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Optimal Placement of Electric Vehicle Charging Station and Shunt Capacitor in Radial Distribution System

By

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A THESIS

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APPROVAL PAGE

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Optimal Placement of Electric Vehicle Charging Station and Shunt Capacitor in Radial Distribution System**" submitted by **Shri Krishna Shrestha** in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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DECLARATION

I hereby declare that the thesis entitled "**Optimal Placement of Electric Vehicle Charging Station and Shunt Capacitor in Radial Distribution System**" submitted to the Department of Mechanical and Aerospace Engineering in partial fulfillment of the requirement for the degree of Master of Science in Renewable Energy Engineering, is a record of an original work done under the guidance of Asst. Prof. Yuvraj Adhikari and Asst. Prof. Tek Raj Subedi, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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ABSTRACT

Increasing sensitivity to climate change and rising fuel prices led to a greater demand for cleaner and sustainable energy sources. Technological advancement and environmental awareness are the main driving force in the transition from conventional vehicle to the electric vehicle. The rapid growth of electric vehicles has prompted the need for an efficient charging infrastructure. The integration of charging stations in the current distribution system is a critical aspect of promoting electric vehicle adoption as it poses threat to the grid stability and reliability. Active and reactive power demand of electric vehicle charging station increases the power loss in the existing distribution system and degrade the voltage profile of the individual buses. Hence, researchers are committed to optimize the integration of EVCS in the distribution system.

This study puts forward the application of genetic algorithm for the optimal placement of EVCS by formulating the objective function minimizing the voltage sensitivity index, reliability indices like ENS, AENS, SAIDI, SAIFI and CAIDI as well as active power losses. Further, using the GA, optimal placement and sizing of shunt capacitor has been proposed to improve the voltage profile and reduce the losses in EVCS integrated system. The optimization task has been performed in MATLAB. Initially, optimization work has been formulated for IEEE 33 bus system. The effectiveness has been validated by collating the voltage profile, active power loss and reactive power loss of base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor in EVCS merged system. Later the work has been authenticated in the Jawalakhel feeder. The optimal location of EVCS has been determined at bus no 2, 19 and 20 in IEEE 33 system and at bus no 3, 4 and 25 in Jawalakhel feeder. Similarly the buses for the installation of shunt capacitor of sizes 472.4 kVAR and 1061.3 kVAR is ascertained at 12 and 30 in IEEE 33 bus and 1244.4 kVAR and 1786.7 kVAR at bus 6 and 20 in Jawalakhel feeder. From the comparative study the voltage profile has appreciably enhanced by the optimal placement of EVCS and capacitor. The total active and reactive power losses reduced from 0.2027 MW to 0.1168 MW and 0.135 MVAR to 0.07 MVAR in IEEE 33 bus system and reduced from 0.177 MW to 0.1378 MW and 0.238 MVAR to 0.1853 MVAR in Jawalakhel feeder.

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LIST OF ABBREVIATION

AC	Alternating Current
BMA	Balanced May Fly Algorithm
CAIDI	Customer Average Interruption Duration Index
ENS	Energy Not Served
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
GA	Genetic Algorithm
GIS	Geographic Information System
ICE	Internal Combustion Engine
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
NEA	Nepal Electricity Authority
PSO	Particle Swarm Optimization
RDS	Radial Distribution System
SAE	Society of Automobile Engineers
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
VRP	Voltage Reliability Power loss
VSF	Voltage Sensitivity Factor

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

In the automotive industry which is hugely relying on the traditional fossil fuel based energy source, the inception of electric vehicles (EVs) marks a pivotal turning point. The importance of transitioning away from fossil fuel-powered vehicles to renewable energy based vehicles is mainly driven by the growing concerns about declining fossil fuels sources, climate change and zero emission to reduce greenhouse gases. Remarkable advancements in battery technology of EVs in recent years, which have led to improved range, faster charging time and cost effectiveness have also fueled the governments, businesses and consumers to shift towards EVs. Fuel price escalation along with adverse impacts of consumption of those fuels necessitate the adoption of alternative energy sources. As a result of these, the future energy requirements for transportation are changing toward electrification using sustainable energy sources. As charging infrastructure becomes more widespread and accessible, and public awareness of environmental issues rises, the adoption of electric vehicles continues to gain momentum in the world.

With the increase in the use of EVs, requirement of properly planned charging stations in the existing distribution system is indispensable which can handle the rapidly increasing use of EVs. Integrating electric vehicle charging stations (EVCS) into radial distribution systems presents multiple challenges that needs to be addressed to ensure a smooth and efficient transition to widespread electric mobility. The addition of EVCS can lead to concentrated loads in certain areas of the distribution system. This uneven distribution of load can cause voltage fluctuations and overload issues, potentially leading to power outages, voltage instability and unpredictability of active and reactive power depending upon the intermittent load demand of EVCS which will affect the stability and reliability of the distribution system. The voltage stability, dependability, and other operating aspects of the electric distribution system will improve with the well-planned deployment of charging stations for electric vehicles. The existing radial distribution systems may not have the capacity to handle the increased demand from EV charging stations. Hence optimal placement of charging station without compromising of grid stability, reliability and power quality needs to be adopted along with additional compensating devices.

In the context of Nepal, the electric vehicle (EV) market is showing promising signs of growth and potential. In order to take advantage of Nepal's hydroelectric potential, the government of Nepal is committed to promoting EVs as long-term clean transportation alternatives (National Transport Policy, 2001). For the country like Nepal whose energy production is hugely dependent on hydroelectricity, the widespread adoption of EVs will help to eliminate the ICE based vehicle which can make the country self-dependent in energy sector.

The concept of EV is not new in Nepal, beginning 1975, electric trolleybus used to operate from Tripureshwor to Suryabinayak, 13 km route which was permanently removed from service in 2009. And Since 1996, safa tempos, battery operated is running in the streets of Kathmandu Valley. In the initial phase, EV industry failed to establish due to several reasons which resulted in its ultimate downfall. But after 2015, statistics have shown that EV is expanding year by year in private and public transportation in Nepal. Taking considerations of these facts, Nepal Electricity Authority (NEA) and other private companies have installed charging stations at different locations of the country and are preparing to extend the charging network to every corner of the country along with the increasing utilization of EVs. It is planned to install around 750 charging stations of different types within 5 years at different locations of the country. The Nepal government has also made an effort to encourage people to procure EVs. To encourage the use of electric vehicles and reduce reliance on fossil fuels, the government has put in place a number of policies. The collective efforts of various stakeholders in promoting and supporting the use of EVs signal a promising and sustainable future for transportation, where clean, efficient, and zero-emission vehicles play a vital role in mitigating the impacts of climate change. However, the government can and ought to be doing much more to encourage Nepalese citizens to convert to electric vehicles. First off, with careful planning and thorough analysis of the current distribution system, the government is able to construct charging stations. As per a recent research by Bloomberg New Energy Finance, battery prices are expected to decrease to USD 73 per kilowatt-hour by 2030. Moreover, battery efficiency is also rising at an incredibly quick pace. The global trend towards electric vehicles is anticipated to benefit Nepal's EV sector. And the number of EV users will rise in the near future if the government makes sure that it truly reaches its electricity-production targets and if it works to support the EV industry for a few more years. As battery technology advances, one of the main demands of contemporary society is the transition to electrical vehicles. The availability of charging stations in strategic locations has become a challenge in and of itself, making it difficult for transportation users to adopt electric vehicles. Frequent charging and discharging of EVs can cause intermittent and sudden fluctuations in load, affecting the voltage profile in the distribution system. These fluctuations may impact voltage stability and require additional control mechanisms to maintain acceptable voltage levels. Initially, it used to take a while for the batteries to charge. These chargers are referred to as fast chargers because of their high current requirements and charging mechanism. These days, research is expanding into the topic of providing high-quality electricity for the charging station without sacrificing the current supply facility for other facilities. The purpose of this thesis is to present a method for positioning these fast chargers in a way that minimizes power loss and voltage drop, as well as to enhance the charging station's ability to supply power by compensating for power loss and voltage drop through the use of an appropriate compensation mechanism.

1.2 Problem Statement

The utilization of conventional vehicles has led to a rise in environmental pollution and the depletion of fossil fuels. These environmental concerns include, among other things, problems with greenhouse gas emissions, air pollution, and climate change. Because of this people are compelled to face many issues. The lack of planning to incorporate EVCS into the current distribution system and the scarcity of charging stations make it difficult to make the switch to EVs. One major difficulty utilities and stakeholders in the fast changing environment of electric mobility confront is where to best locate charging stations for electric vehicles (EVs) in the distribution system. The integration of EV charging infrastructure into the existing distribution network requires careful consideration of multiple factors to ensure efficient, reliable, and sustainable operations. There is challenges in addressing power loss, voltage regulation, grid capacity constraints, and cost-effectiveness to create a robust charging network that accommodates the increasing demand for EVs while maintaining the overall stability and reliability of the distribution system. Since the introduction of charging stations have made Electric Vehicle a suitable alternative at current scenario, however, there are very few research conducted which studies the impact of integrating charging station to the distribution system. To facilitate a smooth transition to electric mobility and support the sustainable development of transportation systems, a study focusing on the optimization of charging station placement in the current distribution system using a tried-and-true algorithm may provide fresh insight into the dynamics of EVCS integration. After the integration of EVCS in the existing system, it causes the degradation in the voltage profile and increase in power loss of the system. So, it is required to connect the compensation devices of suitable size and at appropriate nodes in the system to mitigate the effects of EVCS integration.

1.3 Objectives

The main objective of the research is to determine the optimal placement of Electric Vehicle Charging Station and shunt capacitor using GA in radial distribution system.

Specific Objectives:

- To study and find the optimal location of EVCS in the IEEE 33 bus system and Jawalakhel feeder, RDS within Nepal.
- To analyze the power loss and voltage profile of the RDS in different scenarios of EVCS placement.
- To observe how the radial distribution system's reliability indices are affected by the optimal placement of EVCS.
- To estimate the size of shunt capacitor and analyze the voltage profile correction along with power loss reduction after shunt capacitor placement in EVCS integrated system.

1.4 Limitations

The research work has been carried out for obtaining the best possible results from simulations. However, following limitations has either been identified or may appear under the course of this research work.

1.4.1 Technology

The study considers only the fast-charging station. The size and characteristics of fast charging station are based on the published literatures. There exists a gap between manufacturer’s data and literature data. This work only considers the data given in the literature. The research on optimization or development or design of energy efficient fast chargers is beyond the scope of this thesis. This research output is based on the Genetic Algorithm which might differ from other optimization techniques. Algorithm is based on considering the voltage, reliability and power only during optimization.

1.4.2 Sample size

The feeders in distribution grid considered are of IEEE 33 bus system and Jawalakhel feeder of Lagankhel Distribution System. It may not be suitable to acclaim that the research output shall be valid for other distribution networks of Nepal as well since this study only focuses in one part of the distribution system. This research shall, however, identify further research areas in this particular field that may take this research further in upcoming years. Consideration of more than one distribution center could take a lot of time and the study may not be completed in the provided time-period.

1.5 Report Organization

The thesis has been categorized into five main chapters.

Chapter 1 gives the brief introduction regarding the necessity of switch from traditional fossil fuel based transportation to EVs considering environmental factor and technological advancement and highlighting the problem faced during the grid integration of EVCS in existing distribution system and its solutions.

Chapter 2 gives the overview of the literature review on the need of proper interconnection of EVCS in the distribution network, impact of incorporation in current distribution network and various researches regarding optimal placement of EVCS in the distribution network along with the installation of appropriate size of shunt capacitor to mitigate the impact emerged due to deployment of EVCS in ongoing distribution network.

Chapter 3 provides the overview of the research methodology, the formulation of the optimization problem, the solution algorithm, and the algorithm implementation of GA for finding out the optimum position EVCS plus sizing and placement of shunt capacitor in MATLAB software.

Chapter 4 discusses simulation results obtained from MATLAB and performs output analysis.

Chapter 5 presents the conclusion of this thesis work.

Finally, thesis ends with the list of references followed by the appendices of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

After the discovery of electric vehicles as the potential replacement for fossil fuel based vehicle, it is of major concern and topic of research regarding the energy storage and charging infrastructure of electric vehicle. For the overall convenience of the user and the power utility grid, it is required to integrate the EVCS in the existing distribution network without compromising the grid stability and reliability. Multiple researches have been conducted to study the impact of incorporating the charging station in the distribution network, various methods and algorithms have been developed to address the issue of optimal placement of charging station. Charly et al. [1] have proposed the deployment of EVCS using Geographic Information System (GIS) based approach considering the charging infrastructure. Ademulegan et al. [2] have mentioned in their paper that random placement of charging station might negatively hamper the step towards carbon free transportation. Thiringer et al. [3] have discussed about the impact on the power quality of the distribution network caused by the battery charging infrastructure of electric vehicle. In the paper published by Boonraksa et al. [4], it has highlighted the issue about the voltage stability, reliability and power loss of distribution network to be taken into consideration for the positioning of charging station. For the optimal placement, comprehensive planning models are available which are discussed in the paper published by Singh et al. [5], where they have described about the scheduling of charging activity. Ahmad et al. [6], optimization techniques according to the objective functions, constraints, load modelling, V2G strategy has been reviewed. Mohanty et al. [7], have proposed the fuzzy logic based multi-objective approach for optimal allocation of EVCS, where it is demonstrated that the optimal placement has resulted the reduction of active power loss to 89.65% and the minimum voltage being improved to 0.987 p.u. This paper is the perfect example that proper placement can reduce the power loss and improve the voltage profile of the distribution system compared to the random placement. Rene et al. [8], proposed the hybrid genetic algorithm and particle swarm optimization (GA-PSO) for the optimal allocation of plug-in EVCS along with distributed generation (DG) minimizing the active and reactive power losses as well as the voltage deviation index. Chen et al. [9] have deployed the Balanced Mayfly Algorithm (BMA) in the distribution system of

Allahabad, India considering Voltage Profile Improvement Index (VPII), Reactive Power Loss Index (QLRI), Real Power Loss Reduction Index (PLRI) and the initial installation cost for the optimal placement of EVCS. In [7], [8] and [9], it is mentioned about the impact of EVCS integration in voltage, active power and reactive power of the radial distribution system. Various methods have been researched and implemented to reduce these impacts on the distribution network but it can be clearly identified that it is not possible to improve the voltage and power index of the grid without proper compensating devices to be placed along with EVCS for the enhanced performance of the network. For that Chaudhary et al. [10], have presented the solution through V2G during peak loading period to maintain the reliability of the distribution system. Abou El-Ela et al. [11] have presented the ant colony optimization algorithm considering the loss sensitivity analysis to identify the best location and size of capacitors in radial distribution system. Lee et al. [12] have suggested the capacitor placement using particle swarm optimization algorithm based on Gaussian and Cauchy probability distribution functions. Raju et al. [13] introduced the method based on direct search algorithm to identify the buses to place capacitors considering to minimize the active power loss and maximize the net savings. Tamilselvan et al. [14] have proposed the flower pollination algorithm for the capacitor placement in radial distribution system. Asakarzadeh [15] developed metaheuristic technique known as crow search algorithm to find out the best position in distribution network for shunt capacitors for power loss reduction and voltage improvement. Since power loss and voltage of buses in radial distribution system is the major consideration for the sizing of capacitors and placement, Lohia et al [16] have presented the optimal placement and sizing of shunt capacitor in the distribution network which helps to efficiently helps to reduce the losses in the network using genetic algorithm (GA).

2.2 Classification of distribution system

Based on the orientation of the system, the distribution network is classified into three categories. [17]

a) Radial Distribution System (RDS)

   In this type of system, there is the substation at one end and the single lateral line that will supplies the load to the consumer side as shown in the Figure 2-1.

As depicted in the figure, between the source and the load, there will be the single path that will feed them with required amount of power. Since there is only one path between the source and load, the reliability of the system is too low. If any fault occurs in between the system, whole system will go under successive collapse. However, the initial cost of the RDS system is minimal with compared to other systems and also it is very simple to design, plan and operate.

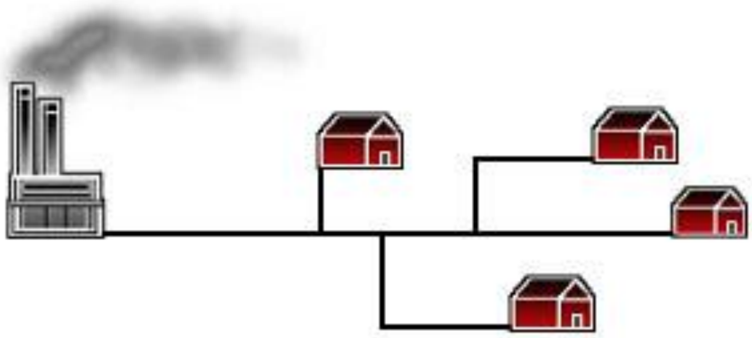

Figure 2-1 Overview of RDS system

b) Loop Distribution System

The load is managed to supply with two parallel paths from the substation as shown in the Figure 2.2. The size of the bus bar is taken to carry the more than the full load as if any one-line outage occurs, it has to carry double of its initial power demand. It has higher system reliability and availability. Also, it causes the lower voltage fluctuations and so have better regulation. As contrast to the design of a RDS system, it is more complicated and also it is more expensive as compared to the RDS system.

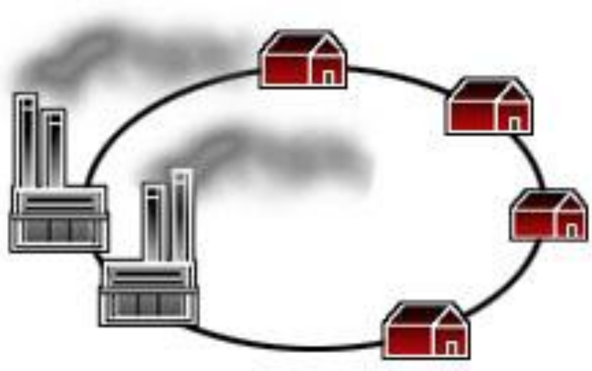

Figure 2-2 Loop Distribution System

c) Network Distribution System

The consumer is supplied with more than two path from the substation. There will be more than single substation in the system and so that the supply reliability of the network is so high. As it forms the interconnected system, the fault impedance becomes too low as it will increase the inertia so the stability of the system. The network configuration is so large and it cost more than that of the radial and loop system. Designing and operating it is more complicated than radial or loop systems. Also, it is more efficient and losses are too low for these cases. The network configuration is as shown in the Figure 2.3 below.

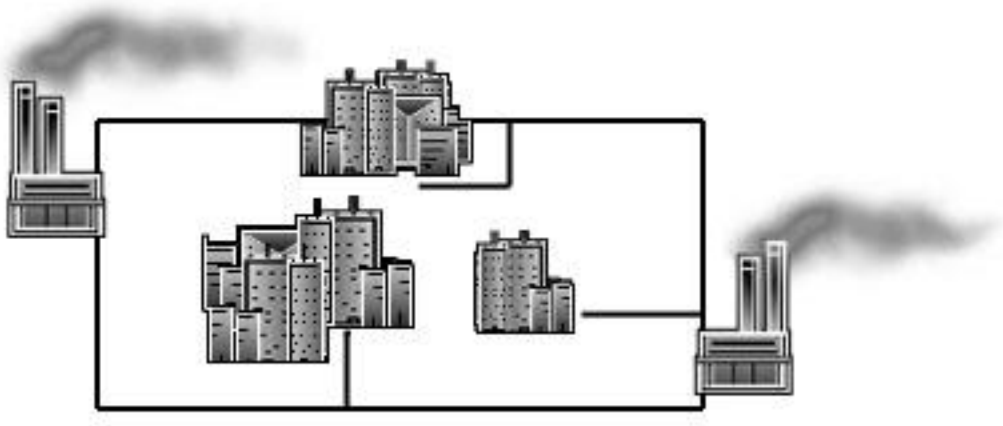

Figure 2-3 Network Distribution System

2.3 Electric Vehicle and Charging Station

2.3.1 History of Electric Vehicle

Electric vehicle are electrically powered automobile with energy storing devices to be periodically charged with zero tailpipe emissions making them environmental friendly means of transportation. In the early 1800, EV was emerged as the means of transportation which was limited by the battery technology at that time. After numerous inventions in the field of EV battery storage, in the early 20^{th} Century, EV could not gain much popularity due to lack of electricity grids so were limited to delivery trucks, taxis and industrial applications [18]. Concerns about air pollution, global warming, and dependence on fossil fuels rekindled interest in electric vehicles in the early 2000. Advances in battery technology, particularly with the development of lithium-ion batteries, significantly improved the energy storage capacity of electric vehicles, enabling longer driving ranges and faster charging times. In 2008, Tesla Motors introduced the Tesla Roadster, an all-electric sports car based on the Lotus Elise chassis.

The Roadster proved that electric vehicles could be high-performance, appealing to enthusiasts and mainstream consumers alike [19]. Countries around the world have started offering subsidies to promote the acquisition of EVs to replace the ICE vehicle. Presently, there are multiple companies engaged in the production of EVs and adoption of EVs have increased demand in the world vehicle market including Nepal. Use of EVs in private and public transportation has been increased exponentially in recent years in Nepal and projected to increase in future observing the recent trends. Reconfiguration in the distribution network is of major concern addressing the integration of charging station. Since the distribution network is owned by Nepal Electricity Authority (NEA), NEA supported by Asian Development Bank (ADB) have planned to expand the EV charging infrastructure deployment to different locations in the coming years. This would require unlocking avenues for private sector investments in Nepal through innovative business models. ADB aims to continue its support to Government of Nepal in this endeavor.

2.3.2 Fundamentals of Electric Vehicle

The fundamental components of EV includes electric motor, battery pack, charging port, power electronics, regenerative braking system and power converter.

a. Electric Motor: The electric motor is the primary source of propulsion in an EV. It converts electrical energy from the battery into mechanical energy, driving the wheels to move the vehicle forward.

b. Battery Pack: The battery pack serves as the energy storage system for an electric vehicle. It is usually made up of multiple lithium-ion cells arranged in a series and parallel configuration. The battery pack's capacity determines the driving range of the EV.

c. Charging Port: Electric vehicles are recharged through a charging port located on the vehicle's exterior. There are various charging options, ranging from standard household outlets to high-power fast chargers available in public charging stations.

d. Power Electronics: The power electronics system in an EV controls the flow of electrical energy between the battery pack and the electric motor. It manages voltage, current, and power distribution to ensure optimal performance and efficiency.

e. Regenerative Braking System: EVs often incorporate regenerative braking technology, which recaptures and stores energy that would otherwise be lost during braking. This energy is sent back to the battery, improving overall efficiency and extending the driving range.

f. Power Converter: The power converter manages the conversion of alternating current (AC) from the grid into direct current (DC) for charging the vehicle's battery.

The Electric vehicle can be mainly categorized into two parts, which are:

a. Battery Electric Vehicles (BEVs): These vehicles are solely powered by electricity. They have a large battery pack installed in the vehicle that stores electrical energy. The battery powers an electric motor, which drives the wheels, propelling the vehicle forward. BEVs are fully charged by plugging them into an electric power source, such as a charging station or a regular electrical outlet.

b. Plug-in Hybrid Electric Vehicles (PHEVs): PHEVs combine both an electric motor and an internal combustion engine. They have a smaller battery pack than BEVs and can be charged using an electric power source. PHEVs can also utilize the internal combustion engine when the battery charge is depleted, giving them an extended range compared to BEVs.

2.3.3 Electric Vehicle Charging Station (EVCS)

An EVCS is a dedicated infrastructure that allows electric vehicles to recharge their batteries. These stations are essential for the widespread adoption of electric vehicles as they provide a convenient and reliable way for EV owners to charge their vehicles away from home. There are different types of EV charging stations with varying charging speeds and capabilities. Level 1, Level 2, and Level 3 are the three levels of electric vehicle charging systems that are based on how long it takes to charge the vehicle. Higher levels correspond to faster charging [20]. A brief overview of the charging duration and standard used by three well-known battery-electric vehicles at the aforementioned levels is provided in Table 2.1.

Table 2.1 Charging time and Standard of popular Electric Cars [20]

Vehicle	Level 1	Level 2	Level 3 (80%)	Fast Charging Standard
2018 Nissan Leaf	28.5 hours	6 hours	40 minutes	ChaDeMo
2018 Chevy Bolt	43 hours	8.5 hours	60 minutes	CCS
2018 Tesla Model 3 Long Range	50 hours	6 hours	40 minutes	Tesla Supercharger (V2)

i. Level 1 Charging: This is the slowest form of charging and uses a standard household outlet (120 volts in the US). Level 1 charging is usually the most basic option, but it is the least efficient and takes the longest time to charge an EV fully.

ii. Level 2 Charging: This is a faster charging option that can be supplied either from 230 V, 1 phase or 400 V, 3 phase supply system and is often installed in public locations. Level 2 charging stations can significantly reduce charging times compared to Level 1.

iii. DC Fast Charging or Level 3 Charging: Level 3 charging is basically a dc based fast charging method and can provide more than a 100 kW of charger capacity which provide rapid charging and are ideal for long-distance travel. They can deliver a high-voltage DC current directly to the vehicle's battery, drastically reducing charging times compared to Level 1 and Level 2 charging.

