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EV Charging Station Placement Strategy Considering Power Grid Impact for Future Expansion of EV in Kathmandu Valley: A Case Study of Sanepa Feeder

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**EV Charging Station Placement Strategy Considering Power Grid Impact for Future Expansion of EV in Kathmandu Valley: A Case Study of Sanepa Feeder**" by Rusha Shrestha in partial fulfilment of the requirements for the degree of Master of Science in Technology and Innovation Management.

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ABSTRACT

Increasing concerns over the unsustainable fossil fuel consumption and initiatives to achieve the Sustainable Development Goals (SDG), the interests over battery operated electric vehicles (EVs) are increasing. While the primary infrastructure to flourish this technology is charging stations, the impact of such load on the distribution network is somehow being shadowed. When the load from EV chargers are being added to existing power system, the voltage fluctuations and power loss are imminent. This study analyzed the impact of addition of EV charging load on the Sanepa distribution network. The system modelling was performed using DigSILENT PowerFactory tool and the optimal placement of EV charging station along the feeder line was determined using Particle Swarm Optimization (PSO) technique in MATLAB environment. The impact of EV charging station load placement on the distribution network were studied through the behavior analysis of Voltage stability, Reliability and Power loss (VRP) parameters of the line before and after load addition. The results from impact analysis on VRP index was used in defining the objective function for optimization. The optimal locations for EV charging station placement were obtained which effectively addressed concerns of power grid impact. This study shows random placement of EV charging station loads cause severe effect on network quality while strategically placed loads not only reduce the power grid impact but also increase system efficiency and reliability.

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
SDG	Sustainable Development Goals
VRP	Voltage Stability, Reliability and Power loss
PSO	Particle Swarm Optimization
CO_2	Carbon Dioxide
UN	United Nations
GHG	Greenhouse Gases
EVCS	Electric Vehicle Charging Stations
NEA	Nepal Electricity Authority
DC	Direct Current
AC	Alternating Current
LV	Low Voltage
DG	Distributed Generator
PV	Photo Voltaic
BESS	Battery Energy Storage System
PHEV	Plugged in Hybrid Electric Vehicle
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
MAIFI	Momentary Average Interruption Frequency Index
ASAI	Average Service Availability Index
ENS	Energy Not Served
AENS	Average Energy Not Served
GA	Genetic Algorithm
ACO	Ant Colony Optimization
ACSR	Aluminum Conductor Steel Reinforced
HT ABC	HT Aerial Bunched Cables
GIS	Geographic Information System

VSF	Voltage Sensitivity Factor
VSI	Voltage Stability Index
Pbest	Personal Best
Gbest	Global Best
PV Curve	Power Voltage Curve
CCS	Combined Charging System

CHAPTER ONE: INTRODUCTION

1.1 Background

With the increasing concern over the climate change and global warming, the need of changes on mobility and power sector has been realized. The fuel powered transportation sector is realized to be one of the most contributors to CO_2 emissions with 22 percent of CO_2 emission in the year 2020 (Giannakis et al., 2020). As per the UN data, between 2010 and 2015 only. The transport sector was responsible for consumption of 28 percent of annual final energy and 60 percent of oil products in global scale as presented on the Policy Briefs in support of the first SDG 7 review at the UN high-level political forum 2018. This has led the world to step forward with the renewable energy sources for sustainable mobility. In addition to reduction of Greenhouse gases (GHG) emission, the transportation sector decarbonization will contribute in reduction of air pollution, health hazards and high pricing of the petroleum products which the world has been facing in the recent years. Globally, many agendas have been placed forward for the electrified transportation sector strengthening the electricity production through renewable resources like solar, wind, hydro, tidal, etc. Nepal being the country blessed with hydro resources, has realized this opportunity to contribute in achieving the electric mobility targets. Road transports dominates the transportation structure of Nepal covering about 90% of it (Acharya et al., 2015). The introduction of ropeways, Trolleybuses and Safa Tempo earlier in the century has demonstrated the rich history of e-mobility in Nepal. However, the number decreased due to lack of policies and infrastructures. Recently, the interest on Electric Vehicle (EV) has gained much popularity in Nepal with introduction of electric-two wheelers and cars. Currently, there are altogether 34,000 EV in the country contributing 1% on the total vehicles of the country (MoFE, 2021). The number is expected to rise with the recent tax reduction in the EVs and development of proper charging infrastructures and policies.

Electric Vehicles are gaining popularity in the Nepali Market. There are many EV brands which are being sold by the authorized distributor while some are being manufactured in here. The brand like TheeGo, Yatri and Nepal Electric Vehicle Industry (NEVI) are the manufacturers of EV in Nepal. Sundar Yatayat and Sajha Yatayat has introduced public EV transport in the country. BYD, Hyundai, KIA, Tata motors, MG motors are the brands of EV being sold in Nepal by authorized distributor. These brands have installed their own EV charging stations (EVCS) in many parts and major cities of the country allowing their own customer with EV charging facilities. Charging is of major concern when it comes to electric vehicle. And currently most of the EVs require hour or more for complete charging. As being said, the charging infrastructure is not enough for the rising customer. The major requirement for flourishing EV business in Nepal is the availability of Charging infrastructure. To provide public EV charging facilities, NEA is building 51 EV charging stations all over Nepal in first phase. Kathmandu valley alone will have 7 EV charging stations. The contract has been awarded, the work has been started and it is expected that within coming two months, the charging stations will come into operation. Each charger will have 142 kW capacity with 3 points (2DC and 1AC charging) providing the power of 60 kW for DC and 22kW for AC charging. As of March 2023, 20 EV charging stations have been already installed in major cities of Nepal, including Kathmandu and Pokhara. There are currently 72 charging stations in Nepal. Further, in second phase, NEA plans to add 500 EV charging stations all over the country. It has been possible due to the addition of 456MW capacity of biggest ever hydropower project of Nepal, Upper Tamakoshi Hydropower Plant. For charging EV, time slots and tariff has been developed by NEA which are Peak hour (5:00pm to 11:00pm) at the rate of Rs. 7 per hour, Peak off hour (11:00pm to 5:00am) at the rate of Rs 3.70 per hour and Normal hour (5:00am to 5:00pm) at the rate of Rs 5.50 per hour.

However, the adverse effect of EV charging loads on the distribution network and its operational parameters must be addressed and minimized. The load due to EV charging is high enough to cause fluctuations on voltage profile and reliability. If neglected, it may severely decrease the reliability of the system causing the outage of the network. There have been investigations carried out by researchers on the impacts potentially caused by the charging station loads on the distribution network. The different scenarios for EV penetration were studied on LV distribution network in which it was found that the node voltage profile was degraded due to placement of multiple charging stations and also the weak buses went through degradation of their voltage profile due to high EV charging loads (Geske et al., 2010). So, it becomes very necessary to find out the optimal placement of EV charging stations in a distribution network. In this project, a distribution network inside Kathmandu Valley is taken into consideration for supporting and facilitating the addition of EV charging stations across the network. The feeder distribution network is analyzed before and after the EV charging load conditions with the calculation and analysis of operational parameters (Voltage Stability and Power Loss). Optimization techniques are used for finding the optimal location for EV charging station placement in the distribution network using the operational parameters.

1.2 Problem Statement

Global concern has been directed towards the alarming issue of global warming, climate change, fossil fuel depletion and environmental pollution. With these alarming concerns the search of the alternatives for the fuel consumption has been increasing. This has mainly affected the areas with high energy consumption including the transportation system. E-mobility came into light amidst these concerns. The demand of electrical energy for powering up the vehicles has grown significantly giving rise to several technologies for utilization of renewable sources for electricity production. With this, the production as well as consumption of EV has also increased. While many countries are struggling to decrease the battery size and increase the battery charging process, most of developing countries are facing the problem of inadequate charging stations for EV. Nepal currently has 72 charging station which are privately owned and offers service to own customers, while the number of public charging stations is very low. The number of EV charging stations increased rapidly in just one-year span of time. In addition to it, NEA has completed the project of building 51 EV charging stations all over the country majority of which recently came into operation. The country was anticipated for this project and the results are affirmative too, however, will that be enough for the growing EV consumers in the country? The answer is negative. The EV adoption target has been set for year 2025 and 2030 with EV adoption target of 25% of all private vehicles and 20% of all 4-wheeler public passenger vehicle by the year 2025 and EV adoption target of 90% of all private vehicles and 60% of all 4-wheeler public passenger vehicle by the year 2030.

Currently, NEA installed 51 and few charging stations across the country which were forecasted and placed as per the EV density in highways, so the concerns related with the effect of charging station load on power networks is less. However, NEA plans to install 500 and more charging stations across the country through private partnerships.

This can take a toll on the existing distribution Network. The effects are seen in voltage profile, stability, efficiency and on other critical factors of power system. This is because, the battery capacity of EV found in Nepal is in the range from 17 kWh to 75 kWh depending upon the brand. When the load of high capacity of this extent is added in the system, the system operating factors fluctuates causing system outage on worst case scenarios as it forces additional burden on the power network.

That's why it is necessary to plan on the optimal positioning of the charging station on the distribution network so that the operational parameters of the network are least or not affected. This paper proposes to optimize the placement of EV charging stations on the distribution feeder buses realizing least impact on the power network due to fast charging and slow charging of the connected EV load.

1.3 Objective

1.3.1 Main Objective

The main objective of the study is to determine optimal location for EV charging stations considering operational parameters in Sanepa distribution network of Kathmandu valley using Particle Swarm Optimization technique.

1.3.2 Specific Objectives

The specific objectives of this project include:

1. To perform feasibility analysis for placement of EV charging station in Sanepa feeder line.
2. To analyze the operational parameters of the distribution network before and after addition of EV charging load.
3. To assess effects on demand for electricity due to EV charging service.
4. To study the financial aspect of EV charging stations.

CHAPTER TWO: LITERATURE REVIEW

(Shakya & Shrestha, 2011) analyzed the combined benefits of electrification of transport sector concerning GHG emission reduction, energy security and energy generation between year 2015 to 2050. The study assessed the impacts of attaining the portion of land transportation energy demand through electric vehicles and electrified mass transportation. The study concluded that the energy import could be decreased by 14.6% in comparison with base case considering 35% of electrified transportation scenario during the year 2015-2050.

(Krupa, 2019) emphasized on the possible barriers as well as opportunities on EV development in Nepal. It points out that for developing EV infrastructures, considering dynamic EV driving experience is equally necessary that accounts for the charging and the distance. It stresses on the availability of public charging stations are necessary for increasing mass involvement particularly in longer travelling distance. However, there should be strategic station location however the unavailability of larger parking space in Kathmandu and the hilly terrain geographical feature of the country sets up peculiar barriers. Yet, the plans for the charging stations are coming up from public as well as private sector allowing joint investment.

(Arif et al., 2021) discussed the recent vehicle technology, charging standards, methods and optimization techniques. The authors emphasized on electrification of transportation system and detailed on Conventional, Hybrid, Fuel Cell and Electric Vehicles. For urban driving, EV is most suitable as the vehicle is frequently started and stopped and during the time vehicle can recapture some of kinetic energy into battery. For the charging methods of EV, the major charging techniques includes conductive charging, battery exchange and wireless charging. There are several levels and standards of AC and DC charging used around the globe. Mostly EV’s integrated with smart grid due to which there is intermittent demand and supply that introduces energy losses on the distribution system. This makes sizing and placement of distributed generator (DG) and charging stations of EV more complicated as it relates to contradictory objectives and constraints. To overcome these issues, optimization techniques are implemented.

(Islam et al., 2015b) presented the methodology for optimal placement of charging station. The major issue in EV system is that the vehicle needs to be recharged before it gets exhausted which is why the location of charging station must be placed carefully ensuring that the users are able to access the charging point within their driving range. The placement should be optimized so that it minimizes the combined cost of grid losses as well as EV transportation. Huge EV entrance number can have inimical impacts on the power system, in terms of power loss and exceeding voltage limit but when the EV position is far from charging station, the transportation energy loss is increased. So, the transportation energy loss also should be considered along with the grid energy losses while designing charging station positions.

(Karki et al., 2019) focused on the management of power flow for charging EV loads by modeling the charging station with battery, PV and grid sources as the grid energy losses requires serious concern when prioritizing power system. The nature of EV load demand in the charging station must be estimated and demand and supply matching are necessary for maintaining the balance. When the fast charging of EV is supported by PV and BESS into the grid, the grid stress due to fast charging is significantly reduced. The sources are prioritized for fulfilling the power demand that supports the uncoordinated EV charging mechanisms. The load is effectively shared between several sources through the implementation of droop regulation technique.

(Eminoglu & Hocaoglu, 2007) idealized the parameters and variables of network that give adequate information on collapsing of the bus based on their sensitivity. The idea proposed was founded on the approach of transferring the active as well as reactive power of the line. The proposed mechanism was able to provide information on sensitive buses likely to collapse in a radial network.

