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

Shri Krishna Shrestha [a], Tek Raj Subedi [b], Yuvraj Adhikari [c]

[a, b] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[c] *Department of Electrical Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 075msree014.shri@pcampus.edu.np, [b] tek.subedi@ioe.edu.np, [c] yr.adhikari@ioe.edu.np

**Abstract**

Increasing sensitivity to climate change and rising fuel prices have led to a greater demand for cleaner and sustainable energy sources. The rapid growth of electric vehicles has prompted the need for an efficient charging infrastructure. The integration of charging stations in the current distribution system is a critical aspect of promoting electric vehicle adoption as it poses threat to the grid stability and reliability. Active and reactive power demand of electric vehicle charging station increases the power loss in the existing distribution system and degrade the voltage profile of the individual buses. This study has put forward the application of genetic algorithm for the optimal placement of EVCS by formulating the objective function minimizing the voltage sensitivity factor, reliability indices SAIDI, SAIFI and CAIDI as well as active and reactive power losses. Further, using the GA, optimal placement and sizing of shunt capacitor has been accomplished to improve the voltage profile and reduce the losses caused because of EVCS integration in existing radial distribution system.The optimization task has been performed in MATLAB. Initially, optimization work has been formulated for IEEE 33 bus system. The effectiveness has been validated by collating the voltage profile, active power loss and reactive power loss of base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor in EVCS merged system. Later the work has been authenticated in the Jawalakhel feeder.The optimal location of EVCS has been determined at bus no 2, 19 and 20 in IEEE 33 system and at bus no 3, 4 and 25 in Jawalakhel feeder. Similarly the buses for the installation of shunt capacitor of sizes 472.4 kVAR and 1061.3 kVAR is ascertained at 12 and 30 in IEEE 33 bus and 1244.4 kVAR and 1786.7 kVAR at bus 6 and 20 in Jawalakhel feeder. From the comparative study the voltage profile has appreciably enhanced by the optimal placement of EVCS and capacitor. The total active and reactive power losses reduced from 0.2027 MW to 0.1168 MW and 0.135 MVAR to 0.07 MVAR in IEEE 33 bus system and reduced from 0.177 MW to 0.1378 MW and 0.238 MVAR to 0.1853 MVAR in Jawalakhel feeder.

**Keywords**

Electric Vehicle Charging Station(EVCS) , Radial Distribution System, Genetic Algorithm (GA), Voltage, Active power loss, Reactive power loss

## 1. Introduction

The importance of transitioning away from fossil fuel-powered vehicles to renewable energy based vehicles has been mainly driven by the growing concerns about declining fossil fuels sources, climate change and awareness regarding zero emission to reduce greenhouse gases.With the increase in the use of EVs, requirement of properly planned charging stations in the existing distribution system is indispensable which can handle the rapidly increasing use of EVs. The addition of EVCS can lead to concentrated loads in certain areas of the distribution system. This uneven distribution of load can cause voltage fluctuations and overload issues, potentially leading to power outages, voltage instability and unpredictability of active and reactive power depending upon the intermittent load demand of EVCS. The well-planned deployment of electric vehicles charging stations will enhance the voltage stability, reliability, and other operating parameters of electric distribution system. The existing radial distribution systems may not have the capacity to handle the increased demand from EV charging stations. Hence optimal placement of charging station without compromising of grid stability, reliability and power quality needs to be adopted along with additional compensating devices to mitigate the impacts of EVCS integration. In the context of Nepal, the electric vehicle (EV) market is showing promising signs of growth and potential. Nepalese government has been determined to promote EVs as long-term clean transportation alternatives (National Transport Policy, 2001), with the aim of utilizing hydropower potential of Nepal. There is challenges in addressing power loss, voltage regulation, grid capacity constraints, and cost-effectiveness to create a robust charging network that accommodates the increasing demand for EVs while maintaining the overall stability and reliability of the distribution system. In this context, a study focusing on the optimization in the placement of charging station in existing distribution system using the proven algorithm might shed new light on the dynamics of EVCS integration thus fostering a seamless transition to electric mobility and supporting the sustainable development of transportation systems. After the integration of EVCS in the existing system, it causes the degradation in the voltage profile and increase in power loss of the system even after the optimal placement. So, it is required to connect the compensation devices of suitable sizes at appropriate nodes in the system to mitigate the effects resulted due to EVCS integration.