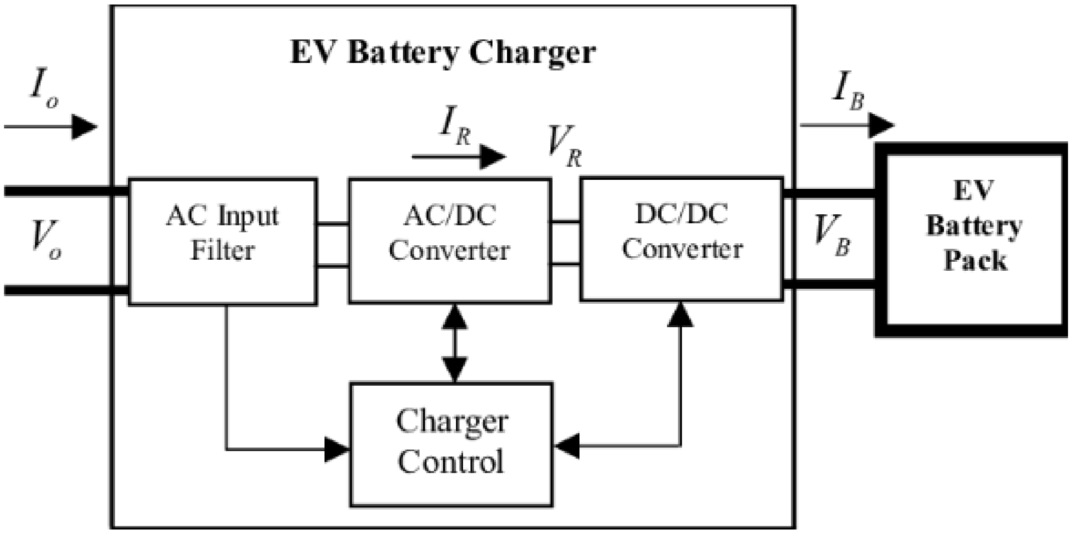

Figure 2-4 Block Diagram of Level 3 Charger [21]

Typical uses, charger location, power input system, as mentioned in the SAE Standard J1772 is presented in Table 2.2.

Table 2.2 Charging levels of the SAE standard J1772 [22]

Level	Input voltage and current	Charger location, Phases	Typical use
AC Level 1	120 VAC-15A (12 A useable)	On-board 1-phase	Home or office
	120 VAC-20A (16 A useable)		
AC Level 2	240 VAC-40 A (32 A useable)	On-board 1-phase/3-phase	Private or public outlets
	400 VAC-80 A (64 A useable)		
DC Level 1	208 VAC-80 A (64 A useable)	Off-board 3-phase	Public, commercial
	600 VAC-80 A (64 A useable)		
DC Level 2	208 VAC-200A (160 A	Off-board	Public, commercial

	useable) 600 VAC-200A (160 A useable)	3-phase	
DC Level 3	208-600 VAC (>200 A)	Off-board 3 phase	Public, commercial

With time various standards are emerging for charging of Electric Vehicles. Society of Automobile Engineers (SAE) has developed various standards for charging cable types, safety and charging methods of the electric vehicle. SAE J1772 reports the different connectors for ac charging as well as dc fast charging system of the Electric Vehicles. International Electro-technical Commission (IEC) has also stepped in to develop the standards for Electric vehicle charging. IEC 61851 series explains the cable and plug setups, safety and communication for charging system. SAE J2293, J2847 and J2344 are other standards from SAE that lay out the communication between the charger and the vehicle as well as the safety concerns in Electric Vehicle Charging. IEC 60364 is often found to be used for electrical vehicle charger installation for household use. This standard is applicable for electrical installations in the building. Table 2.3 presents the summary for different standards applicable for Electric Vehicle Charging Standards. [22]

Table 2.3 Summary of Electric Vehicle Charging Standards [22]

S.N.	Standards		Scope
1	IEC 61851: conductive charging systems		Defines cables and plug setups
		IEC 61851-1 IEC 61851-23	Describes electrical safety, harmonics, grid connection, and communication architecture for DCFC station (DCFCS)
		IEC 61851-24	Explains digital communication for DC charging control
2	IEC 62196: Plugs, socket-outlets, vehicle connectors and	IEC 62196-1	Explains general requirements for EV connectors
		IEC 62196-2	Describes coupler types for different charging modes

S.N.	Standards		Scope
	inlets	IEC 62196-3	Defines connectors and inlets for DCFCS
34	IEC 60309-Plugs, socket-outlets and couplers	IEC 60309-1 IEC 60309-2	Explains general requirements for CS
			Describes different sizes of plugs and sockets with different number of pins based on current supply and number of phases, also defines color coded connector based on voltage range and frequency
4	IEC 60364		Describes about electrical installations for buildings
5	SAE J1772: conductive charging systems		Defines connectors for AC charging Describes new Combo connector for DCFCS
6	SAE J2847: Communication	SAE J2847-1 SAE J2847-2	Describes the communication medium and criteria for the EV to connect to the utility for AC Level 1 and AC Level 2 energy transfer
			Define additional messages for DC energy transfer
7	SAE J2293,	SAE J2293-1	Describes the total EV energy transfer system and allocates requirements to the EV or EVSE for the various system architectures
8	SAE J2344		Describes guidelines for electric vehicle safety
9	SAE J2954:inductive charging		Under development

2.4 Integration of EVCS in Distribution Network

The integration of electric vehicle (EV) charging stations into the distribution network presents both opportunities and challenges for utilities and grid operators. Load Management and Grid Planning, Distribution System Upgrades, Renewable Energy Integration, Energy Storage Solutions, Monitoring and Data Analytics and Regulatory Support are some of the major considerations to be taken care of for the successful integration of EVCS into the distribution network. Installation of EV charger in electric power system impacts the operation of the power system.

2.4.1 Positive Impact of Integrating EVCS in Distribution Network

- Reduced Greenhouse Gas Emissions
- Diversification of Energy Sources
- Load Balancing and Demand Response
- Grid Stabilization through Vehicle-to-Grid (V2G) Technology
- Reduced Energy Losses
- Promotion of Sustainable Transportation

2.4.2 Negative Impact of Integrating EVCS in Distribution Network

- Increased Peak Demand
- Remodeling of Distribution Network
- Impact on Distribution Transformers
- Grid Congestion
- Electricity Demand Forecasting Challenges
- Increase in the Line Losses
- Node Voltage Deviations

Some of the negative impact of EVCS and its remedies are highlighted in [22]

Table 2.4 Negative impact and remedy measures of charging station

Negative Impact	Remedy measures
Voltage Stability	• Application of wide area control method to damp out the oscillations • Adaptation of tap changing transformer to control the voltage
Increased peak demand	• Use of smart charging system • Use of controlled charging system
Power quality problems	• Application of smart grid compatible power conditioning unit for controlled charging • Installation of harmonic filter in supply side • Installation of smart appliances passive filter banks • Application of smart grid with load management strategy
Increased power loss	• Application of coordinated charging • Introduction of uniformly distributed charging system
Transformer Overloading	• Use of smart load management strategy • Application of K-factor de-rating method

Along with the above remedies, one of the most common remedy is to place the shunt capacitors in the distribution network to mitigate the power loss and voltage fluctuations created by the integration of EVCS in distribution network. To address the loss reduction and voltage profile improvement, the distribution systems are normally equipped with shunt capacitors for reactive power compensation [23].

2.5 Optimal Placement of EVCS in Distribution Network

In power system studies there is a dearth of indices giving information about the three main operating parameters like voltage stability, reliability, and power losses together. As a result, in this study, a new measure called the Voltage Stability, Reliability, and Power Loss (VRP) index is developed. Following any kind of disruption to the network, this index provides details on the distribution network's three primary operating characteristics. This index can be applied for:

- Optimal placement of charging stations.

- Distribution network planning in presence of distributed generation.
- Microgrid planning.
- Reconfiguration of distribution networks.

The primary goal of the charging station placement challenge is to distribute EVCS throughout the distribution network as optimally as possible while minimizing any negative effects on the distribution network's operational characteristics. Consequently, the VRP index is selected as the objective function for the EVCS placement issue because to its ability to integrate variables including power losses, voltage stability, and dependability.

The VRP index's mathematical formulation is demonstrated as:

The objective function [24] is

$$min\ (VRP)\ = w_1 A + w_2 B + w_3 C$$

Where,

$$VRP = f(d, f)$$

$$d = buses\ of\ the\ distribution\ network\ where\ EVCS\ will\ be\ placed$$

$$f = Number\ of\ fast\ charging\ stations\ placed\ at\ the\ buses$$

Subject to following constraint:

$$0 \leq n_i \leq n_{fastCS}$$

Where,

$A = \frac{1}{a}$ and $a = \frac{VSI_i}{VSI_{base}}$

$$B = w_{21}\frac{SAIFI_i}{SAIFI_{base}} + w_{22}\frac{SAIDI_i}{SAIDI_{base}} + w_{23}\frac{CAIDI_i}{CAIDI_{base}}$$

$$C = \frac{P_{loss}^{l}}{P_{base}}$$

The preceding formula uses the following notations: i is the bus index, VSI stands for voltage stability index, n_i is the number of charging stations in the i_thbus, and n_fast is the maximum number of fast charging outlets that may be installed at each bus is known as n_fastCS. [24] further provides the dependability indices that may be used to choose the best site. Algorithms are utilized in optimizations after the objective function is formulated. The ideal location for EVs has been the subject of several research employing a variety of optimization techniques. [22] have outlined many methods that are currently in use for the best location of EV charging stations. They are presented here in Table 2.5.

Table 2.5 Optimization Algorithms used in Optimal Placement of EV Charging Station

S.N.	Algorithm	Benefits
1	Genetic Algorithm	Easy to implement, suitable for placement problems as it is originally a describe algorithm
2	Particle Swarm Optimization	Simple computation and ability to find near optimal solution
3	Ant Colony Optimization	Positive feedback accounts for rapid discovery of good solutions
4	Greedy Algorithm	Fast and guaranteed to produce feasible solution
5	Integer (linear) Programming	Simple and solve many diverse combinations of problems

Since the objective functions are nonlinear and non-continuous, the artificial intelligence-based optimization techniques such as genetic algorithm, particle swarm optimization, may fly algorithm, ant colony optimization etc. are suitable for this optimization problem. In many literatures, the use of genetic algorithms has received more attention than other optimization methods.

2.5.1 Genetic Algorithm

Genetic Algorithm (GA) is a popular optimization technique inspired by the principles of natural selection and evolution. It is used to solve complex problems that involve finding the best or near-optimal solutions from a large search space. Developed by John Holland and his colleagues in the 1970s and 1980s, genetic algorithms are part of a broader class of evolutionary algorithms [18]. The process of a genetic algorithm simulates the process of evolution and natural selection to improve a population of potential solutions iteratively. The algorithm evolves the population over generations, mimicking the principles of selection, crossover, and mutation.

Here's an overview of how a genetic algorithm typically works:

i. **Initialization**: Create an initial population of potential solutions (often referred to as "chromosomes" or "individuals"). These individuals usually represent possible solutions to the problem at hand and are encoded as strings, arrays, or other data structures.

ii. **Fitness Evaluation**: Each individual in the population is evaluated for its fitness, i.e., how well it solves the problem. The fitness function measures the quality of each solution, assigning a numerical value to it. The higher the fitness value, the better the solution.

iii. **Selection:** Individuals are selected from the population for the next generation based on their fitness. Solutions with higher fitness have a higher chance of being selected. The idea is to favor solutions that perform better, similar to natural selection where fitter individuals have a higher chance of survival.

iv. **Crossover (Recombination):** Selected individuals (parents) are combined to create new individuals (offspring) through crossover. Crossover involves exchanging parts of the parent solutions to create new solutions. This step introduces exploration and helps combine beneficial traits from different parents.

v. **Mutation:** In some cases, a random mutation operation is applied to the offspring. Mutation introduces small random changes to the solution, allowing the algorithm to explore different regions of the search space that might not be reachable through crossover alone.

vi. **Replacement:** The new offspring population replaces the old population, and the process continues from step 2 for the next generation.

The GA iterates through these steps for a predefined number of generations or until a termination condition is met (e.g., a satisfactory solution is found, or the maximum number of generations is reached). Genetic algorithms are applicable to a wide range of problems, such as optimization, scheduling, machine learning, and more. They are particularly useful when dealing with complex, non-linear, and multi-modal search spaces, where traditional optimization methods may struggle. Though powerful, genetic algorithms may require tuning of various parameters, such as population size, crossover rate, mutation rate, and selection mechanisms, to achieve optimal performance for a specific problem. They are also computationally intensive, especially for large-scale problems. However, their ability to find good solutions in complex spaces makes them a valuable tool in the field of optimization and artificial intelligence.

2.6 Modeling of Electric Vehicle Charging Station

A analytical load model is considered in which a dc fast charger consists of an active rectifier supply end and a buck converter at the battery end. The universal charger configuration is shown in Figure 2.5.

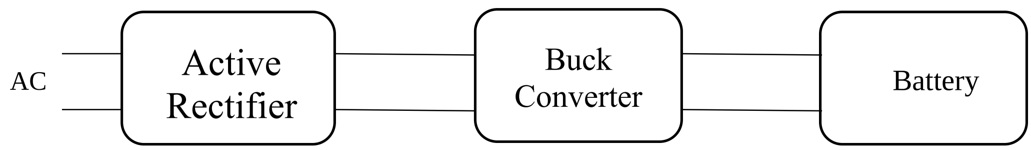

Figure 2-5 Block Diagram of universal charger configuration

Load modeling of EVCS requires the identification of load demand variation with respect to the supply voltage. The analytical derivation is used to establish the power voltage relationship as shown in figure 2.6

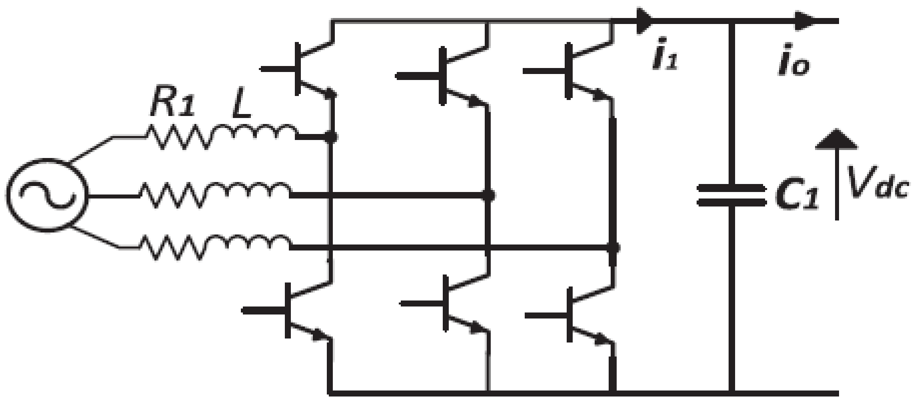

Figure 2-6 Schematic diagram of the controlled rectifier in the grid interface

The equation for the first stage active rectifier shown in figure 2.6 can be represented as follows [25]:

$$V_a = L\frac{di_a}{dt} + Ri_a + (2S_{11} - 1)\frac{V_{dc}}{2} + V_{no}$$

$$V_b = L\frac{di_b}{dt} + Ri_b + (2S_{12} - 1)\frac{V_{dc}}{2} + V_{no}$$

$$V_c = L\frac{di_c}{dt} + Ri_c + (2S_{13} - 1)\frac{V_{dc}}{2} + V_{no}$$

With dq transformation [26],

$$V_d = L\frac{di_d}{dt} + R_1 i_d - L\omega i_q + d_d V_{dc}$$

$$V_q = L\frac{di_q}{dt} + R_1 i_q + L\omega i_d + d_q V_{dc}$$

$$C_1\frac{dV_{dc}}{dt} = \frac{3}{2}\left(d_d i_d + d_q i_q\right) - i_0$$

R_1 refers the total resistance of rectifier switches. L is the inductance of input filter and V_d, V_q, i_d and i_q refers to direct axis and quadrature axis voltages and currents respectively. d_d and d_q refer the switching functions in dq model. In steady state,

$$V_d = R_1 i_d - L\omega i_q + d_d V_{dc}$$

$$V_q = R_1 i_q + L\omega i_d + d_q V_{dc}$$

$$i_0 = \frac{3}{2}\left(d_d i_d + d_q i_q\right)$$

Then the real and reactive power drawn by the charger is given by:

$$P = \frac{3}{2}\left(V_d i_d + V_q i_q\right)$$

$$Q = \frac{3}{2}\left(V_d i_q - V_q i_d\right)$$

The second stage of the charger consists of buck converter as shown in figure 2.7

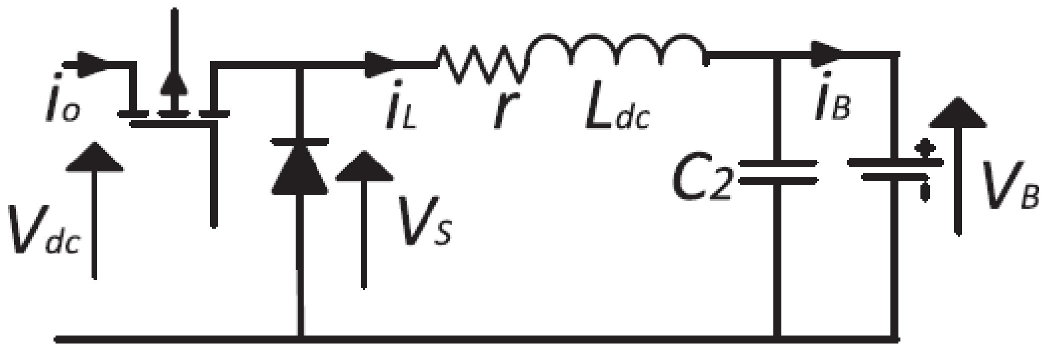

Figure 2-7 Buck converter in the dc-dc stage of the EVCS

$$V_s = V_B + L_{dc}\frac{di_L}{dt} + ri_L$$

$$i_L = i_B + C_2\frac{dV_B}{dt}$$

When EV is connected to the charger, the modelling of battery is done as variable voltage source connected in series with a resistor (R_{B1}) and parallel combination of capacitor and resistor (R_{B2}) as shown in figure 2-8.

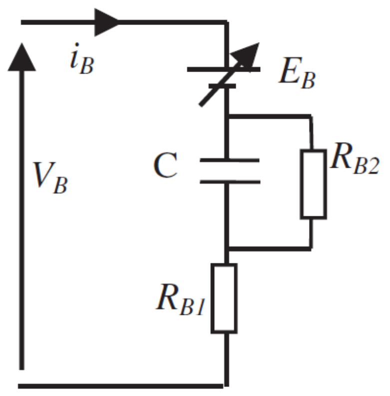

Figure 2-8 Equivalent circuit model of battery

For steady state analysis, battery equivalent becomes as resistor ($R_B = R_{B1} + R_{B2}$). The steady state representation is given by:

$$\mathrm{i_L} = \mathrm{i_B}$$

$$\mathrm{V_S} = \mathrm{E_B} + R_\mathrm{B}\mathrm{i_B} + r\mathrm{i_B}$$

It is assumed as lossless switching and continuous mode operation of buck converter. So, the steady state equation is given by,

$$\mathrm{i_B} = \frac{\mathrm{i_0}}{\mathrm{k}}$$

$$\mathrm{V}_s = k\mathrm{V}_{dc}$$

To incorporate the impedance of branches, simplified model of the charger connected to bus is shown in figure 2-8 [23].

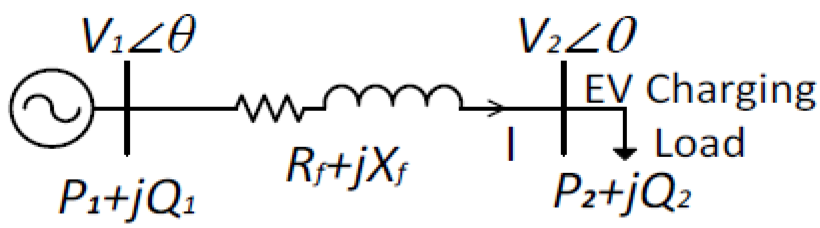

Figure 2-9 Model of charger connected to bus

where V_1, P_1 and Q_1 are voltage, real and reactive power input to the charger respectively and V_2, P_2 and Q_2 are voltage, real and reactive power respectively consumed by the charger at the load end. Complex power consumption by charger is given by,

$$V_2 I^* = P_2 + jQ_2$$

$$P_1 = P_2 + I^2 R_f$$

From above equations variations of P_1 with respect to V_1 is given by,

$$P_1 = P_2 + \frac{R_f(P_2{}^2 + Q_2{}^2)}{V_2{}^2}$$

From above equation of complex power,

$$V_1 V_2 cos\theta + jV_1 V_2 sin\theta \; = V_2{}^2 + (P_2 - jQ_2)(R_f + jX_f)$$

Where, $f(V_1) = (V_1{}^2 - 2P_2 R_f - 2Q_2 X_f)$

From above equation it is evident that the V_1 decreases with increase in P_2 and Q_2.

2.7 Reliability Indices of Distribution Network

The detail categorization of reliability indices [22] can be summarized in the following figure:

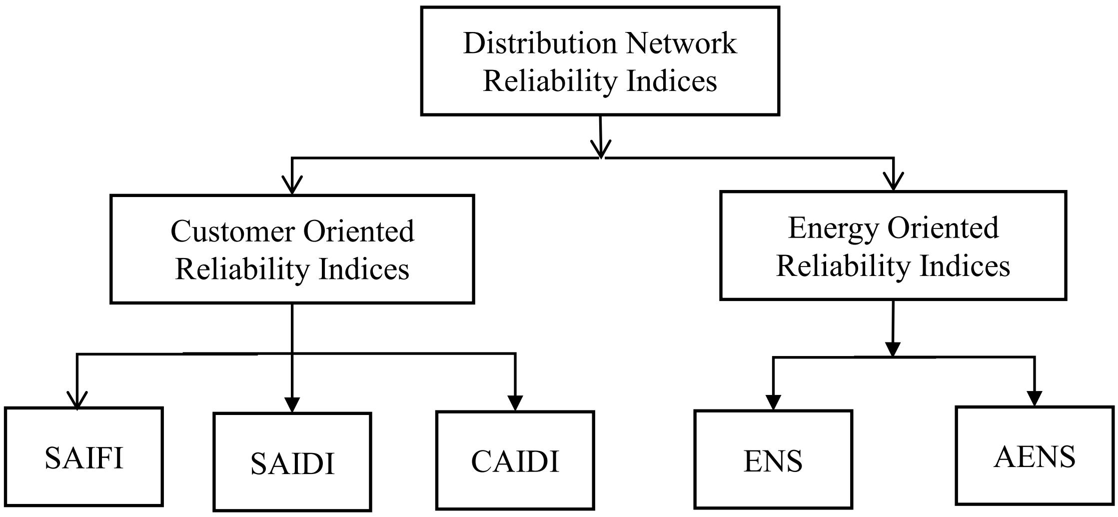

Figure 2-10 Reliability Indices of distribution network

These reliability indices of distribution network are discussed below:

2.7.1 SAIFI

It is defined as the number of times a system customer experiences interruption during a particular time period. It signifies the power system condition in terms of interruption.

$$SAIFI = \frac{\sum \lambda_j N_j}{\sum N_j}$$

2.7.2 SAIDI

It is defined as The average duration of an interruption for each client serviced. It also represents the interruption level of the power system.

$$SAIDI = \frac{\sum \mu_j N_j}{\sum N_j}$$

2.7.3 CAIDI

It is defined as the mean duration of interruptions for customers who experienced disruptions over the course of a year. It represents the typical length of an outage that every particular client will encounter.

$$CAIDI = \frac{\sum \mu_j N_j}{\sum \lambda_j N_j}$$

2.7.4 ENS

It is defined as the entire energy that the system is unable to supply. It serves as a signal for the system's energy shortage.

$$ENS = \sum L_j \mu_j$$

2.7.5 AENS

It is defined as the curtailment index for average system load. It provides an estimate of the amount of energy that is wasted at any given moment.

$$AENS = \frac{\sum L_j \mu_j}{\sum N_j}$$

Where,

N_j is number of customers at j^{th} bus.

λ_j is failure rate at j^{th} bus.

μ_j is interruption duration at j^{th} bus.

L_j is load at j^{th} bus.

2.7.6 Voltage Sensitivity Factor (VSF)

Voltage sensitivity factor is defined as the percentage relationship between voltage change and loading change, which represents the trend of voltage change with increasing active power.

$$VSF = \frac{|dV|}{|dP|} * 100\%$$

The high VSF value indicates that the simple change in loading causes considerable voltage drop.

2.8 Shunt Capacitor Placement in Distribution Network

A shunt capacitor is a common device used in distribution networks rated in KVAr to improve the power factor and voltage regulation. Integration of EVCS to the distribution network effects the voltage profile along with increase in active and reactive power losses. In RDS, EVCS can cause reactive power loss due to increased demand of power since reactive power is required to maintain the voltage levels. And even though, EVCS is active load, the converters used to charge the batteries can draw reactive power as the charging of capacitive components require reactive power. Its primary role is to provide reactive power compensation, which helps optimize the efficiency and performance of the distribution system. The major contribution of shunt capacitor in a distribution network are:

i. <u>Power Factor Improvement</u>: By connecting shunt capacitors across the distribution lines, the reactive power drawn by the load is offset by the capacitors, thereby improving the power factor closer to unity (1.0) reducing the voltage drop and power losses.

ii. <u>Reactive Power Compensation</u>: Shunt capacitors provide reactive power locally to the distribution system. By supplying reactive power from the capacitors, the distribution network can reduce the reactive power demand from the main power source, which can help relieve stress on generators and transformers.

iii. <u>Voltage Regulation</u>: When loads draw more reactive power, it causes a voltage drop in the distribution lines. By compensating for the reactive power with shunt capacitors, voltage levels are maintained within acceptable limits, ensuring proper functioning of connected equipment and minimizing voltage fluctuations.

iv. <u>Line Loss Reduction</u>: In a distribution network, power losses occur due to the resistance of the conductors. When the power factor is improved using shunt capacitors, the system's current reduces for the same amount of real power transmitted, resulting in reduced I^2R losses in the distribution lines.

v. <u>Increase in the power transfer capacity</u>: Improved power factor and reduced losses due to shunt capacitors increase the effective current-carrying capacity of the distribution network. This means that more real power can be transmitted through the existing infrastructure without overloading the conductors and transformers.