(Amin et al., 2020) highlighted the importance and advantages of smart grid. The grid is equipped with information and communication features that makes it self-regulated system. The system allows vehicle to grid feature for supporting the services that includes load regulation and frequency tuning. Moreover, with this optimized scheduling of EV charging is possible. It is necessary to stress over the negative impacts imposed by random and uncoordinated EV charging techniques which includes increase in power loss, severe variation in voltages, network overload, etc. The operating performance of the utility can be improved with coordinated charging mechanisms.

(Ardakanian et al., 2013) presents a different approach to control EV charging. The heavy load of EV and unpredictable EV mobility is a challenge for the distribution network. As per the smart grid, the algorithm for distributed control of load assists in adaption of EV charging rate with the network capacity ensuring each EV load is fulfilled with fair portion of the resource. It is better to rely on rapid measurements and communication to prevent obstinate congestion and supplication of protection techniques rather than forecasting EV and non-EV numbers for further hours and cracking the optimization problem. With the application of mathematical framework developed for rate control, EV chargers can update their charging rate independently. Through EV charging, the control algorithm can implement demand response in the distribution network. However, the system requires rapid and heavy communication that makes it difficult to achieve its responsiveness.

(Deb et al., 2018a) stated the adverse effects introduced by charging loads of EV on several operational parameters of distribution network has been increased with the universal resurgence of EVs. The higher charging loads imposed by fast charging stations has resulted in increment of peak load demand, decrement pf reserve margins, reliability issues and voltage instabilities. The impacts are so severe which cannot be neglected. That is why, it is necessary to understand severity of the impacts in the distribution network on several cases. Before the placement of charging stations, the strength of bus and the load due to charging must be considered. A strategy can be devised for the charging station placement in the network on the basis of voltage stability, reliability and power loss (VRP) index which can minimize the severity of high load impact.

(Rahman et al., 2013) discussed a method for site selection of PHEV charging station considering the voltage sensitivity factor in the commercial distribution network. The method presented analysis of the specific system through PV curve. While the PV curve have the maximum system ability of loading, it was further used for calculating the voltage sensitivity factor of all buses associated with the system. The study declared that the bus with smallest percentage change in VSF can be regarded as the best bus for siting the charging station.

(Sangob & Sirisumrannukul, 2021) proposed a method or guidelines which would be useful for utilities in supporting mass adoption of EV in future. Since, the distribution system is single phase type, the system is exposed to higher unbalance degree and requires a three-phase power flow analysis. Generally, the amount of loading and bust location are two factors which impacts the bus voltage. The load current increment accompanies the voltage level reduction in the circuit. This study draws out the conclusion that even though the utilization factor of distribution transformer is improved by smart charging, it can lead to higher accumulated energy loss in longer period. The research offers deterministic judgement for this problem. Further, considering the long-term plan, the application of traditional LV distribution plan led to inaccurate investments for which the study proposes sequential decision as adaptive solution for beneficial LV reinforcement short lead time and for tackling the uncertain EV load penetration.

(Okorie et al., 2015) discussed about certain indicators that portray the reliability of an Electrical Distribution Network. System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI), Momentary Average Interruption Frequency Index (MAIFI), Average Service Availability Index (ASAI) and CEMI5 which are customer-oriented reliability indices while the indicators like ENS and AENS provide energy-oriented reliability indices Any of these indicators can be used for determining the reliability of the network.

(Muthukannan & Karthikaikannan, 2022) presented development of newer multi-objective planning model for EV considering the coverage, loss reduction and improvement of voltage profile as objective function. The study explained why the EV deployment give rise to challenges for operating distribution system securely. So, the location problem must be capable of reducing the hazardous impact in power system. While many conventional optimization techniques are available, the optimal locating EV infrastructure, being a planning activity, the offered solution impacts the capital investment and hence a correct optimization technique algorithm is necessary.

(Raj Kunwar et al., 2020) proposed the techniques of power flow in concern for charging Electric Vehicles by designing the topology that supports fast EV charging with PV and BESS penetration in the grid for as to reduce the grid stress. The study emphasized on load sharing effectively by several sources through droop regulation application. The study concluded that the renewable energy source penetration of EV charging reduces the grid electricity charges resulting in faster investment return.

(Islam et al., 2015a) presented a comprehensive review on optimization techniques for placement problem of EV. The optimal placement for the charging station is necessary from several viewpoint like, economic impact and power grid impact. There are methods like Genetic algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), etc. regarding the problem. The comparative analysis of these techniques delivers several benefits and limitations for each system.

Different research studies have been conducted regarding the optimal placement of EV charging station in distributed system. The study of impact made by EV load on grid has been studied and optimizing the EV load placement has also been conducted considering the operating parameters of distribution network. However, the nature of placement problem is different according to the real time data so, the variation of distribution network, EV availability and density are some of the factors that provides uniqueness to this optimal placement problem.

CHAPTER THREE: METHODOLOGY

This work emphasizes on the study of Sanepa distribution feeder of Kathmandu valley for EV charging station placement in view of the fact that the valley being densely populated city in terms of EV customers as well as EV charging stations. The methodology for this study can be divided into two sections: impact analysis and optimization. Impact analysis stresses on determining operational parameters with the addition of EV charging station load. The impact analysis is performed through DigSILENT PowerFactory modelling. Followed by impact analysis is optimization. The optimal locations for EVCS are allocated based on the results by the former. The optimization is conducted using MATPOWER in MATLAB environment.

The general methodology for this study is shown in figure below.

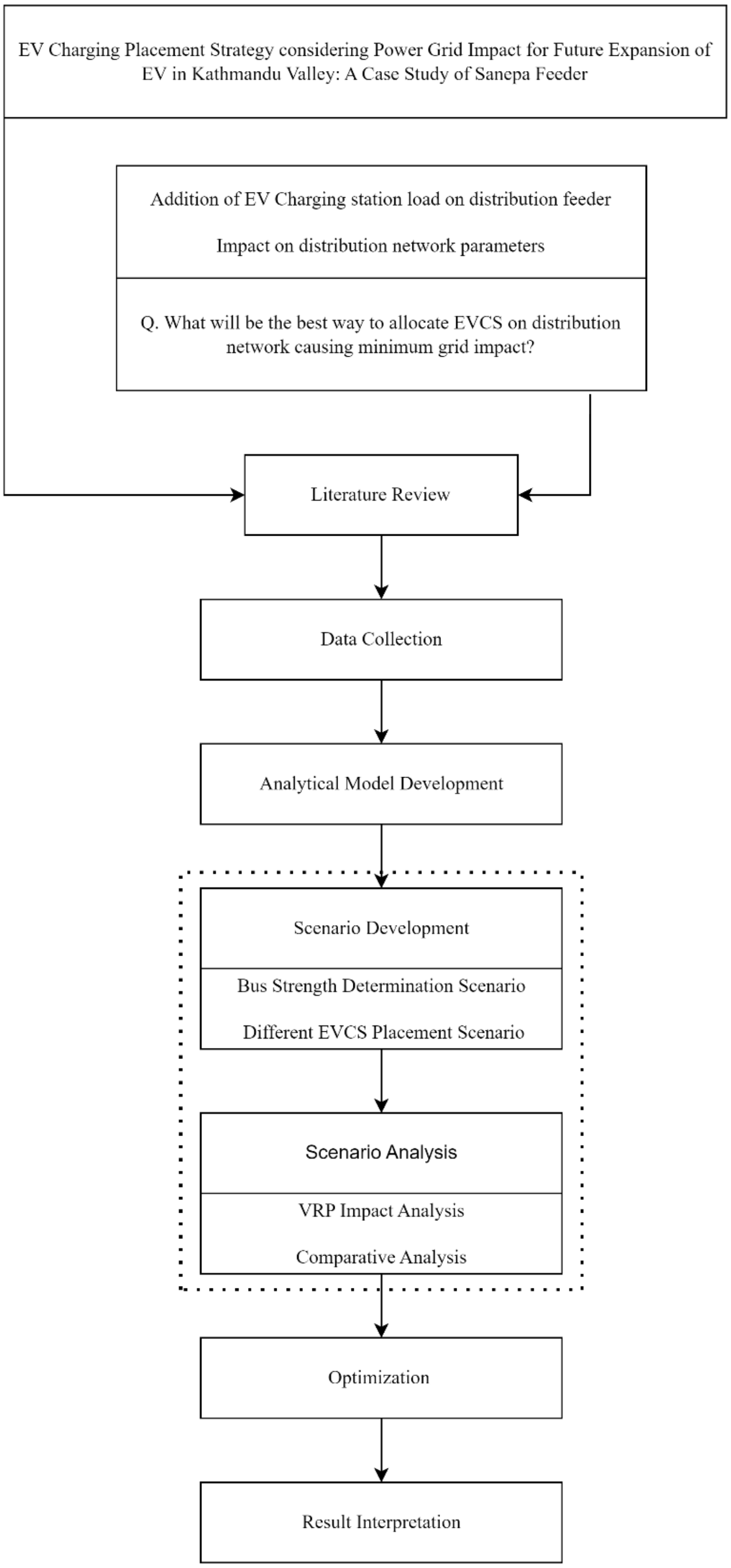

Figure 1: Overall Methodology

3.1 System Description

There are 220, 132, 66 and 33 kV network that are feeding Kathmandu Valley which includes Siuchatar Substation(132/66/11kV), Balaju Substation(132/66/11kV), Matatirtha Substation(132/33/11kV), Chapali Substation(132/66/11kV), Bhaktapur Substation(132/66/11kV), Lamosanghu Substation(132/33kV), Chabahil Substation(66/11kV), Lainchaur Substation(66/11kV), K-3 Substation(66/11kV), Teku Substation, Patan Substation(66/11kV), Banepa Substation(66/11kV), Panchkhal Substation(66/11kV) and Baneshwor Substation(66/11kV). The feeder under study Sanepa feeder is supplied through Thapathali Switching Station. The EV charging stations are to be provided with 3-phase, 400V, 50 Hz AC supply through the distribution transformers connected at 11 kV feeder line as per the specifications on (NEA, 2020).

The radial feeder under study is Sanepa feeder supplied by Thapathali Switching Station. The feeder consists of 21 buses and 20 lines. This 11kV system caters commercial as well as residential loads and has combination of ACSR Dog and HT ABC conductors for distribution. The transformers are taken as the buses or load points on the system. 11kV lines are taken as distribution lines with the grid substations feeding the line as source and transformers as load points or buses. This study involved primary as well as secondary method of data collection. The primary data is collected from NEA substation and interpreted according to need. The assumptions are also made to accommodate for the unavailability of the data. The physical nature of feeder is studied using GIS software. The GIS image of the feeder is shown in the figure below:

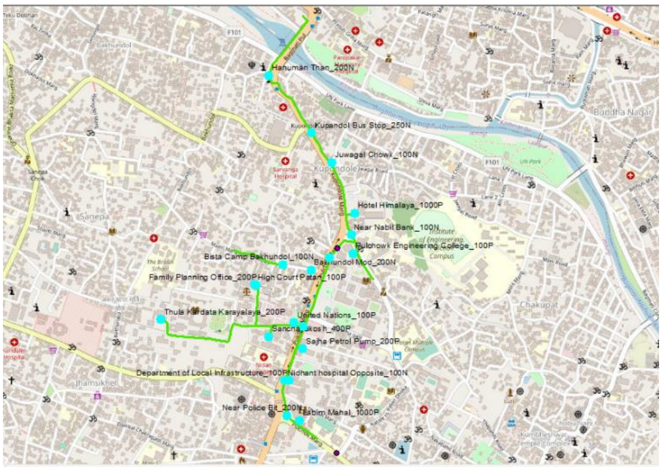

Figure 2: Sanepa feeder GIS map

3.2 Distribution network operational parameters

The major operational parameter of the distribution system network is given by VRP i.e., voltage stability, reliability and power losses. This index helps to analyze the impact of charging load addition in the distribution network. Each of the index are computed and analyzed separately considering before and after loading conditions. So, it can be said that this index provides information about three major operating parameters of the network when the network is imposed with any sort of disturbances. Under this exertion, the major three operational parameters of the distribution line network voltage, reliability and power loss (VRP) is considered. This section provides brief overview on calculation of major operational parameters.

3.2.1 Voltage Stability

The voltage stability gives the voltage conditions in the line considering the voltage drop and fluctuations. Voltage stability can be defined as the capability of the power system to maintain its steady voltage at every system bus at the normal load conditions as well as at application of external disturbances(Kessel and Glavitsch, 1986). For a system to be stable, it's voltage levels should be within the acceptable limits under any load conditions. For the analysis of voltage stability, the computation of Voltage Stability Index (VSI) and Voltage Sensitivity Factor (VSF) are carried out in this study.