After the discovery of electric vehicles as the potential replacement for fossil fuel based vehicle, it is of major concern and topic of research regarding the energy storage and charging infrastructure of electric vehicle. Numerous studies have been carried out to study the impact of incorporating the charging station in the distribution network, various methods and algorithms have been developed to address the issue of optimal placement of charging station. The random placement of charging station might negatively hamper the step towards carbon free transportation[1]. In the paper published by [2], it has highlighted the issue about the voltage stability, reliability and power loss of distribution network to be taken into consideration for the positioning of charging station.Optimization techniques according to the objective functions, constraints, load modelling, V2G strategy has been reviewed[3].The hybrid genetic algorithm and particle swarm optimization (GA-PSO) is proposed for the optimal allocation of plug-in EVCS along with distributed generation (DG) minimizing the active and reactive power losses as well as the voltage fluctuation index[4]. Various methods have been researched and implemented to reduce these impacts on the distribution network but it can be clearly identified that it is not possible to improve the voltage and power index of the grid without proper compensating devices to be placed along with EVCS for the enhanced performance of the network. The ant colony optimization algorithm have been presented considering the loss sensitivity analysis to identify the best location and size of capacitors in radial distribution system[5]. The method based on direct search algorithm has been introduced to identify the buses to place capacitors considering to minimize the active power loss and maximize the net savings[6]. Since power loss and voltage of buses in radial distribution system is the major consideration for the sizing of capacitors and placement,the optimal placement and sizing of shunt capacitor in the distribution network have been executed which helps to efficiently reduce the losses in the network using genetic algorithm (GA)[7].

## 2. Methodology

With reference to the objective function and optimization algorithm; GA has been implemented considering the voltage, reliability and power loss (VRP) as the objective function for optimal placement of EVCS in the RDS. Initially the optimization algorithm has been formulated in the IEEE 33 standard test system. After achieving the optimal placement of EVCS considering the voltage profile, power loss and reliability indices in the IEEE 33 system, overall procedure is carried out in the Jawalakhel feeder in Nepal to validate the algorithm in real world data. Jawalakhel feeder data is considered for the study because of the fact that it is a radial distribution system in the city area along the road which is relevant for the EVCS placement. Bus voltage, active power and reactive power demand of each buses along with resistance and reactance of each distribution section of considered feeder are taken as major variables for the analysis to achieve the objective of the research. And total number of consumers, failure rate and interruption rate has been taken into consideration for reliability indices. Similarly, GA has been executed to find the optimal placement and size of shunt capacitor to improve the voltage profile and power losses in the branches in the system with optimal location of EVCS.

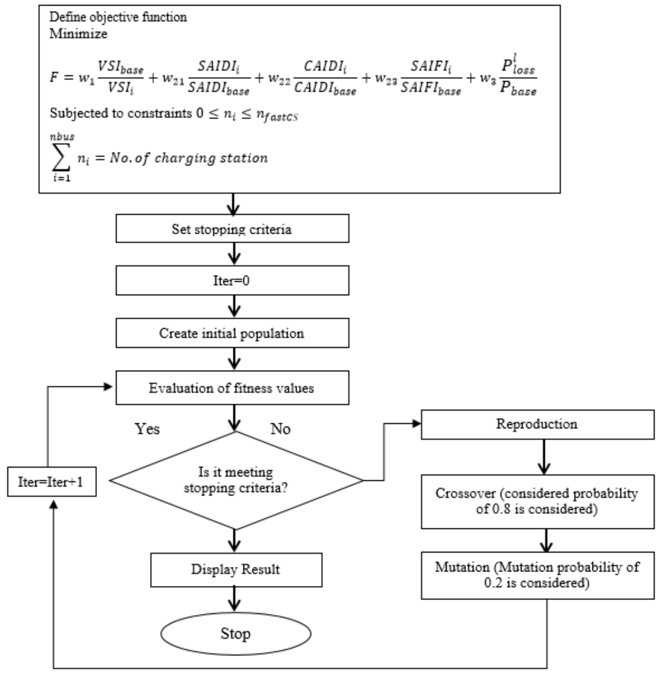


**Figure 1:** Flowchart of formulation of GA for optimal placement of EVCS [8]

Load flow analysis is carried out in MATLAB with the help of Matpower extension. In MATLAB, the distribution system is modeled with grid substation as source, 11 kV lines as distribution lines and transformers as load points/buses. And as these load locations have a transformer feeding all loads, they are lumped as single consumer for reliability analysis. The substation is modeled as a generator, i.e. as a complex power injection at a specific bus. It is the standard model of Matpower. Modelling of distribution line is represented in terms of F-Bus as from-bus number, T-bus as to-bus number, BR-R as resistance and BR-X as reactance in Matpower. Loads of distribution system are modeled as constant power loads and are specified as quantity of real and reactive power directly connected to the bus. During the optimal placement of EVCS and shunt capacitor, it has been considered that all the EVCS are operating at the same time to evaluate the system for the worst case scenario.

