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Optimal Placement of Electric Vehicle Charging Stations by Genetic Algorithm in Pokhara's Radial Distribution Network

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Abstract

An unplanned installation of electric vehicle charging stations at various buses of the radial distribution system will impose a very high load demand depending upon time, location, charging interval, and unpredictability of active power which leads to an adverse situation on the operation of the grid. The optimal placement of Electric Vehicle charging stations will enhance the voltage stability, reliability, and other operating parameters of the electric distribution system. Thus, in this paper, the optimal placement of electric vehicle charging stations is carried out in the city feeder of the Pokhara distribution network. Genetic Algorithm as an optimization tool is used to determine the optimal placement of electric vehicle charging stations in MATLAB. The impact of EV installation on voltage stability, reliability indices, and power loss is also carried out before and after placement of EV charging stations in this paper. After placement of electric vehicle charging stations, the voltage in the bus with EV placement is reduced due to load increase, power loss has also been increase but the reliability indices (SAIFI, SAIDI, CAIDI) does not change.

Keywords

Electric vehicle, VSI, VRP, Charging Stations, Optimal location, SAIFI, SAIDI, CAIDI

1. Introduction

The concern for cleaner environment and depleting fossil fuel resources has resulted in renaissance of electric vehicle[1]. Because of these economic and environmental impacts, the future transportation energy demands will electrify through renewable sources. The world has already been stepping forward for the electrification of transportation sector in order to achieve sustainability in the development.The properly planned and efficient charging stations are indispensable to handle the increasing number of electric vehicle in urban areas. The placement of electric vehicle charging stations at various buses of radial distribution system will impose a very high load demand which depend upon time, location, charging interval, and unpredictability of active and reactive power which leads to an adverse situation on the operation of grid. The well-planned deployment of EV charging stations will enhance the voltage stability, reliability, and other operating parameters of electric distribution system. To soar up the electric vehicle penetration in the existing radial distribution system, the optimal placement of charging infrastructures is crucial. In the context of Nepal, the government has implemented various policies in order to operate electric vehicle and to increase an independency on fossil fuels [2]. Also, air pollution and greenhouse gas emissions are becoming emerging issues which should get addressed by optimal planning of the electrified transportation sector. Because of an inefficient and uneconomical operation of the conventional vehicle, the smart transition towards clean and sustainable transportation leads to deployment of electric vehicle.The implementation of electric vehicle is necessary to de-carbonize road transport and to mitigate urban air pollution. The key issues in this system are recharging EVs batteries and locating charging stations. The charging stations are necessary to charge the batteries of electric vehicle periodically at different locations. To adopt EVs in the market, optimal sizing and arrangement of charging stations and its impact on the electricity grid should be analyzed. With development in battery system, transportation, one of the major needs of modern society is shifting towards electrical vehicle. This has posed a challenge on its own of availability of charging station at suitable location. The electric demand variation of the charging station varies over a time as initially it takes larger power to cope with the system and then demand goes down. The electrical demand of charging requirement has changed over time. Initially, the batteries took a long time to charge. Nowadays, development in solid state devices has resulted in quicker charging methodologies. These chargers demand high current and due to their nature of charging, they are commonly known as fast chargers. Providing quality electricity for the charging station without compromising the existing supply facility for other facilities is a growing area of research these days. This paper aims to provide a solution of placing such fast chargers in a suitable location, such that, the utility is able to provide a quality power supply.

2. Literature Review

Table 1: Charging time and Standard of popular Electric Cars in 2019[3]

Vehicle	Level1	Level2	Level3 (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 Super charger (V2)

Electric vehicle charging systems are categorized into three levels based on time taken to charge the vehicle namely Level 1, Level 2 and Level 3. The higher the level means the quicker the charging. Table 1 shows the quick sight of charging time and standard used by three popular battery electric vehicle at the aforementioned levels.

2.1 Impacts of EV in Electric Power Grid

Different studies have been carried out in the past to evaluate the impact of electric vehicle in power distribution system[4, 5, 6].The EV charging technologies have changed since then and such studies are still ongoing that consider the impact of Electric Vehicle Charging Station Load while distribution system planning. In [7, 8] authors have presented the impact of Electric Bus charging in distribution system. In [9] authors present the impact of EV fast charging stations on the power distribution network.