It is important to note that while shunt capacitors offer several benefits, their installation and sizing should be carefully planned and monitored to avoid overcompensation or resonance issues, which could lead to adverse effects on the system's performance. Proper system analysis, including load characteristics and power factor measurements, is essential for successful shunt capacitor deployment in a distribution network.

Typically, shunt capacitors are added to the main distribution system to lower power losses and enhance the buses' voltage profiles. The best position and rating for shunt capacitors should be determined in conjunction with the installation of EV charging infrastructure, as the EV infrastructure adds a load to the current distribution system [25] . In order to do so, it is necessary to develop an objective function that will lower power losses—both reactive and active—while also improving the voltage profile.

2.8.1 Load and Capacitor Model

The loads and capacitors are modeled as impedance [16]. The equation for the impedance model of loads and capacitors are given below:

$$Z_{loadi} = R_{loadi} + jX_{loadi}$$

i=1, 2, 3… N

Where,

N=No. of buses

$Z_{load\,i}$=*impedance of* i^{th} *bus*

$R_{load\,i}$=*resistance of* i^{th} *bus*

$X_{load\,i}$=*reactance of* i^{th}*bus*

In the distribution network, capacitive reactance of shunt capacitor neutralize the effect of inductive reactance which helps to minimize the losses and results in the voltage profile. Excessive capacitive reactive power will cause to inject the leading current which is unacceptable condition resulting the production of heating losses. Hence, proper objective function is proposed considering the balanced three phase system with time invariant loads. Mathematically, the presented objective function of the issue of the optimal placement is based on the minimization of the loss and deviation in voltage from the existing values. The definition of the objective function is given by [16].

$$F = W_1 X\, P_{loss} + W_2 X\, Q_{loss} + W_3\, X\, \sum_{i=1}^{n}(1 - v_i)^2$$

Where,

W_1, W_2 and W_3 are weights used in the objective function corresponding to active power loss, reactive power loss and voltage deviation.

P_{loss} is total active power loss and Q_{loss} is total reactive power loss in distribution network.

v_i is voltage magnitude at i^{th} bus of the radial distribution system

$v_{min} < |v_i| < v_{max}$ *; where* $|v_i|$ *is voltage magnitude of the of* i^{th} *bus,* v_{min} *is bus minimum voltage limit and* v_{max} *is bus maximum voltage limit.*

CHAPTER 3: METHODOLOGY

3.1 Research Design

Research Methodology is designed in such way to address the main objective of this thesis work with analyzing the problem statement and data collection considering the limitations in the course of study. The methodology adopted is summarized in the points below:

i. Problem formulation
ii. Literature review
iii. Identification of parameters
iv. Model development based on literature review
v. Data collection
vi. Optimization using GA in MATLAB
vii. Data analysis
    - Voltage profile
    - Reliability Indices
    - Power loss
viii. Documentation

With reference to the numerous research articles related to the title of this thesis work, objective function and optimization algorithm; GA has been identified considering the voltage, reliability and power loss (VRP) of the RDS. Initially the optimization algorithm is formulated in the IEEE 33 standard test system. After achieving the optimal placement of EVCS and sizing of shunt capacitor considering the voltage profile, power loss and reliability indices in the IEEE 33 system, overall procedure is carried out in the Jawalakhel feeder in Nepal to validate the study. Bus voltage, active power and reactive power demand of each buses along with resistance and reactance of each distribution section of considered feeder are taken as major variables for the analysis to achieve the objective of the research. For the analysis of IEEE 33 bus system and feeder of RDS, The case file for MATPOWER has been created using the info that is currently available. After modeling the EVCS load, the VRP index is further analyzed by allocating the appropriate weight. Genetic algorithms are used to formulate and optimize the EVCS placement problem. Load flow analysis is done of the system with the optimized location of EVCS. Shunt capacitors are sized and placed optimally in EVCS integrated system to reduce power losses and enhance the bus voltage profile. Because the Genetic Algorithm ensures convergence and the system is simple, it is employed in place of other optimization approaches. The flowchart shown in figure 3.1 demonstrate the basic methodology of this thesis.

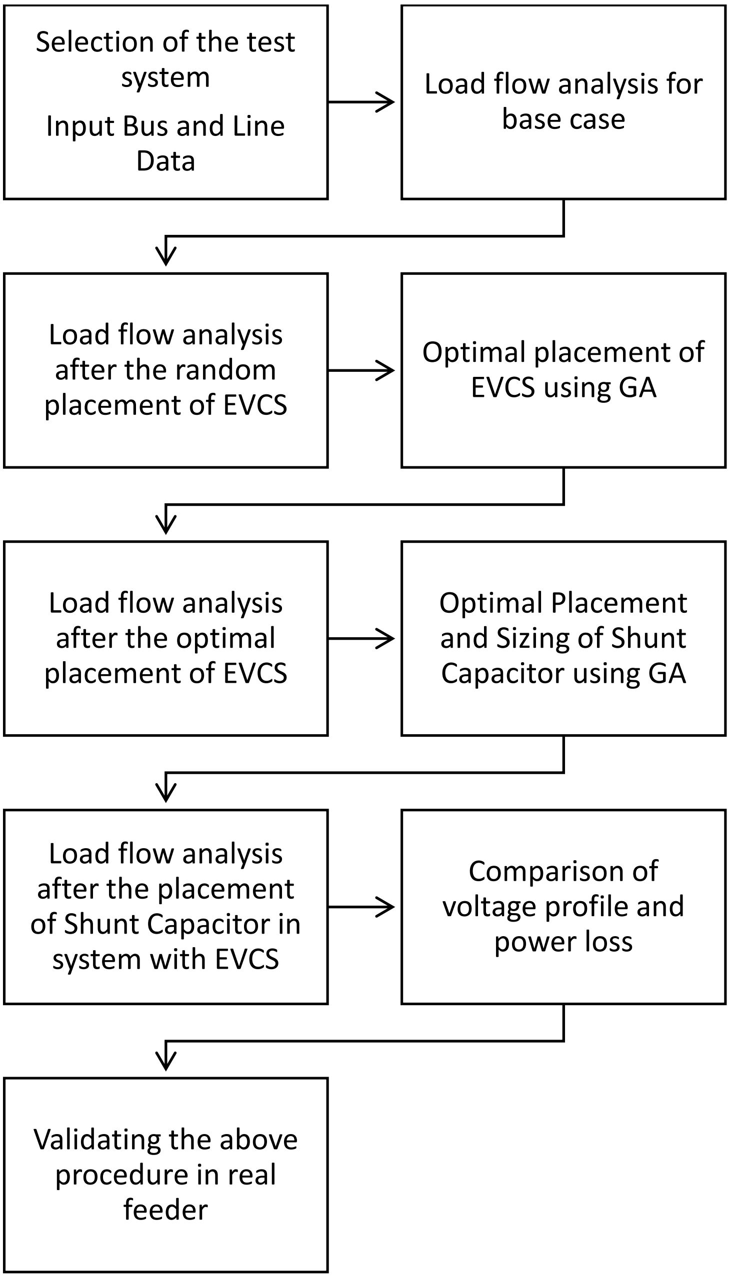

Figure 3-1 Flowchart showing the overall outline of the methodology

3.2 Modeling of the Distribution System

Transformers, distribution lines at different voltage levels, distribution lines, and the grid substation make up the distribution system. Since an EVCS uses a lot of power, it is installed on an 11 kV bus. Therefore, if a load is being serviced from an 11 kV system via a secondary transformer, any load with a voltage level lower than 11 kV can be lumped. On the other side, installing a charging station in a 33 kV system requires a large amount of capital due to the increased cost of the bus bar and 33 kV bay. As such, it might not be the most cost-effective solution.

Transformers are used as load points/buses, 11 kV lines as distribution lines, and grid substations as sources in the distribution system concept. Additionally, since a transformer feeds all of the loads at these load sites, they are included as a single consumer for reliability analysis purposes since a transformer failure results in the loss of the load on the secondary side of the transformer. The modeling of the distribution system parameters is described hereafter.

3.2.1 Modeling of Grid Substation

The substation is modeled as a generator, i.e. as a complex power injection at a specific bus. It is the standard model of Matpower. Active and reactive power of substation is identified as the limit of the substation. Matpower case file consists of following information on the generator.

Table 3.1 Modeling of grid substation

Name	**Column**	**Description**
GEN_BUS	1	Bus number
PG	2	Real Power Output (MW)
QG	3	Reactive Power Output (MVAr)
QMAX	4	Maximum Reactive Power Output (MVAr)

QMIN	5	Minimum Reactive Power Output (MVAr)
VG	6	Voltage Magnitude Set point (pu)
MBASE	7	Total MVA base of the machine, defaults to base MVA
GEN_STATUS	8	Machine status, >0 =machine in-service ≤ 0 =machine out of service
PMAX	9	Maximum Real Power Output (MW)
PMIN	10	Minimum Real Power Output (MW)
PC1	11	Lower Real Power Output of PQ Capability Curve (MW)
PC2	12	Upper Real Power Output of PQ Capability Curve (MW)
QC1MIN	13	Minimum Reactive Power Output at PC1 (MVAr)
QC1MAX	14	Maximum Reactive Power Output at PC1 (MVAr)
QC2MIN	15	Minimum Reactive Power Output at PC2 (MVAr)
QC2MAX	16	Maximum Reactive Power Output at PC1 (MVAr)

3.2.2 Modeling of Distribution Line

The modeling of distribution line is represented by following table in MATPOWER.

Table 3.2 Modeling of distribution line

Name	Column	Description
F_BUS	1	"from" bus number
T_BUS	2	"to" bus number
BR_R	3	Resistance (p.u.)
BR_X	4	Reactance (p.u.)
BR_B	5	Total line charging susceptance (p.u.)
RATE_A*	6	MVA rating A (long term rating), set to 0 for unlimited
RATE_B*	7	MVA rating B (short term rating), set to 0 for unlimited
RATE_C*	8	MVA rating C (emergency rating), set to 0 for unlimited

3.2.3 Modeling of load and slack bus determination

Loads of distribution system are modeled as constant power loads and are specified as quantity of real and reactive power directly connected to the bus. The bus type mentioned in second data of the case file for load defines whether the bus will be used as load bus or generator bus or slack bus.[3]

Table 3.3 Modeling of load and slack bus determination

Name	Column	Description
BUS_I	1	Bus number (positiive integer)
BUS_TYPE	2	Bus type (1= PQ, 2 = PV, 3 = ref, 4 = isolated)
PD	3	Real power demand (MW)
QD	4	Reactive power demand (MVAr)
GS	5	Shunt conductance (MW demanded at V = 1.0 p.u.)

BS	6	Shunt susceptance (MVAr injected at V = 1.0 p.u.)
BUS_AREA	7	Area number (positive integer)
VM	8	Voltage magnitude (p.u.)
VA	9	Voltage angle (degrees)
BASE_KV	10	Base voltage (kV)
ZONE	11	Loss zone (positive integer)
VMAX	12	Maximum voltage magnitude (p.u.)
VMIN	13	Minimum voltage magnitude (p.u.)

3.3 Approach for the EVCS Placement

From the literature review, the equivalent model of EVCS is represented as active load and reactive load as mentioned in [23] by the following equation,

$$P = \frac{3}{2}\left(\mathrm{V_d i_d} + \mathrm{V_q i_q}\right)$$

$$Q = \frac{3}{2}\left(\mathrm{V_d i_q} - \mathrm{V_q i_d}\right)$$

From the above equation, the active and reactive power load is dependent on the voltage and current demand of the charger. For this study, the assumption of the sizing of dc fast charger EVCS is as three 50 kW charging load in one EVCS. And for the consideration of reactive load of charging station, EVCS is considered as linear load so considering the displacement power factor only. The power factor assumption for the study is taken as 0.8 lagging.

For the optimization of EVCS placement the equation is taken from the literature review considering the VRP index is given by,

$$min\ (VRP)\ = w_1A + w_2B + w_3C$$

Where,

$A = \frac{1}{a}$ and $a = \frac{VSI_i}{VSI_{base}}$

$$B = w_{21}\frac{SAIFI_i}{SAIFI_{base}} + w_{22}\frac{SAIDI_i}{SAIDI_{base}} + w_{23}\frac{CAIDI_i}{CAIDI_{base}}$$

$$C = \frac{P_{loss}^{l}}{P_{base}}$$

Similarly, the reliability of the system is also investigated by ENS and AENS index given by, $ENS = \sum L_j \mu_j$, $AENS = \frac{\sum L_j \mu_j}{\sum N_j}$

$$where\ L\ is\ load, \mu_j\ is\ interruption\ duration\ and\ N\ is\ number\ of\ customer$$

The flowchart shown in figure 3.2 is showing the formualtion of GA for the optimal placement in RDS.

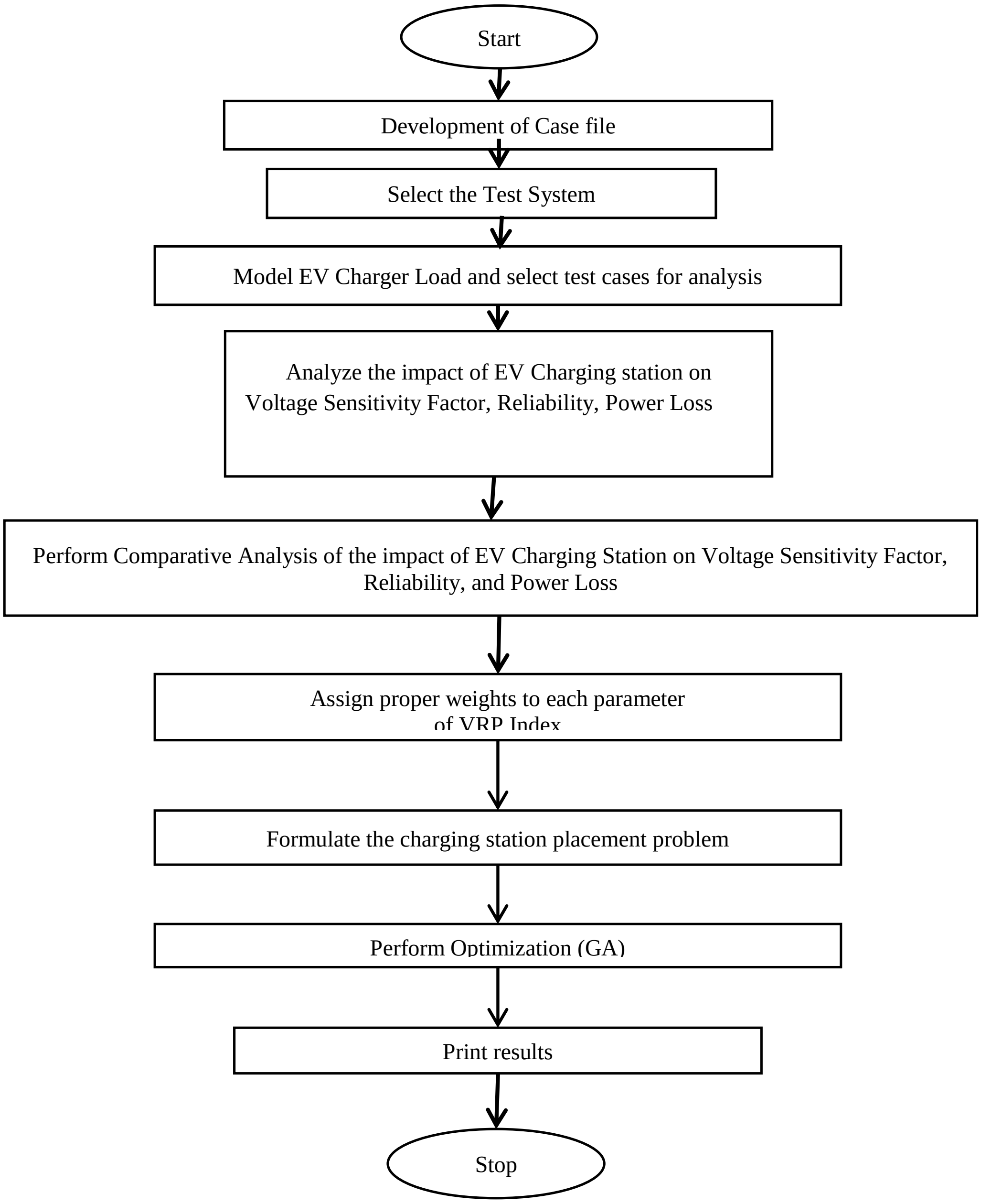

Figure 3-2 Flowchart of formualtion of GA for the optimal placement of EVCS

Flowchart showing the GA optimization during the optimal placement is shown in figure 3.3

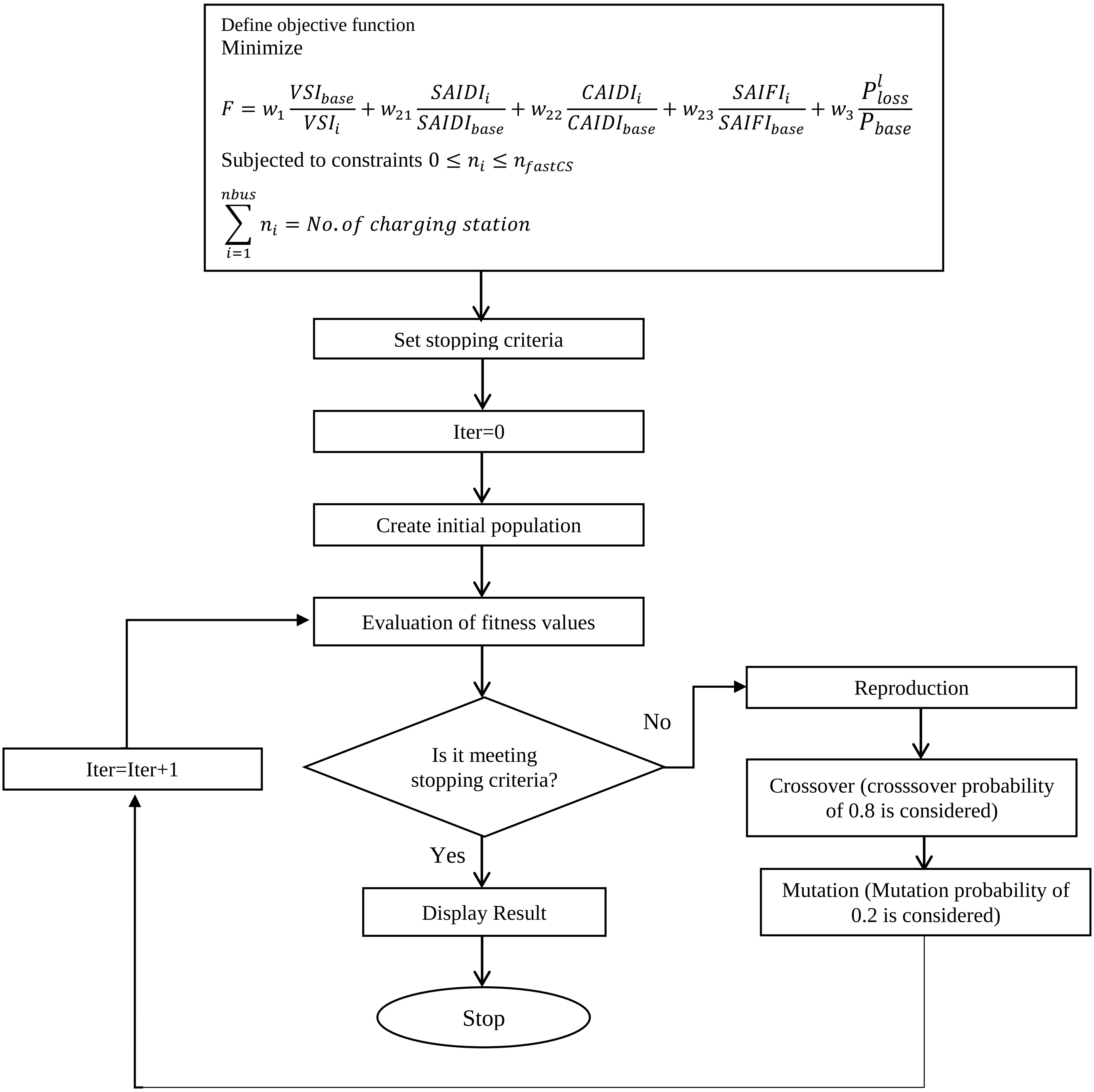

Figure 3-3 Flowchart of Optimization Algorithm

Optimal location of EVCS using GA based method takes the following steps.

Step 1: Define objective function and all constraints.

Step 2: Set stopping criteria

Step 3: Create initial population (number of length of chromosomes and number of population)

Step 4: Evaluate fitness function

Step 5: Perform Reproduction

Step 6: Perform crossover

Step 7: Perform mutation

Step 8: Increase number of iteration until stopping criteria not met.

Step 9: If stopping criteria met display result

Step 10: Stop.

3.4 Distribution System Load Flow Analysis

Distribution load flow studies ascertain if equipment, such as transformers and conductors, is overloaded and whether system voltages stay within predetermined bounds under regular or emergency operation situations. The extensive research has been done for the development of efficient and reliable power system load flow solution. The most commonly used load flow solutions in the operation, control and planning of power systems are Newton Raphson, Gauss-Seidel, and Fast Decoupled methods. But in case of distribution system, these methods become inefficient due to high R/X ratio. Usually, the distribution system is radial in nature and in case of radial structure, many researchers have purposed different algorithms. Basically, these methods belong to two groups. The first group is based on basic circuit laws and direct methods. The examples of this group are backward-forward sweep and node equivalent based method. The second group consists of traditional Newton Raphson, Fast Decoupled, and its modified version method. The most effective power flow technique for medium-sized and large radial distribution networks is the backward-forward sweep. This is due to the fact that this approach offers the most computing efficiency and accuracy.

A few key differences between distribution and transmission systems include the characteristic radial topology, the magnitudes of xs and rs, and the xs/rs branch ratio. Owing to these variations, many techniques for solving power flow problems have been devised to take into consideration the unique characteristics of distribution networks. Three more radial network-specific AC power flow techniques are included in MATPOWER. These three methods are current summation method, power summation method, admittance summation method. And for the purpose of this thesis, the current summation approach is applied.

3.4.1 Current Summation Method

The Current Summation Method voltage calculation process is carried out in the following 5 steps.

1. Set all voltages to 1 p.u. (flat start). Set iteration count ν = 1.
2. Adjust the branch current flow to equal the total of the current drawn in the admittance linked to bus k and the current of the demand at the receiving end.
3. Backward sweep: Perform the current summation, moving toward the branch whose index equals 1 from the branch with the largest index. The current of the branch whose index equals i = fk is increased by the current of branch k.
4. Forward sweep: Using known branch currents and transmitting bus voltages, the receiving end bus voltages are computed.
5. Examine and compare the voltages from iteration ν − 1 with those from iteration ν. If the greatest magnitude difference is smaller than the given tolerance.

3.5 Procedure for Optimal Placement and Sizing of Shunt Capacitor

the minimizing of active power loss, reactive power loss, and voltage drop, the mathematical objective function for the best location and size of shunt capacitors is provided by, as stated in the literature study is given by,

$$F = W_1 X\ P_{loss} + W_2 X\ Q_{loss} + W_3\ X\ \sum_{i=1}^{n}(1 - v_i)^2$$

The iteration is carried out using GA in MATLAB number of times taking the different values of W_1, W_2 and W_3 to obtain the optimized outcome.

The detailed procedure of GA used for the optimized location and size of shunt capacitor for loss minimization and improvement of voltage profile of each bus is given below:

Step 1: Random solution as initial population of capacitor of given values placed at random nodes in the distribution feeder is generated

Step 2: New solutions is obtained using the initial population during genetic cycle by the crossover and mutation operators

Step 3: The optimized solution is obtained with the help of selection procedure of the objective function values which are estimated and decoded for each new solution.

Step 4: The better solution is carried forward to new population discarding the worst solution

Step 5: Individuals in the original population with higher order in perspective of fitness value are employed to restore the decreased population.

Step 6: Iteration is carried out till the termination criterion is achieved.