### 2.1 Approach for the EVCS placement

From the study done in [9], the equivalent model of EVCS is represented as active load and reactive load considering the displacement power factor only which have been adopted for this study as well. For this study, the assumption of the sizing of dc fast charger EVCS is considered as three 50 kW charging load in one EVCS which will be 150 kW per EVCS load. And for the consideration of reactive load of charging station, EVCS is considered as linear load so considering the displacement power factor only. The power factor assumption for the study is taken as 0.8 lagging.The flowchart shown in figure 1 is representing the formulation of GA for the optimal placement of EVCS in RDS. For the optimization of EVCS placement, the equation is taken from the review of [8] considering the VRP index is given by,

$$\min(\text{VRP}) = w_1 A + w_2 B + w_3 C \qquad ([8])$$

Where,

$A = 1/a$ and $a = \mathrm{SF}_i/\mathrm{VSF}_{\mathrm{base}}$

$B = w_{21}\dfrac{\mathrm{SAIFI}_i}{\mathrm{SAIFI}_{\mathrm{base}}} + w_{22}\dfrac{\mathrm{SAIDI}_i}{\mathrm{SAIDI}_{\mathrm{base}}} + w_{23}\dfrac{\mathrm{CAIDI}_i}{\mathrm{CAIDI}_{\mathrm{base}}}$

$C = \dfrac{P_{(\mathrm{loss})_i}}{P_{\mathrm{base}}}$

The main aim of implementing the GA is to minimize the value of objective function with the help of load flow analysis to find out the best node to connect the EVCS load in the RDS.

### 2.2 Procedure for the optimal placement and sizing of shunt capacitor

The mathematical objective function proposed by [7]for the optimal placement and sizing of shunt capacitor considering the minimization of active power loss, reactive power loss and voltage drop is adopted in this study which is given by,

$$F = w_1 P_{loss} + w_2 Q_{loss} + w_3 (1 - v_i)^2 \qquad ([7])$$

During the implementation of GA, capacitor place and size are taken as the variables which is optimized by conducting the load flow analysis considering the reactive power compensation to the existing system with optimized size and location. The flowchart using genetic algorithm for the optimal placement and sizing of shunt capacitor is shown in figure 2.

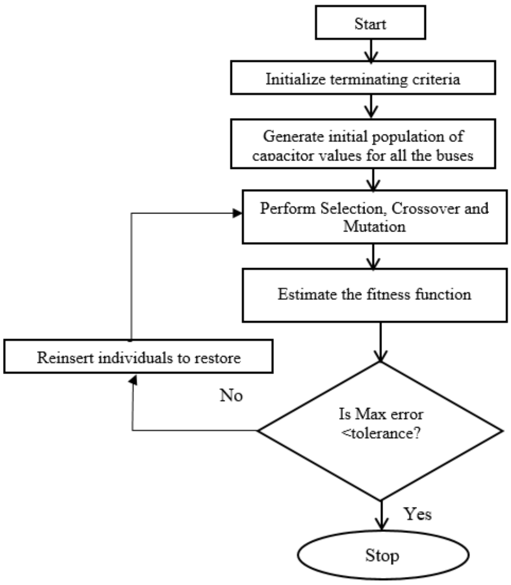


**Figure 2:** Flowchart of formulation of GA for optimal placement of shunt capacitor[7]

## 3. Results and Discussions

After performing the optimization in MATLAB using GA, the optimal position of 150 kW fast charger, has been found out to be at bus no. 2 with two numbers, bus no. 19 with one number and bus no. 20 with two numbers of EVCS in IEEE 33 bus system.Similarly, the placement of EVCS in Jawalakhel feeder has been found out to be at bus no.3 with two numbers, bus no.4 with one number and bus no.25 with two numbers which are shown in figure 3 and 4 respectively.

