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Impact Assessment of Plug-in-Electric Vehicles on Distribution System through Home Charging

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Abstract

Global environmental issues have brought several international agreements to reduce carbon emission. In this context, electric vehicles (EVs) can be the best alternatives to reduce petroleum consumption and carbon emission simultaneously. EVs getting massive popularity with new policies initiated by several governments. But the rapid deployment of EVs can be burden to power distribution network. This research is focused on impacts of plug-in-electric vehicles(PEVs) on distribution system with stochastic behaviours of PEVs. The distribution system is analyzed in terms of feeder peak, total power loss and energy loss, voltage deviation, transformer loading, and line loading before and after the penetration of PEVs over a wide range considering home charging scenario. The results is analyzed to determine the withstand capacity of distribution system for PEVs. The line loading reached 104.63% violating the limit with 80% of PEVs but the voltage deviation is under limit..

Keywords

Distribution system, DigSILENT, Electric Vehicle, Monte Carlo Simulation, Plug-in-electric vehicle

1. Introduction

With several issues regarding Greenhouse emissions and reduction in fossil fuel consumption, EVs became an interest of every country worldwide. As the transportation sector has a leading role in emissions EVs can be a boon to both environment and the economy. Despite the covid pandemic, electric cars on worlds road reached 10 million in 2020[1]. As the battery of electric vehicles is charged by connecting to the distribution system.Extensive penetration of PEVs can bring out several issues in power quality and reliability of the system.The utility needs to determine the withstand capacity of the distribution system and strategic management is necessary for effective penetration of PEVs[2].

The load of PEVs is highly stochastic as it depends upon the daily driving distance and home arrival time of the vehicle owner that vary day to day. Several papers used different algorithms for stochastic modeling of PEVs. The paper[3] modeled the load of PEV composing driving pattern model and energy consumption model and is addressed in a stochastic framework considering the random charging start time, initial battery state-of-charge (SOC), vehicle locations, and ambient temperature effect. The stochastic load profile of PHEV-30 has been modeled using the different characteristics of PHEV-30 and daily driving distance and arrival time of national household travel survey NHTS 2009 survey[4]. In [5] the charging characteristics of batteries have been considered in linear and nonlinear separately and compared with each other.

An increment in the penetration percentage of PEVs will impose huge load demand in the distribution network which will cause different problems such as increased power losses, phase imbalances and power quality problems with overloading and aging of transformer [6]. A study of the distribution network in Hungary shows the violation of transformer and feeder thermal loading at 60 percent penetration of PEVs under uncoordinated charging[7]. The study on the real case of Gothenberg shows the overloading of lines and transformer at simultaneous charging of vehicle at peak load time but there was no problem with voltage drop[8]. Different penetration percentage of PEVs under different scenario has been simulated on standard grids and the result shows the acceptable penetration level in terms of bus voltage and total grid loss[9]. Large-scale integration of PHEVs and BEVs will undoubtedly influence distribution system design and operation. All distribution circuits may not adopt the same level of PHEV. Utilities must determine distribution feeder capacity to penetrate the electric vehicles[10].

The purpose of this paper is to present the impact of PEVs on the 11kV distribution system in the context of the Nepalese distribution system with a case study of Bageshwori feeder, Nepalgunj Nepal. The distribution system is modeled on DigSILENT Powerfactory 15.1. The stochastic Load profile of PEVs is modeled and integrated into the distribution system at a wide range of penetration considering the uncoordinated charging. The impacts of PEVs on feeder peak power, total power, and energy loss, voltage deviation, line loading, and transformer loading has been studied considering the distribution load profile of summer peak.

2. Research methodology

2.1 PEV Modelling

2.1.1 Vehicle Model

The Nissan-Leaf 24 kWh, 100 miles vehicle with specific energy consumption of 0.24 kWh/miles is selected for PEV modeling. The minimum state of charge is considered as 5%[11]. The charger capacity of 3.3 kW is considered for the home charging scenario. The charger efficiency is considered 88%[7].