The above explained steps is shown in the flowchart shown in the figure 3.4

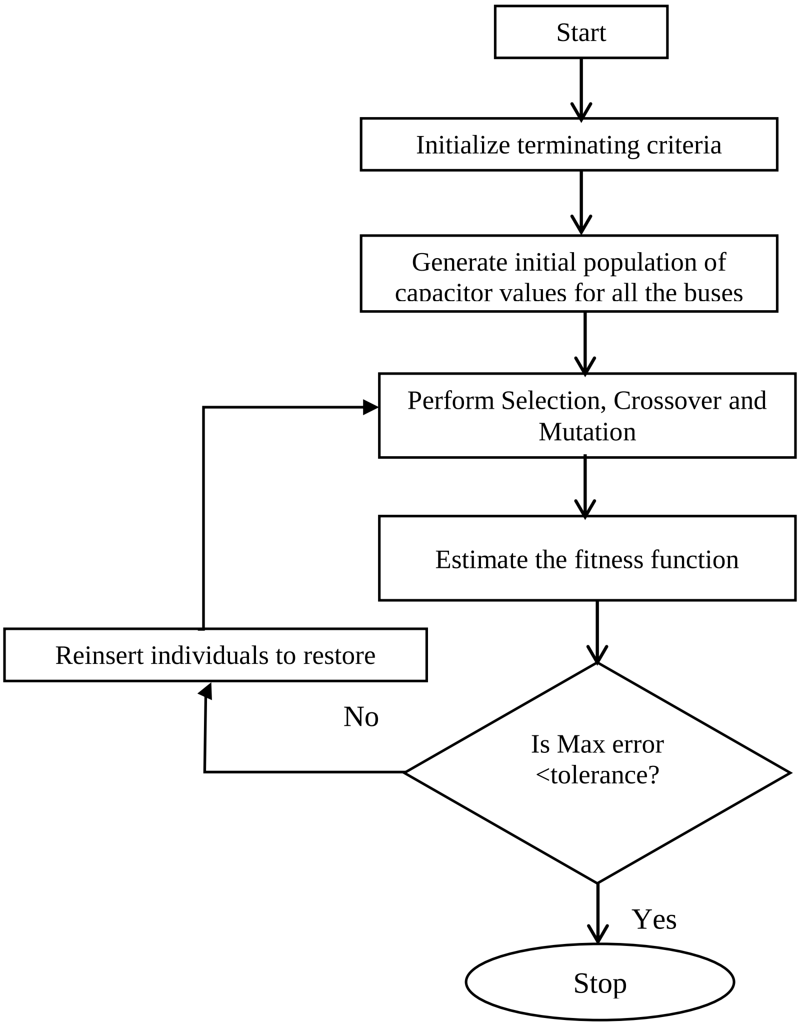

Figure 3-4 Flowchart of GA for optimization of capacitor

3.6 System under Consideration

The EVCS is taken as an active load placed in each bus with the rating of the 50 kW of each with maximum number of three chargers in each bus and such EVCS is limited to five placement in the buses in this study. For the test of the study IEEE 33 bus system is used. The IEEE 33-bus system is a well-known standard test system used in power system research and analysis. As a standard test system, the IEEE 33-bus system is well-documented, and its data is publicly available for research and analysis purposes. The system is composed of 33 buses, 32 branches. The single line diagram of IEEE 33 bus system is shown in the figure 3.5 below.

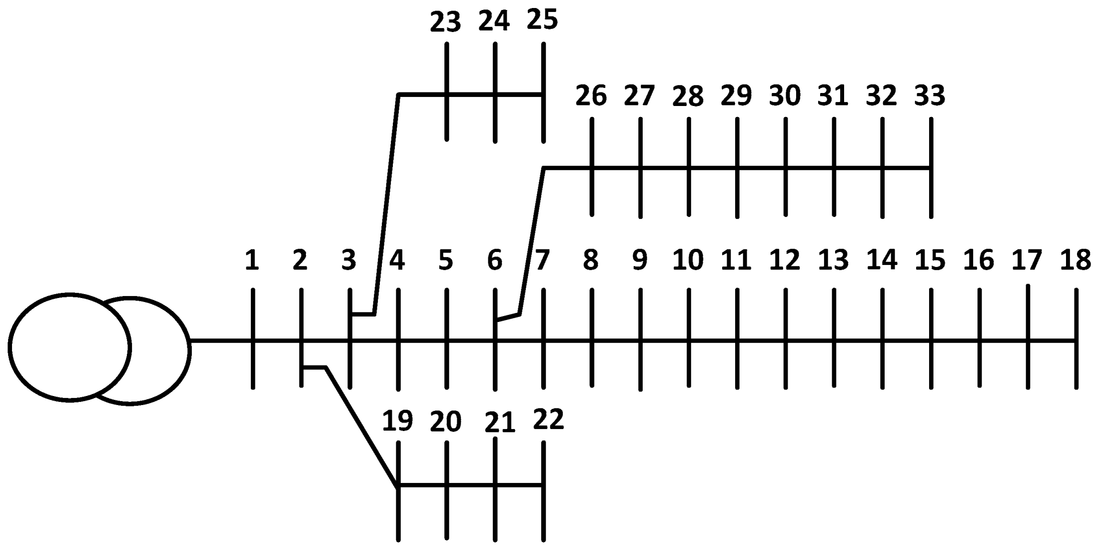

Figure 3-5 IEEE 33 bus system

3.7 Software and Tools

The technological advancement in computer architecture, software and programming tools have made the modelling and analysis of RDS easy. In the past, the modelling and analysis were difficult, time-consuming and inaccurate. Many software tools use the mathematical model to simulate the performance of a RDS to that of the real component. These mathematical models are integrated into a single module to simulate an actual RDS. MATLAB has been used in this thesis for solving the optimization problem and MATPOWER is used for the load flow analysis of RDS.

3.7.1 MATLAB

MATLAB stands for Matrix Laboratory. It is the user-friendly highly interactive programming tool developed by MathWorks which can be used for simulating a large number of engineering problems. In this thesis, MATLAB has been used for implementing GA for solving the multi-objective optimization problem. Moreover, Matpower 7.0 package is also integrated with MATLAB for simulating bus system.

CHAPTER 4: RESULTS AND DISCUSSIONS

The main objective of this study is to reduce the active and reactive power loss along with voltage profile correction of radial distribution system by optimal placement of EVCS and sizing of shunt capacitor in the RDS. For this, firstly the study was carried out in IEEE 33 bus system inspecting the load flow analysis of four different cases. Initially, the load flow analysis was carried out of the base case scenario. After that the random placement of EVCS was done and voltage profile and power loss were compared with the base case. Similarly, the load flow analysis was operated after the optimal placement of EVCS using GA in the RDS. After the optimal placement of EVCS, the best location and dimensions of the shunt capacitor were determined with the aid of GA in order to reduce power loss and enhance the voltage profile. Voltage profile, active power loss and reactive power loss of all four cases have been compared. After the objective of the study is verified in the IEEE 33 bus test system, the load flow analysis has been carried out in the Jawalakhel feeder of Lagankhel Distribution System to validate the results.

4.1 Results in IEEE 33 Bus System

4.1.1 Optimal placement of EVCS

Load flow analysis of base case system was done in MATLAB using Matpower. Then, the random placement of 150 kW five EVCS with each station having three 50 kW fast dc chargers has been done at bus no. 3,5,6,28 and 29 in IEEE 33 bus system. After the random placement of EVCS, load flow analysis was conducted.

For performing optimization algorithm, input parameters for weightage factors are assigned as $w_1 = 0.1, w_2 = 0.7, w_3 = 0.2, w_{21} = 0.2, w_{22} = 0.4, w_{23} = 0.1$. Maximum two number of fast EVCS is considered to be placed at single bus. After performing the optimization in MATLAB using GA, the optimal position of 150 kW fast charger, is found out to be at bus no. 2 with two number of fast chargers, bus no. 19 with one number of fast charger and bus no. 20 with two number of fast chargers. The optimal placement of EVCS with fast chargers is shown in figure 4.1 below.

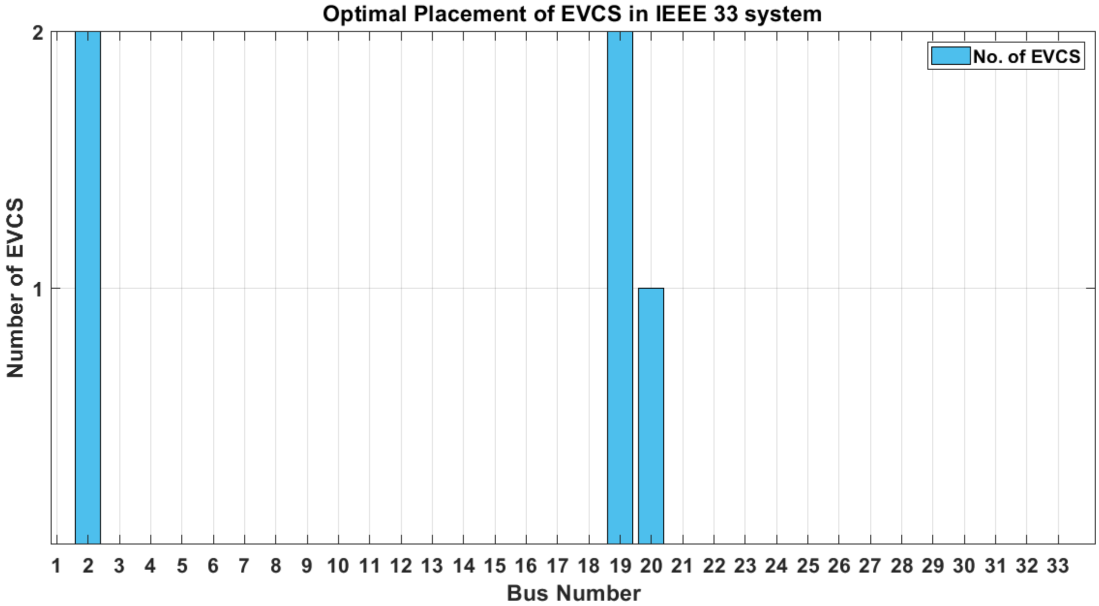

Figure 4-1 position of EVCS with fast chargers in IEEE 33 system

4.1.2 Voltage Profile

Addition of EVCS in the distribution system, results in the degradation of voltage profile. Voltage profile comparison of base case system, random placement of EVCS and optimal placement of EVCS is carried out in MATLAB using load flow analysis with the help of MATPOWER tool.

During the random placement of EVCS, the maximum voltage drop has been observed at bus no. 14,15,16,17,18,31,32 and 33 from 0.9185 pu, 0.9171 pu, 0.9157 pu, 0.9137 pu, 0.9131 pu, 0.9178 pu, 0.9169 pu and 0.9166 pu to 0.833 pu, 0.831 pu, 0.828 pu, 0.825 pu, 0.823 pu, 0.836 pu , 0.834 pu and 0.834 pu respectively. Since the maximum voltage drop is observed during random placement. Then after the optimal placement of EVCS, the maximum voltage drop has been observed at bus no. 13,14,15,16,17,18,32 and 33 from 0.9208 pu, 0.9185 pu, 0.9171 pu, 0.9157 pu, 0.9137 pu, 0.9131 pu, 0.9169 pu and 0.9166 pu to 0.873 pu, 0.869 pu, 0.866 pu, 0.864 pu, 0.861 pu, 0.86 pu, 0.871 pu and 0.87 pu respectively. It is observed that the voltage magnitude is gradually decreasing from bus no 2 to bus no 18 and from bus no 26 to bus no 33 in IEEE 33 bus system. Voltage profile comparison of all the three cases: base case system, system with random placement of EVCS and optimal placement of EVCS during the optimization process is shown in figure 4-2.

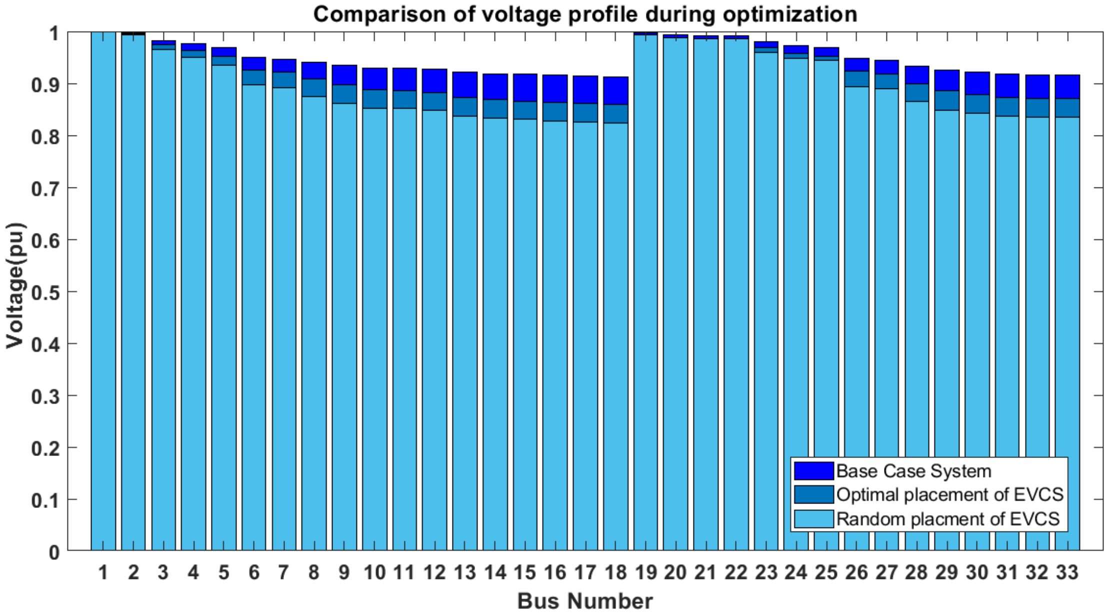

Figure 4-2 Voltage profile comparison during optimization of IEEE 33 Bus System

While optimizing the position of fast dc charger EVCS in buses of IEEE 33 bus system, voltage sensitivity factor (VSF) has also been compared to see the effect of loading on the voltage magnitude. In Figure 4-3, the voltage sensitivity factor after the placement of EVCS is compared with the base case scenario and there is a noticeable voltage variation in every bus. The voltage sensitivity factor at buses 2, 19, and 20 rises, according to the result from 9.323, 25.87 and 180.7 to 9.328, 25.9, 180.7 respectively. Hence, it is justified that the voltage sensitivity factor is maintained after the optimal placement of load i.e. EVCS in this case. VSF comparison at each buses is depicted in figure 4-3.

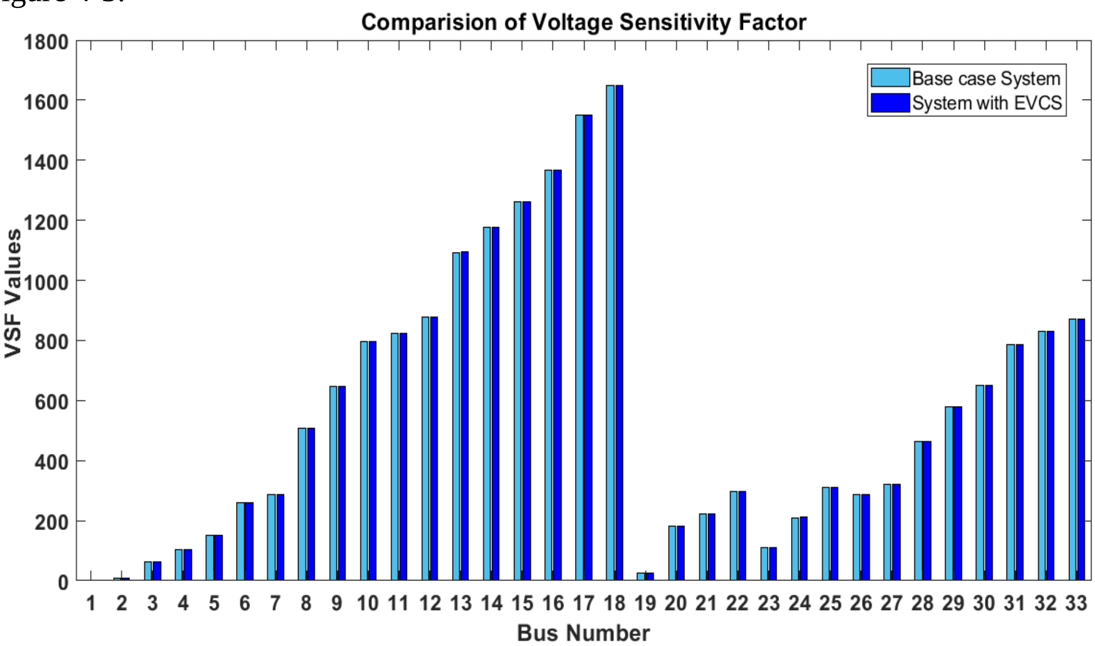

Figure 4-3Comparison of Voltage Sensitivity Factor of IEEE 33 Bus

4.1.3 Power loss and Energy Indices

During the optimal placement of EVCS, another important factor under consideration is the minimization of active power loss. After the optimal placement of charging station, active power loss and reactive power loss in the branches of IEEE 33 bus was calculated from load flow analysis considering no EVCS load in base case, EVCS loads at bus no. 3, 5, 6, 28 and 29 in random placement and EVCS loads at bus no. 2, 19 and 20 in optimal placement. Total active power losses at base case, random placement and optimal placement has been found out to be 0.2027 MW, 0.499 MW and 0.388 MW respectively. And total reactive power losses at base case, random placement and optimal placement has been found out to be 0.135 MVAR, 0.31 MVAR and 0.22 MVAR respectively. The comparison of active power loss and reactive power loss is shown in figure 4-4. It is observed that the placement of EVCS has increased the power loss in the branches of the system compared to the base case and power loss is more in the random placement of EVCS as compared to the random placement of EVCS.

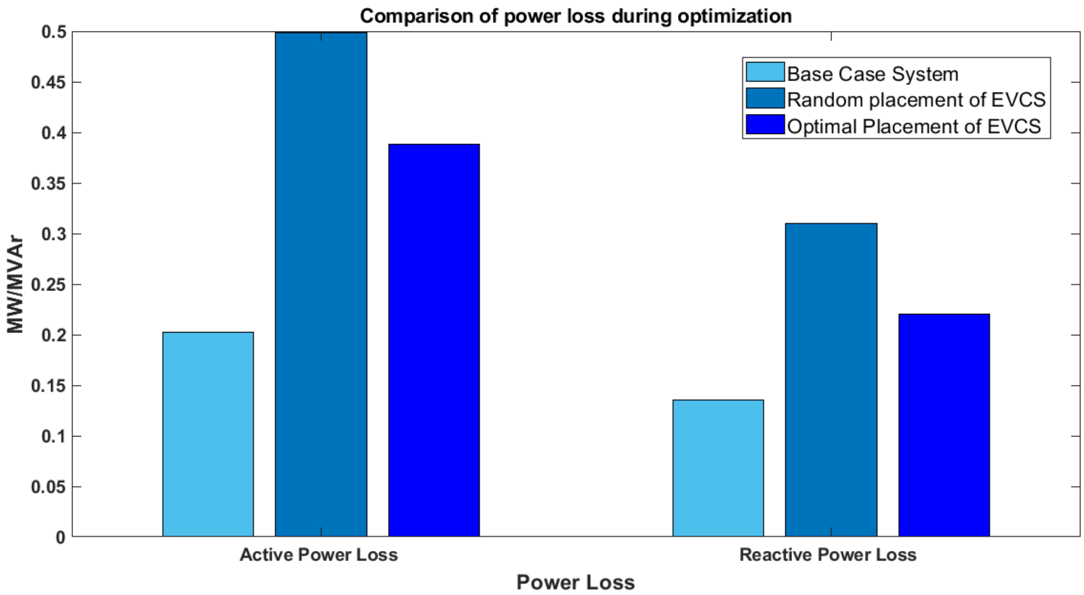

Figure 4-4 Comparison of Power loss of IEEE 33 Bus system

The variation observed in Energy Not Served (ENS) and Average Energy Not Served (AENS) has been demonstrated in figure 4-5 and figure 4-6 respectively. In figure 4-5, it is observed that, the system with EVCS has a higher ENS rating than the base case system due to an increase in bus loads following the installation of EVCS. When comparing the system with chargers to the basic case scenario, Figure 4-6 demonstrates the large rise in the Average Energy Not Served (AENS). Considering the number of customers of IEEE bus system as 919, the value of ENS in a standard case system is 1.8248 MWh, whereas in a system with an EVCS, it is 2.0048 MWhr. Furthermore, the AENS value for the system with EVCS is 0.04798 MWhr, while the AENS value for the base case scenario is 0.04061 MWhr. We may deduce that the location of EV charging stations affects system dependability by causing ENS and AENS to grow above the base case system.

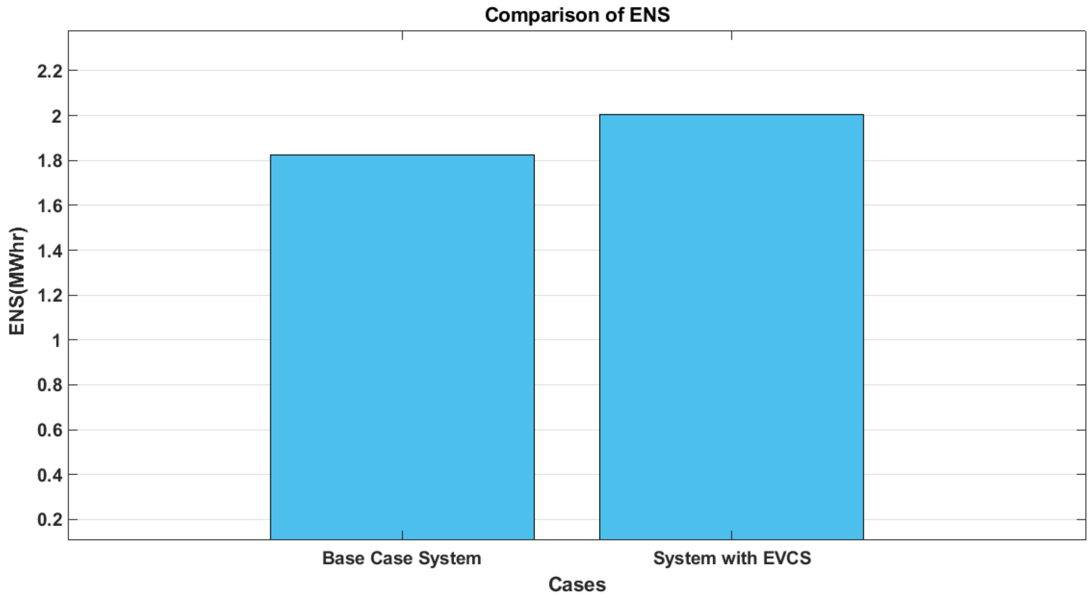

Figure 4-5 Comparison of ENS of IEEE 33 Bus system

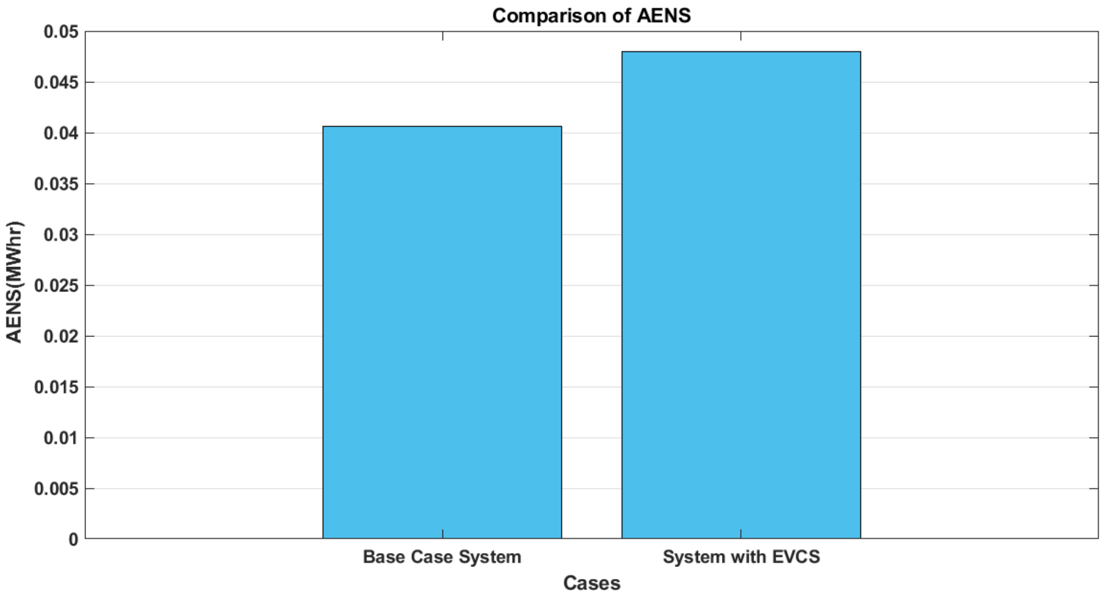

Figure 4-6 Comparison of AENS of IEEE 33 Bus system

4.1.4 Reliability Indices

Before and after the EVCS was installed in the IEEE 33 bus system, comparisons of the reliability indexes SAIDI, SAIFI, and CAIDI has been made. The positioning of EVCS in the IEEE 33 bus system has been determined to have no effect on the values of SAIFI, SAIDI, and CAIDI. The values of SAIDI, SAIFI and CAIDI found out are 0.49443, 0.09824 and 5.03301 respectively which is shown in the figure 4-7, 4-8 and 4-9.