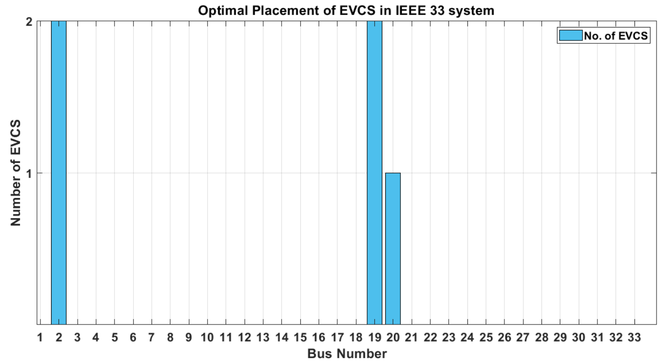


**Figure 3:** Optimal placement of EVCS in IEEE 33 bus system

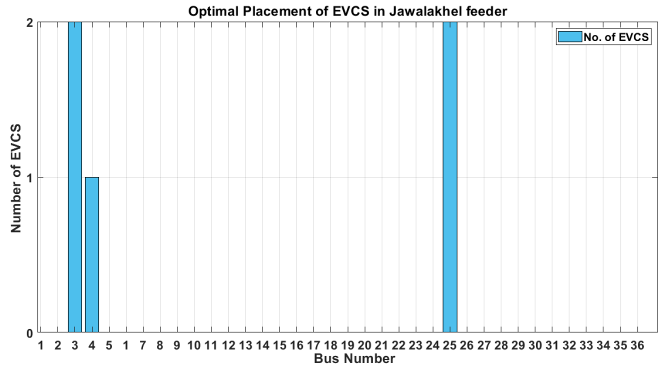


**Figure 4:** Optimal placement of EVCS in Jawalakhel feeder

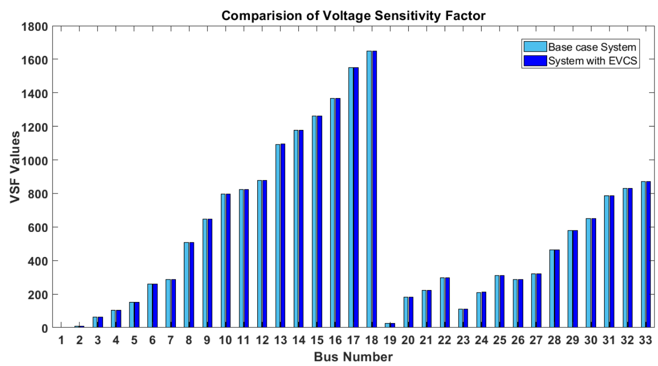


**Figure 5:** Comparison of Voltage Sensitivity Factor during EVCS placement of IEEE 33 Bus system

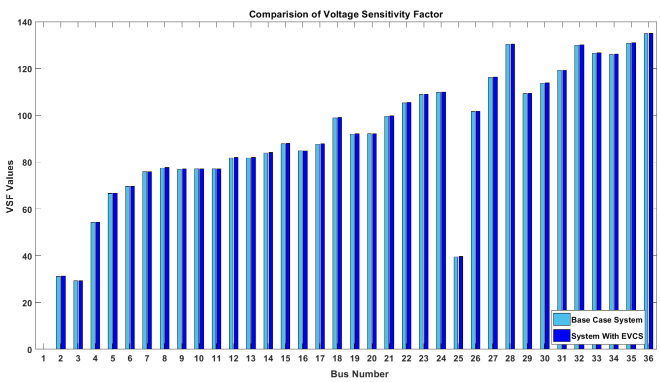


**Figure 6:** Comparison of Voltage Sensitivity Factor during EVCS placement of Jawalakhel feeder

While optimizing the position of fast dc charger EVCS in buses of radial distribution system, voltage sensitivity factor (VSF) has also been compared with the base case which is found out to maintained to least deviation by the application of GA during the EVCS placement.

After the optimal placement of EVCS it has been found out that the voltage profile is degraded and increment in the active and reactive power losses in the branches from the base case system. Using the GA, the optimal sizes and locations of shunt capacitor have been found out to be 472.4 kVAr and 1061.3 kVAr at bus no 12 and 30 respectively in IEEE 33 bus system .Similarly in Jawalakhel feeder, optimal sizes and locations of shunt capacitor have been found out to be 1244.4 kVAr and 1786.7 kVAr at bus no 6 and 20 respectively.