3.2.1.1 Voltage Sensitivity Factor (VSF)

VSF denotes the ratio of voltage change (dV) to the change in active load(dP). It is the measure sensitivity of the system voltage with stepwise loading increment. Mathematically, it is expressed as:

$$\text{VSF}= \left|\frac{dV}{dP}\right| \; \forall \; P < P_{max} \tag{1}$$

High value of VSF indicates lesser voltage stability, that means even with small changes on loading behavior, there is significant change in voltage drop (Deb et al., 2018). The analysis of voltage stability suggests all voltage drop to be within 6% of their nominal value. The calculation of VSF is done directly through modelling in PowerFactory with the determination of PV curve. The methodology for VSF computation is shown in the following figure

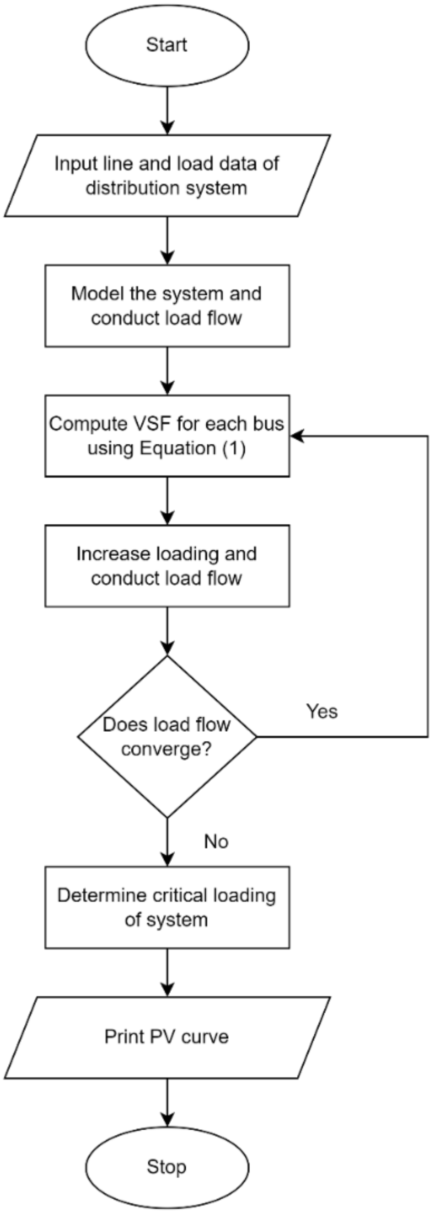

Figure 3: VSF determination

3.2.1.2 Voltage Stability Index (VSI)

Voltage collapse is one of the evident problems in distribution system which occurs due to instability of the system. It is necessary to compute an index for checking in the voltage stability of the system which helps to determine the behavior and bus proximity that is highly subjected to voltage collapse. (Eminoglu and Hocaoglu, 2007) developed a stability index using the transferred active as well as reactive power distribution line equation after the execution of power flow analysis in the network. For the determination of this index, its mathematical formulation is presented through illustration of 2 bus system as shown in the figure.

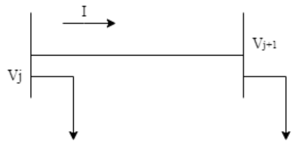

Figure 4: 2-bus system single line diagram

After the execution of load flow analysis in the distribution network, the node voltage and branch currents are obtained along with active and reactive power flow in the system. Using the load flow results, VSI can be calculated by following equation.

$$VSI = 2V_j^2V_{j+1}^2-V_j^4-2V_{j+1}^2(P_{j+1}r+Q_{j+1}x)-|Z|^2(P_{j+1}^2+Q_{j+1}^2)\geq 0 \qquad (2)$$

Where V = Voltage at bus

P = Active Power

Q = Reactive Power

I = current through the branch

r = resistance of the branch

x = impedance of the branch

j = bus number

3.2.2 Reliability

From engineering point of view, reliability refers to the system's capability to achieve its function for its anticipated lifetime under different conditions of operation. While, from consumer's point of view, the uninterrupted power supply in their homes and offices is regarded as reliability. In both cases, the duration and frequency of interruption at load point acts as important elements for determination of reliability indices(Mazidi and Sreenivas, 2015).

The reliability indices can be divided into two groups which are customer oriented and energy oriented. There are subdivisions among these categories. SAIFI, SAIDI and CAIDI are the major sub category of customer-oriented reliability indices which is used in this study. While the energy-oriented category is sub divided into ENS and AENS. The total indices can be determined through summation of the index of all buses. The indices are defined as:

SAIFI: It can be defined as a number of times a customer encounters system interruption in a certain time period. It signifies the condition of system based on interruption. Mathematically,

$$\text{SAIFI} = \frac{\Sigma \lambda j N j}{\Sigma N j} \; ; \qquad (3)$$

N_j = customer number at jth-bus,

λ_j = rate of failure at jth-bus

SAIDI: It can be defined as average duration of interruption per served customer. It signifies the system condition on the basis of interrupted duration. Mathematically,

$$\text{SAIDI} = \frac{\Sigma u j N j}{\Sigma N j} \; ; \; u_j = \text{duration of interruption at } j^{th}\text{-bus} \qquad (4)$$

CAIDI: It can be defined as the average duration time of interruption faced by the customers interrupted during a year. It provides the average duration of outage experience by any customer. Mathematically,

$$\text{CAIDI} = \frac{\Sigma u j N j}{\Sigma \, \lambda j N j} \qquad (5)$$

ENS: It can be defined as the total energy that was not supplied by system. It indicates system deficiency. Mathematically,

$$\text{ENS} = \boldsymbol{\Sigma} L_j u_j \; ; \; L_j = \text{load at } j^{th}\text{-bus} \qquad (6)$$

AENS: It can be defined as the index of average system load curtailment. It gives the notion of energy which was not served during a certain time period. Mathematically,

$$\text{AENS} = \frac{\Sigma \text{Ljuj}}{\Sigma \text{Nj}} \tag{7}$$

3.2.3 Power Losses

Addition of EV charging load on a distribution line raises serious concerns over power loss. In simpler terms, power loss is the I^2R loss of a system or line. The greater load addition means higher power consumption leading to increased power loss that might pose a threat towards achieving power security in the distribution system(Yuvaraj et al., 2023). Mitigation of power loss is necessary for ensuring grid stability and efficient operation. The effective solution to properly address the power loss due to EVCS load addition is to choose optimal locations which results in significantly lower change in power loss even with addition of load. The power loss of the network can be calculated by mathematical modelling. After the execution of load flow analysis in DigSILENT PowerFactory, the active and reactive power loss are computed. Total power loss is given by:

$$P_t = \sum_{j=1}^{n} \text{Pj} \tag{8}$$

Where, P_t = total power loss

P_j = power loss at bus j

3.3 Impact analysis on VRP parameters

The growth in EVCS load addition and integration on distribution network is expected to increase significantly. The behavior of the power distribution network with the integration of such anticipated load needs to be studied. The change in distribution parameters like voltage stability, power loss and reliability are analyzed in this study considering different scenarios of load addition. The behavior of VRP indices before and after load addition are studied and comparatively analyzed in order to determine the most and least affected parameter with the addition of load. According to the results of comparative analysis, the weightage for these indices are assigned in order to formulate the optimization problem of this study. The methodology for this analysis is presented in following flowchart.

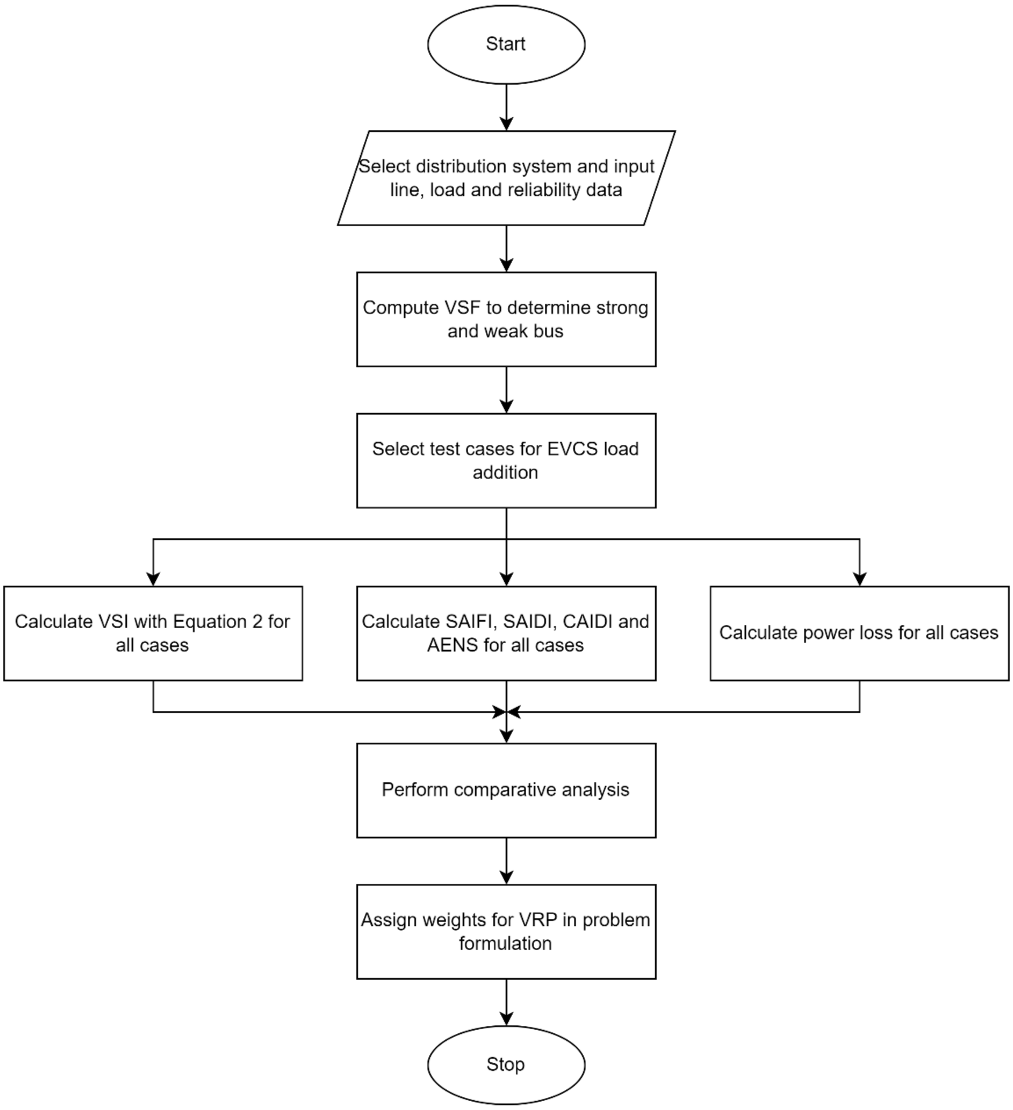

Figure 5: Impact analysis methodology

3.4 Formulation and Optimization of Charging station placement problem

3.3.1 Formulation of EV charging station problem on the basis of VRP Index

Optimal placement of EV charging is one of the applications of VRP index as this index provides us information about impacts subjected to power grid with addition and removal of load. A system remains stable until the impact on this index is not or least affected. The major objective of this problem formulation is to locate the EVCS position in the distribution line so as to minimize the impact on parameters of distribution system(Deb et al., 2018b). VRP Index can be mathematically formulated as:

$$VRP = w_1A + w_2B + w_3C \tag{9}$$

Where, $A = \frac{1}{a}$, $a = VSI_l / VSI_{base}$ (10)

$$B = w_{21}SAIFI_l/SAIFI_{base} + w_{22}SAIDI_l/SAIDI_{base} + w_{23}CAIDI_l/CAIDI_{base} \tag{11}$$

$$C = P^l_{loss}/P_{loss\,base} \tag{12}$$

Here w_1, w_2 (w_{21}, w_{22} and w_{23}) and w_3 are the weights assigned to the individual operational parameters term in the objective function. The weights are assigned after comparative analysis of change in VRP indices before and after load addition. The weightage depends on the severity of the impact on the parameters. In this study, the EV stations are allocated in the distribution network in such a manner that the effect on VRP index due to addition of EV load is minimum. For this purpose, VRP index is chosen as the objective function as it allows inclusion of voltage stability, reliability and power loss on a single equation.

For the formulation of placement problem, VRP index acts as the objective function laying out the decision variables and constraints for the case. The decision variables for this problem are number of buses in the distribution network where EVCS are placed (d) and number of charging station to be placed at the buses (n). The power flow balance equation is also taken as constraint in addition to following constraints.