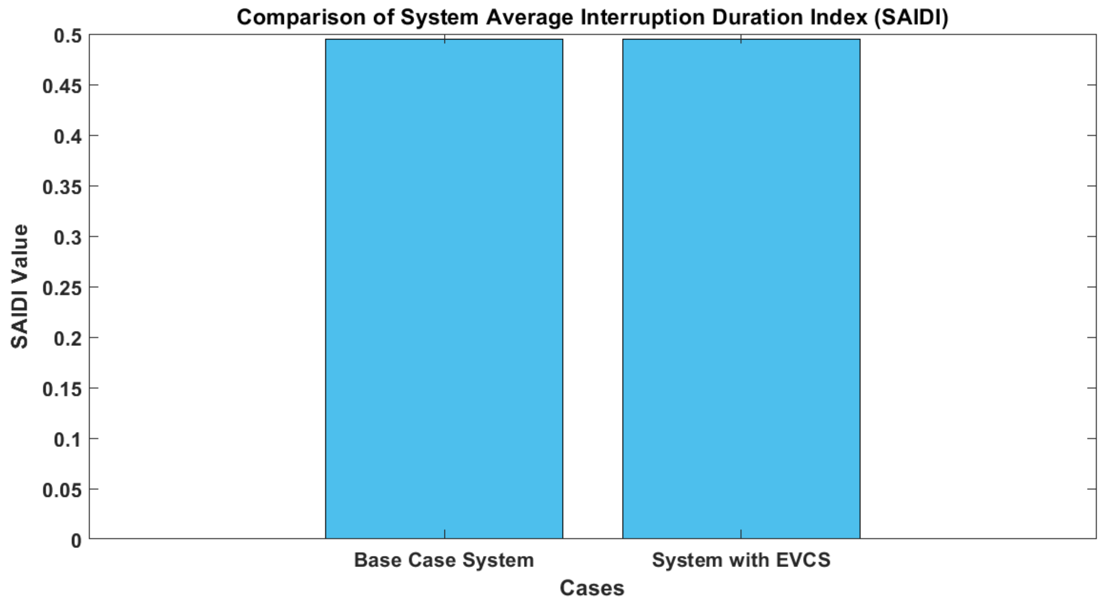

Figure 4-7 Comparison of SAIDI of IEEE 33 bus system

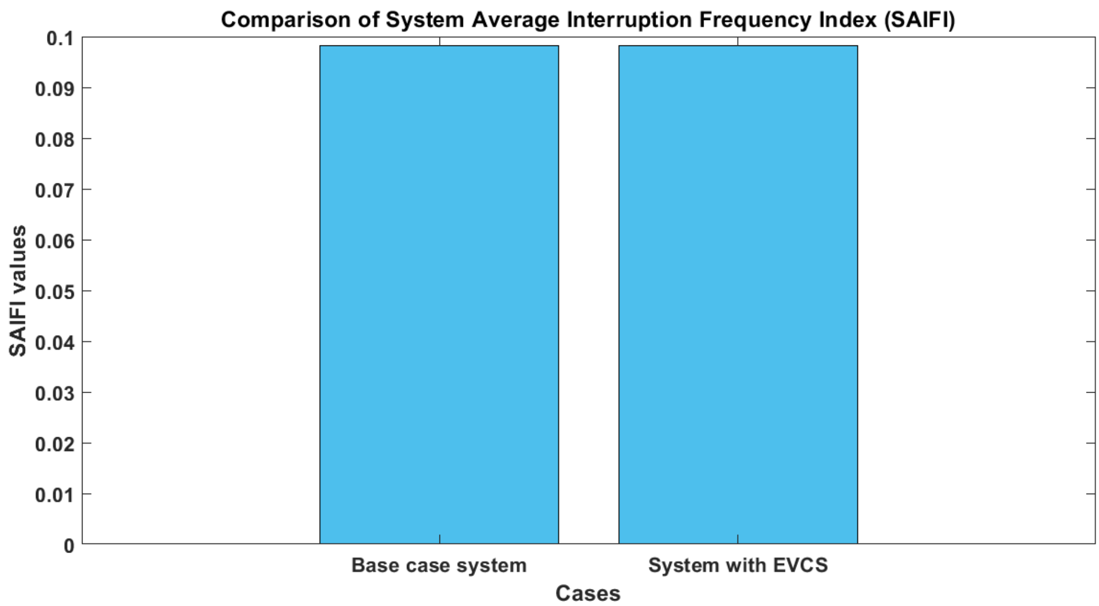

Figure 4-8 Comparison of SAIFI of IEEE 33 bus system

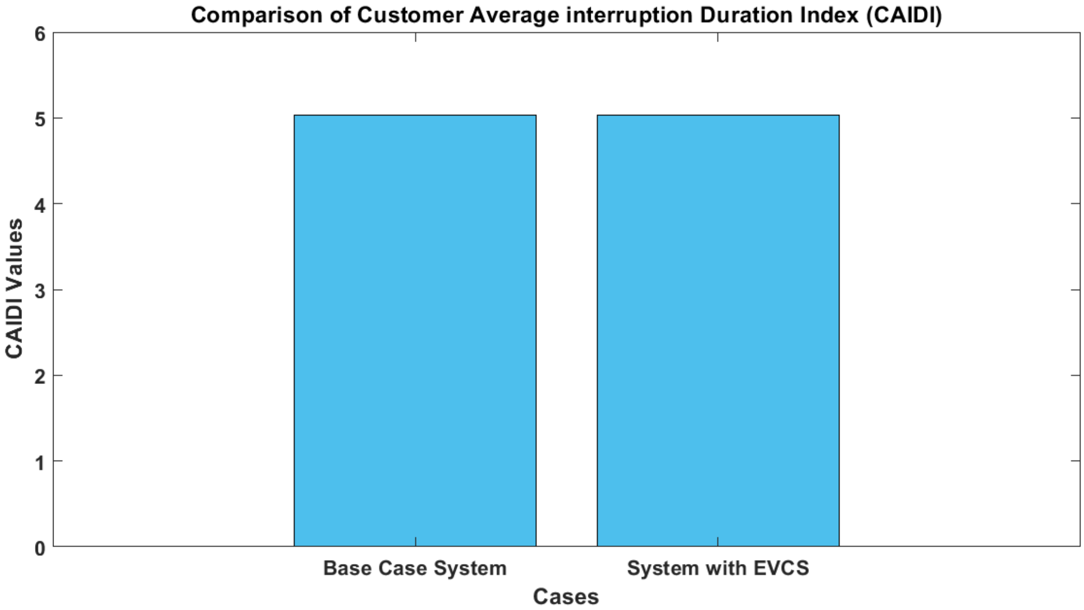

Figure 4-9 Comparison of CAIDI of IEEE 33 bus system

4.1.5 Optimal Placement and Sizing of Shunt Capacitor

After the optimal placement of EVCS it has been found out that the voltage profile is degraded and increment in the active and reactive power loss in the branches from the base case system. So, the static compensating device in the form of shunt capacitor is sized and optimally placed in the IEEE 33 bus system to mitigate the impact of EVCS placement. Using the GA, the optimal sizes of shunt capacitor have been found out to be $0.4724*10^3$ kVAr and $1.0613*10^3$ kVAr. Similarly the shunt capacitor optimal location has been determined at bus no 12 and 30 respectively. The MATLAB output of the optimal placement and sizing of shunt capacitor is shown in figure 4-10.

```
MATLAB Command Window                                                Page 1

Optimization terminated: average change in the penalty fitness value less than options.↙
FunctionTolerance
and constraint violation is less than options.ConstraintTolerance.

ans =

    30    12


ans =

   1.0e+03 *

    1.0613    0.4724
```

Figure 4-10 MATLAB output of optimal placement and sizing of capacitor

After the placement of capacitor in the system with EVCS the voltage profile is improved as shown in figure 4-11.

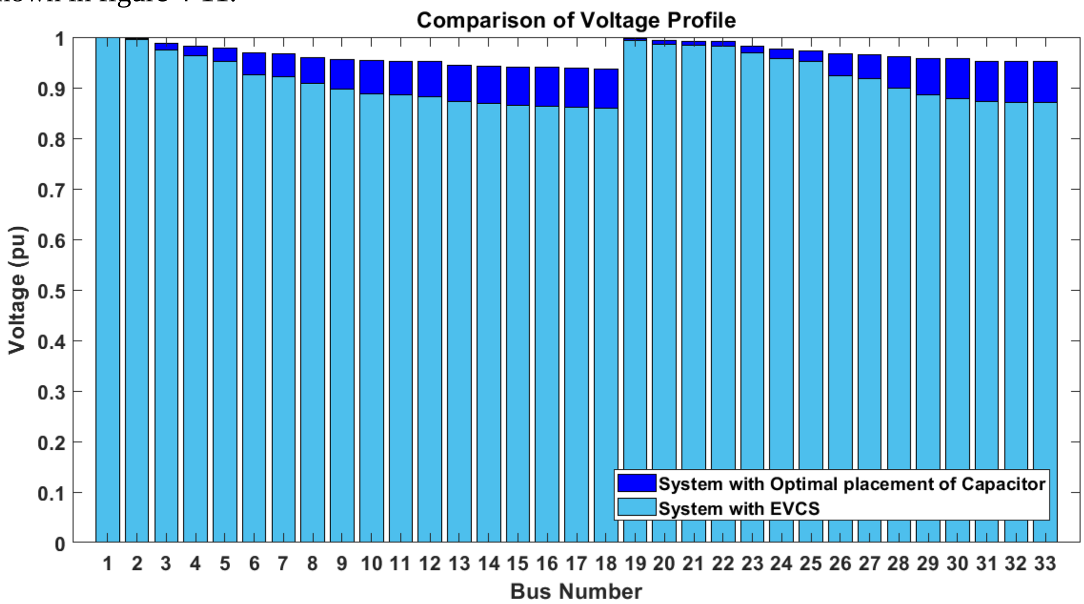

Figure 4-11 Voltage profile of the system with EVCS and capacitor placement

From the figure 4-11, it is evident that the optimal placement of the capacitor has improved the voltage profile of overall buses of IEEE 33 bus system. For instance, the voltages of bus no 16, 17, 18, 31, 32 and 33 from 0.864 pu, 0.861 pu, 0.86 pu, 0.872 pu, 0.871 pu and 0.87 pu is improved to 0.94 pu, 0.938 pu, 0.937 pu, 0.952 pu, 0.952 pu and 0.952 pu respectively.

4.1.6 Summarization of Voltage and Power Loss of IEEE bus system

The first phase of this thesis of optimal placement of EVCS in IEEE 33 bus system and optimal placement and sizing of shunt capacitor to mitigate the impact of EVCS in the voltage, active power and reactive power has been accomplished, The overall comparison of the voltage profile of the base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor in the IEEE 33 bus system is shown in the figure 4-12. In the figure, it has been shown that the random placement of EVCS resulted the appreciable degradation of voltage profile from the base case system. Furthermore, it is obvious that the voltage profile deterioration has been reduced following the optimal placement of EVCS. Even yet, the EVCS system's voltage curve is lower than that of the base case system. Finally, the system voltage profile has improved as a result of the shunt capacitor's optimal location.

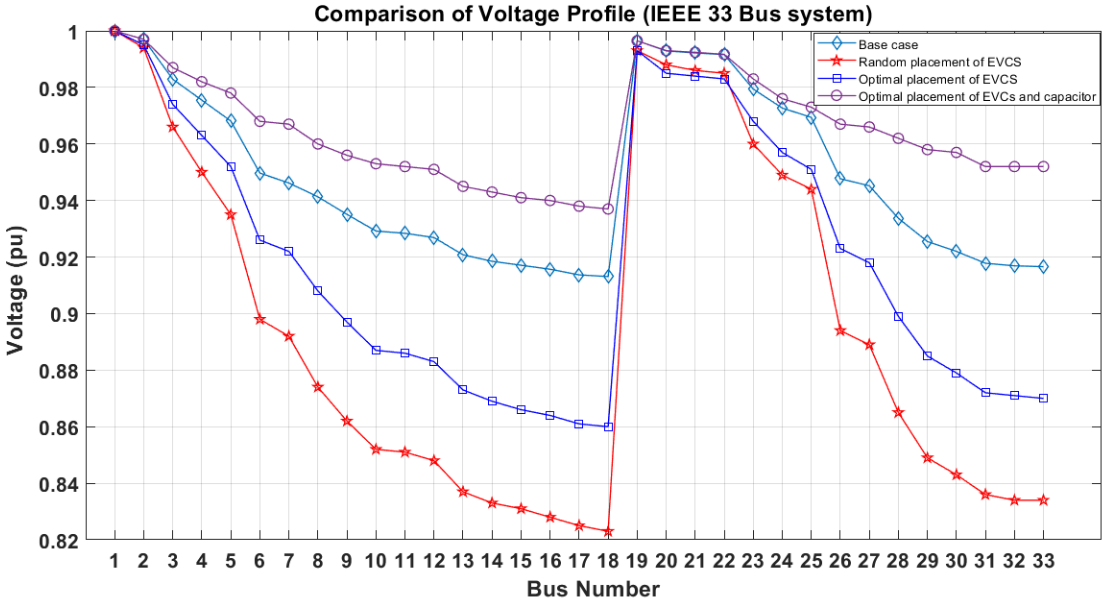

Figure 4-12 Comparison of voltage profile of different cases in IEEE 33 system

Similarly, the active power losses and reactive power losses at the 32 branches of IEEE 33 bus system has been compared as shown in figure 4-13 and 4-14.

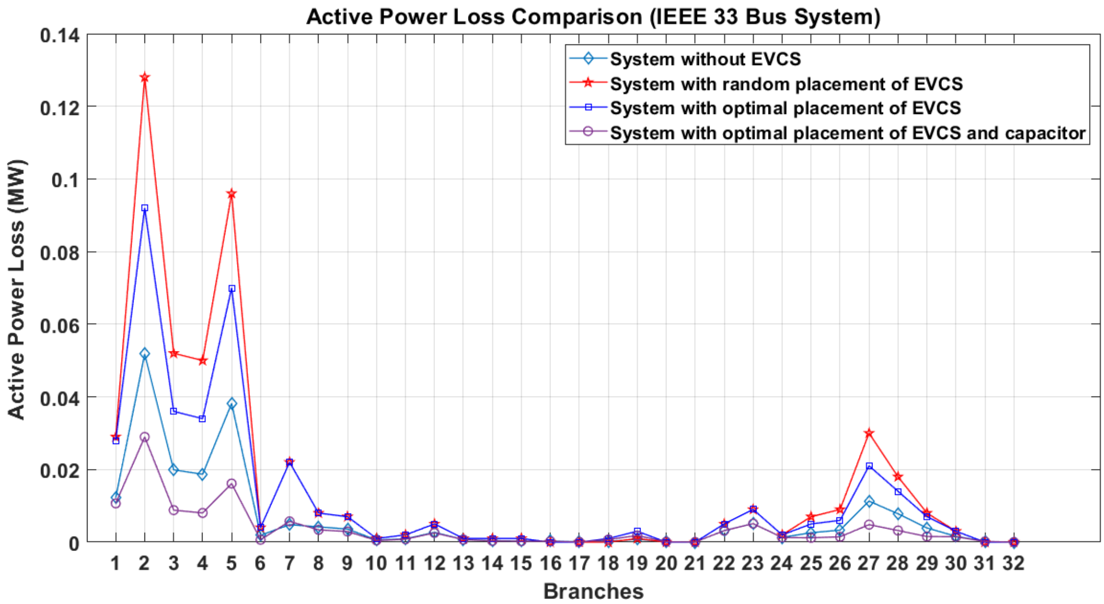

Figure 4-13 Comparison of active power losses of different cases in IEEE 33 system

From the figure 4-13, maximum active power losses have been noted at each branch of the IEEE 33 bus system when EVCS are arranged at random. Even though the loss was lessened when the EVCSs were positioned optimally as opposed to randomly, the active power loss was still discovered to be higher than in the basic scenario. Thus, the system's active power loss has decreased as a result of the capacitor's optimal placement. Similarly in the figure 4-14, when comparing the best placement of EVCS and shunt capacitor to the random placement of EVCS in the IEEE 33 bus system, the comparison of reactive power loss has shown that a reduction in reactive power loss has been obtained.

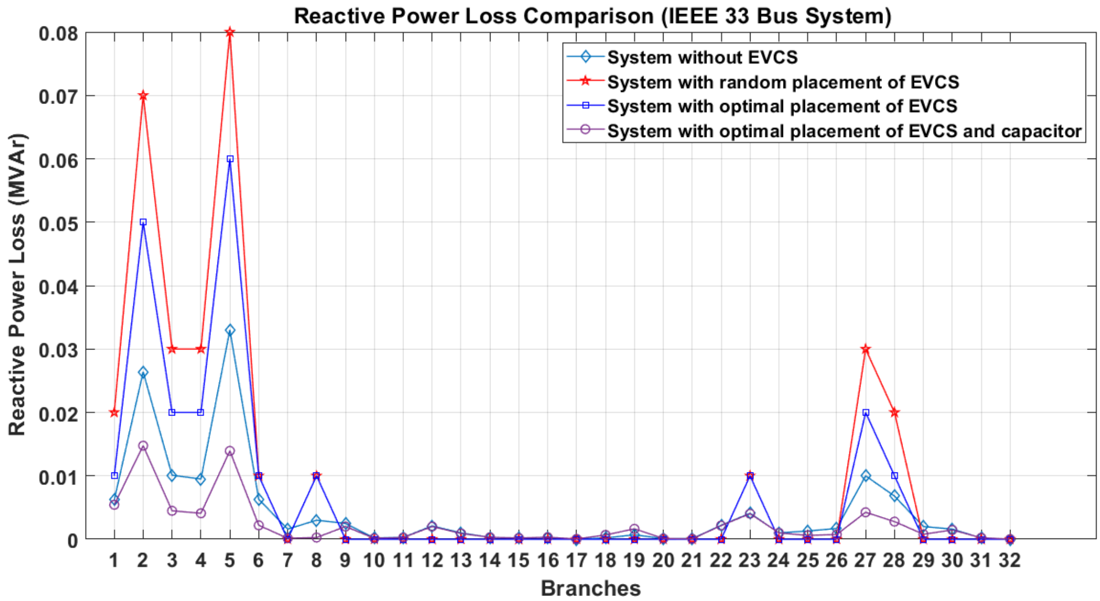

Figure 4-14 Comparison of reactive power losses of in IEEE 33 bus system

Figure 4-15 compares the overall active and reactive power losses.

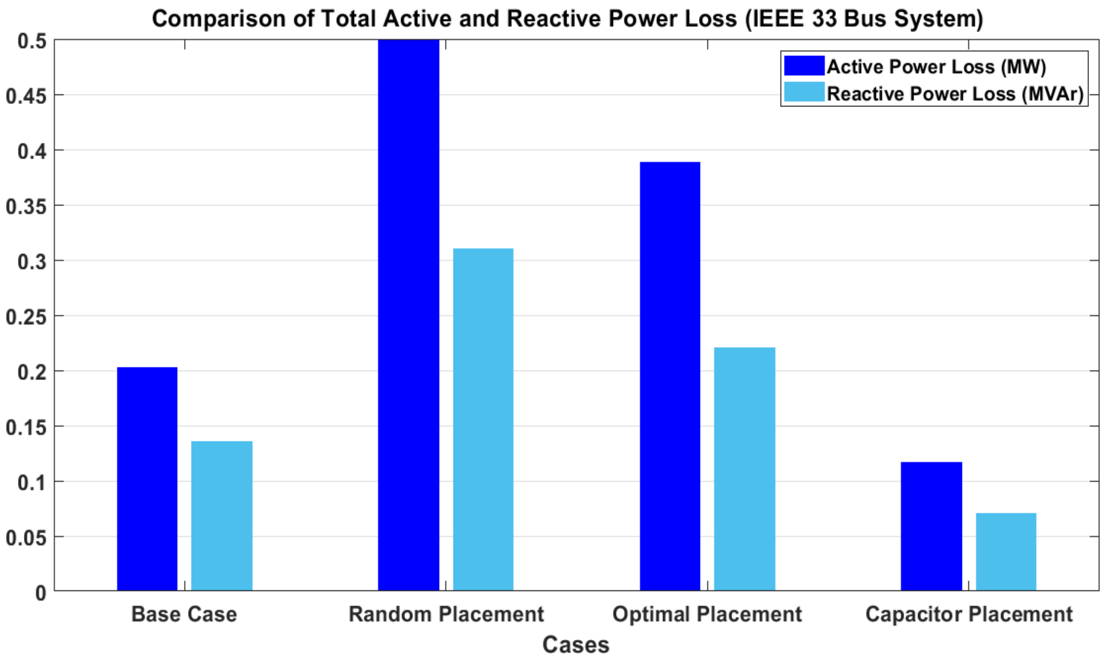

Figure 4-15 Comparison of total power loss in the IEEE 33 bus system

As shown in the figure 4-15, the total active power losses are 0.2027 MW, 0.499 MW, 0.388 MW and 0.1168 MW and reactive power losses are 0.135 MVAR, 0.31 MVAR, 0.22 MVAR and 0.07 MVAR in the base case system, during the random placement of EVCS, during the optimal placement of EVCS and during the optimal placement of shunt capacitor in EVCS integrated system respectively.

4.2 Results in Jawalakhel Feeder

4.2.1 Optimal placement of EVCS

For the validation of the results in real RDS within Nepal, Jawalakhel feeder of Lagankhel Distribution Center with 36 buses is considered. Load flow analysis of base case system was done in MATLAB using Matpower. Then, the random placement of 150 kW five EVCS with each station having three 50 kW fast dc chargers has been done at bus no. 6,12,15,19 and 25 in Jawalakhel feeder. After the random placement of EVCS, load flow analysis was conducted.

For performing optimization algorithm, input parameters for weightage factors are assigned as $w_1 = 0.1, w_2 = 0.7, w_3 = 0.2, w_{21} = 0.2, w_{22} = 0.4, w_{23} = 0.1$. Maximum two number of fast EVCS is considered to be placed at single bus. After performing the optimization in MATLAB using GA, the optimal position of 150 kW fast charger, is found out to be at bus no. 3 with two number of fast chargers, bus no. 4 with one number of fast charger and bus no. 25 with two number of fast chargers. The optimal placement of EVCS with fast chargers is shown in figure 4.16 below

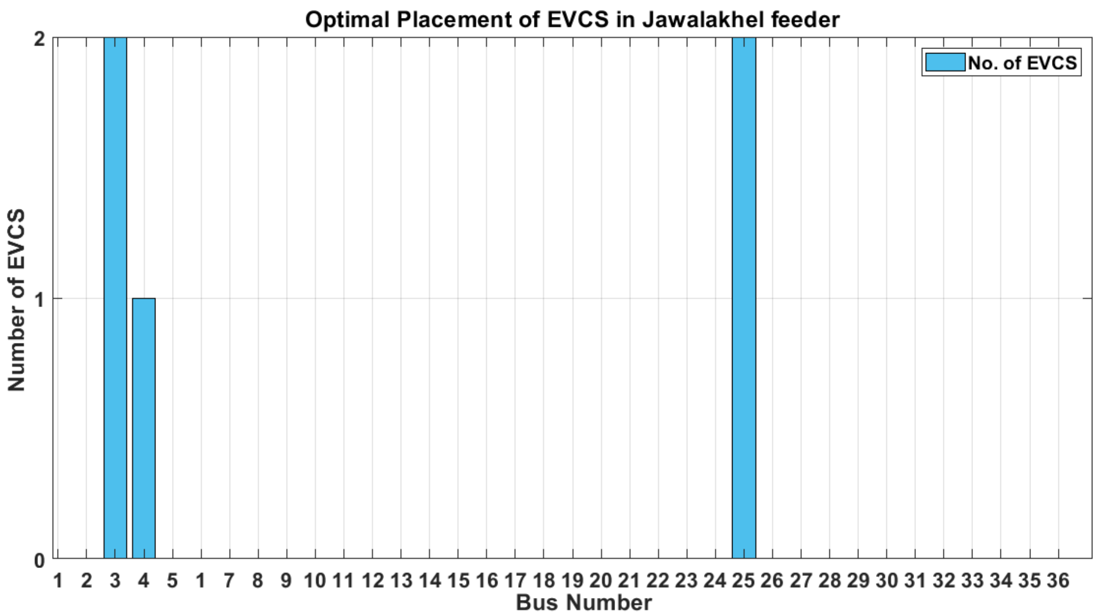

Figure 4-16 Position of EVCS with fast chargers in Jawalakhel feeder

4.2.2 Voltage Profile

Addition of EVCS in the distribution system, results in the degradation of voltage profile. Voltage profile comparison of base case system, random placement of EVCS and optimal placement of EVCS is carried out in MATLAB using load flow analysis with the help of MATPOWER tool.

During the random placement of EVCS, the voltage drop has been observed at each buses among which maximum voltage drop has been seen at bus no. 22,23,24,26,32,34,35 and 36 from 0.9476 pu, 0.9478 pu, 0.9474 pu, 0.9469 pu, 0.9445 pu, 0.9441 pu, 0.9439 pu and 0.9438 pu to 0.9418 pu, 0.9417 pu, 0.9417 pu, 0.9412 pu, 0.9387 pu, 0.9383 pu, 0.9381 pu and 0.9380 pu respectively. Since the maximum voltage drop is observed during random placement. Then after the optimal placement of EVCS, the maximum voltage drop has been observed at bus no. 20,21,22,24,28,34,35 and 36 from 0.9485 pu, 0.9479 pu, 0.9476 pu, 0.9474 pu, 0.9444 pu, 0.9441 pu, 0.9439 pu and 0.9438 pu to 0.9465 pu, 0.9460 pu, 0.9456 pu, 0.9455 pu, 0.9425 pu, 0.9421 pu, 0.9419 pu and 0.9418 pu respectively. It has been observed that the voltage magnitude is gradually decreasing from bus no 5 to bus no 24 and from bus no 26 to bus no 36 in Jawalakhel feeder. Voltage profile comparison of all the three cases: base case system, system with random placement of EVCS and optimal placement of EVCS during the optimization process is shown in figure 4-17.