2.1.1 Negative Impacts of EV in Electric Power Grid

- Voltage Instability
- Increased peak demand
- Power quality problems
- Increased power loss
- Transformer overloading

2.1.2 Positive Impacts of EV in Electric Power Grid

- Benefits of Vehicle to Grid
- Environmental Benefits
- Economic Benefits

2.2 Optimal Placing of Charging Station in Electric Power Network

The main objective of charging station placement problem is optimal allocation of EV charging stations in the distribution network in such a way that the operating parameters of the distribution network are least affected. Thus, VRP index is selected as the objective function for charging station placement problem because of its capability of taking into account voltage stability, reliability and power losses under a single umbrella. The mathematical formulation of the VRP index is illustrated as: The objective function [8] is

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

subject to

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

$$0 \le n_i \le n_{slowCS}$$

$$S_{min} \le S_i \le S_{max}$$

$$L \le L_{max}$$

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

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

$$C = \frac{P^l_{loss}}{P_{base}}$$

In above mathematical formulation, i is the index which denotes the bus, VSI denotes voltage stability index, n_i denotes number of charging stations located in $i^{th} bus$, n_{fastCS} is the maximum number of charging stations that can be placed at each bus, n_{slowCS} is the maximum number of charging stations that can be placed at each bus. S denotes the reactive power, S_{min} and S_{max} denote the upper and lower bound of reactive power, respectively. L denotes the increase in load of the system after placement of charging station and L_{max} denotes the loading margin of the network.

2.3 Reliability Indices

- SAIFI (System Average Interruption Frequency Index): 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. It is calculated as $SAIFI = \frac{\Sigma \lambda_j N_j}{\Sigma N_j}$
- SAIDI (System Average Interruption Duration Index): It is defined as the average interruption duration per customer served. It also signifies the condition of the power system in terms of interruption. It is calculated as $SAIDI = \frac{\Sigma \mu_j N_j}{\Sigma N_j}$
- CAIDI (Customer Average Interruption Duration Index): It is defined as the average interruption duration time for those customers interrupted during a year. It signifies the average outage duration that any given customer would experience.It is calculated as $CAIDI = \frac{\Sigma \mu_j N_j}{\Sigma \lambda_j N_j}$
- ENS (Energy Not Served): It is defined as the total energy not supplied by the system. It is an indicator of energy deficiency of the system. It is calculated as $ENS = \Sigma L_j \mu_j$
- AENS (Average Energy Not Served): It is defined as the average system load curtailment index. It gives an idea of how much energy is not serving during a particular time period.It is calculated as $AENS = \frac{\Sigma L_j \mu_j}{\Sigma N_j}$ 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.

In [7] author also presents the reliability indices for use in determining the optimal location. Apart from that another approach for optimization that involves use of Voltage Stability Index has been used in [7] itself. In Paper [10] author presents the optimal location and charging of Electric Vehicle based on sensitivity indices. After formulation of the objective function, optimization algorithms are used in Engineering Optimizations. Different studies have been carried out in optimal placement of EV with use of various optimizing algorithms. In [4] authors have listed out different algorithms in practice for optimal EV charging station placement.

3. Methodology

The study of this paper is carried out in the city feeder of Pokhara Distribution network. Figure 1 shows the flowchart for optimal placement of charging station based on VRP index. For the analysis of city feeder of Pokhara DCS, the MATPOWER's case file has been developed with reference to available data. Table 2 shows the per unit data for making case file of city feeder at base kV 11 for base voltage with power factor of 0.85 lagging. For performing load flow assuming ACSR dog conductor for all branch parameters. The city feeder is taken as a test system. The EV charger load is modeled as per discussed below in 3.1 and 3.2. The further analysis of VRP index is done with assigning proper weight of voltage stability index, reliability index and power loss index. The formulation of charging station placement problem is performed and optimized by using Genetic Algorithm. Genetic Algorithm is used despite other optimization techniques considering the simplicity of the system and the guaranteed convergence.