2.1.2 Daily Driving Distance

The daily driving distance of Nepalgunj city is determined by tracing the frequent route map around the city. The data traced are analyzed to obtain the probability distribution of daily driving distance. MATLAB Best curve fit analysis is used to obtain the lognormal distribution of daily driving distance expressed by equation 1[4]. The lognormal distribution with the mean value of driving distance 3.416 is 30.45km and a standard deviation of 2.928 is obtained.

$$f(x) = \frac{1}{X\sigma\sqrt{2\pi}} e^{\frac{-(lnX-\mu)^2}{2\sigma^2}} \tag{1}$$

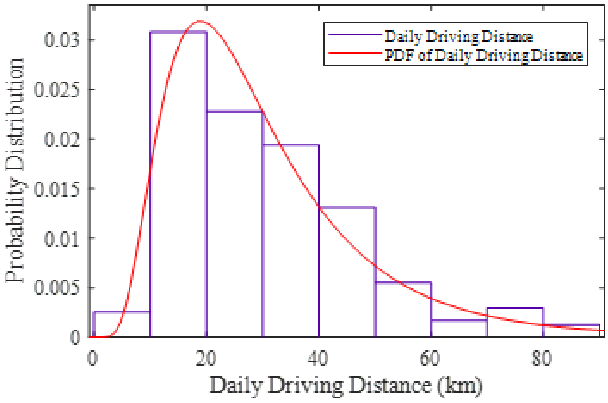

Figure 1: PDF of Daily Driving Distance of Nepalgunj City

2.1.3 Battery Performance during Driving

The state of charge (SOC) of the battery after a certain trip can be estimated by equation 2[12].

$$\text{SOC} = \frac{1-(D_i * E_c)}{\text{Battery Capacity}} \tag{2}$$

where, D_i = Daily distance travelled (km)
E_c = Specific energy consumption(kWh/km)

2.1.4 Battery Performance during Charging

The battery of the vehicle during charging acts as a load to the distribution system when connected to the charger. The charging time required to the battery after the plug-in is given by equation 3 [12].

$$\text{Charging Time (CT)} = \frac{(1-\text{SOC})(\text{Battery Capacity})}{P_c * Eff_c} \tag{3}$$

where, P_c = Power rating of charger,
Eff_c = Efficiency of charger,
SOC = State of charge before plug-in

2.1.5 Charge Start Time

Charging start time also plays a major role in the modeling of PEVs charging profile. For the case of home charging, the arrival time of the vehicle at home will be considered as the charge start time. The vehicle arrival time is totally dependent upon the vehicle owner and is highly stochastic. This research assumed a mean value of arrival time of 17.4 hours with a standard deviation of 3.3 hours.

2.2 PEV Individual and Fleet Modelling

Single PEV is modeled according to the sequential diagram shown in figure 2. A model developed for a single PEV is aggregated with the appropriate method to determine the overall fleet model. This research uses Monte- Carlo Simulation (MCS) method to develop an overall model of the fleet by combining a single PEV model using python 3.0. The flowchart of fleet modeling is shown in figure 3. The daily load profile of 100 PEVs with the peak of 121.52kW is shown in figure 4.