The overall comparison of the voltage profile of the base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor in the IEEE 33 bus system and Jawalakhel feeder is shown in the figure 7 and 8 respectively. In the figure, it has been shown that the random placement of EVCS resulted the appreciable degradation of voltage profile from the base case system. And after the optimal placement of EVCS, the voltage profile degradation is mitigated which is clearly evident. Still the voltage curve of the system with EVCS is below the base case system. Lastly, after the optimal placement of shunt capacitor which has resulted the improvement of voltage profile of the system.

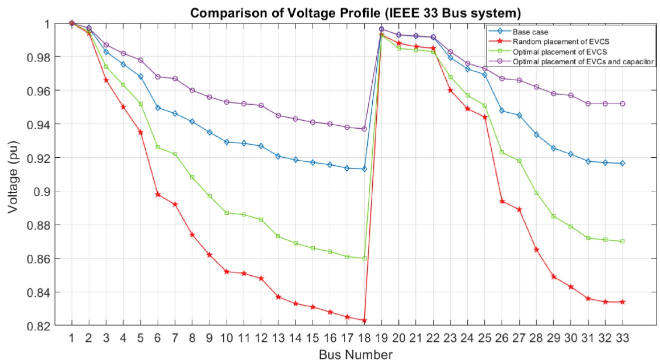


**Figure 7:** Comparison of voltage profile of different cases in IEEE 33 Bus system

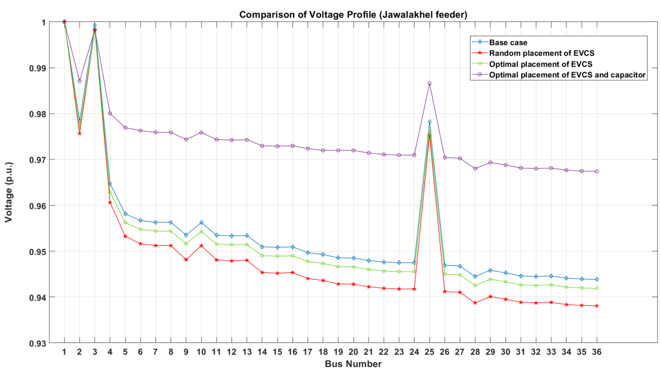


**Figure 8:** Comparison of voltage profile of different cases in Jawalakhel feeder

Since the objective of the research is to reduce the active power loss and reactive power loss of the radial distribution system branches during the optimal placement of EVCS. For that, both the active and reactive power loss comparison is done for the base case, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor.The active power loss comparison of IEEE 33 bus system and Jawalakhel feeder is shown in figure 9 and figure 10 respectively.

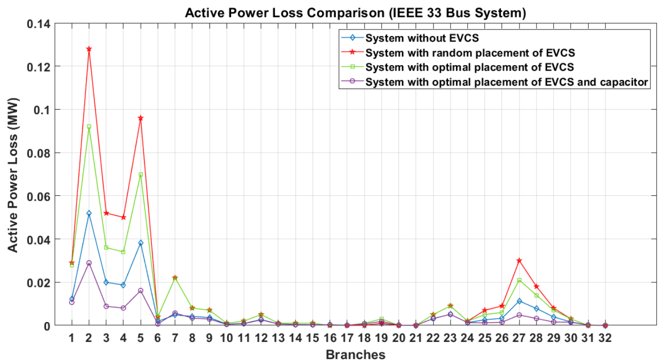


**Figure 9:** Comparison of active power losses of different cases in IEEE 33 Bus system

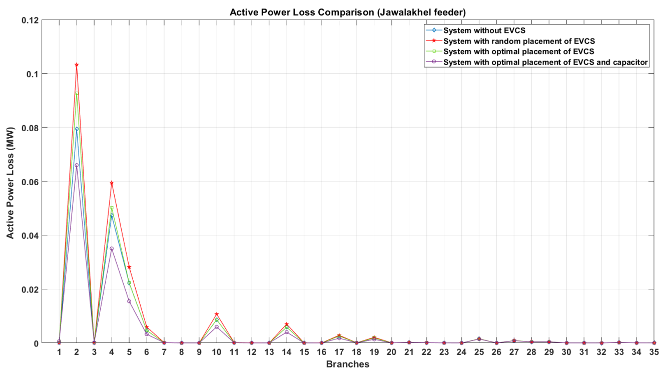


**Figure 10:** Comparison of active power losses of different cases in Jawalakhel feeder

The reactive power loss comparison of IEEE 33 bus system and Jawalakhel feeder is shown in figure 11 and figure 12 respectively.