3.1 Modeling of Electric Vehicle Charging Station

A foremost thing to do would be to model the electric vehicle charging station in terms of electrical load. In [11, 12] authors have presented models for Electric Vehicle Charging Station for simulations of power systems. The mathematical model of EV charger load

Table 2: Bus data and component reliability data for city feeder of pokhara distribution network

Bus no.	P(MW)	Q (MVAr)	Failure Rate (f/ yr)	Outage (hrs/ yr)	No. of con- sumers
2	0.085	0.053	100	70.13	0
3	0.085	0.053	100	70.13	33
4	0.085	0.053	100	70.13	33
5	0.17	0.105	124	86.97	65
6	0.17	0.105	124	86.97	65
7	0.17	0.105	124	86.97	65
8	0.085	0.053	124	86.97	33
9	0.17	0.105	124	86.97	65
10	0.17	0.105	124	86.97	65
11	0.085	0.053	124	86.97	33
12	0.085	0.053	124	86.97	33
13	0.17	0.105	124	86.97	65
14	0.17	0.105	124	86.97	65
15	0.255	0.158	124	86.97	100
16	0.085	0.053	124	86.97	33
17	0.17	0.105	124	86.97	65
18	0.2125	0.132	124	86.97	82
19	0.17	0.105	124	86.97	65
20	0.085	0.053	124	86.97	33
21	0.17	0.105	124	86.97	65
22	0.085	0.053	124	86.97	33
23	0.085	0.053	124	86.97	33
24	0.136	0.084	124	86.97	65
25	0.17	0.105	124	86.97	65
26	0.085	0.053	124	86.97	33
27	0.085	0.053	124	86.97	33
28	0.136	0.084	124	86.97	65
29	0.0425	0.026	124	86.97	15
30	0.595	0.369	124	86.97	200
31	0.085	0.053	124	86.97	33
32	0.085	0.053	124	86.97	33
33	0.02125	0.013	124	86.97	1
34	0.085	0.053	124	86.97	33

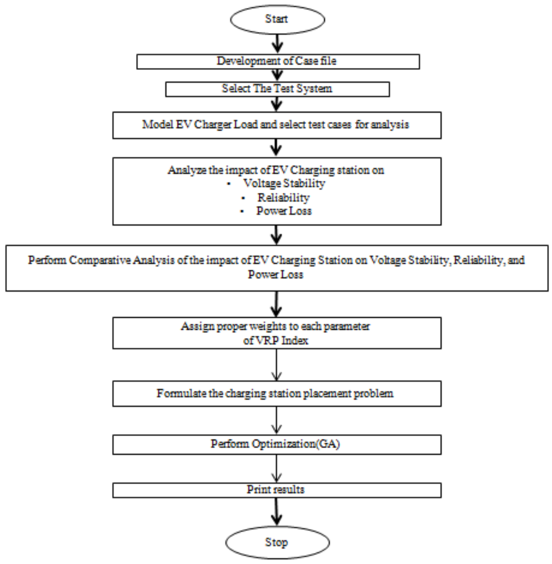

Figure 1: Flowchart for Optimal Placement of charging station based on VRP index

expressed in [11] as follows which seems suitable for the consideration of study in this paper.

$$\frac{P}{P_0} = 0.9061 + 0.0939(\frac{V}{V_0})^{-3.715}$$

where, P is the net input power, P_0 is the power consumption at reference voltage V_0 and V is the input voltage.

3.2 Modeling of System

Distribution System consists of the grid substation, distribution lines at various voltage levels, distribution lines and transformers. An Electric Vehicle Charging Station is placed in a 11 kV bus as its power consuming. Thus, any load in voltage level less than 11 kV can be lumped, if the load is being served from 11 kV system via secondary transformer. On the other side, installation of charging station in 33 kV is capital intensive with higher cost of 33 kV bay and bus bar; So, it may not be economic to install the charging station in 33 kV system. Hence, the distribution system is modeled with grid substation as source, 11 kV lines as distribution lines and transformers as load points/buses. The modeling of Grid substation, distribution lines, load and slack bus is on matpower format to make case file of system. And as these load locations have a transformer feeding all loads, 80% of rating of transformer considered as load for respective transformers for reliability analysis, since, with failure of transformer the load in the secondary side of the transformer is lost. For easy analysis of placement of charging station in feeder, 50 KW constant power is considered for fast charger and 19.2 KW constant power is considered for slow charger in the system. Each Fast charging station consists of five fast charger.