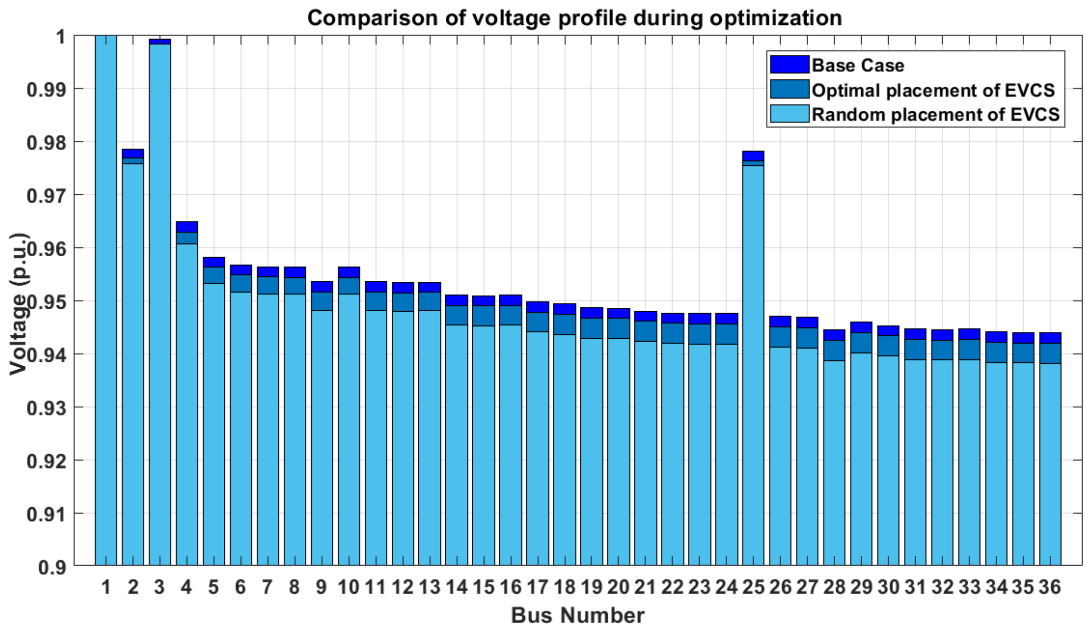

Figure 4-17 Voltage profile comparison during optimization in Jawalakhel feeder

While optimizing the position of fast dc charger EVCS in buses of Jawalakhel feeder, voltage sensitivity factor (VSF) has also been compared to see the effect of loading on the voltage magnitude. In Figure 4-18, following the installation of EVCS, the voltage sensitivity factor is compared to the base case scenario; each bus exhibits a considerable voltage variance. The outcome demonstrates that busses 3, 4, and 25's voltage sensitivity factor increases from 29.3, 54.26 and 39.58 to 29.33, 54.37 and 39.66 respectively. Hence, it is justified that the voltage sensitivity factor increases after the placement of load i.e. EVCS in this case. VSF comparison at each buses is depicted in figure 4-18.

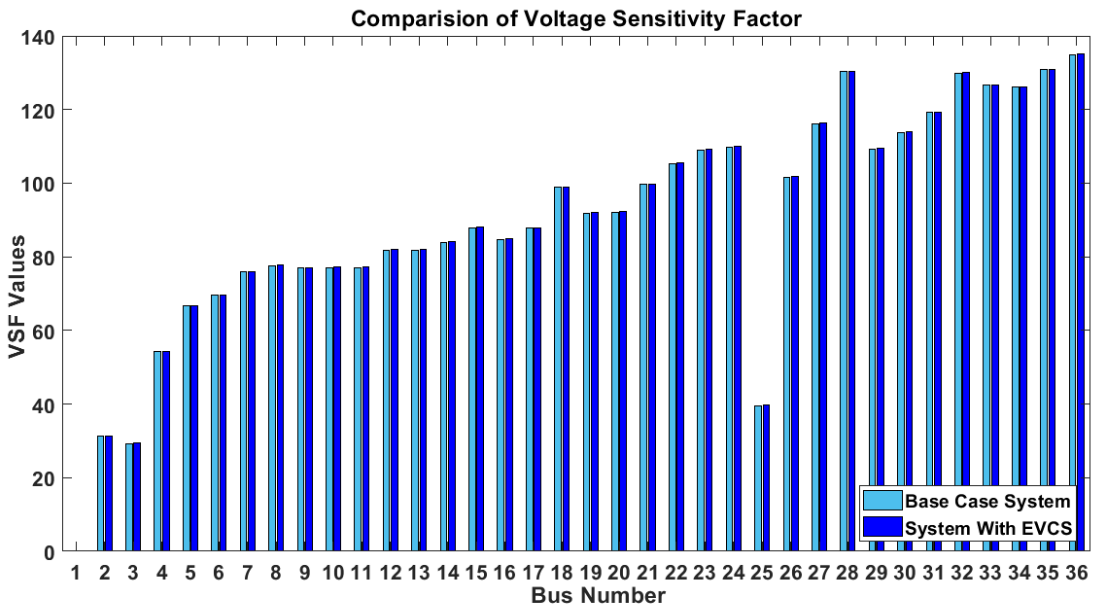

Figure 4-18 Comparison of Voltage Sensitivity Factor of Jawalakhel feeder

4.2.3 Power loss and Energy Indices

Minimizing active power loss is an essential issue to take into account while placing EVCS optimally. Following the best location for the charging station, load flow analysis was used to determine the active and reactive power losses in each of the Jawalakhel feeder's branches while assuming a base scenario with no EVCS demand, EVCS loads at bus no. 6, 12, 15, 19 and 25 in random placement and EVCS loads at bus no. 3, 4 and 25 in optimal placement. Total active power losses at base case, random placement and optimal placement has been found out to be 0.177 MW, 0.224 MW and 0.194 MW respectively. And total reactive power losses at base case, random placement and optimal placement has been found out to be 0.238 MVAR, 0.301 MVAR and 0.261 MVAR respectively. The comparison of active power loss and reactive power loss is shown in figure 4-19. It has been noted that, in comparison to the base case, the placement of EVCS has increased power loss in the system's branches, and that power loss is greater in the random placement of EVCS than in the optimum placement of EVCS.

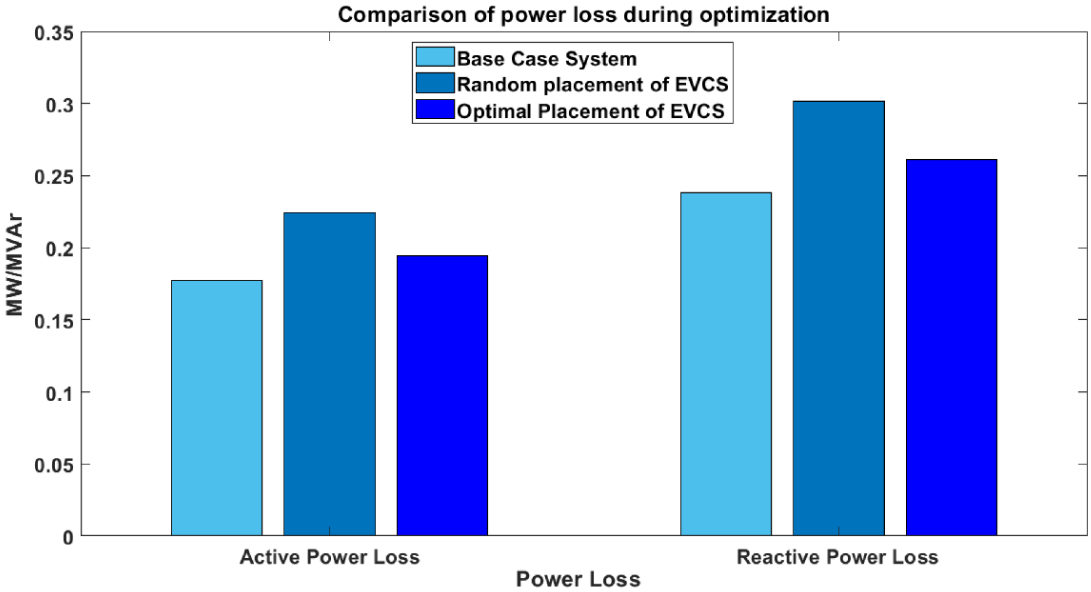

Figure 4-19 Comparison of Power loss of Jawalakhel feeder during EVCS placement

The variation observed in Energy Not Served (ENS) and Average Energy Not Served (AENS) has been demonstrated in figure 4-20 and figure 4-21 respectively. In figure 4-20, it is observed that, the system with EVCS has a higher ENS rating than the base case system due to an increase in bus loads following the installation of EVCS. When compared to the base case scenario, Figure 4-21 illustrates how the average energy not served (AENS) number has grown dramatically in the case of a system with chargers. With 1929 as the Jawalakhel feeder's customer base, the value of ENS in the basic case system is 382 MWhr, while in the system with EVCS, it is 402 MWhr. Furthermore, the AENS value for the system with EVCS is 0.2082 MWhr, whereas the value for the base case scenario is 0.1978 MWhr. The positioning of EV charging stations causes ENS and AENS to rise during EVCS deployment compared to the base case system, which impacts the system's reliability.

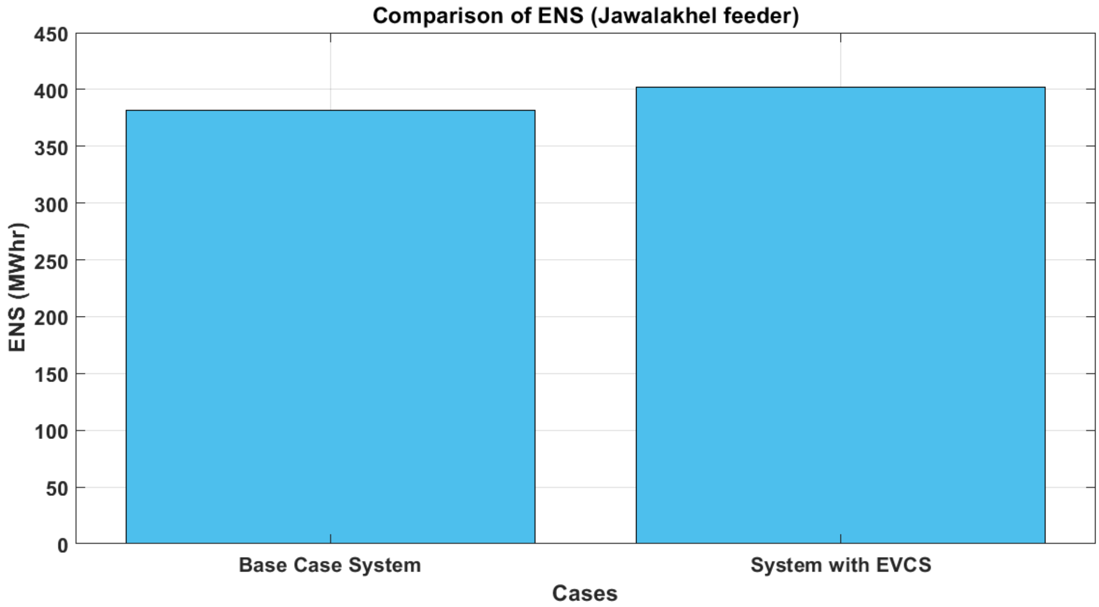

Figure 4-20 Comparison of ENS of Jawalakhel feeder

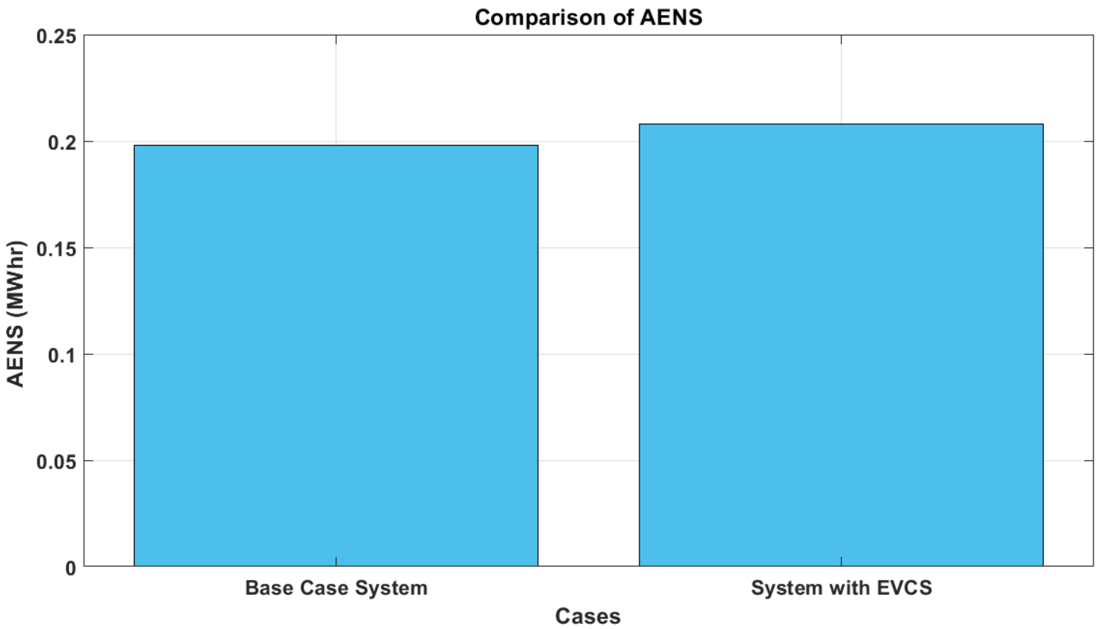

Figure 4-21 Comparison of AENS of Jawalakhel feeder

4.2.4 Reliability Indices

The reliability indices SAIDI, SAIFI, and CAIDI were compared before and after the EVCS was installed in the Jawalakhel feeder. The positioning of EVCS in the IEEE 33 bus system has been determined to have no effect on the values of SAIFI, SAIDI, and CAIDI. The values of SAIDI, SAIFI and CAIDI found out are 79.18, 99.12 and 0.798 respectively as shown in the figure 4-22, 4-23 and 4-24.

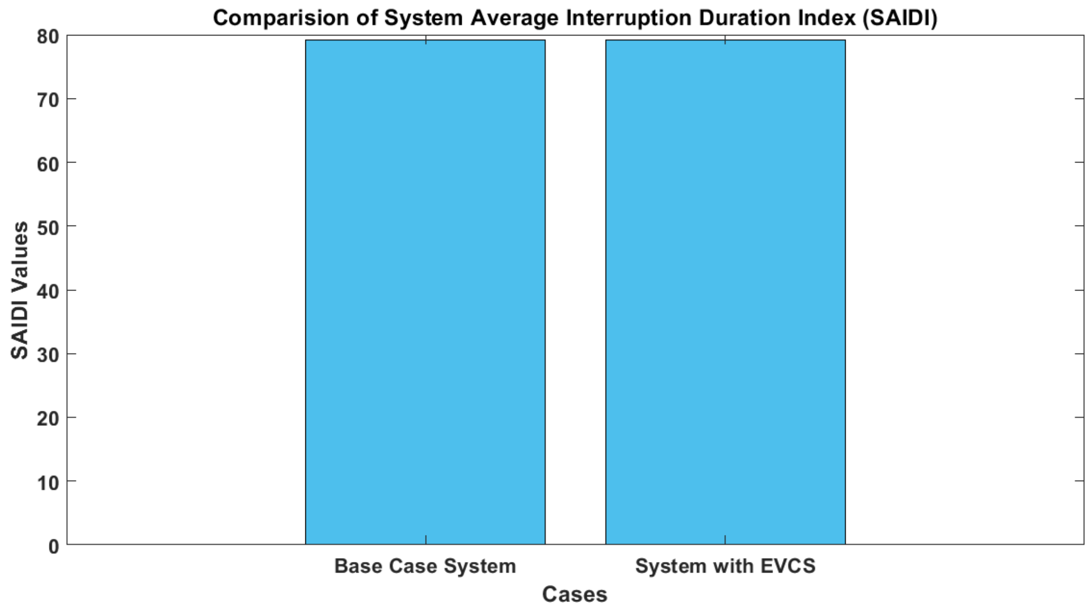

Figure 4-22 Comparison of SAIDI of Jawalakhel feeder

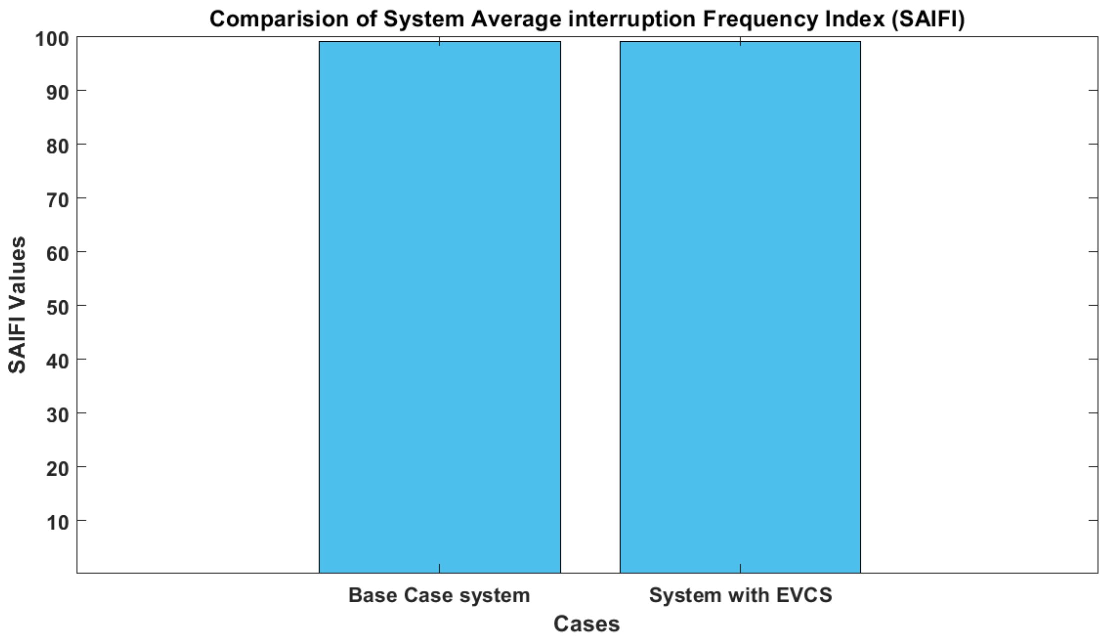

Figure 4-23 Comparison of SAIFI of Jawalakhel feeder

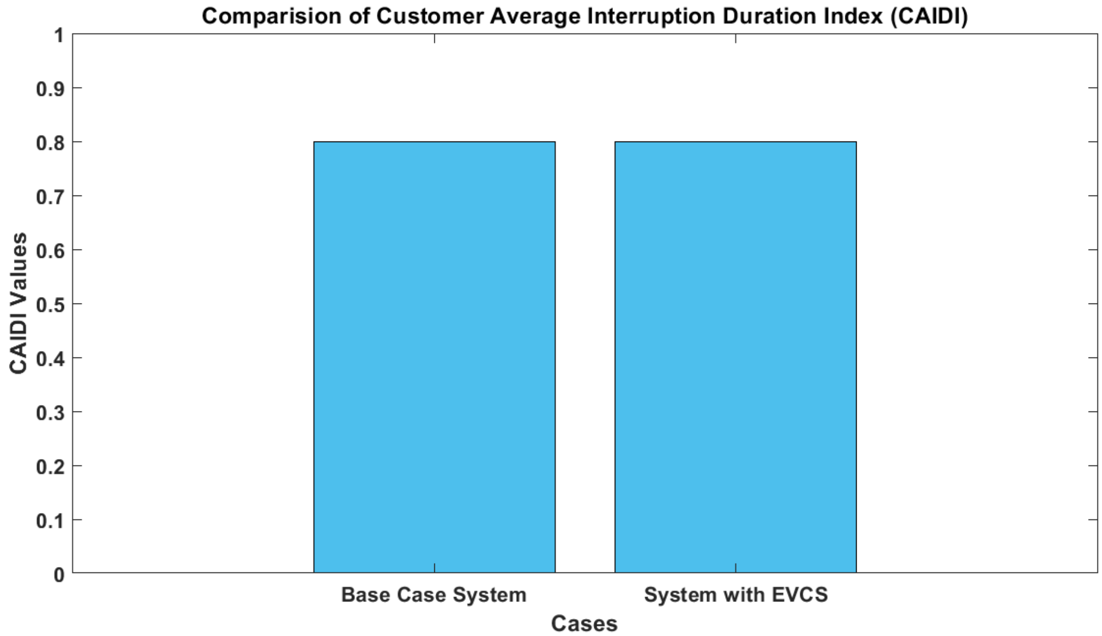

Figure 4-24 Comparison of SAIFI of Jawalakhel feeder

4.2.5 Optimal Placement and Sizing of Shunt Capacitor

It has been discovered that the voltage profile is still impaired and the active and reactive power loss in the branches from the base case system increases after the optimal placement of EVCS. So, the static compensating device in the form of shunt capacitor has been sized and optimally placed in the Jawalakhel feeder to mitigate the impact of EVCS placement. Using the GA, the optimal sizes of shunt capacitor have been found out to be 1.244 $*10^3$ kVAr and 1.786 $*10^3$ kVAr. Similarly the shunt capacitor optimal location has been determined at bus no 6 and 20 respectively. The MATLAB output of the optimal placement and sizing of shunt capacitor is shown in figure 4-10.

```
MATLAB Command Window                                                    Page 1

Optimization terminated: average change in the penalty fitness value less than options.↙
FunctionTolerance
and constraint violation is less than options.ConstraintTolerance.

ans =

    20     6


ans =

   1.0e+03 *

    1.7867    1.2444
```

Figure 4-25 MATLAB output of optimal placement and sizing of capacitor

After the placement of capacitor in the system with EVCS the voltage profile is improved as shown in figure 4-26.

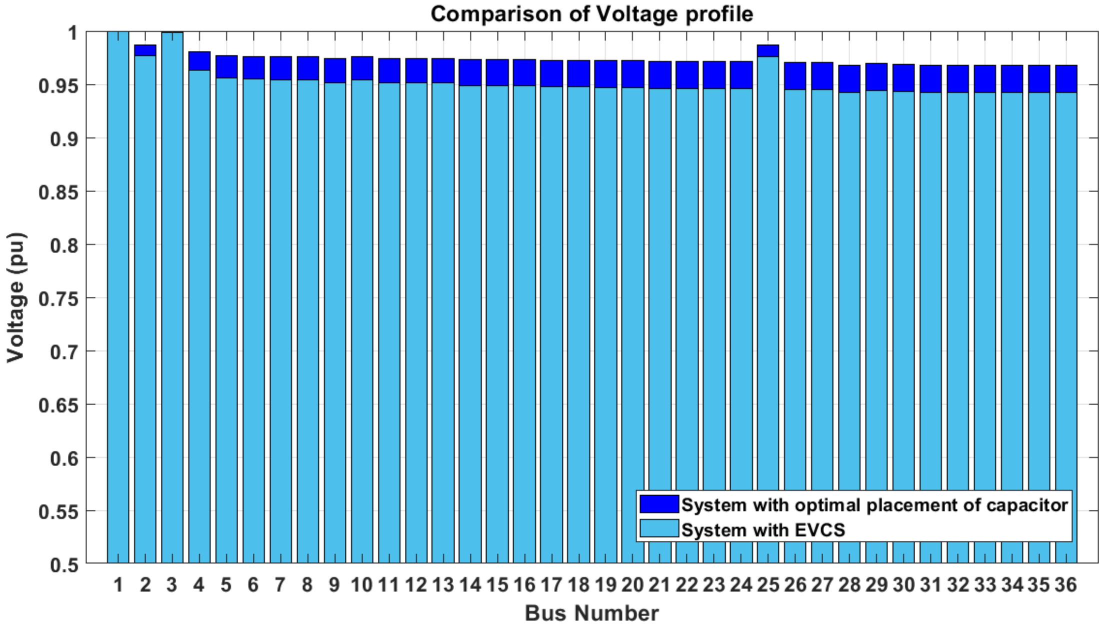

Figure 4-26 Voltage profile of the system with EVCS and capacitor placement

From the figure 4-26, it is evident that the optimal placement of the capacitor has improved the voltage profile of overall buses of Jawalakhel feeder. For instance, the voltages of bus no 18, 22, 26, 30, 35 and 36 from 0.9473 pu, 0.9456 pu, 0.9445 pu, 0.9433 pu, 0.9419 pu and 0.9418 pu is improved to 0.9719 pu, 0.9711 pu, 0.9704 pu, 0.9687 pu, 0.9674 pu and 0.9673 pu respectively.

4.2.6 Summarization of Voltage and Power Loss of Jawalakhel feeder

The second phase of this thesis of optimal placement of EVCS in Jawalakhel feeder of Lagankhel Distribution system and optimal placement and sizing of shunt capacitor to mitigate the impact of EVCS in the voltage, active power and reactive power has been accomplished. The overall comparison of the voltage profile of the base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor in the Jawalakhel feeder is shown in the figure 4-27. The figure illustrates how the base case system's voltage profile significantly degraded as a result of the EVCS's random placement. Furthermore, it is obvious that the voltage profile deterioration has been lessened following the optimal positioning of EVCS. Still the voltage curve of the system with EVCS is below the base case system. Lastly, after the optimal placement of shunt capacitor has resulted the improvement of the system voltage profile.