The objective function can be stated as:

$$\text{Min } f(d, n): VRP = w_1A + w_2B + w_3C \tag{13}$$

subject to,

$2 \le d_i \le d$; d = no. of buses for EVCS addition (14)

$1 \le n_i \le n_{cs}$; n_i = no. of charging stations at i^{th} bus, (15)

n_{cs} = max number of charging station to be placed at each bus

$Q_{min} \le Q_i \le Q_{max}$; Q = reactive power (16)

$L \le L_{max}$; L = load increment due to EV charging station (17)

$V_{imin} \leq V_i \leq V_{imax}$ V = bus voltage limits (18)

By assigning appropriate weights on the operational parameters, the optimization of the function can be performed using any of the optimization techniques which are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Integer Programming (IP), Greedy Algorithm, Cplex commercial software, etc. In this study, PSO will be incorporated as the optimization technique because of its easy implementation and high degree of accuracy in results. Incorporating PSO while determining the location of charging station maximizes their coverage, minimize costs, meeting the demands of EV users. The placement of EV charging stations has complex and multi-dimensional search space. PSO's ability to explore in such dimensional space is very effective for this work.

3.3.2 Particle Swarm Optimization Technique

In a distribution network, the minimizing system losses and attaining optimal power flow is always of a concern. The optimal power flow problems stresses over optimizing the power loss adjusting the power control variables meeting equality as well as inequality constraints. PSO is a powerful population-based optimization technique employed in such power system problems that focuses on voltage stability enhancement, power loss minimization and several other network problems. PSO considers global information for directing their solution towards optimal one. The global and personal best positions are determined every iteration for finding the optimal solution(Kita and Shin, 2012).

The application of PSO is done after calculation of certain parameters obtained after the load flow analysis of the system. After each iteration, new position and velocity is calculated updating the Personal best (Pbest) and Global best (Gbest) of the particle. The load flow analysis is conducted for every iteration and new values of voltage, active power and reactive power are used for parameters calculation. The incorporation of PSO is carried out until the optimal solution for the problem is attained. The flowchart illustrating the optimization methodology is shown in the following figure. In this study, the PSO is combined with MATPOWER toolbox and is used as an optimization tool for obtaining the optimal location of EVCS placement.

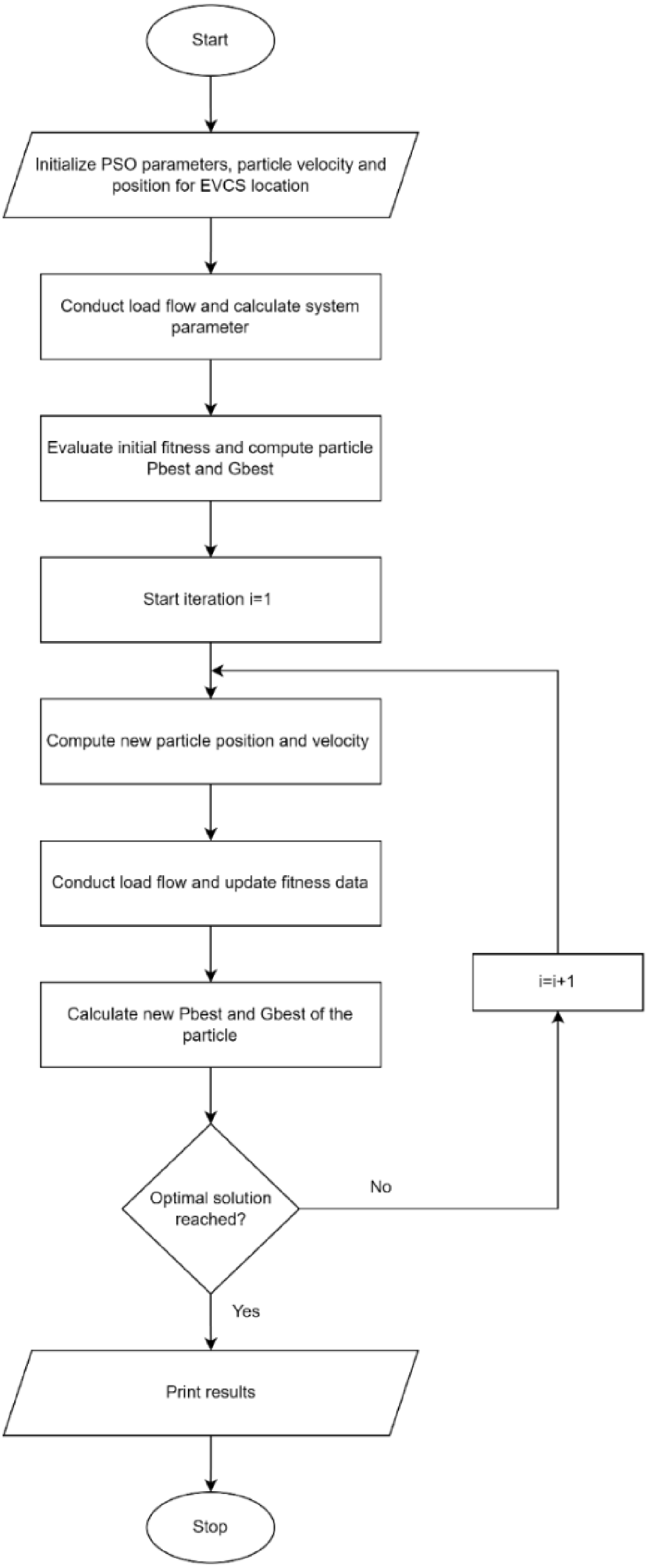

Figure 6: PSO flowchart for optimal EVCS placement

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 System modelling

While studying a real case scenario, the data collection and availability plays a major role. The feeder components and lengths are obtained from GIS mapping. The data of this study consists of load data (active and reactive power), line data (resistance and reactance) and reliability data (failure rate, outage hours and number of consumers) associated with the considered feeder. So, the real time data related to the line, load and outage were collected and tabulated in Table 4, 5 and 6 in appendix section. The system under study is 21 bus and 20 branch radial system. The single line diagram depicting the 21-bus system is shown in following figure:

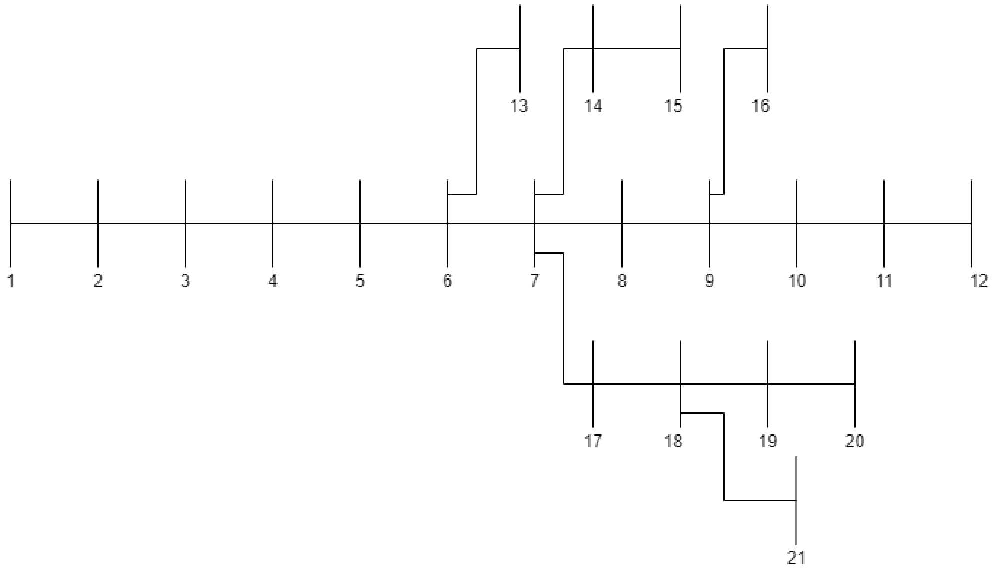

Figure 7: 21 bus Sanepa Feeder Network

4.1.2 Sanepa 21 bus system model

The model is created on DigSILENT PowerFactory software which provides a simple environment for load system modelling and load flow analysis. The line, load and customer data are provided into the system. First of all, the base case system is modelled at the base conditions of load and no external loads added to the system. The base case system model is shown in the figure below.

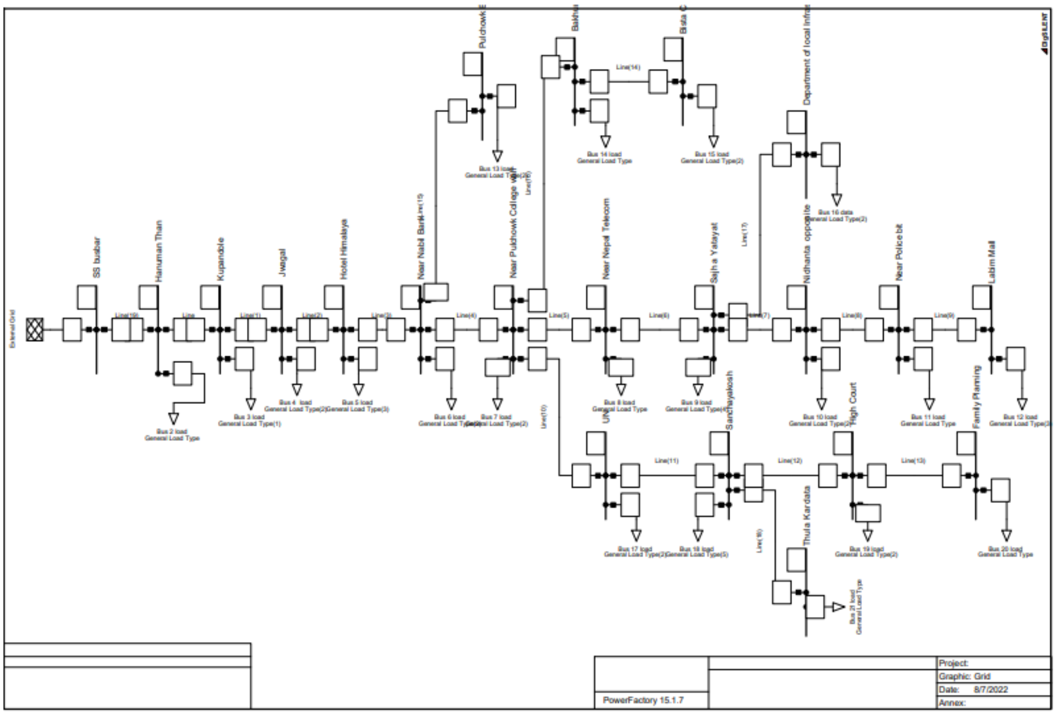

Figure 8: Sanepa Feeder Network Model

The load flow calculation is executed using Newton-Raphson power equation method. The results from the load flow analysis can be summarized as the voltage, phase angle, real, reactive power and line losses of the system. The voltage profile of the system at base case is illustrated in the graph below. The bus voltages range from 0.993 p.u. to 0.977 p.u.

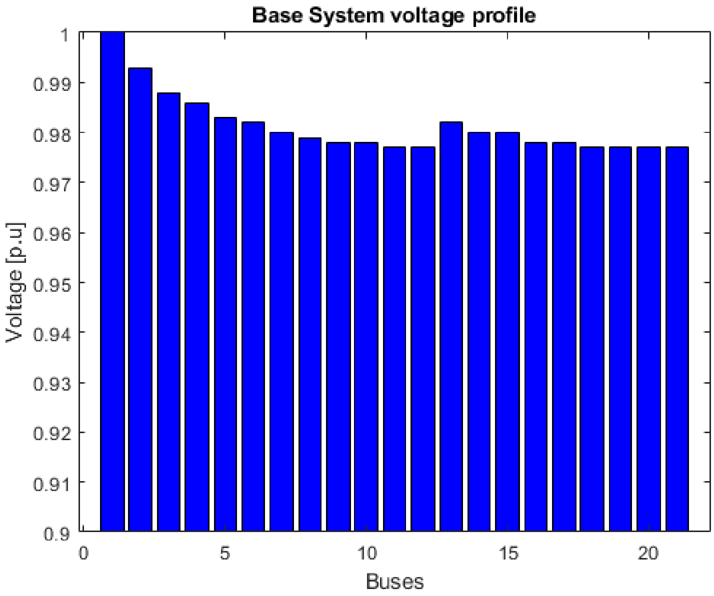

Figure 9: Voltage profile at base case

The PV curve of the system is also plotted alongside the execution of load flow analysis. PV curve illustrates the bus voltage variation along with the percentage loading increment(Ashwin et al., 2019). PV curves allows the computation of real power margin and helps on assessing the voltage to MW transfer relationship. The following diagram is PV curve of the system showing the loading characteristics of each bus in the system.