4. Results and Discussions

The city feeder of Pokhara Distribution System has 34 bus system. The power flow analysis of this system is carried out by [7] and the study is done to evaluate the optimal location of charging station. Ten slow chargers, each bus having two slow chargers, are optimally located at bus 4, 14, 24, 25, and 26 respectively.

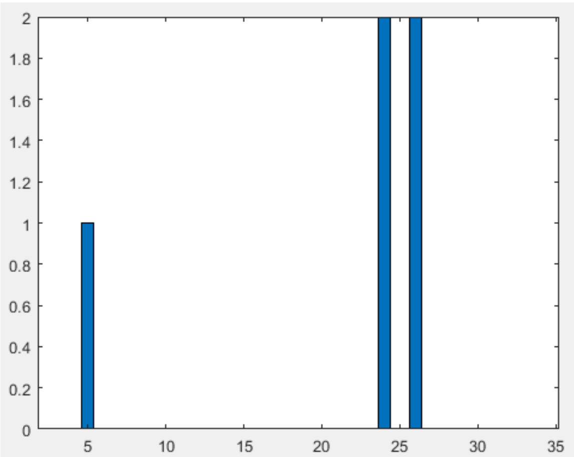

Figure 2: Placement of Fast Charging stations in City Feeder

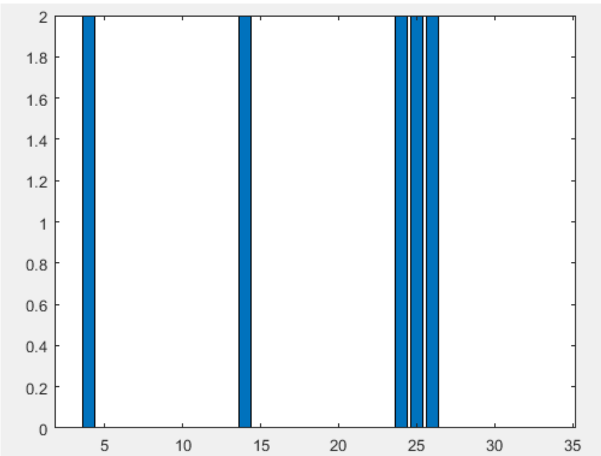

Figure 3: Placement of slow charger in City Feeder

Each slow charger has a capacity of 19.2kW. Five fast charging stations are optimally located in which two at bus 24, two at bus 26, and one at bus 5, are optimally located. A single fast charging station has ten fast chargers with individual capacity of 50kW. So, the capacity of each fast charging station is 500kW. Figure 3 shows the placement of slow chargers in city feeders of Pokhara distribution system. According to this result, the slow charging station's placement should be done at bus number 4, 14, 24, 25, and 26 respectively. In the mean time, the placement of fast charging station in the same city feeders should be done at bus number 5, 24 and 26 respectively which is shown at figure 2. The variation in active power

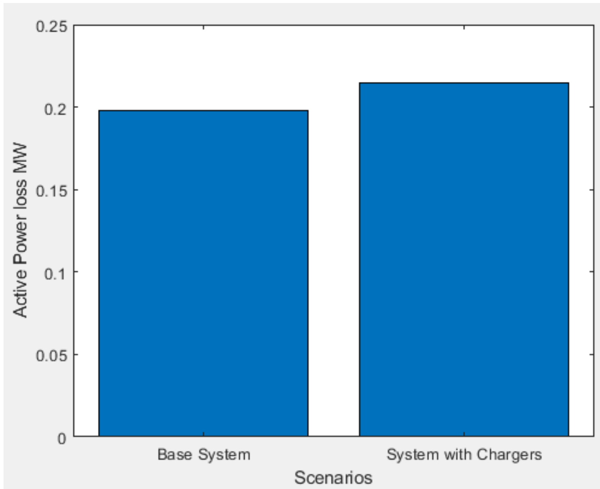

Figure 4: Comparison of Active Power loss of City Feeder

loss with and without charging station is shown in the figure 4. In case of base system, the active power loss is 0.1976 MW whereas in case of system with chargers the active power loss is 0.2143 MW. Hence, it is observed that, the active power loss is increased with the charging stations.