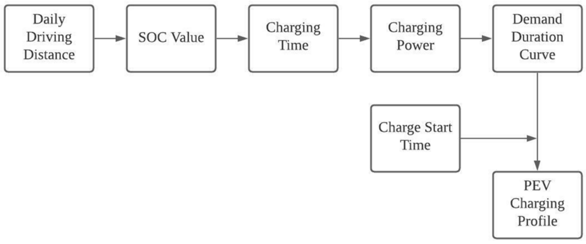

Figure 2: Sequential Modelling of Single PEV

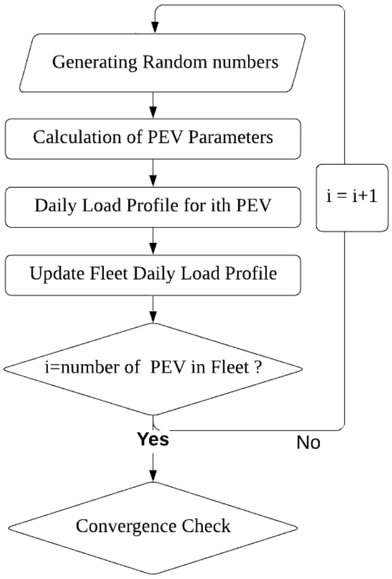

Figure 3: PEVs Fleet Modelling Procedure

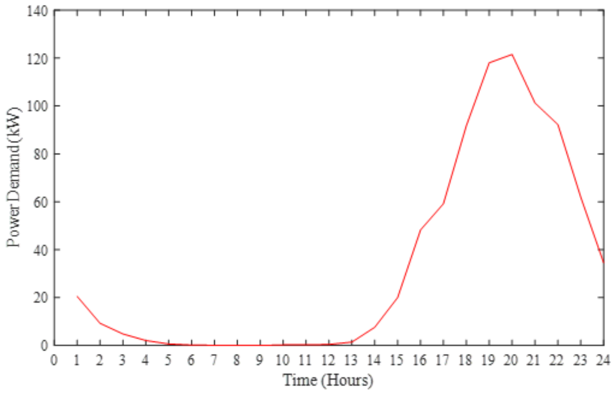

Figure 4: Load Profile of 100 PEVs

2.3 Distribution System Modelling

The distribution system of Bageshwori feeder is modeled in DigSILENT Powerfactory 15.1. This feeder consists of 54 transformers with 35 utility and 19 private. The 24-hour load profile of each transformer is loaded on a model of DigSILENT using DigSILENT Programming Language(DPL) for 24-hour load flow analysis. The power factor of each load is taken 0.9 lagging. The line routing and location of distribution transformer of Bageshwori feeder is shown in figure 5.

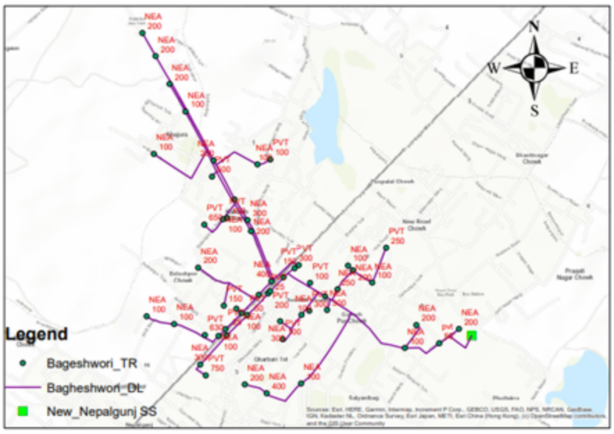

Figure 5: Line routing and location of distribution transformer

2.4 Integration of PEVs on Distribution system

PEVs fleet load is aggregated with the transformer load individually until the criterion of penetration converges. 10 percent penetration means PEV will be added until the transformer peak load increases by 10 percent. For example, if 200kW is the peak load of a transformer, PEV will be added to the transformer until the new peak of the transformer reaches 220kW. The number of the loop will give the number of PEV. Random 15 location is selected from 35 utility transformers for the Penetration of PEV. The randomly selected transformers for PEV penetration are given in the table 1. The load flow is performed with a wide range of PEV penetration i.e 10,30, 60, and 80 percent for the summer peak

3. Results and Discussion

3.1 Load Flow of Bageshwori Feeder

The 24-hour load flow is performed for the base case and with the penetration of PEV at a different level of