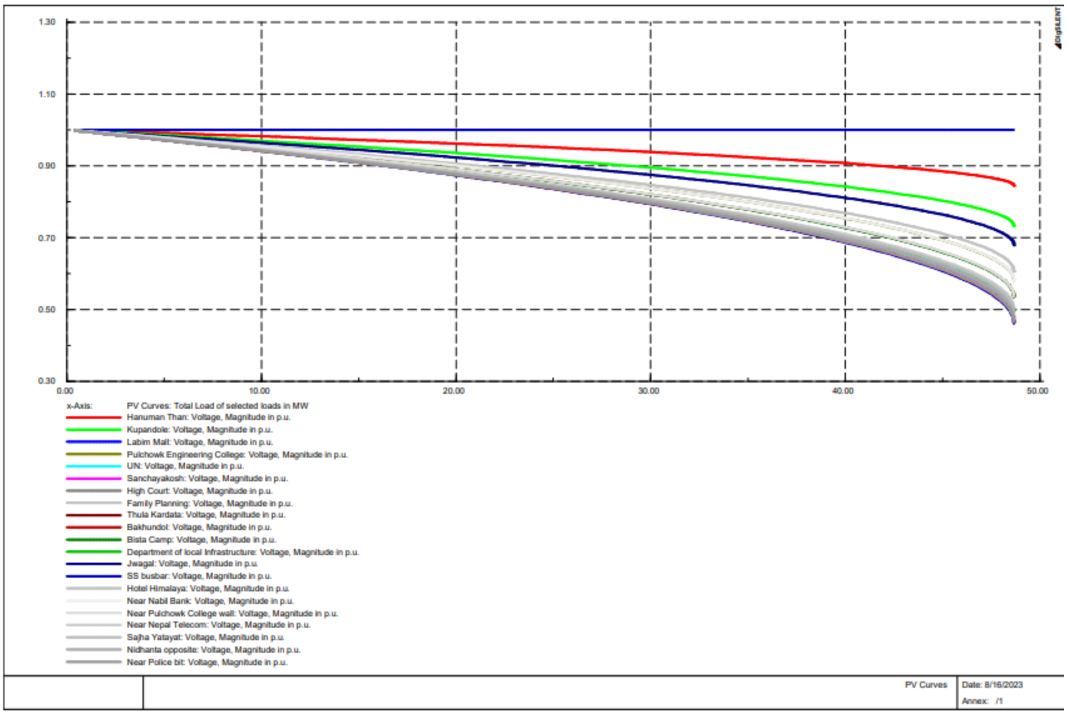

Figure 10: PV curve with load increment

The extreme points of the PV curve are determined through load flow analysis. The distance between the extremes or nose points and current operating points of the system is the area or criteria of stability for the system. The PV curve provides critical loading ability of the system by providing the proximity of voltage collapse as well as loading margin(Ahiakwo et al., 2022). From the above PV curve, it can be seen that with the increased loading, there's increased slope in the graph and beyond the nose point or curved point, the increment of load will cause severe instability in the system causing voltage collapse. Considering the PV curve, critical loading of 3 is loading margin in this study given that the system converges.

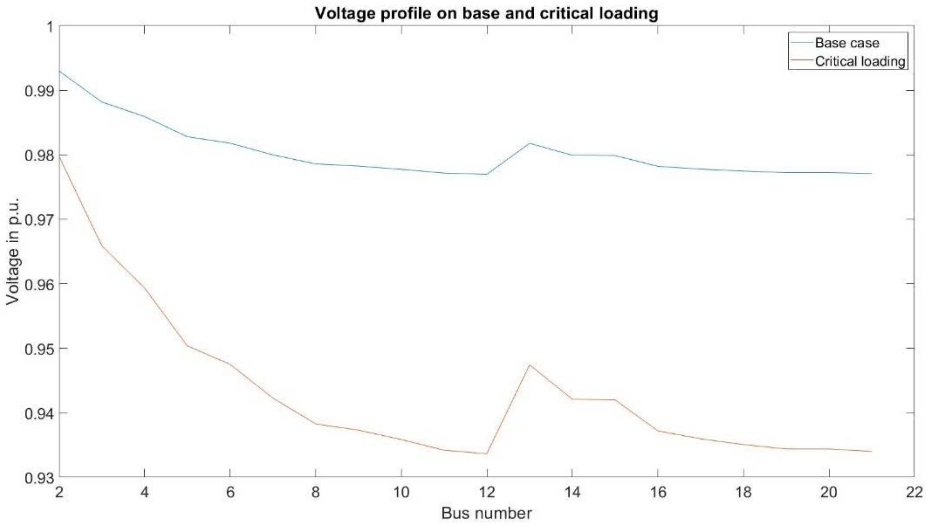

Figure 11: Voltage profiles at base and critical loading

The voltage sensitivity factor is calculated in different loading conditions for the determination of strongest and weakest bus to exist in the system. VSF is a measure of sensitivity of the bus due to addition of load. The higher value of VSF denotes higher sensitivity of bus on load addition. In simpler terms, the bus with higher VSF reacts extremely with the change in loading and vice versa. Hence, the strong bus will have lower VSF while the weaker bus will have higher VSF value. The increment of loading causes increment on the value of sensitivity factor. VSF at loading factor 2 and 3 are computed which is tabulated in the following table.

Table 1: VSF computation

Voltage Sensitivity Factor		
Bus no	Loading factor 2	Loading factor 3
2	0.007081337	0.007087442
3	0.012197484	0.012308503
4	0.014699369	0.014898101
5	0.018081379	0.018360713
6	0.019290667	0.019662018
7	0.021299831	0.021729288
8	0.022892241	0.023393248
9	0.023351191	0.023907644
10	0.023934239	0.024519933
11	0.024605138	0.02522398
12	0.024840068	0.025478172
13	0.019196179	0.019501622
14	0.021346832	0.021767596
15	0.021391357	0.021813752
16	0.023366145	0.023908463
17	0.02377221	0.024291329
18	0.024249964	0.024850429
19	0.024527575	0.025143614
20	0.0245414	0.025162993
21	0.02467951	0.025303232

From the above table, the lowest values of VSF computed is of Bus 2 which are 0.007081 and 0.007087 for loading factor 2 and 3 respectively. It can be concluded that bus 2 is the strongest and bus 3 is the second strongest bus of the system. The highest values of VSF is calculated for Bus 12 which are 0.02484 and 0.02548 for loading factor 2 and 3 respectively. The weakest and second weakest bus on the system are bus 12 and bus 21.

4.2 Impact Analysis

After the study of system in base case and different loading, the impact on system due to addition of EVCS load is analysed. The modelling of EVCS load on the existing system is carried out through consideration of different cases. The cases are considered such that one bus from the lower VSF group or strong group, one bus from average group and two buses from weaker group are included. The reason for this is to create diverse platforms for modelling the EVCS load in the network composed of high as well as less sensitive load points. The cases can be summarized in the table below:

Table 2: Selection of cases for EVCS load addition

Cases considered	Description	Load addition (kW)
Case 1	1 charger in strong bus group: Bus 5	142
Case 2	5 chargers in strong bus group: Bus 5	710
Case 3	2 chargers each in strong bus group and average group: Bus 5 and Bus 8	598
Case 4	1 charger in weak bus group: Bus 12	142
Case 5	2 chargers each in weak bus group: Bus 12 and Bus 21	568

EVCS loads are modelled in a respective manner and the results are used to analyse the impact of integrated load in VRP operational parameters. As designed by NEA, each charging station to be installed is of 142 kW capacity that consists of DC as well as AC chargers of capacity 60 kW for fast charging and 22 kW for AC charging. After performing the load flow analysis, the Voltage Stability Index and Power Losses for each case are calculated for each bus. Similarly, the reliability indices SAIFI, SAIDI, CAIDI and AENS are also calculated for each case. The voltage profile of the system due to these test cases is shown in following figure:

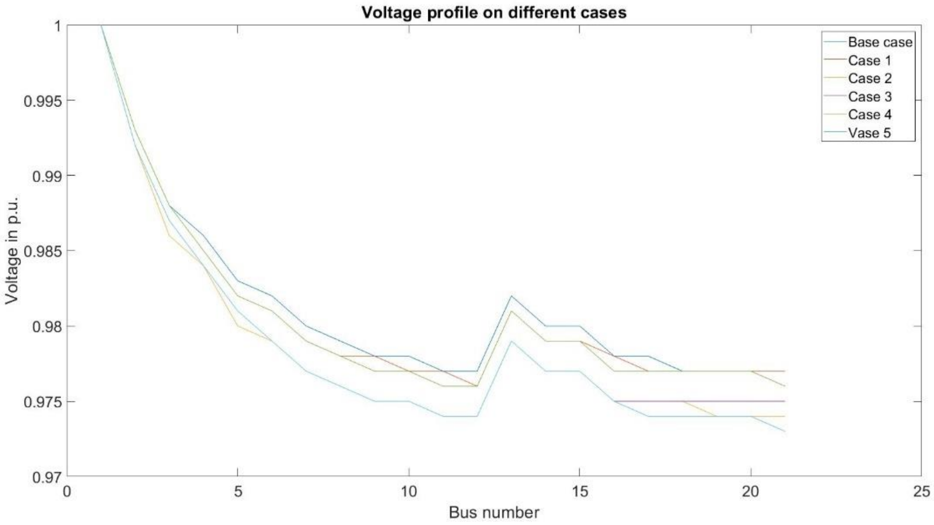

Figure 12: System voltage profile for test cases

4.2.1 Impact analysis on voltage stability

Voltage Stability Index is calculated after load flow analysis using Equation 2 for base case and different cases of EVCS load addition. This index gives the measure of stability the buses are able to maintain when the loads are added and removed from these points. The values of VSI are observed and tabulated in the following table.

Table 3: VSI calculation

Voltage Stability Index						
Bus no	Base	Case 1	Case 2	Case 3	Case 4	Case 5
2	0.97673	0.97609	0.97331	0.97434	0.97641	0.97434
3	0.89941	0.89603	0.88485	0.88550	0.89680	0.88628
4	0.91872	0.91750	0.90587	0.91133	0.91750	0.91133
5	0.89897	0.89345	0.88412	0.88457	0.89345	0.88510
6	0.91909	0.91532	0.90783	0.91066	0.91460	0.90900
7	0.90327	0.89954	0.89212	0.88988	0.89813	0.88805
8	0.90599	0.90226	0.89484	0.89274	0.90099	0.89274
9	0.91473	0.91099	0.90355	0.90355	0.91065	0.90275
10	0.90880	0.90881	0.89809	0.89809	0.90466	0.89662
11	0.90638	0.90264	0.89525	0.89525	0.90148	0.89338
12	0.90840	0.90841	0.89728	0.89728	0.90409	0.89655
13	0.92923	0.92545	0.91792	0.91792	0.92545	0.91792
14	0.92141	0.91765	0.91017	0.91017	0.91765	0.91017
15	0.92140	0.91764	0.91016	0.91016	0.91764	0.91016
16	0.91424	0.91424	0.90307	0.90307	0.91050	0.90307
17	0.89723	0.89353	0.88614	0.88614	0.89353	0.87776
18	0.91016	0.90643	0.89901	0.89901	0.90643	0.89399
19	0.90728	0.90728	0.89986	0.89986	0.90728	0.89751
20	0.91107	0.91107	0.89993	0.90364	0.91107	0.89993
21	0.90531	0.90531	0.89790	0.89790	0.9053	0.88843

From the table, it is seen that the value of VSI gradually decreases with the load addition in the system. The change in VSI is even more evident in the buses with EVCS load. In case 1, when EVCS load is added to one of the strong buses in the system, there is slight decrease in VSI in all buses. However, the change seen on the weak bus is much less which indicates the overall stability of the system is less affected when the load is added to strong bus.

In case 2, the load on bus 5 is increased by five times, which means 5 EVCS are integrated in bus 5. The impact of this greater load addition is seen on all buses. There is significant drop on value of VSI. So, higher load addition significantly affects every other bus on the system even if the load is added on the strong bus.

When the load is integrated in strong and average bus in case 3, the impact is similar to case 2, but there is slight increment on VSI value on some buses. It is observed that rather than adding the higher load in single bus, the load can be distributed in different bus in order to maintain stability of the system.

One EVCS is added on weakest bus, bus 12 in case 4. There is slight decrement in value of VSI in case 4 than in case 1. That means, placing the EVCS in the strong bus rather than weak bus is better and causes minimal impact on the overall distribution network.

In case 5, two EVCS are placed in each of the two weakest bus of the system. In this case, the impact due to load addition is quite evident rather than on other cases. The impact is higher on the weaker bus group. The fluctuations on the voltage stability parameter is comparatively increased with load addition. So, it is observed that weak buses are not favourable for addition of EVCS.

4.2.2 Impact analysis on reliability indices

The reliability indices SAIFI, SAIDI, CAIDI and AENS are calculated for studying the impact of EVCS load addition. The calculation is carried out for all cases mentioned in Table 2. The computation of reliability indices for different cases were carried out using unitary method for the failure rate and outage duration. For the calculation, the formula in Equation 3, 4, 5 ad 7 are used. The failure rate data, outage duration data and number of consumer data used for calculation is shown in Appendix.