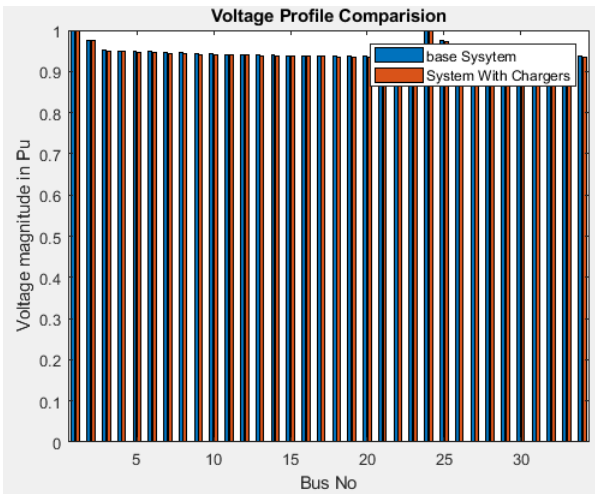

Figure 5: Comparison of Voltage Profile of City Feeder

The voltage indices include the voltage parameters. Here, comparison of voltage profile before and after addition of the charging stations is observed. The result is then compared with Voltage Sensitivity Factor. The Voltage Sensitivity Factor is defined as the ratio of change in voltage to the change in loading. In this case,evidently, there is not much variation in the system for it.The comparison of voltage profile is analyzed. At bus 4, the voltage at base case scenario is 0.9497 pu and the voltage after charger placement is 0.948 pu. The voltage at bus 5 is reduced from 0.9492 pu to 0.9474 pu after having fast charging stations. Similarly, the voltage profile at bus 24, 25, and 26 decreases from 0.9993 pu, 0.9741 pu, 0.9593 pu to 0.9989 pu, 0.9737 pu, 0.9577 pu respectively.

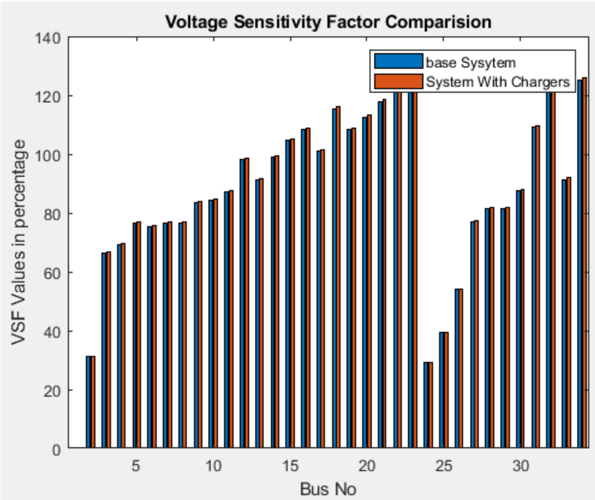

Figure 6: Comparison of Voltage Sensitivity Factor of City Feeder

After having charging station, the voltage profile decreases comparing to base case scenario which is shown is figure 5. In this figure, the base case system is compared to system with chargers placement. In Figure 6, the Voltage Sensitivity Factor is compared with the base case scenario and the system with charger which shows the deviation of the voltage is significant in each bus. The voltage sensitivity factor increases with the increase in load. The result shows that the voltage sensitivity factor at buses 4, 5, 14, 24, 25, 26, 34 increases from 69.07, 76.55, 98.91, 29.29, 39.44, 53.89, 125.3 to 69.51, 77.02, 99.49, 29.33, 39.57, 54.22, 125.9 respectively. Hence, the voltage sensitivity factor is increases significantly after placing the charging station in the distribution system. The variation observed in Average Energy Not Served (AENS) is presented in figure 7 and variation observed in Energy Not Served (ENS) which is presented in figure 8. In figure 8, it is observed that,