Table 1: Location of PEVs

S.N	Name of Transformer
1	AG Bank NEA Tr
2	Bageshwori Mandir vitra NEA Tr
3	Dailekhi Tol NEA Tr
4	Dewa Fulbari NEA Tr
5	Dhomboji Chowk 2 NEA Tr
6	Gulariya Buspark NEA Tr
7	Gumba Nera NEA Tr
8	Hotel Shrinet NEA Tr
9	Jumli Tole NEA Tr
10	Plywood Industries NEA Tr
11	Regional West NEA Tr
12	Senthomas School NEA Tr
13	Seto BK Chowk New NEA Tr
14	Shiva Mandir 1 NEA Tr
15	Subodh Sir Ghar NEA Tr

penetration. Following parameters are analyzed after penetration of PEVs.

3.1.1 Feeder Load Curve

In the base case, the peak load of the feeder is 4.325 MVA at 17:00 hours. As PEVs are integrated with the feeder, the peak of the feeder increases With the increase in PEV penetration. Up to 10% PEVs, the peak is at 17:00 hours but after that peak shifts towards 19:00 hours. The peak load of feeder reached 4.498 MVA at 10% PEVs, 4.841 MVA at 30% PEVs, 5.308 MVA at 60% PEVs, and 5.615 MVA at 80% PEVs. The peak load of feeder increases from 4.325 MVA at 0% PEVs to 5.615 MVA at 80% PEVs. The feeder load curve at different penetration of PEV is shown in figure 6.

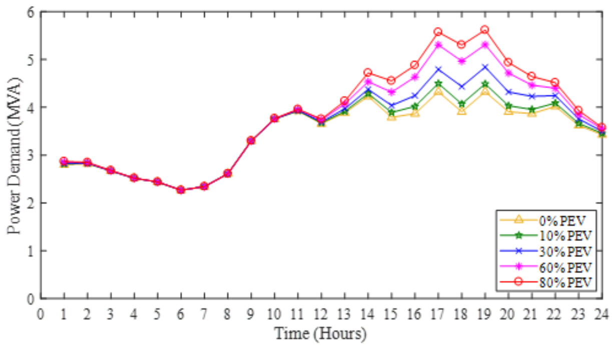

Figure 6: Apparent Power of Feeder with PEVs

3.1.2 Feeder Power Loss

The feeder peak active power loss is found to be 0.0478 MW at peak time 17:00 hours without penetration of PEV. It increases with an increment in penetration of PEV. The peak power loss reached 0.0518 MW at 10% PEVs, 0.0604 MW at 30% PEVs, 0.0734 MW at 60% PEVs and 0.0824 MW at 80% of PEVs. The overall 24-hour loss for a different level of penetration is shown in figure 7.

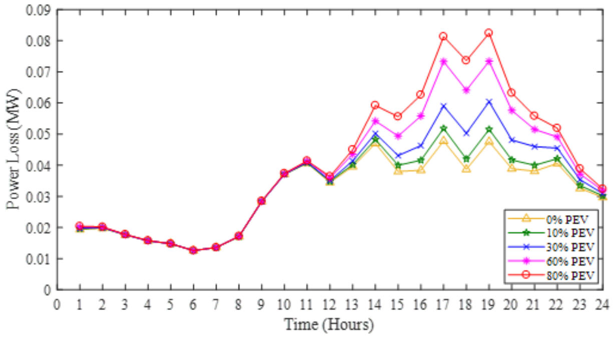

Figure 7: Active Power Loss of Feeder with PEVs

3.1.3 Energy Loss

Daily energy loss is calculated from 24 hour load flow of summer peak case for different level of penetration of PEVs. The daily energy loss rise from 0.75 MWh to 0.98 MWh at 80% penetration of PEV. The total energy loss for a day is given in figure 8.

