	0.1053	2.87
71	4	55	10	64.3305	0.1081	4.02
72	4	55	11	64.3316	0.1014	1.95
73	4	56	10	64.3367	0.1037	2.72
74	4	56	11	64.3379	0.1025	2.62
75	4	57	10	64.3442	0.1117	4.26

APPENDIX III

Table III.1: Voltage magnitude in p.u. of each node bus for IEEE 33-Bus Test system in case of different number of CS placement considering only distribution and travelling loss

Voltage Magnitude with one CS				
Bus No.	Objective Function			
	Base Case (No Obj.)	Distribution loss	Travelling Loss	Distribution & Travelling Loss
1	1.0000	1.0000	1.0000	1.0000
2	0.9970	0.9968	0.9968	0.9968
3	0.9829	0.9827	0.9814	0.9815
4	0.9754	0.9752	0.9729	0.9731
5	0.9680	0.9678	0.9645	0.9648
6	0.9495	0.9493	0.9438	0.9444
7	0.9460	0.9457	0.9397	0.9404
8	0.9323	0.9321	0.9218	0.9267
9	0.9260	0.9258	0.9128	0.9203
10	0.9201	0.9199	0.9044	0.9144
11	0.9192	0.9190	0.9030	0.9135
12	0.9177	0.9175	0.9006	0.9120
13	0.9115	0.9113	0.8908	0.9058
14	0.9092	0.9090	0.8885	0.9035
15	0.9078	0.9076	0.8870	0.9020
16	0.9064	0.9062	0.8856	0.9007
17	0.9044	0.9042	0.8835	0.8986
18	0.9038	0.9036	0.8829	0.8980
19	0.9965	0.9963	0.9963	0.9963
20	0.9929	0.9927	0.9927	0.9927
21	0.9922	0.9920	0.9920	0.9920
22	0.9916	0.9914	0.9913	0.9914
23	0.9793	0.9791	0.9778	0.9779
24	0.9726	0.9724	0.9711	0.9712
25	0.9693	0.9691	0.9678	0.9679
26	0.9475	0.9473	0.9419	0.9425
27	0.9450	0.9448	0.9393	0.9399
28	0.9335	0.9333	0.9278	0.9284
29	0.9253	0.9251	0.9195	0.9201
30	0.9218	0.9216	0.9159	0.9165
31	0.9176	0.9174	0.9117	0.9123
32	0.9167	0.9165	0.9108	0.9114
33	0.9164	0.9162	0.9105	0.9111

Table III.2: Voltage magnitude in p.u. of each node bus for IEEE 33-Bus Test system in case of multiple CS placement considering three objective functions.

Voltage Magnitude with Two CS					
Bus No.	**Objective Function**				
	Base Case (No Obj.)	**Distribution loss**	**Travelling Loss**	**Distribution & Travelling Loss**	**Distribution & Travelling loss and Utilization factor**
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9970	0.9968	0.9968	0.9968	0.9968
3	0.9829	0.9827	0.9814	0.9820	0.9821
4	0.9754	0.9752	0.9730	0.9741	0.9742
5	0.9680	0.9678	0.9647	0.9661	0.9663
6	0.9495	0.9493	0.9441	0.9466	0.9468
7	0.9460	0.9457	0.9403	0.9428	0.9431
8	0.9323	0.9321	0.9244	0.9269	0.9294
9	0.9260	0.9258	0.9168	0.9193	0.9230
10	0.9201	0.9199	0.9096	0.9121	0.9172
11	0.9192	0.9190	0.9085	0.9110	0.9163
12	0.9177	0.9175	0.9065	0.9091	0.9148
13	0.9115	0.9113	0.8985	0.9011	0.9086
14	0.9092	0.9090	0.8955	0.8981	0.9063
15	0.9078	0.9076	0.8934	0.8960	0.9048
16	0.9064	0.9062	0.8911	0.8946	0.9034
17	0.9044	0.9042	0.8890	0.8925	0.9014
18	0.9038	0.9036	0.8884	0.8919	0.9008
19	0.9965	0.9961	0.9963	0.9963	0.9961
20	0.9929	0.9926	0.9927	0.9927	0.9909
21	0.9922	0.9918	0.9920	0.9920	0.9898
22	0.9916	0.9912	0.9913	0.9914	0.9884
23	0.9793	0.9791	0.9779	0.9784	0.9785
24	0.9726	0.9724	0.9712	0.9718	0.9718
25	0.9693	0.9691	0.9678	0.9684	0.9685
26	0.9475	0.9473	0.9422	0.9446	0.9449
27	0.9450	0.9448	0.9396	0.9421	0.9423
28	0.9335	0.9333	0.9281	0.9306	0.9309
29	0.9253	0.9251	0.9198	0.9223	0.9226
30	0.9218	0.9216	0.9162	0.9188	0.9190
31	0.9176	0.9174	0.9121	0.9146	0.9149
32	0.9167	0.9165	0.9111	0.9137	0.9140
33	0.9164	0.9162	0.9109	0.9134	0.9137

Table III.3: Voltage magnitude in p.u. of each node bus for different number of charging stations for 80 Bus Om Distribution Feeder.