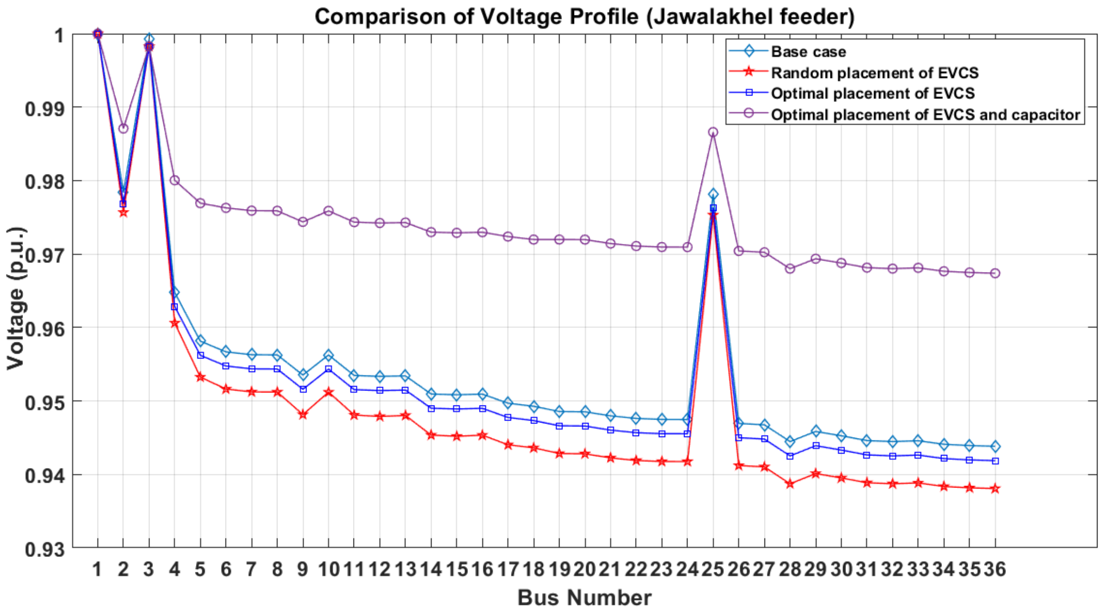

Figure 4-27 Voltage profile of Jawalakhel feeder with EVCS and capacitor placement

Similarly, the active power losses and reactive power losses at the 36 branches of Jawalakhel feeder has been compared as shown in figure 4-28 and 4-29.

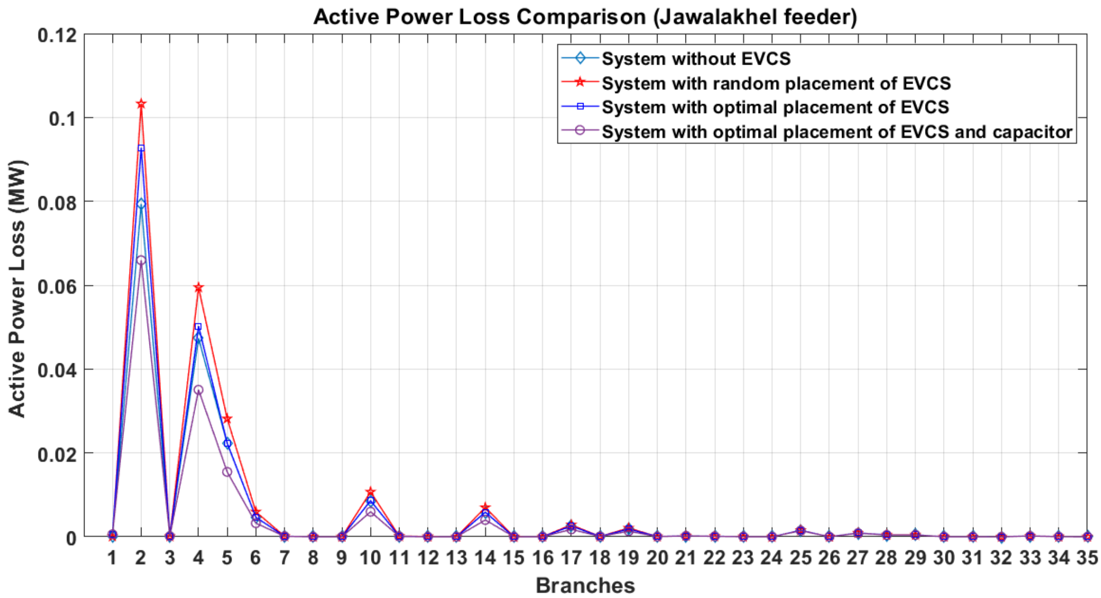

Figure 4-28 Comparison of active power losses of different cases in Jawalakhel feeder

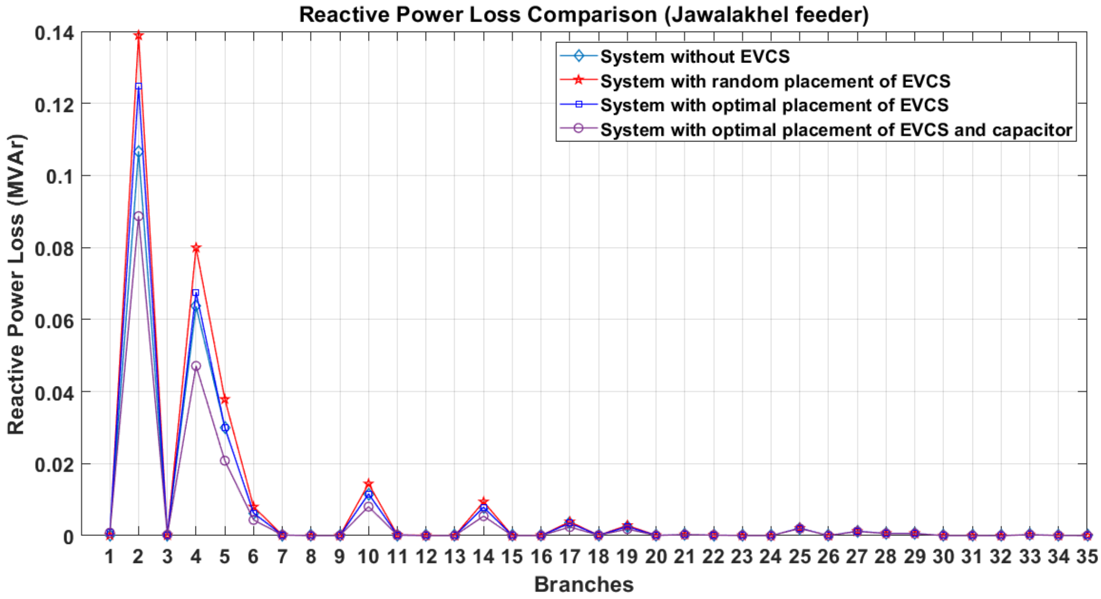

Figure 4-29 Comparison of reactive power losses of different cases in Jawalakhel feeder

From the figure 4-28, maximum active power losses have been noted for each Jawalakhel feeder branch during the EVCS's haphazard installation. Even though the loss was less after the EVCSs were positioned optimally than it was after they were randomly placed, the active power loss was still higher than in the base situation. Thus, when the capacitor was positioned optimally, the system's active power loss decreased. Similarly in the figure 4-29, the comparison of reactive power loss has been indicated that the reduction in the reactive power loss has been achieved from the optimal placement of EVCS and shunt capacitor in comparison to the random placement of EVCS in Jawalakhel feeder. Both active and reactive power losses are maximum near the slack bus i.e. bus no 1 which are gradually decreasing towards the later buses which is valid for the radial distribution system. Optimal placement of EVCS has been done with the optimization function for the active power loss of the system. Simultaneously, reactive power loss reduction has been observed in the optimal placement of EVCS after the load flow analysis. Similar to this, reactive power loss and active power loss in the branches have decreased when shunt capacitors were added to the system with EVCS because of local correction of reactive power demand. Total active and reactive power losses during optimization are compared is shown in figure 4-30.

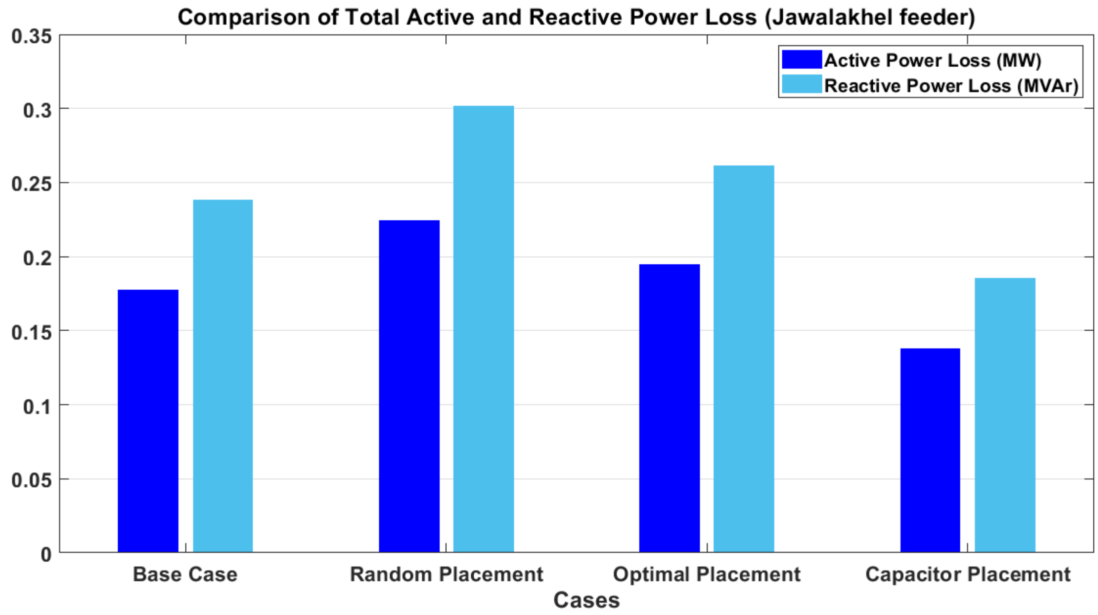

Figure 4-30 Comparison of total power loss of different cases in Jawalakhel feeder

As shown in the figure 4-30, the total active power losses are 0.177 MW, 0.224 MW, 0.194 MW and 0.137 MW and reactive power losses are 0.238 MVAR, 0.301 MVAR, 0.261 MVAR and 0.185 MVAR in the base case system, during the random placement of EVCS, during the optimal placement of EVCS and during the optimal placement of shunt capacitor in EVCS integrated system respectively.

The total power loss of the system increases if the EVCS is randomly placed in the RDS, and the total power loss is mitigated after the optimal placement of EVCS, according to an overall comparison of the base case's active and reactive power losses, EVCS placement, and optimal placement of the shunt capacitor. But the overall active and reactive power losses of the system is more than the base case system. So, to overcome the effect of EVCS integration, the shunt capacitor compensation has resulted the appreciable reduction in total active and reactive power losses of the Jawalakhel feeder.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The requirement for the placement of EVCS in the optimal nodes of the RDS is because of the fact that the integrating EVCS in the existing RDS impacts the system stability and reliability as these EVCS increases the active and reactive power demand which escalates the power losses in the branches as well as degrading the voltage profile of the buses. In order to attenuate these negative consequences, optimal allocation of EVCS is required which can be done using the GA. Even though, the optimal placement of EVCS minimizes the power losses and voltage drop, additional compensating devices should be used to restore the voltage profile and maintain the system active power and reactive power loss below than that of base system. Shunt capacitor provides reactive power compensation resulting the power factor improvement of the RDS which aids in loss reduction and voltage sensitivity factor of the network.

Here, in this thesis, in first phase the optimal planning of EVCS and shunt capacitor has been done for the IEEE 33 test system and in second phase, the work has been validated for the Jawalakhel feeder of Lagankhel distribution system. To ascertain the voltage profile and power losses in each branch of the base case system, load flow analysis was performed in the IEEE 33 system. To see the impact of unplanned installation, load flow analysis is carried out by fixing five EVCS of capacity 150 kW each with three 50 kW fast dc chargers at bus no. 3, 5, 6, 28 and 29. Voltage profile of individual buses deteriorated and power losses in each branches elevated than base case. Then, with the assistance of GA, optimum placement of EVCS has been ascertained at bus no 2 with two numbers, bus no 19 with two numbers and bus no 20 with one number considering the minimization of VRP parameters resulting the improvement of voltage magnitude of individual buses and reduction of total active power loss from 0.499 MW to 0.388 MW and reactive power loss from 0.31 MVAR to 0.22 MVAR in comparison to random placement respectively. This result has suggested the placement of EVCS near to the slack bus is the best option and it has been concluded that the voltage sensitivity factor increases and the reliability indices SAIDI, SAIFI and SAIFI have no impact and reliability indices ENS and AENS increases with integration of dc fast charger EVCS in RDS. Irrespective of the optimum placement of EVCS, the voltage magnitude has been observed to be diminished from base case. In addition, the reactive and active power losses have grown, going from 0.2027 MW and 0.135 MVAR to 0.22 MVAR and 0.388 MW, respectively. Hence, sizing and optimal placement of shunt capacitor has been suggested with the minimization function of active and reactive power loss using GA of capacity 472.4 kVAR and 1061.3 kVAR at bus no. 12 and 30 respectively. Load flow analysis of the system with EVCS compensated by the shunt capacitor resulted the voltage profile improvement along with that the active power loss and reactive power loss has been reduced from 0.388 MW and 0.22 MVAR to 0.1168 MW and 0.07 MVAR correspondingly.

Similarly in Jawalakhel feeder, load flow analysis has been carried out to determine the voltage profile and power losses in each branches of base case system. To see the impact of unplanned installation, load flow analysis has been carried out by fixing five EVCS of capacity 150 kW each with three 50 kW fast dc chargers at bus no. 6, 12, 15, 19 and 25. Voltage profile of individual buses deteriorated and power losses in each branches elevated than base case. Then, with the assistance of GA, optimum placement of EVCS is ascertained at bus no 3 with two numbers, bus no 4 with one number and bus no 25 with two numbers considering the minimization of VRP parameters resulting the improvement of voltage magnitude of individual buses and reduction of total active power loss from 0.224 MW to 0.194 MW and reactive power loss from 0.302 MVAR to 0.261 MVAR in comparison to random placement respectively. The voltage sensitivity factor increases, the reliability indices SAIDI, SAIFI, and CAIDI have no effect, and the reliability indices ENS and AENS have increased with the integration of dc fast charger EVCS in RDS, according to this result, which suggests that placing EVCS close to the slack bus is the best option. Irrespective of the optimum placement of EVCS, the voltage magnitude has been observed to be diminished from base case. Along with that the active power loss and reactive power loss have increased from 0.177 MW and 0.238 MVAR to 0.194 MW and 0.261 MVAR correspondingly. Hence, sizing and optimal placement of shunt capacitor has been suggested with the minimization function of active and reactive power loss using GA of capacity 1244 kVAR and 1786.7 kVAR at bus no. 6 and 20 respectively. The system's voltage profile improved as a consequence of load flow analysis with EVCS balanced by the shunt capacitor. Additionally, the system's active and reactive power losses decreased from 0.194 MW and 0.261 MVAR to 0.138 MW and 0.185 MVAR, respectively.

5.2 Recommendations

From this study, the optimum allocation of EVCS in addition to the sizing and placement of shunt capacitors were performed based on minimization of voltage sensitivity factor, active power loss and reactive power loss. Distortion load factor of EVCS can be considered during the placement of EVCS. Similarly, varying capacity of fast charger of different types can be considered for future work considering its harmonics analysis. Even though GA is simplified method to implement, other modified optimization algorithm can be applied for better convergence in limited operating time. Since technical parameters such as voltage, active power loss, reactive power loss has been considered during the optimization, other constraints such as geographical location and EV user charging requirements can be taken into consideration for further study.

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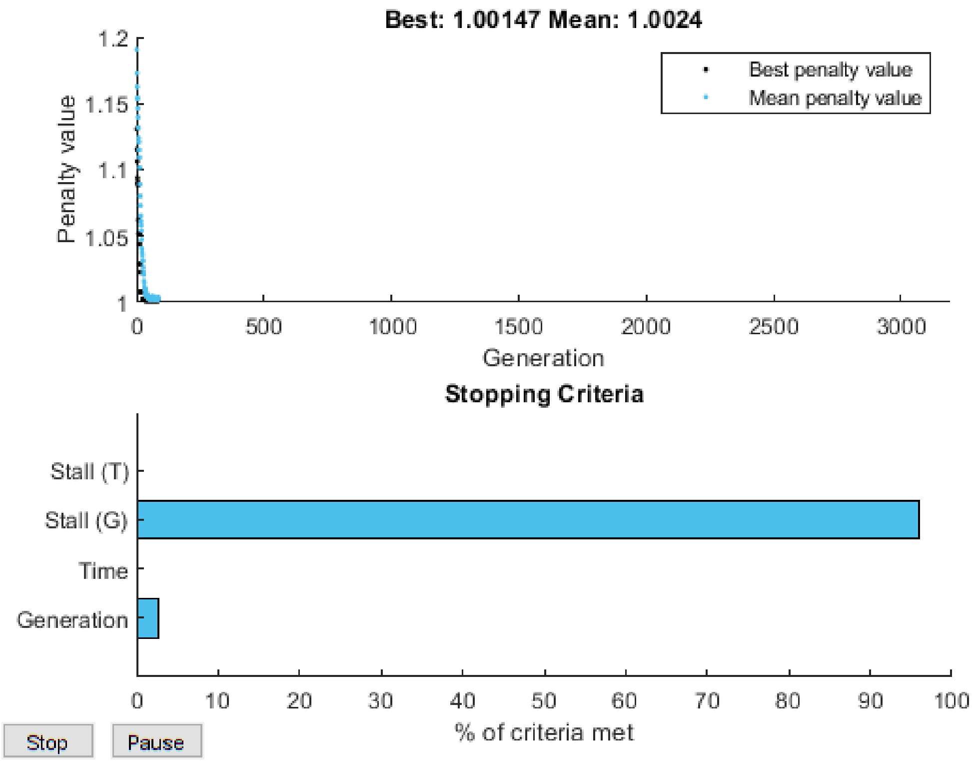
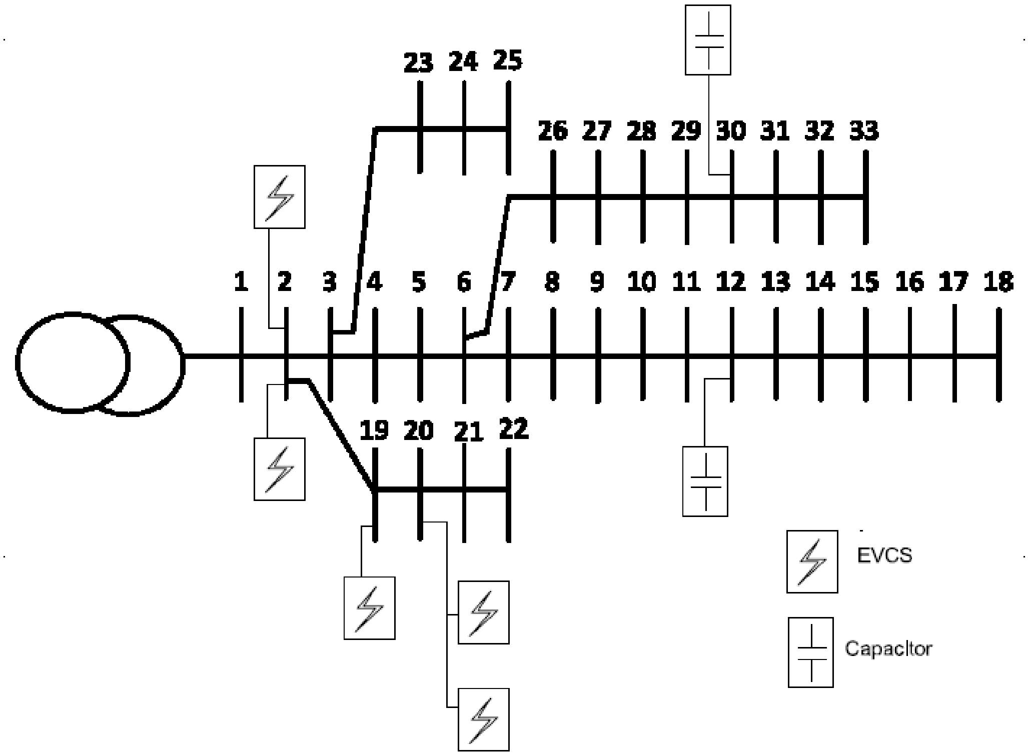
APPENDIX

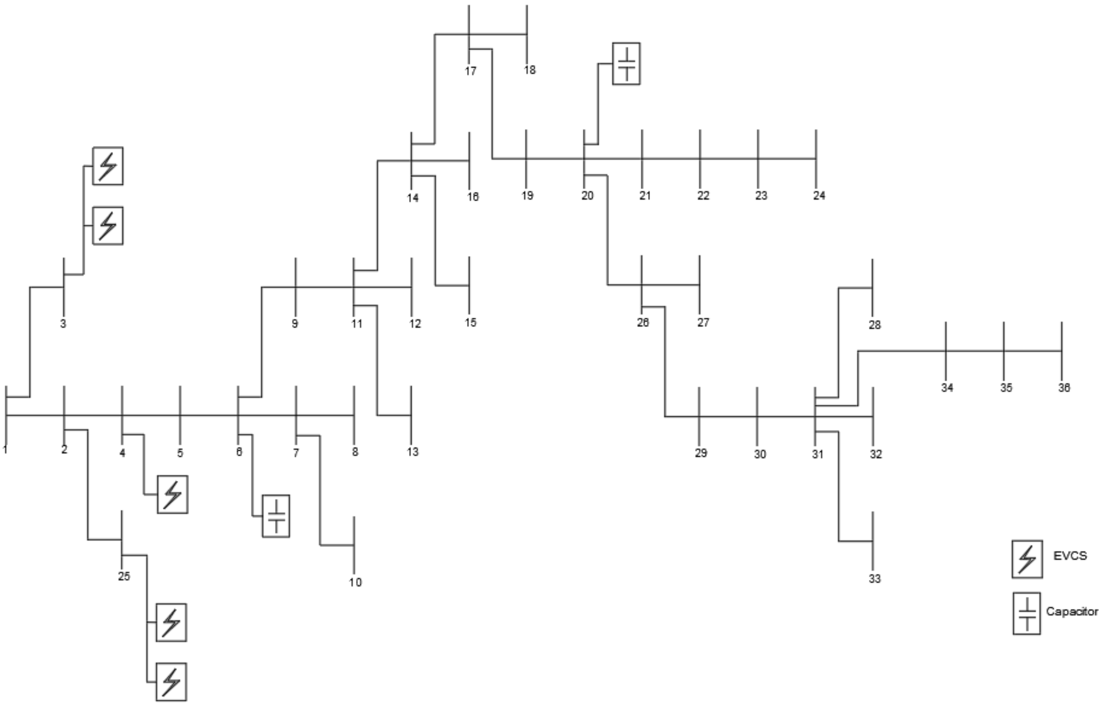
Genetic Algorithm during the optimization



Single Line Diagram of EVCS and capacitor placement in IEEE 33 bus system



Single Line Diagram of EVCS and capacitor placement in Jawalakhel feeder



Data for IEEE 33 Bus System

Bus No.	**No of customer**	**Outage rate (hr)**	**Failure Rate (hr)**	**Bus No.**	**No of customer**	**Outage rate (hr)**	**Failure Rate (hr)**
1	0	0	0	17	16	0.2	0.03
2	26	0.3	0.05	18	23	0.2	0.04
3	23	0.3	0.04	19	23	0.2	0.04
4	31	0.3	0.06	20	23	0.2	0.04
5	16	0.2	0.03	21	23	0.2	0.04
6	16	0.2	0.03	22	23	0.2	0.04
7	52	0.6	0.09	23	23	0.2	0.04
8	52	0.6	0.03	24	109	1.1	0.19
9	15	0.2	0.03	25	109	1.1	0.19
10	15	0.1	0.02	26	16	0.2	0.03
11	12	0.2	0.03	27	16	0.2	0.03
12	16	0.2	0.03	28	16	0.2	0.03
13	16	0.3	0.06	29	31	0.3	0.54
14	31	0.2	0.03	30	25	0.3	0.09
15	16	0.2	0.03	31	39	0.4	0.07
16	16	0.2	0.03	32	35	0.6	0.1
				33	16	0.03	0.03

Branch No.	From bus	To Bus	R (Ω)	X(Ω)	Load at to bus	
					P (MW)	Q (MVAR)
1	1	2	0.0922	0.0477	0.1	0.06
2	2	3	0.493	0.2511	0.09	0.04
3	3	4	0.366	0.1864	0.12	0.08
4	4	5	0.3811	0.1941	0.06	0.03
5	5	6	0.819	0.707	0.06	0.02
6	6	7	0.1872	0.6188	0.2	0.1
7	7	8	1.7114	1.2351	0.2	0.1
8	8	9	1.03	0.74	0.06	0.02
9	9	10	1.04	0.74	0.06	0.02
10	10	11	0.1966	0.065	0.045	0.03
11	11	12	0.3744	0.1238	0.06	0.035
12	12	13	1.468	1.155	0.06	0.035
13	13	14	0.5416	0.7129	0.12	0.08
14	14	15	0.591	0.526	0.06	0.01
15	15	16	0.7463	0.545	0.06	0.02
16	16	17	1.289	1.721	0.06	0.02
17	17	18	0.732	0.574	0.09	0.04
18	2	19	0.164	0.1565	0.09	0.04
19	19	20	1.5042	1.3554	0.09	0.04
20	20	21	0.4095	0.4784	0.09	0.04
21	21	22	0.7089	0.9373	0.09	0.04
22	3	23	0.4512	0.3083	0.09	0.05
23	23	24	0.898	0.7091	0.42	0.2
24	24	25	0.896	0.7011	0.42	0.2
25	6	26	0.203	0.1034	0.06	0.025
26	26	27	0.2842	0.1447	0.06	0.025
27	27	28	1.059	0.9337	0.06	0.02
28	28	29	0.8042	0.7006	0.12	0.07
29	29	30	0.5075	0.2585	0.2	0.6
30	30	31	0.9744	0.963	0.15	0.07
31	31	32	0.3105	0.3619	0.21	0.1
32	32	33	0.341	0.5302	0.06	0.04