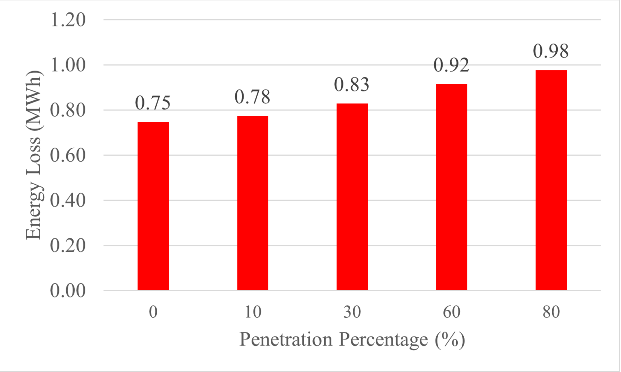

Figure 8: Daily Energy Loss of Feeder with PEVs

3.1.4 Voltage Profile of 11kV Bus

As the PEVs are penetrated in the feeder, the voltage starts to reduce. In the radial feeder, the last point gets the poorest voltage, but due to the shorter length of the feeder, its voltage is within a limit. The main lateral end is observed for analysis of voltage deviations.

a) Voltage Profile of Senthomas School 11kV Bus: The lateral end of the feeder at the Senthomas school 11kV bus is facing the lowest voltage of 0.98182pu before penetration of PEV and up to 10% Penetration of PEV. As the penetration level increases the low voltage is observed at Gulariya Buspark Bus after 30%

up to 80% PEVs. The voltage profile of Senthomas School 11kV Bus for 24 hours is shown in figure 9

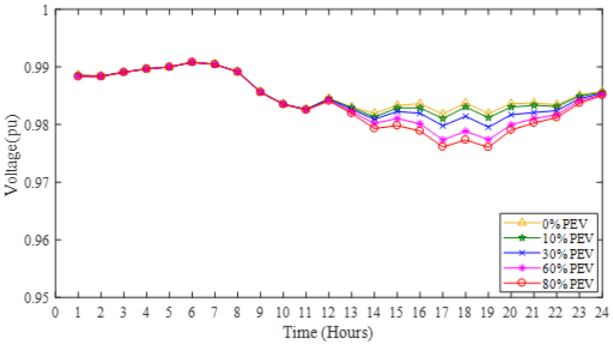

Figure 9: Voltage Profile of Senthomas School 11kV Bus with PEVs

b) Voltage Profile of Gulariya Buspark 11kV Bus: Observing the Gulariya bus park 11kV bus as farthest end the minimum voltage is observed after 30% of PEVs. The minimum voltage at 80% of PEVs is 0.97588. Here the minimum voltage is also under limit because of the short length of the feeder. The voltage profile of the Gulariya Buspark 11kV Bus for 24 hours is shown in figure 10.

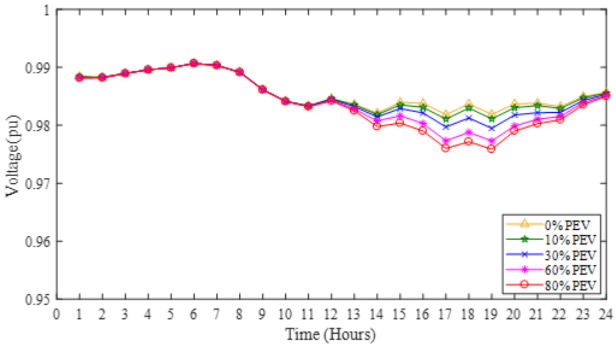

Figure 10: Voltage Profile of Gulariya Buspark 11kV Bus with PEVs

3.1.5 Line Loading

Before the penetration of PEVs, the base case loading of the line or feeder is 79.84%. As the PEV is integrated into the feeder, the loading of the conductor increase. It increases to 83.13% at 10% of PEVs, 89.67% at 30% of PEVs, 98.67% at 60% PEVs, and reached 104.63% with 80% of PEVs. Thus no more vehicle can be penetrated into the feeder. As there is coincide of residential load and vehicle load line loading gets violated during peak hour time. The 24-hour loading of the line is shown in figure 11.