Bus No.	Voltage Magnitude with One CS		Voltage Magnitude with Two CS		
	Objective Function		Objective Function		
	Base Case (No Obj.)	Network & Travel Loss	Base Case (No Obj.)	Network & Travel Loss	Network & Travel Loss and Utilization Factor
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9971	0.9971	0.9971	0.9971	0.9971
3	0.9937	0.9937	0.9937	0.9937	0.9937
4	0.9921	0.9921	0.9921	0.9921	0.9921
5	0.9910	0.9910	0.9910	0.9910	0.9910
6	0.9900	0.9899	0.9900	0.9899	0.9900
7	0.9876	0.9874	0.9876	0.9875	0.9875
8	0.9873	0.9872	0.9873	0.9873	0.9873
9	0.9864	0.9863	0.9864	0.9863	0.9863
10	0.9801	0.9800	0.9801	0.9799	0.9800
11	0.9800	0.9799	0.9800	0.9799	0.9800
12	0.9797	0.9796	0.9797	0.9796	0.9797
13	0.9792	0.9791	0.9792	0.9790	0.9791
14	0.9790	0.9789	0.9790	0.9788	0.9789
15	0.9789	0.9788	0.9789	0.9787	0.9788
16	0.9786	0.9785	0.9786	0.9785	0.9786
17	0.9786	0.9785	0.9786	0.9785	0.9785
18	0.9786	0.9785	0.9786	0.9784	0.9785
19	0.9970	0.9970	0.9970	0.9970	0.9970
20	0.9970	0.9970	0.9970	0.9970	0.9970
21	0.9937	0.9936	0.9937	0.9936	0.9936
22	0.9921	0.9921	0.9921	0.9921	0.9921
23	0.9898	0.9898	0.9898	0.9898	0.9898
24	0.9898	0.9897	0.9898	0.9897	0.9897
25	0.9891	0.9890	0.9891	0.9890	0.9891
26	0.9889	0.9888	0.9889	0.9888	0.9888
27	0.9888	0.9887	0.9888	0.9887	0.9888
28	0.9884	0.9883	0.9884	0.9883	0.9883
29	0.9883	0.9882	0.9883	0.9882	0.9882
30	0.9882	0.9881	0.9882	0.9881	0.9881
31	0.9881	0.9880	0.9881	0.9880	0.9881
32	0.9888	0.9887	0.9888	0.9887	0.9888
33	0.9888	0.9887	0.9888	0.9887	0.9887
34	0.9882	0.9882	0.9882	0.9882	0.9882

35	0.9920	0.9919	0.9920	0.9919	0.9920
36	0.9919	0.9918	0.9919	0.9918	0.9919
37	0.9915	0.9914	0.9915	0.9914	0.9915
38	0.9918	0.9918	0.9918	0.9918	0.9918
39	0.9919	0.9918	0.9919	0.9918	0.9919
40	0.9876	0.9874	0.9876	0.9875	0.9875
41	0.9863	0.9862	0.9863	0.9862	0.9863
42	0.9862	0.9861	0.9862	0.9861	0.9862
43	0.9862	0.9861	0.9862	0.9861	0.9861
44	0.9862	0.9861	0.9862	0.9861	0.9861
45	0.9863	0.9862	0.9863	0.9862	0.9863
46	0.9801	0.9800	0.9801	0.9799	0.9800
47	0.9800	0.9799	0.9800	0.9799	0.9800
48	0.9801	0.9800	0.9801	0.9799	0.9800
49	0.9784	0.9783	0.9784	0.9783	0.9784
50	0.9782	0.9781	0.9782	0.9781	0.9782
51	0.9774	0.9773	0.9774	0.9773	0.9774
52	0.9745	0.9744	0.9745	0.9743	0.9744
53	0.9701	0.9700	0.9701	0.9700	0.9701
54	0.9699	0.9698	0.9699	0.9697	0.9698
55	0.9693	0.9692	0.9693	0.9691	0.9692
56	0.9690	0.9689	0.9690	0.9689	0.9690
57	0.9688	0.9687	0.9688	0.9686	0.9687
58	0.9687	0.9686	0.9687	0.9686	0.9687
59	0.9784	0.9783	0.9784	0.9783	0.9784
60	0.9782	0.9781	0.9782	0.9781	0.9782
61	0.9692	0.9691	0.9692	0.9691	0.9692
62	0.9691	0.9690	0.9691	0.9690	0.9691
63	0.9687	0.9686	0.9687	0.9686	0.9687
64	0.9800	0.9799	0.9800	0.9799	0.9800
65	0.9799	0.9798	0.9799	0.9798	0.9799
66	0.9799	0.9798	0.9799	0.9797	0.9798
67	0.9795	0.9794	0.9795	0.9794	0.9795
68	0.9795	0.9794	0.9795	0.9794	0.9795
69	0.9794	0.9793	0.9794	0.9793	0.9794
70	0.9791	0.9790	0.9791	0.9790	0.9791
71	0.9789	0.9788	0.9789	0.9788	0.9789
72	0.9788	0.9787	0.9788	0.9787	0.9788
73	0.9786	0.9785	0.9786	0.9785	0.9785
74	0.9786	0.9784	0.9786	0.9784	0.9785
75	0.9786	0.9785	0.9786	0.9784	0.9785
76	0.9786	0.9785	0.9786	0.9784	0.9785

77	0.9786	0.9785	0.9786	0.9784	0.9785
78	0.9785	0.9784	0.9785	0.9784	0.9785
79	0.9786	0.9785	0.9786	0.9784	0.9785
80	0.9785	0.9784	0.9785	0.9784	0.9785