Table 4: Reliability indices calculation

Cases	SAIFI	SAIDI	CAIDI	AENS
Base	51.85473684	9.605894737	0.185246234	85.63526316
Case1	50.17746306	9.295178829	0.18524609	85.29758563
Case2	44.43704257	8.231762716	0.185245512	84.14189415
Case3	55.94136709	10.36504452	0.185284076	85.30057106
Case4	50.18052505	9.295757204	0.185246312	85.78920439
Case5	45.89162733	8.501293757	0.185247163	86.19609856

From above table, it is observed that the value of SAIFI and SAIDI decreases in cases 1, 2, 4 and 5, whereas, there is increment case 3. The load increment in case 1 and case 4, as well as, case 2 and case 5 is equal, so the similar values of SAIFI and SAIDI is observed in these cases. The equal increment of loads results in linear increment if average loads which causes slight decrease of SAIFI as well as SAIDI in the beginning and later on increase with the average load line, which is not the desired solution(Bhadra and Chattopadhyay, 2016). The decrement in the value of reliability indices like SAIFI, SAIDI and CAIDI can be because of following reasons:

- Load balancing: Load addition might lead to better load balancing across distribution network reducing overloads.
- Load diversity: Adding different types of loads such as residential, industrial and commercial can lead to more stable and diverse power consumption patterns which may result in fewer and shorter interruptions.

Even though, the reliability indices might have decreased in this case, the value of reliability indices for the network is quite concerning. The better approach for decreasing the interruption time and outage duration would be to improve infrastructure and enhance maintenance of the network. With the addition of new load in this system, the installation of improved and new infrastructure like transformers is a requirement which is expected to contribute for the reliability of the system. The more reliable system has almost constant line of SAIFI and SAIDI indicating the constant failure rate as well as outage duration during loaded conditions. Hence, it is seen that SAIFI and SAIDI are significantly affected with the EVCS load addition.

Further, the value of CAIDI remains almost same in all of the test cases that means customer-based index for average interruption duration is almost constant for all test cases denoting, this parameter of reliability is least or not affected due to the EVCS load addition. When the load is added non-uniform manner, the value of average energy not supplied tends to fluctuate but the impact is less severe than that of SAIFI and SAIDI.

4.2.3 Impact analysis on power loss

Power loss on each bus after the load addition according to the test cases is calculated. The power loss is calculated directly through load flow analysis in this study. The active power loss on each bus are summed up to calculate total power loss in the case. The total active power loss for the several cases are tabulated in following table.

Table 5: Power loss on different test cases

Cases	Power loss (MW)
Base	0.076029
Case 1	0.080328
Case 2	0.099032
Case 3	0.096435
Case 4	0.08192
Case 5	0.099743

From the above scenario, it is observed that power loss of the distribution network is increased with the introduction of EVCS load in the system. In case 1 has the lowest active power loss while case 5 results in highest power loss among all cases. In case 1, one EVCS load is added on one of the strong bus while in case 5, two EVCS load are added to each of the two weak buses. Also, the power loss in case 2 is lower than case 5. This means, the addition of higher load on one strong bus is more suitable than addition of divided load in weaker buses in terms of power loss. Furthermore, the power loss in case 3 is lower than that of case 2. In case 2, five number of EVCS load are integrated while in case 3, four EVCS are placed in two buses. Hence, the concentrating load on one bus, even though the bus is strong one produces higher power loss. So, distributing the load among the buses significantly reduces power loss. With the number of EVCS load addition, the impact on power loss also increases.

4.2.4 Comparative analysis

After studying the impact of EVCS load placement in the system, the comparative analysis is conducted. The results from individual analysis of impact on voltage stability, power loss and reliability due to placement of EVCS in the system are brought together for this analysis. The change in each parameter from base case to different considered cases are calculated and tabulated in following table.

Table 6: Change in VRP indices

Cases	ΔVSI	ΔPower loss	ΔSAIFI	ΔSAIDI	ΔCAIDI
Case 1	0.002644	0.056551	0.032346	0.032346	7.81E-07
Case 2	0.011879	0.302563	0.143048	0.143051	3.9E-06
Case 3	0.011352	0.268404	0.078809	0.07903	0.000204
Case 4	0.003525	0.07749	0.032287	0.032286	4.19E-07
Case 5	0.013337	0.311906	0.114996	0.114992	5.01E-06

From this analysis, it is observed that the placement of EV charging station in weaker bus created highest impact on operational parameters as case 5 has the highest changes in VRP index. The parameter which is severely affected due to placement of EVCS is power loss. Power loss ranges from 5% increment on least affected case to 31% on severely affected case. It is then followed by reliability indices SAIFI and SAIDI and finally voltage stability. SAIFI and SAIDI change ranges from 3% at the least to 14% at the most. In case of SAIFI and SAIDI, case 2 with 5 EVCS placed on strong bus has the severe impact. The impact on voltage stability index is also not severe in comparison to Power loss, SAIFI and SAIDI. CAIDI is least to not affected due to the load increment.

4.3 Optimal EVCS placement considering VRP index

The optimization process is carried out according to the flowchart presented in Figure 6 using Particle swarm optimization technique in MATPOWER.

4.3.1 Assigning weights

For the formulation of placement problems, the weights are assigned to the operational parameters term in the objective function based on the severity of impact experienced by VRP parameters.

The steps for assigning weights to each parameter is described as:

1. The objective function y_0 is calculated assigning equal weights to w_1, w_{21}, w_{22}, and w_3.

   For $w_1 = w_{21} = w_{22} = w_3 = 0.25$, $y_0 = 42.63$
2. The objective function values are calculated for complete weightage of each parameter simultaneously.

   For $w_1 = 1$ and $w_{21} = w_{22} = w_3 = 0$, $y_1 = 1$

For $w_{21} = 1$ and $w_1 = w_{22} = w_3 = 0$, $y_{21} = 1.53511$

For $w_{22} = 1$ and $w_1 = w_{21} = w_3 = 0$, $y_{22} = 1.0013$

For $w_3 = 1$ and $w_1 = w_{21} = w_{22} = 0$, $y_3 = 167.022$

3. The deviation (Δe) of objective function values from y_0 is calculated.

   $\Delta e_1 = |y_1 - y_0| = 41.63$

   $\Delta e_{21} = |y_{21} - y_0| = 41.1$

   $\Delta e_{22} = |y_{22} - y_0| = 41.63$

   $\Delta e_3 = |y_3 - y_0| = 124.39$

   $\mathbf{\Sigma}\, \Delta e = \Delta e_1 + \Delta e_{21} + \Delta e_{22} + \Delta e_3 = 248.75$
4. The weightages are calculated as:

   $w_1 = \frac{\Delta e1}{\Sigma\, \Delta e} = 0.167$

   $w_{21} = \frac{\Delta e21}{\Sigma\, \Delta e} = 0.165$

   $w_{22} = \frac{\Delta e22}{\Sigma\, \Delta e} = 0.167$

   $w_3 = \frac{\Delta e3}{\Sigma\, \Delta e} = 0.5$

The parameters assigned for optimization are summarized in following table.

Table 7: Weightage on input parameters

Input parameters	Values
w_1	0.167
w_2	0.332
w_3	0.5
w_{21}	0.165
w_{22}	0.167
n_{cs}	3
L_{max}	710 kW
V_{min}	0.95 p.u.
V_{max}	1.05 p.u.

4.3.2 Optimal placement

The PSO algorithm is incorporated in this system using optimization toolbox in MATPOWER. The required input parameters and constraints are defined. The objective function for minimization is defined and the repetitive power flow analysis is conducted throughout the optimization process. The power flow is conducted by calling runpf() function in MATPOWER. With the new power flow solutions, the particle and velocities are updated for finding the personal and global best of the system. The optimization process is exited after the conditions for optimality is satisfied. The optimal locations for the placement of EVCS considering operational parameters are reported in following table.

Table 8: Optimal placement of EVCS

Optimal locations	Bus 2	Bus 5	Bus 13
Number of EVCS	3	1	1

Three optimal locations for the placement of Electric vehicle charging stations are obtained. Bus 2 being the strongest bus of system is observed to be capable of harbouring more than three loads. But since, the maximum number of EVCS to be placed in one bus is limited to three because of concerns over voltage drop and power loss, not more than three loads are added to the bus. Hence, Bus 2, 5 and 13 are the most appropriate location for 3, 1 and 1 number of EVCS placement. The convergence graph is shown in the figure below.

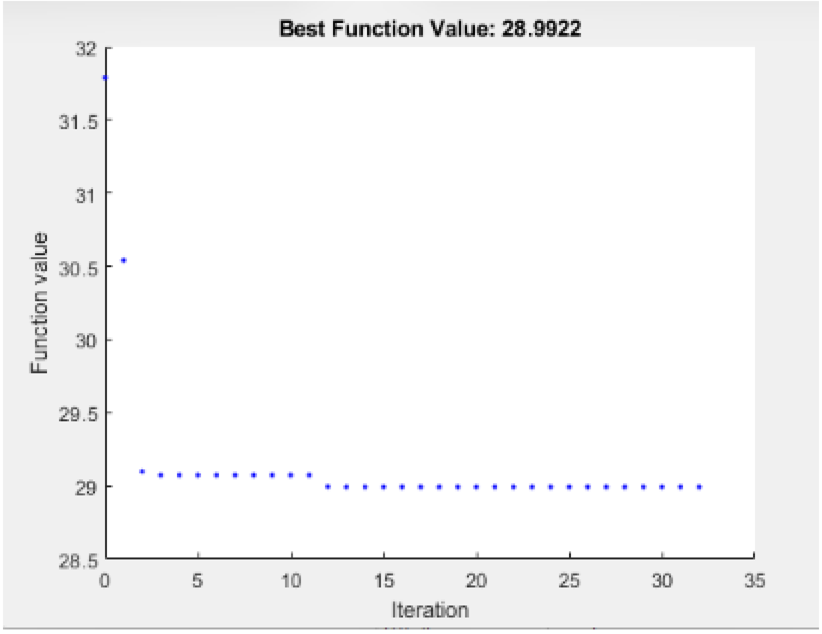

Figure 13: Convergence graph after optimal placement

4.4 Discussion

4.4.1 Result Interpretation

After the placement of EVCS on optimal locations, the VRP parameters are again analyzed for assessing the grid impact. The voltage profile before and after addition of EVCS load is shown in Figure 14. It is observed that there is slight decrease in overall bus voltages after EVCS load addition which, however, acquires similar nature as the prior system. The lowest voltage is seen at the weakest bus which is 0.974957p.u. The voltage magnitude deviation is within the limits for all buses. Hence, there is minimization in voltage drop of the system after the introduction of EVCS load.

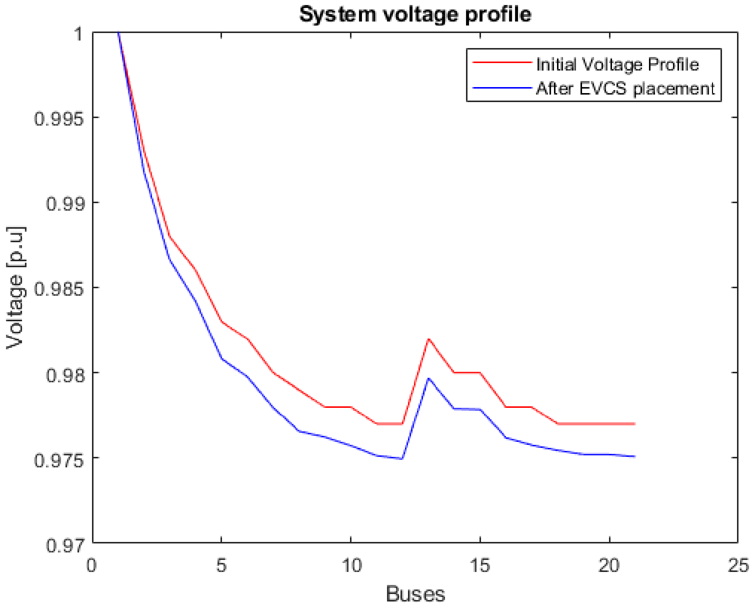

Figure 14: Voltage profile before and after optimal placement of EVCS

After placement of EVCS in the network, the power loss, SAIFI and SAIDI also show minimal increment than the former case. The active power loss of the system before load addition is 76.1 kW and the active power loss due to optimal placement of five EVCS is 92.8 kW. This obtained loss is significantly less than the power loss in Case 3 which had the placement of only four chargers. The reactive power losses before and after EVCS load addition are 59.45kVAR and 70.4kVAR respectively. Hence, it can be observed that the optimal placement of EVCS has minimized the power loss in the system. Further, the slight increase in values of SAIFI and SAIDI after optimal EVCS placement can be addressed with the improved equipment maintenance and new infrastructure installation. Hence, the optimal location for placement of electric vehicle charging station is determined considering the power grid impact.