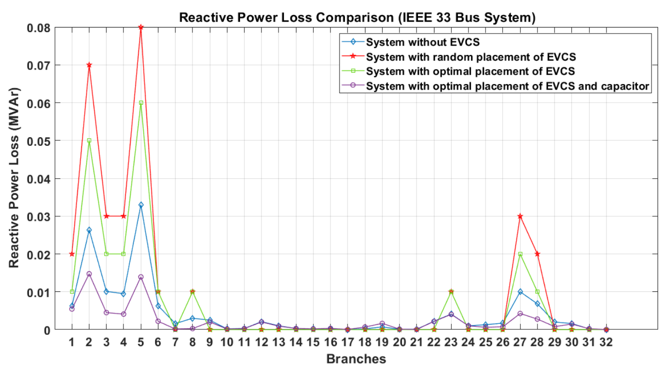


**Figure 11:** Comparison of reactive power losses of different cases in IEEE 33 Bus system

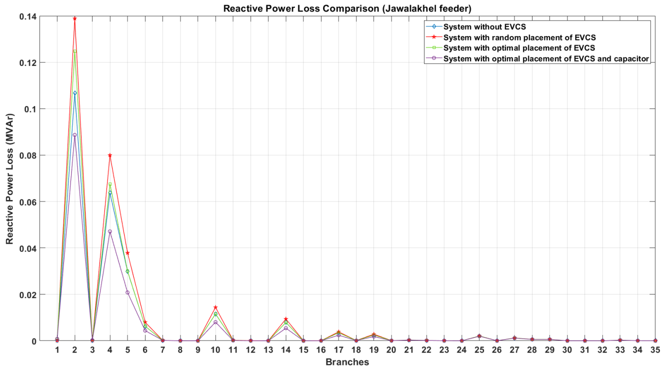


**Figure 12:** Comparison of reactive power losses of different cases in Jawalakhel feeder

From the figure showing the comparison of active and reactive power loss, it has been confirmed that the both the active and reactive power losses have increased after the random placement of EVCS in IEEE 33 bus system and Jawalakhel feeder. Using the GA, from the optimal placement of EVCS, active and reactive power losses mitigated but still found to be more than the base case scenario. Hence from the optimal placement and sizing of shunt capacitor in both IEEE 33 system and Jawalakhel feeder has resulted the reduction in active and reactive power loss.Total active power loss of base case system, random placement of EVCS, optimal placement of EVCS and optimal placement of shunt capacitor are 0.2027 MW, 0.499 MW, 0.388 MW and 0.1168 MW respectively for IEEE 33 bus system and 0.177 MW, 0.224 MW, 0.194 MW and 0.137 MW respectively for Jawalakhel feeder. Similarly, total reactive power loss for above mentioned cases are 0.135 MVAr, 0.31 MVAr, 0.22 MVAr and 0.07 MVAr respectively in IEEE 33 bus system and 0.238 MVAr, 0.302 MVAr, 0.261 MVAr and 0.185 MVAr respectively in Jawalakhel feeder.

## Conclusion

Optimum placement of EVCS has been ascertained at bus no 2 with two numbers, bus no 19 with two numbers and bus no 20 with one number and at bus no 3 with two numbers, bus no 4 with one number and bus no 25 with two numbers in IEEE 33 bus and Jawalakhel feeder respectively considering the minimization of VRP parameters resulting the improvement of voltage magnitude of individual buses and reduction of total active power loss from 0.499 MW to 0.388 MW in IEEE 33 system and reactive power loss from 0.31 MVAR to 0.22 MVAR in IEEE bus system and active power loss from 0.224 MW to 0.194 MW and reactive power loss from 0.302 MVAR to 0.261 MVAR in Jawalakhel feeder comparison to random placement respectively. Sizing and optimal placement of shunt capacitor has been suggested with the minimization function of active and reactive power loss using GA of capacity 472.4 kVAR and 1061.3 kVAR at bus no. 12 and 30 in IEEE 33 bus system and of capacity 1244 kVAR and 1786.7 kVAR at bus no. 6 and 20 in Jawalakhel feeder respectively.

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