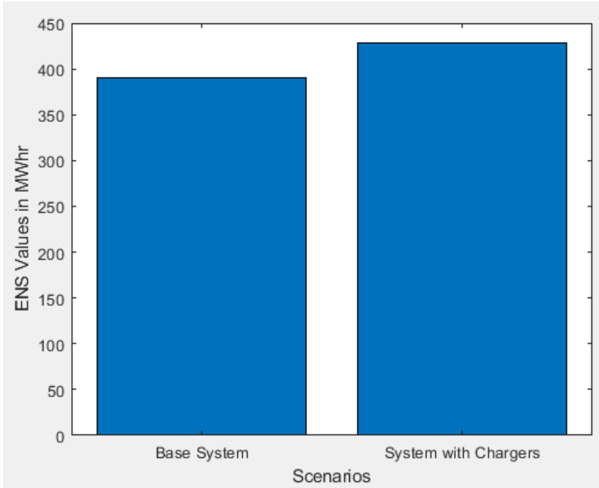

Figure 7: Energy not served

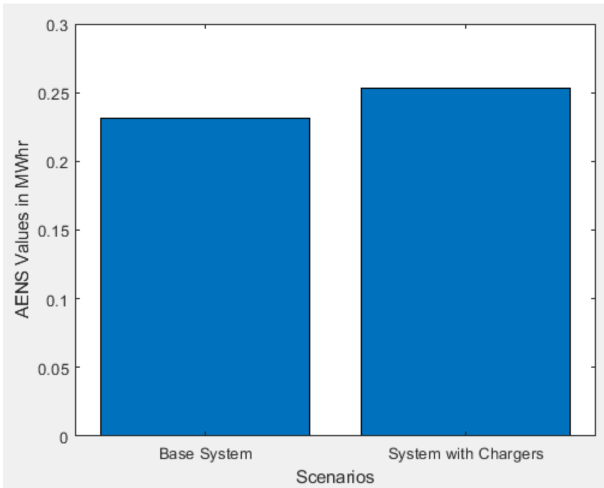

Figure 8: Average energy not served

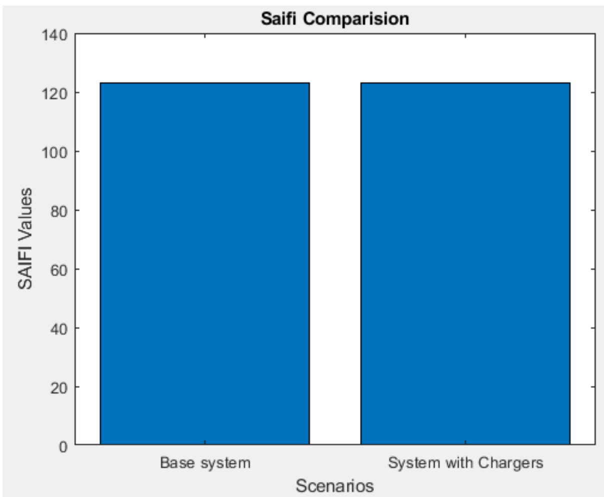

Figure 9: Comparison of SAIFI of City Feeder

the value of ENS for the system with charger is more than the base case system. Hence it is concluded that the placement of charging station at bus 4,14,24, 25, and 26 has a significant impact in ENS. Figure 7 shows that the value of average energy not served (AENS) is significantly increased in case of system with chargers comparing to base case scenario. In case of base system, the value of ENS is 390.8 MWh whereas in case of system with chargers the value of ENS is 428.6 MWh. Moreover, the value of AENS for base case scenario is 0.2313 Mwh whereas the value of AENS for the system with chargers is 0.2356 MWh. It can be concluded that, the placement of charging station will increase the value of active power loss, ENS and AENS by a significant amount. All these adverse scenarios should analyze carefully in the radial distribution network before placing the charging stations. The impacts of the placement of