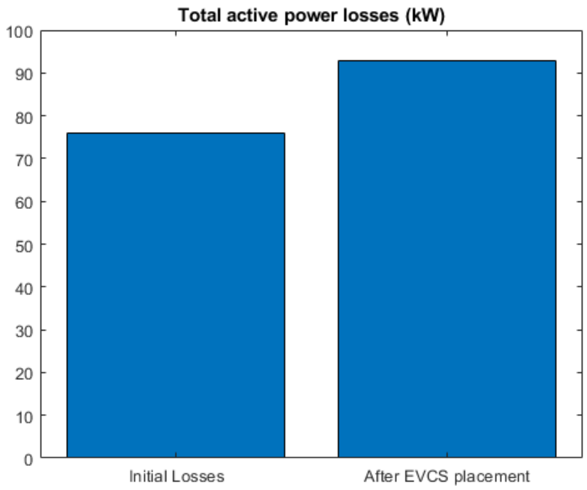

Figure 15: Active Power loss before and after optimal placement of EVCS

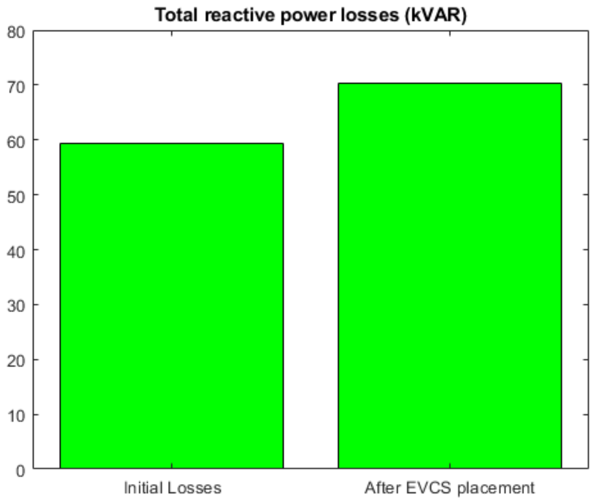

Figure 16: Reactive power loss before and after optimal placement of EVCS

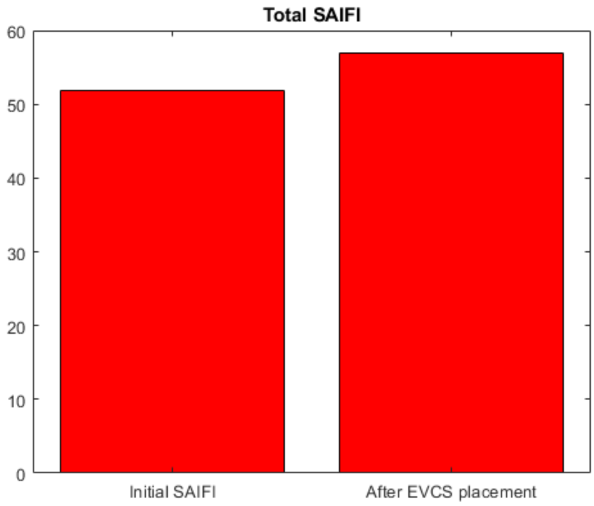

Figure 17: SAIFI before and after optimal placement of EVCS

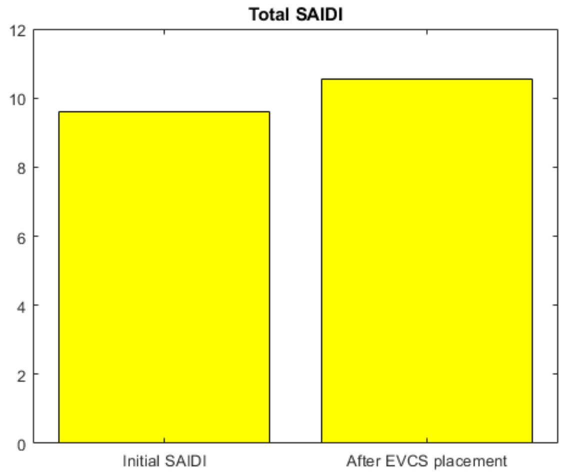

Figure 18: SAIDI before and after optimal placement of EVCS

4.4.2 Electricity Demand Assessment

Figure 18 is the daily load curve of the Sanepa distribution network supplied by Thapathali switching station. It depicts the load variation on the system during different hours of day. The peak demand of the system occurs at 11:00 am and 2:00 pm of the day which is 385 kW and the total demand of the system is 6.292 MW for the day. The peak demand of a certain day was recorded to be 902 kW on previous month. The load remains high from 10:00 am to 3:00 pm of the day while the demand is less at the night time. It would be very beneficial for the system, if optimally placed EVCS can operate at off-peak time of the day.

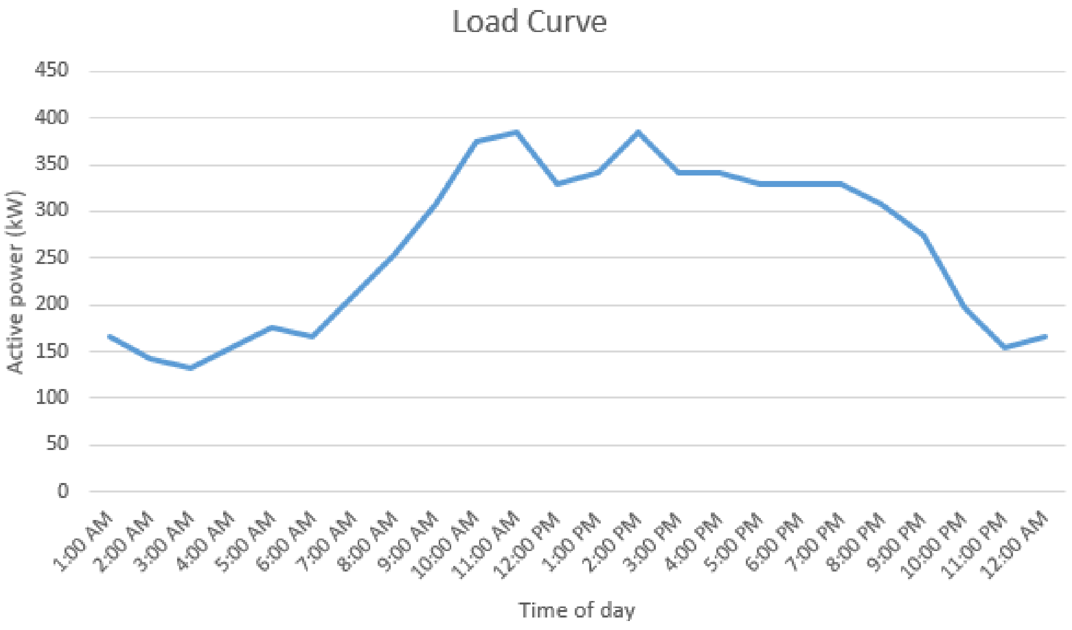

Figure 19: Daily load curve of Sanepa Feeder line

The demand factor of the existing system is low, with the addition of EVCS load in the line, the demand factor of the system can be improved. When the optimally placed five EVCS load are connected in the system, the total load demand of the system becomes 6.860 MW for that certain day. Assuming all five charging stations are being operated at the same time of day as peak load conditions, the load factor is affected. So, the operation time of EVCS should be maintained at off-peak load if possible to balance the load curve of the system. It helps on energy management as well as demand side management of the system.

4.4.3 Financial Analysis

NEA adopts the tariff method consisting of demand charge and energy charge for billing the commercial consumers. The demand charge is charged per kVA consumption and energy charge is charged per kWh consumption. The demand charge and energy charge are different for public and private consumers. The demand charge is NRs 200/kVA/month and the energy charge are NRs 5.75/kWh for public consumers.

The table below shows maximum demand recorded this year on one of NEA charging stations installed in Ratnapark DC which is 117 kVA with total of 14387 kWh energy.

Table 9: Meter reading history of a charging station in Ratnapark DC

Year	Month	Demand (kVA)	Previous Reading	Current Reading	Units (kWh)
2080	1	117	15369	29756	14387

For random placement if 5 chargers in case 2, the power loss is 99.032 kW and for optimal placement of 5 chargers, the power loss is 92.8 kW. In a certain day, if the peak demand is 902 kW, then, random placement results in 11% while optimal placement results in 10% loss of energy for that certain time of the day. This 1% energy saved through optimal placement in a month result in energy bill savings of:

Energy bill savings = 1%*14387*5.75 = NRs 827.2525.

CHAPTER FIVE: CONCLUSION

5.1 Conclusion

The number of Electric Vehicles in context of Nepal is rising rapidly. To accommodate such technology, its infrastructures are also being extended throughout the country. While the installation of EV charging stations on different parts of country is being carried out, the study of its impact on the distribution network is also necessary. This study realizes the analysis of operational parameters of distribution network and the impact caused by such load addition. This work revolves around the Sanepa distribution feeder line consisting of 21 buses. The strong and weak bus in this feeder line were recognized by determining the Voltage Sensitivity Factor. The impact with the addition of EV charging station load in this feeder line is studied by making several cases. The load flow analysis along with the results from VSF determination were the basis for the formulation of 5 cases in this study. The change in VSI, reliability indices and power loss on these cases concluded that, the weak buses are to be provided with least number of charging stations to improve the system stability, reliability and efficiency. With the increased load addition on the line, the voltage profile keeps on degrading and power loss increases. The number of charging station on each bus should not be more than 5 to avoid severe case of power loss. The power loss is the mostly affected parameter in this study so, heavier weightage is assigned to the power loss while formulating optimization function. Adding constraints to the formulated optimization problem of VRP index, the optimal locations for EVCS placement are determined. The load addition certainly caused the distribution parameters to fluctuate but the optimal placement minimized the extent of such fluctuations. The results obtained effectively reduce the impact on VRP parameters. Hence, the EVCS are optimally located considering least impact to the power distribution grid.

5.2 Recommendation

The further work can be directed towards the integration of distributed generations which can uplift the scenario for placement of EV charging station catering higher number of consumers and also improving the overall reliability, voltage deviation and power loss of the system.

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APPENDIX A: LINE DATA

Line no	Voltage level (kV)	From	To	Length (km)	Conductor	Resistance Ohm/km
1	11	Bus 1	Bus 2	0.2925	XLPE	0.0754
2	11	Bus 2	Bus 3	0.3129	Dog	0.273
3	11	Bus 3	Bus 4	0.1558	Dog	0.273
4	11	Bus 4	Bus 5	0.2195	Dog	0.273
5	11	Bus 5	Bus 6	0.0907	Dog	0.273
6	11	Bus 6	Bus 7	0.1766	Dog	0.273
7	11	Bus 7	Bus 8	0.3072	HT ABC	0.206
8	11	Bus 8	Bus 9	0.0840	HT ABC	0.206
9	11	Bus 9	Bus 10	0.1539	HT ABC	0.206
10	11	Bus 10	Bus 11	0.1500	Dog	0.273
11	11	Bus 11	Bus 12	0.0588	Dog	0.273
12	11	Bus 6	Bus 13	0.0870	Dog	0.273
13	11	Bus 7	Bus 14	0.0607	Dog	0.273
14	11	Bus 14	Bus 15	0.1228	Dog	0.273
15	11	Bus 9	Bus 16	0.1539	HT ABC	0.206
16	11	Bus 7	Bus 17	0.8733	HT ABC	0.206
17	11	Bus 17	Bus 18	0.1068	Dog	0.273
18	11	Bus 18	Bus 19	0.2448	Dog	0.273

19	11	Bus 19	Bus 20	0.0052	Dog	0.273
20	11	Bus 18	Bus 21	0.5706	Dog	0.273

APPENDIX B: LOAD DATA

Bus no.	Bus name	Load (kVA)	P(kW)	Q(kVAr)
1	Thapathali SS	0	0	0
2	Hanuman Than_200N	200	170.0	105.36
3	Kupandol Bus Stop_250N	250	212.5	131.70
4	Juwagal Chowk_100N	100	85.0	52.68
5	Hotel Himalaya_1000P	1000	850.0	526.78
6	Near Nabil Bank_100N	100	85.0	52.68
7	Near Engineering Collage Wall_100N	100	85.0	52.68
8	Near Telecom Office_200N	200	170.0	105.36
9	Sajha Petrol Pump_200P	200	170.0	105.36
10	Nidhant hospital Opposite_100N	100	85.0	52.68
11	Near Police Bit_200N	200	170.0	105.36
12	Labim Mahal_1000P	1000	850.0	526.78
13	Pulchowk Engineering College_100P	100	85.0	52.68
14	Bakhundol Mod_200N	200	170.0	105.36
15	Bista Camp Bakhundol_100N	100	85.0	52.68
16	Department of Local Infrastructure_100P	100	85.0	52.68
17	United Nations_100P	100	85.0	52.68