Data for Jawalakhel feeder of Lagankhel Distribution System

Bus No.	No of customer	Outage rate (hr/yr)	Failure Rate (/year)	Bus No.	No of customer	Outage rate (hr/yr)	Failure Rate (/year)
1	0	0	0	19	68	80.12	100
2	34	66.1	80	20	68	80.12	100
3	68	80.12	100	21	34	66.1	80
4	68	80.12	100	22	68	80.12	100
5	85	90	115	23	68	80.12	100
6	68	80.12	100	24	34	66.1	80
7	68	80.12	100	25	68	80.12	100
8	34	66.1	80	26	34	66.1	80
9	68	80.12	100	27	34	66.1	80
10	68	80.12	100	28	34	66.1	80
11	34	66.1	80	29	34	66.1	80
12	68	80.12	100	30	34	66.1	80
13	34	66.1	80	31	68	80.12	100
14	34	66.1	80	32	34	66.1	80
15	68	80.12	100	33	8.5	40.45	50
16	34	66.1	80	34	102	95.94	125
17	102	95.94	125	35	34	66.1	80
18	102	95.94	125	36	68	80.12	100

Branch No.	From bus	To Bus	R (Ω)	X(Ω)	Load at to bus	
					P (MW)	Q (MVAR)
1	1	3	0.292169	0.392925	0.17	0.105
2	1	2	0.290374	0.390511	0.085	0.052678
3	2	25	0.081332	0.10938	0.17	0.10535
4	2	4	0.19335	0.260028	0.17	0.105
5	4	5	0.098187	0.132048	0.2125	0.132
6	5	6	0.022683	0.030505	0.17	0.105
7	6	7	0.057527	0.077365	0.17	0.105
8	7	8	0.016277	0.02189	0.085	0.0526
9	7	10	0.011808	0.015881	0.17	0.10535
10	6	9	0.057664	0.07755	0.17	0.10535
11	9	11	0.001013	0.001362	0.085	0.0526
12	11	12	0.044551	0.059915	0.17	0.10535
13	11	13	0.044387	0.059694	0.085	0.0526
14	11	14	0.054243	0.072949	0.085	0.0526
15	14	16	0.008083	0.01087	0.085	0.0526
16	14	15	0.036645	0.049283	0.17	0.10535

Branch No.	From bus	To Bus	R (Ω)	X(Ω)	Load at to bus	
					P (MW)	Q (MVAR)
17	14	17	0.030555	0.041092	0.255	0.158
18	17	18	0.102269	0.137537	0.255	0.158
19	17	19	0.034039	0.045778	0.17	0.10535
20	19	20	0.001392	0.001872	0.17	0.10535
21	20	21	0.067713	0.091064	0.085	0.0526
22	21	22	0.051452	0.069195	0.17	0.10535
23	22	23	0.033389	0.044904	0.17	0.10535
24	23	24	0.007257	0.009759	0.085	0.0526
25	20	26	0.081601	0.109742	0.085	0.0526
26	26	27	0.134373	0.180713	0.085	0.05267
27	26	29	0.065115	0.08757	0.085	0.05267
28	29	30	0.038624	0.051944	0.085	0.05267
29	30	31	0.046715	0.062825	0.17	0.10535
30	31	32	0.098903	0.133011	0.085	0.05267
31	31	28	0.10254	0.137901	0.085	0.05267
32	31	33	0.068678	0.092362	0.02125	0.01316
33	31	34	0.061339	0.082491	0.255	0.158
34	34	35	0.042789	0.059246	0.085	0.05267
35	35	36	0.037655	0.048255	0.17	0.1053

MATLAB Code

```
%% Definitions
define_constants;                    %Defines constants for named column indices to
data matrices for matpower/Initialize
loadIncrement=0.001;                    %single step load increment for VSF
fastChargerRating=15e-4;             %fast charger pu 100 MVA rating (50 kW fast
charger)
fastChargerLimit=2;                   %Maximum no of fast charging station in a bus
fastChargerInStation=3;              %No. of  fast charger in a charging station
noofFastChargingStation=5;              %No. of fast charging station to be kept in
system


%% Genetic Algorithm Parameters and working
populationSize=100;
options = optimoptions('ga', 'PopulationSize',
populationSize,'PlotFcn',{@gaplotbestf,@gaplotstopping});
w1=0.1;
w2=[0.2,0.4,0.1];
w3=0.2;

%%Matpower, case loading
mpc = loadcase('ieee33.m');           %matpower case file
nBus=numel(mpc.bus(:,1));                %No. of bus in the system
nCustomers=sum(mpc.comp_rel(:,8));         %No. of customers, 8th column of
reliability
results=runpf(mpc,mpoption('verbose',0,'out.all',0,'pf.alg','ISUM','pf.radial.max_it',10
00));   %carry out the base load flow using matpower and obtain the results
%nBus=numel(mpc.bus(:,1));
%nCustomers=sum(mpc.comp_rel(:,8));

% Store information of the base load flow
Plossbase=real(sum(get_losses(results)));   %Sum up the active power loss
vsfbase=zeros(1,nBus);
VSI=zeros(1,nBus);
saifi=zeros(1,nBus);
saidi=zeros(1,nBus);
ens=zeros(1,nBus);
voltageArray=results.bus(:,8).*exp(1i*results.bus(:,9));


for x=1:nBus
  mpc1=mpc;
  mpc1.bus(x,PD)=mpc1.bus(x,PD)+loadIncrement*mpc.baseMVA;

results=runpf(mpc1,mpoption('verbose',0,'out.all',0,'pf.alg','ISUM','pf.radial.max_it',1
000));
```

```
  voltage=results.bus(x,8).*exp(1i*results.bus(x,9));
  vsfbase(x)=abs((abs(voltageArray(x))-abs(voltage))/loadIncrement);
  saifi(x)=mpc.comp_rel(x,3)*mpc.comp_rel(x,8);
  saidi(x)=mpc.comp_rel(x,6)*mpc.comp_rel(x,8);
  ens(x)=mpc.comp_rel(x,6)*mpc.bus(x,3);
end


%%Base Case Values
VSFbase=sum(vsfbase);
SAIFIbase=sum(saifi)/nCustomers;
SAIDIbase=sum(saidi)/nCustomers;
CAIDIbase=SAIDIbase/SAIFIbase;
ENSbase=sum(ens);
AENSbase=ENSbase/nCustomers;


%fastChargers=zeros(1,1);
LB=zeros(1,(nBus-1)); %Sets lower limit of charger in all buses to Zero (i.e. no
charger connected)
UB=zeros(1,(nBus-1)); %Sets upper limit of charger in all buses to Zero
UB(1:(nBus-1))=fastChargerLimit; %Updates upper limit of charger in all buses as
defined above
nvars=(nBus-1);


objective =
@(x)fitness(x,mpc,SAIFIbase,SAIDIbase,CAIDIbase,Plossbase,w1,w2,w3,fastCharg
erRating,loadIncrement,VSFbase);
%The constraints are for load flow and that are addressed while carrying
%out the load flow analysis


intCon=1:(nBus-1);
Aeq=zeros(1,(nBus-1));
Aeq (1:(nBus-1))=-1;
Beq=-noofFastChargingStation;
[x,fval]=ga(objective,nvars,Aeq,Beq,[],[],LB,UB,[],intCon,options);

%% Obtained  output of the position of fast chargers in buses
u=[(2:nBus)',x(1:(nBus-1))']; %merge bus no. column with output of ga
position=["Bus","Fast Chargers"];
position=[position;u];

%% Calculating reliability indices
VSF=zeros(1,nBus);
VSI=zeros(1,nBus);
saifiNew=zeros(1,nBus);
```

```
saidiNew=zeros(1,nBus);
ensNew=zeros(1,nBus);
fastChargers=x(1:(nBus-1));

for bus=2:nBus
    mpc.bus(bus,PD)=mpc.bus(bus,PD)+fastChargers(bus-
1)*fastChargerRating*mpc.baseMVA;
    mpc.comp_rel(bus,3)=mpc.comp_rel(bus,3)+(fastChargers(bus-1)*0.001);
end
results=runpf(mpc,mpoption('verbose',0,'out.all',0));
Ploss=real(sum(get_losses(results)));
voltageArrayNew=results.bus(:,8).*exp(1i*results.bus(:,9));

for q=1:nBus
    mpc1=mpc;
    mpc1.bus(q,PD)=mpc1.bus(q,PD)+loadIncrement*mpc.baseMVA;
    results=runpf(mpc1,mpoption('verbose',0,'out.all',0));
    voltage=results.bus(q,8).*exp(1i*results.bus(q,9));
    VSF(q)=abs((abs(voltageArrayNew(q))-abs(voltage))/loadIncrement);
    saifiNew(q)=mpc.comp_rel(q,3)*mpc.comp_rel(q,8);
    saidiNew(q)=mpc.comp_rel(q,6)*mpc.comp_rel(q,8);
    ensNew(q)=mpc.comp_rel(q,6)*mpc.bus(q,3);
end

%% Calculations of indices
SAIFI=sum(saifiNew)/nCustomers;
SAIDI=sum(saidiNew)/nCustomers;
CAIDI=SAIDI/SAIFI;
caidiNew=saidiNew./saifiNew;
ENS=sum(ensNew);
AENS=ENS/nCustomers;
VRP=w1*VSFbase/sum(VSF)+sum(w2.*[SAIFI/SAIFIbase, SAIDI/SAIDIbase,
CAIDI/CAIDIbase])+w3*Ploss/Plossbase;

display(position);

%% Graph Plotted here onwards
% ENS Comparision
T = categorical({'Base System','System with Chargers'});
S = [ENSbase,ENS];
f1 = figure('Name','Comparision of ENS');
title('Comparision of ENS');
bar(T,S);
xlabel('Scenarios') ;
ylabel('ENS Values in MWhr');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

% AENS Comparision
```

```
T = categorical({'Base System','System with Chargers'});
Y = [AENSbase,AENS];
f2 = figure('Name','Comparision of AENS');
title('Comparision of AENS');
bar(T,Y);
xlabel('Scenarios') ;
ylabel('AENS Values in MWhr');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

% Fast charger placement
f9 = figure('Name', 'Fast CS in Buses');
 title('Fast CS in Buses');
 X= u(:,1);
 Y= u(:,2);
 bar(X,Y);
 xlabel('Bus No')
 ylabel('Fast CS Numbers')
% Ploss Comparision
T = categorical({'Base System','System with Chargers'});
Y = [Plossbase,Ploss];
f3 = figure('Name','Comparision of Active Power Loss');
title('Comparision of Active Power Loss');
bar(T,Y);
xlabel('Scenarios') ;
ylabel('Active Power loss MW');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

%SAIFI Comparision
Y = [SAIFIbase,SAIFI];
f4 =  figure('Name','Comparision of SAIFI');
bar(Y);
title('Comparision of SAIFI');
xlabel('Scenarios') ;
ylabel('SAIFI Values');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

%SAIDI Comparision
Y = [SAIDIbase,SAIDI];
f5 =  figure('Name','Comparision of SAIDI');
bar(Y);
title('Comparision of SAIDI');
xlabel('Scenarios') ;
ylabel('SAIDI Values');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

%CAIDI Comparision
Y = [CAIDIbase,CAIDI];
f6 =  figure('Name','Comparision of CAIDI');
```

```
bar(Y);
title('Comparision of CAIDI');
xlabel('Scenarios') ;
ylabel('CAIDI Values');
%legend({'base Sysytem','System With Chargers'},'Location','northeast');

%Voltage Profile Comparision
f7 =  figure('Name','Comparision of Voltage Profile');
bar([abs(voltageArray),abs(voltageArrayNew)]);
title('Comparision of Voltage Profile');
xlabel('Bus No') ;
ylabel('Voltage magnitude in Pu');
legend({'base Sysytem','System With Chargers'},'Location','northeast');

% VSF Comparision
f8 = figure('Name','Comparision of Voltage Sensitivity Factor');
bar([vsfbase'*100,VSF'*100]);
title('Comparision of Voltage Sensitivity Factor');
xlabel('Bus No') ;
ylabel('VSF Values in percentage');
legend({'base Sysytem','System With Chargers'},'Location','northeast');
```

Fitness Function

```
%% Definitions
define_constants;              %for matpower
  nBus=numel(mpc.bus(:,1));
  nCustomer=sum(mpc.comp_rel(:,8));
  VSF=zeros(1,nBus);
  VSI=zeros(1,nBus);
  saifi=zeros(1,nBus);
  saidi=zeros(1,nBus);
  ens=zeros(1,nBus);
  fastChargers=x(1:(nBus-1));

for bus=2:nBus
    mpc.bus(bus,PD)=mpc.bus(bus,PD)+fastChargers(bus-
1)*fastChargerRating*mpc.baseMVA;
    mpc.comp_rel(bus,3)=mpc.comp_rel(bus,3)+(fastChargers(bus-1)*0.001);
end



results=runpf(mpc,mpoption('verbose',0,'out.all',0,'pf.alg','ISUM','pf.radial.max_it',10
00));
  Ploss=real(sum(get_losses(results)));
  voltageArray=results.bus(:,8).*exp(1i*results.bus(:,9));
```

```
for x=1:nBus
   mpc1=mpc;
   mpc1.bus(x,PD)=mpc1.bus(x,PD)+loadIncrement*mpc.baseMVA;

results=runpf(mpc1,mpoption('verbose',0,'out.all',0,'pf.alg','ISUM','pf.radial.max_it',1
000));
   voltage=results.bus(x,8).*exp(1i*results.bus(x,9));
   VSF(x)=abs((abs(voltageArray(x))-abs(voltage))/loadIncrement);
   saifi(x)=mpc.comp_rel(x,3)*mpc.comp_rel(x,8);
   saidi(x)=mpc.comp_rel(x,6)*mpc.comp_rel(x,8);
   ens=mpc.comp_rel(x,6)*mpc.bus(x,3);
end

 %% Reliability Indices calculation
 SAIFI=sum(saifi)/nCustomer;
 SAIDI=sum(saidi)/nCustomer;
 CAIDI=SAIDI/SAIFI;
 ENS=sum(ens);
 AENS=ENS/nCustomer;

%Merging all output for providing to genetic algorithm function of MATLAB
 VRP=w1*VSFbase/sum(VSF)+sum(w2.*[SAIFI/SAIFIbase, SAIDI/SAIDIbase,
CAIDI/CAIDIbase])+w3*Ploss/Plossbase;
```

For Capacitor Placement

```
clear ;
clc;
close;
global ldata_o ncap ;
%ldata_o= [ Ln   sn   rn     r       x     ]
 ldata_o= [  1    1    2   0.0922   0.0470
             2    2    3   0.4930   0.2511
             3    3    4   0.3660   0.1864
             4    4    5   0.3811   0.1941
             5    5    6   0.8190   0.7070
             6    6    7   0.1872   0.6188
             7    7    8   1.7114   1.2351
             8    8    9   1.0300   0.7400
             9    9   10   1.0440   0.7400
            10   10   11   0.1966   0.0650
            11   11   12   0.3744   0.1238
            12   12   13   1.4680   1.1550
            13   13   14   0.5416   0.7129
            14   14   15   0.5910   0.5260
            15   15   16   0.7463   0.5450
            16   16   17   1.2890   1.7210
```

```
        17   17   18   0.7320   0.5740
        18    2   19   0.1640   0.1565
        19   19   20   1.5042   1.3554
        20   20   21   0.4095   0.4784
        21   21   22   0.7089   0.9373
        22    3   23   0.4512   0.3083
        23   23   24   0.8980   0.7091
        24   24   25   0.8960   0.7011
        25    6   26   0.2030   0.1034
        26   26   27   0.2842   0.1447
        27   27   28   1.0590   0.9337
        28   28   29   0.8042   0.7006
        29   29   30   0.5075   0.2585
        30   30   31   0.9744   0.9630
        31   31   32   0.3105   0.3619
        32   32   33   0.3410   0.5302];

dim=size(ldata_o);
nbus=dim(1)+1;
ldata=ldata_o(1:dim(1),2:dim(2));

[sn rn lr lx s ne e p ncu uca ucd nbu ubd nmat] = fbase_conf( ldata,nbus );
[bcPloss,bcQloss,bctmpv,bctmpd,bcPL,bcQL,bciter,bcmaxerror] =fdist_loadflow();



ncap=2;
options = gaoptimset;
options = gaoptimset('PopulationSize', 50,'Generations',
500,'StallGenLimit',100,'TimeLimit', 500,'StallTimeLimit',
50,'PlotFcn',@gaplotbestf);

%[x fval]= ga(fun,nvars,A,b,Aeq,Beq,lb,ub,nonlcon,IntCon,options)
[capplcsz_opt,fval]=ga(@fdist_loadflow_cap_plcsz,2*ncap,[],[],[],[],[2 0 2 0],[33 2
33 2],[],[1 3],options);
capplcsz_opt([1 3])
capplcsz_opt([2 4])*1000
fval*1000
[Ploss,Qloss,tmpv,tmpd,PL,QL,iter,maxerror]
=fdist_loadflow_cap_plcsz(capplcsz_opt);
% display  result of Loadflow

  fprintf('\n\n total iteration number=%g\t\t\t\t\n\n',bciter);
  fprintf('\n Maximum error deviation=%8.7f\t\t\t\n\n',bcmaxerror);


  head =['          RESULT SHOWING VOLTAGE PROFILE              '
       '   Bus        Magnitude of Voltage          Voltage Angle'
```

```
      '  Number              (pu)                 (rad)     '];

   disp(head);
   for m=1:nbus

fprintf('\n%5g\t\t\t\t%8.7f\t\t\t\t%8.7f\t\t\t\t%8.7f\t\t\t\t',m,bctmpv(m),bctmpd(m));
   end
fprintf('\n\n');
head1 =['RESULT SHOWING ACTIVE POWER&REACTIVE POWER LOSSES
IN THE BRANCHES'
     '   Branch       SBranch-RBranch          Branch Losses         '
     '   Number           SBN-RBN         RealPL(kW)   ReactivePL(kVAR)'];

   disp(head1);
   for bn=1:nbus-1
       fprintf('\n %5g\t\t\t\t %2g-
%2g\t\t\t\t%5.3f\t\t\t\t%5.3f\t\t\t\t',bn,sn(bn),rn(bn),bcPL(bn)*1000,bcQL(bn)*1000);
   end
fprintf('\n\nReal power Loss(kW)     = %5g\t\t\t\t\n',bcPloss*1000);
fprintf('\nReactive power Loss(kVar)= %5g\t\t\t\t\n',bcQloss*1000);
figure(1);
bar(bctmpv);
axis([1 33 0 1.1]);

% display  result of Loadflow

  fprintf('\n\n total iteration number=%g\t\t\t\t\n\n',iter);
  fprintf('\n Maximum error deviation=%8.7f\t\t\t\n\n',maxerror);


  head =['           RESULT SHOWING VOLTAGE PROFILE              '
      '   Bus        Magnitude of Voltage         Voltage Angle'
      '  Number              (pu)                 (rad)     '];

   disp(head);
   for m=1:nbus
       fprintf('\n%5g\t\t\t\t%8.7f\t\t\t\t%8.7f\t\t\t\t%8.7f\t\t\t\t',m,tmpv(m),tmpd(m));
   end
fprintf('\n\n');
head1 =['RESULT SHOWING ACTIVE POWER&REACTIVE POWER LOSSES
IN THE BRANCHES'

     '   Branch       SBranch-RBranch          Branch Losses         '
     '   Number           SBN-RBN         RealPL(kW)   ReactivePL(kVAR)'];

   disp(head1);
   for bn=1:nbus-1
```

```
        fprintf('\n %5g\t\t\t\t %2g-
%2g\t\t\t\t%5.3f\t\t\t\t%5.3f\t\t\t\t',bn,sn(bn),rn(bn),PL(bn)*1000,QL(bn)*1000);
    end
fprintf('\n\nReal power Loss(kW)     = %5g\t\t\t\t\n',Ploss*1000);
fprintf('\nReactive power Loss(kVar)= %5g\t\t\t\t\n',Qloss*1000);
figure(2);
bar(tmpv);
axis([1 33 0 1.1]);


% initialization FOR LOADFLOW
bKVA=1000; %1MVA
bKV=11;    %jawalakhel
maxerror=1;
tolerance=0.0001;

% end of initialization FOR LOADFLOW

dim=size(ldata_o);
n=dim(1)+1;
mldata=ldata_o(1:dim(1),2:dim(2));

[sn rn lr lx s ne e p ncu uca ucd nbu ubd nmat ] = fbase_conf( mldata,n );
bp=busdata(:,2);
bq=busdata(:,3);


%%%%%%%%%%%%%%%%
maxerror=1;
bZ=bKV*bKV*1000/bKVA;
S=complex(bp,bq);
Spu=S/bKVA;
bppu=bp/bKVA;
bqpu=bq/bKVA;
for tt=1:ncap
    bqpu(capplcsz(1,2*tt-1))=bqpu(capplcsz(1,2*tt-1))-capplcsz(1,2*tt);
end
real=sum(bppu);
Reactive=sum(bqpu);
lrpu=lr/(bZ);
lxpu=lx/(bZ);

% initialization
v1=1;
v2=0;
del1=0;
del2=0;
Ploss=0;
```

```
Qloss=0;
PL=zeros(1,n-1);
QL=zeros(1,n-1);

iter=0;
tmpv0=zeros(1,n)+1;
tmpv=tmpv0;
tmpd0=zeros(1,n);
tmpd=zeros(1,n);
mm=0;
flag1=0;
%  end of initialization
while (maxerror>tolerance)
   Ploss=0;
   Qloss=0;
   iter=iter+1;
   v1=1;
   del1=0;
   for m=1:1:ne
      for k=1:nbu(m)   % no of node for each lateral
         cbn=ubd(m,k);
         crn=rn(cbn);
         csn=sn(cbn);
         if((tmpv(crn)==tmpv0(crn))&&(tmpd(crn)==tmpd0(crn)))
            v1=tmpv(csn);
            del1=tmpd(csn);
            v2=tmpv(crn);
            del2=tmpd(crn);
            P2=0; Q2=0;
            row=nmat(crn,:);
            for l=1:1:n % also from l= k to n
               if(l==crn)
                  P2=P2+bppu(l);
                  Q2=Q2+bqpu(l);
                  else if(row(l)==1)
                        P2=P2+bppu(l)+PL(find(l==rn)); % from the current node l>k
                        Q2=Q2+bqpu(l)+QL(find(l==rn));
                     end
               end
            end % end of for loop made for summation at a node
            A(crn)=P2*lrpu(cbn)+Q2*lxpu(cbn)-0.5*v1^2;
            img=(A(crn))^2-((lrpu(cbn))^2+(lxpu(cbn))^2)*(P2^2+Q2^2);
            if (img<0)
               fprintf('\n LF: load flow not converged imaginary voltage ');
               flag1=1;
               break;
            end
```

```
            B(crn)=sqrt(img);
            imgg=B(crn)-A(crn);
            if (imgg<0)
                fprintf('\n LFF: load flow not converged imaginary voltage ');
                flag1=1;
                indlfnc=1;
                break;
            end
            v2=sqrt(imgg);
            dd=(P2*lxpu(cbn)-Q2*lrpu(cbn))/(P2*lrpu(cbn)+Q2*(lrpu(cbn)+v2^2));
            del2=del1-atan(dd);
 %  branch loss calculation
            PL(cbn)=lrpu(cbn)*(P2^2+Q2^2)/v2^2;
            QL(cbn)=lxpu(cbn)*(P2^2+Q2^2)/v2^2;

 % storing data
            tmpv(crn)=v2;
            tmpd(crn)=del2;
            Ploss=Ploss+PL(cbn);
            Qloss=Qloss+QL(cbn);
        end  %end of calculation of node
    end     %end of calculation of lateral
    if (flag1==1)
        fprintf('\n LF1: load flow not converged imaginary voltage ');
        flag1=2;
        indlfnc=1;
        break;
    end
end         %end of calculation of iteration
if (flag1==2)
        fprintf('\n LF2: load flow not converged imaginary voltage ');
        fprintf('\n the current iteration =%d\n',iter)
        flag1=3;
        indlfnc=1;
        break;
end




 % end of for loop for each bus load flow

v_err=abs(tmpv0-tmpv);
del_err=abs(tmpd0-tmpd);
maxr=max(v_err,del_err);
maxerror=max(maxr);
```

```
  tmpv0=tmpv;
  tmpd0=tmpd;% assigning the current value for next error calculation


end % end of while


del_deg=tmpd*180/pi;
V_act=tmpv*bKV;
Ploss_act=Ploss*bKVA;
Qloss_act=Qloss*bKVA;
PL_act=PL*bKVA;
QL_act=QL*bKVA;



end
```

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