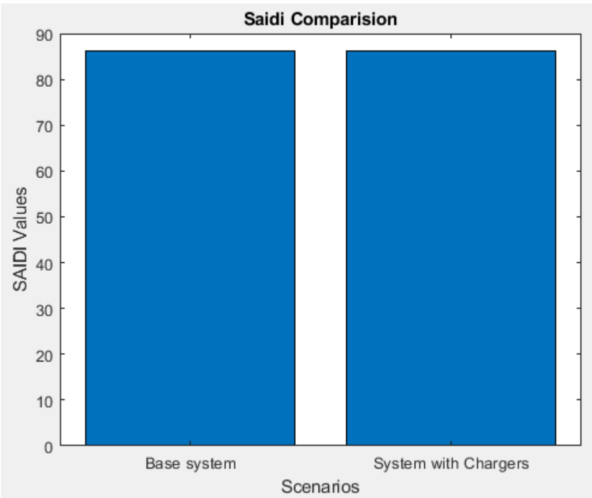

Figure 10: Comparison of SAIDI of City Feeder

charging stations on various reliability indices are scrutinized. The reliability indices (SAIFI, SAIDI, CAIDI) are calculated by using formula discussed in 2.3. The comparison of the reliability index SAIFI, after placing the charging stations is done with base case scenario which is illustrated in figure 9. The value of SAIFI is 123.1 before and after placement of chargers. It shows that the reliability index SAIFI does not change.

The comparison of the reliability index SAIDI, after placing the charging stations is done with base case scenario which is illustrated in figure 10. The value of SAIDI is 86.31 before and after placement of chargers. It shows that the reliability index SAIDI does not change.

The comparison of the reliability index CAIDI, after

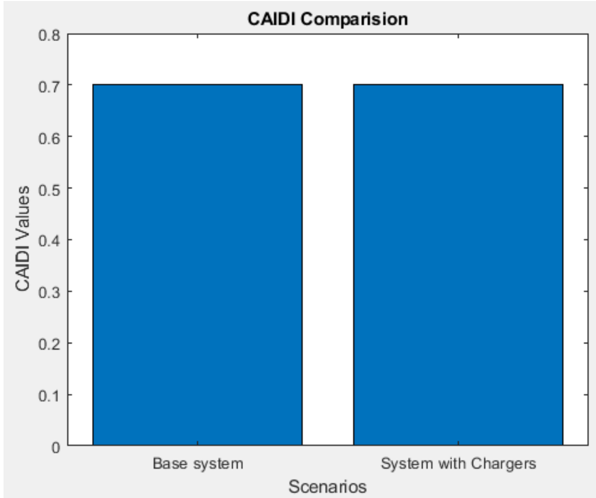

Figure 11: Comparison of CAIDI of City Feeder

placing the charging stations is done with base case scenario which is illustrated in figure 11. The value of CAIDI is 0.7014 before and after placement of chargers. That is the reliability index CAIDI also does not change. The SAIFI, SAIDI and CAIDI reliability indices has no any effect on placement of charging station. After placing of charging station, the demand will get increased due to increasing number of EV charging stations and this will have not any effect on reliability indices.

5. Conclusion

The demanding popularity of Electric vehicle has led to the installation of charging stations (CS) by optimally placing the Charging Stations in the pokhara's radial distribution networks.The whole work is done on the city feeder of Pokhara Distribution Network. The entire work is done by using Genetic Algorithm techniques. It is concluded that for the city feeder of Pokhara Distribution network, the optimal location of fast charging station is obtained at bus number 4, 24, and 26 respectively. Moreover, the optimal location of slow chargers is obtained at bus number 4, 14, 24, 25, and 26 respectively. In case of radial distribution network, the effect of placement of charging stations on voltage stability, active power loss and reliability indices has also been carried out. It is concluded that the voltage sensitivity factor increases, active power loss increases, and the reliability indices (SAIFI, SAIDI,CAIDI) does not have any effect before and after placement of charging station. Thus, in overall, it can be concluded that the optimal placement and study the effect of installation of electric vehicle charging stations in radial distribution network is done successfully by using the genetic algorithm technique and the several electrical parameters are also analyzed.

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