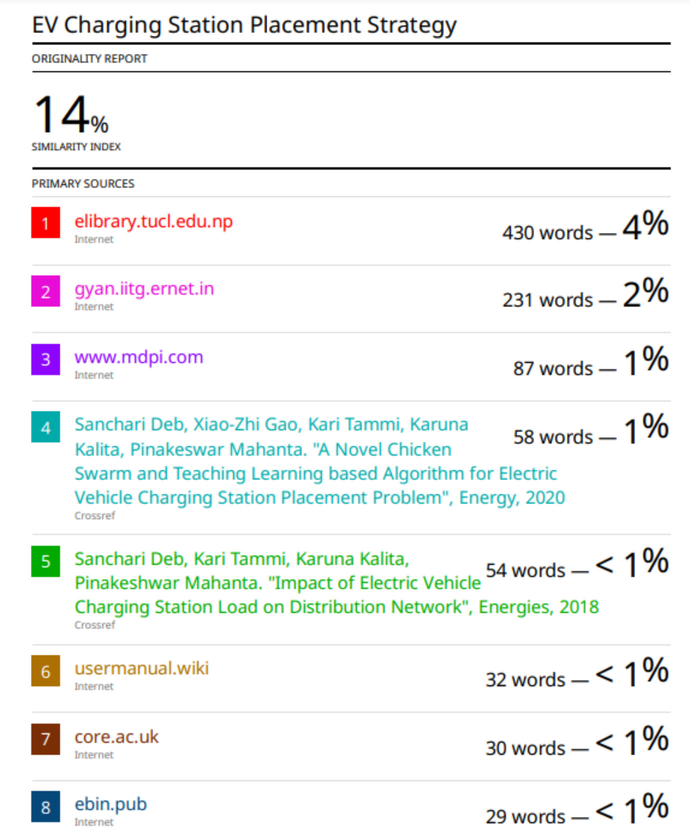
18	Sanchayakosh_400P	400	340.0	210.71
19	High Court Patan_100P	100	85.0	52.68
20	Family Planning Office_200P	200	170.0	105.36
21	Thula Kardata Karayalaya_200P	200	170.0	105.36

APPENDIX C: RELIABILITY DATA

Bus no.	Bus name	Failure Rate (F/year)	Outage Duration (hours/year)	Consumer Number	Load (kW)
2	Hanuman Than_200N	46	8.5	60	170
3	Kupandol Bus Stop_250N	46	8.5	75	212.5
4	Juwagal Chowk_100N	46	8.5	30	85
5	Hotel Himalaya_1000P	46	8.5	1	850
6	Near Nabil Bank_100N	55	10.2	30	85
7	Near Engineering Collage Wall_100N	55	10.2	30	85
8	Near Telecom Office_200N	55	10.2	60	170
9	Sajha Petrol Pump_200P	55	10.2	1	170
10	Nidhant hospital Opposite_100N	55	10.2	30	85
11	Near Police Bit_200N	55	10.2	60	170
12	Labim Mahal_1000P	55	10.2	1	850
13	Pulchowk Engineering College_100P	55	10.2	1	85
14	Bakhundol Mod_200N	55	10.2	60	170
15	Bista Camp Bakhundol_100N	55	10.2	30	85
16	Department of Local Infrastructure_100P	55	10.2	1	85
17	United Nations_100P	55	10.2	1	85

18	Sanchayakosh_400P	55	10.2	1	340
19	High Court Patan_100P	55	10.2	1	85
20	Family Planning Office_200P	55	10.2	1	170
21	Thula Kardata Karayalaya_200P	55	10.2	1	170

APPENDIX D: PLAGIARISM REPORT



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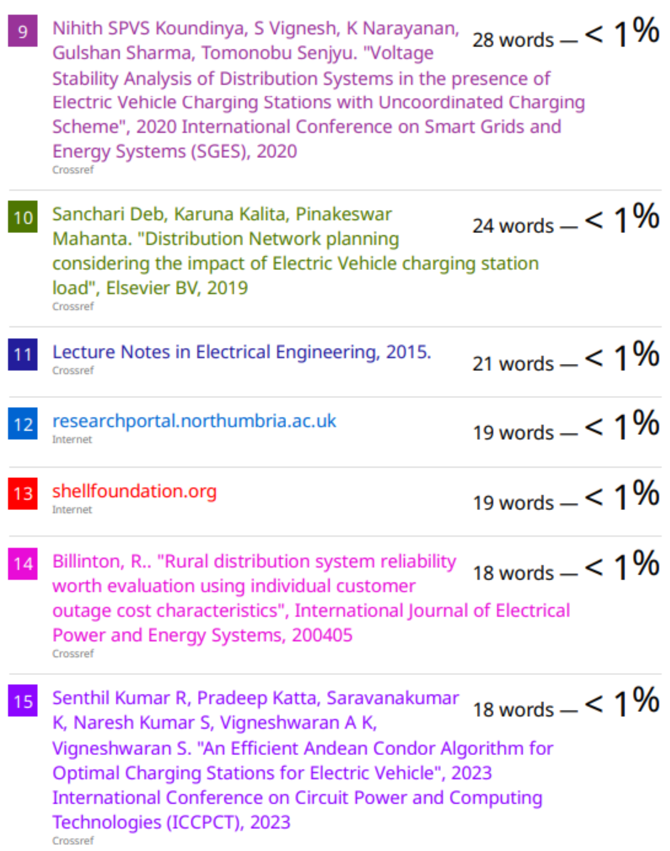

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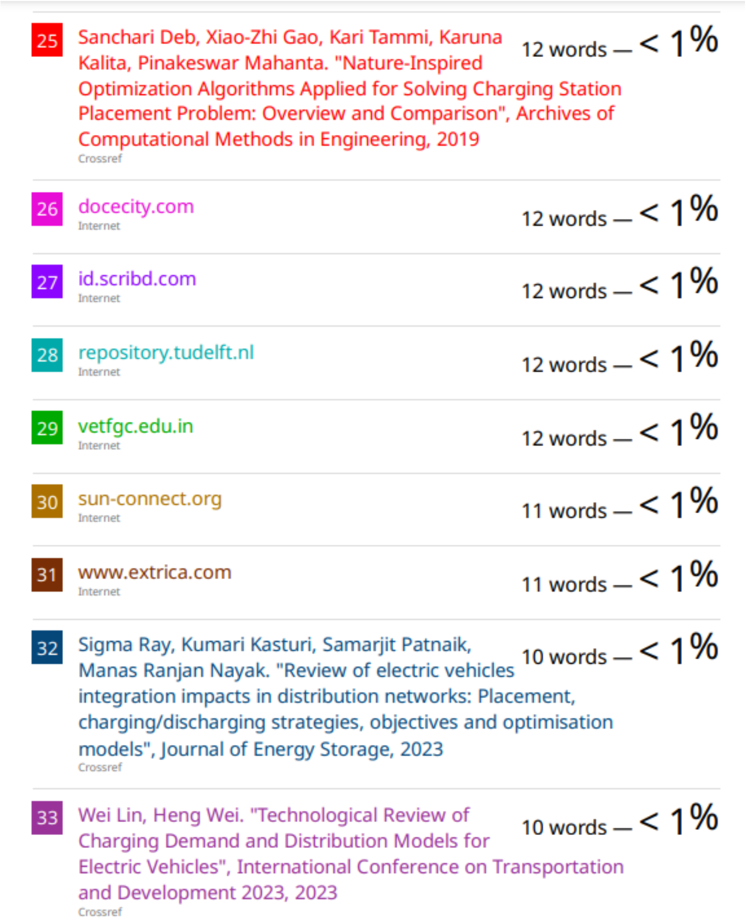

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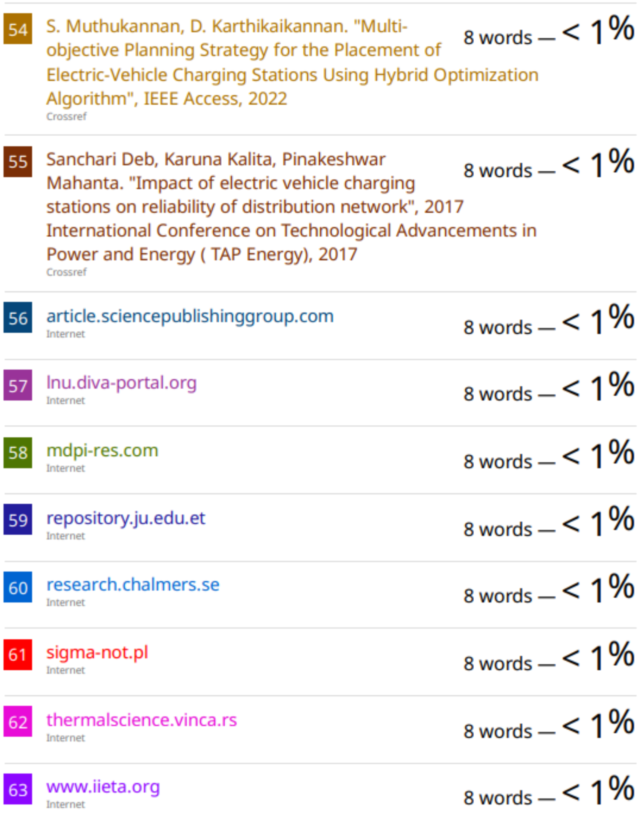

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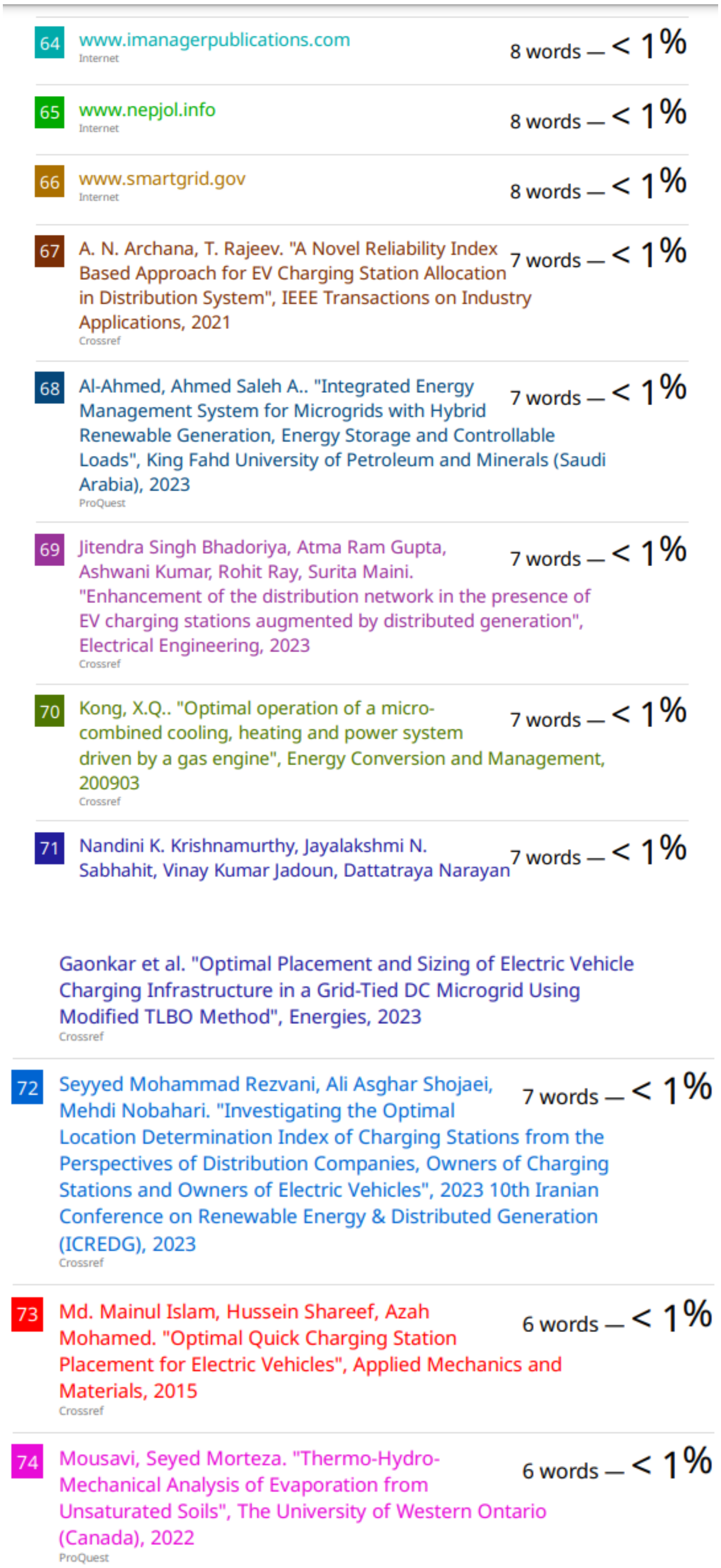

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