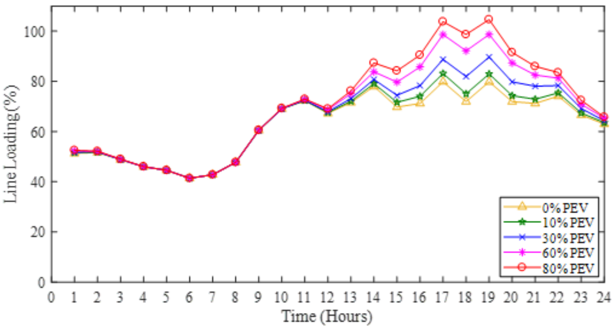

Figure 11: Line Loading with PEVs

3.1.6 Transformer Loading

PEVs are penetrated at 15 random locations in the feeder. The loading of the transformer needs to be studied where the PEVs are penetrated to determine whether the transformer gets overloaded or not. As the penetration percentage increases the loading of the transformer will increases. Out of 15 utility transformers, 10 get overloaded with 80% of PEVs, The most critical transformer is AG Bank NEA which was already overloaded without PEVs. The loading of transformers at different penetration of PEVs is shown in figure 12.

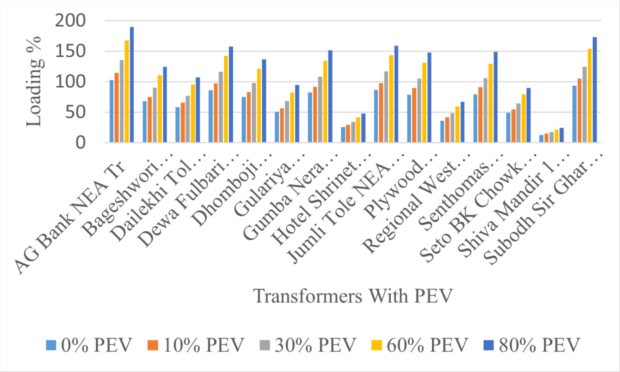

Figure 12: Transformer Loading with PEVs

3.1.7 Load Factor

Load factor of feeder degrades with increasing penetration of PEV. It changes from 0.79 (without PEV) to 0.68 at 80 percent of PEV. It shows the degrading nature of the load factor because of the coinciding of residential load and vehicles load. Table 4.8 shows the load factor at a different level of penetration of PEV.

Table 2: Load Factor with PEV

PEV Penertration Percentage	Load Factor
0	0.79
10	0.77
30	0.74
60	0.70
80	0.68

4. Conclusion

In this research, an impact study of PEVs charging on the Nepalese low voltage distribution system is conducted. Different distribution system parameters are assessed, like the feeder peak, feeder power loss, energy loss, voltage profile, line loading, and transformer loading. The stochastic load profile of PEVs is modeled and integrated with the distribution system. The system is found critical at 80% of PEV. The peak load of feeder increased by 29.82% at 80% (with 1678 PEVs) of PEVs which leads to line loading of 104.63% violating the line loading. The feeder peak power loss increased by 72.38% while daily energy loss increased by 30.67%. The voltage profile of the feeder seems to be under the limit. The farthest end of the radial feeder, Gulariya Buspark 11kV Bus facing the lowest voltage of 0.97588pu. Out of 15 transformers with PEVs, 10 get overloaded and five can still penetrate more PEV. The critical transformer is AG Bank NEA transformer which needs to be replaced soon. Similarly, the load factor of the distribution system degrades to 0.68 after 80% penetration of PEVs. Hence up to 60% of PEV(1221 PEVs) the distribution system can withstand without violating any parameters. But at 80% PEVs(1678 PEVs) line loading violates the limit and no more vehicles can be penetrated into the feeder.

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