PLACING PARKING LOT OF PLUG-IN ELECTRIC VEHICLES WITHIN A DISTRIBUTION GRID CONSIDERING HIGH PENETRATION LEVEL OF PHOTOVOLTAIC GENERATION

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ABSTRACT

The main aim of this paper is to devise a stochastic approach based on Monte Carlo simulation to site and size a parking lot of plug-in electric vehicles within a distribution network. At first, considering parking lot arrival time, daily travelled distance and parking lot departure time of randomly selected private ICE vehicles, a probabilistic method to derive the load demand of a fleet of commuter plug-in electric vehicles is proposed. Probability density function of the aggregated load of the PEVs within each hour is estimated by applying the Monte Carlo simulation and then, the expected value of the hourly load demand is calculated. Afterwards, with aim of minimizing the power loss of the grid as well as the maximum voltage deviation of the nodes, siting and sizing of the parking lot is accomplished.

INTRODUCTION

The anticipation of occupying an appreciable part of the future vehicle market by plug-in electric vehicles (PEV) [1], according to their various merits, brings up an in-depth need to consider related aspects of this technology. The possibility of bidirectional power transfer with the grid is one of the salient characteristics of PEVs. Based on the aforementioned attribute, conventional energy storages can be replaced by PEV batteries to break through the barriers like the intermittency of the power generated by solar photovoltaic (PV) systems [2].

Within Tehran as a huge capital city, majority of light duty vehicles are employed as commuter cars, so these vehicles are in the parking lots near the owners' working places for several hours. The transportation electrification makes it critical to thoughtfully site the parking lots of PEVs within the distribution grid of Tehran. Specially, the plan of installing a large number of PV panels within the commercial as well as official centers of this city makes it essential to perform an accurate coordination between the power generated by PVs and the power consumed in parking lots to charge the PEV batteries. Therefore, from the grid operator's point of view modeling the power demand of the PEVs to evaluate its effects on the aforesaid topic can be considered as a critical subject. However, uncertainties such as the number of available vehicles, charging start time of the vehicles, charging stop time of the vehicles and initial state-of-charge of the PEV batteries (SOC_{init}) can be listed as difficulties in precise modeling of the power consumption of a parking lot.

This paper addresses the issue of placing a parking lot of PEVs within the official center distribution grid of Tehran with assuming a considerably large number of PVs to be installed. With the aim of fulfilling the abovementioned coordination, a stochastic method based on Mont Carlo simulation is proposed to effectively determine the optimum point to connect the parking lot as well as the appropriate number of vehicles.

Tehran is a crowded city with a heavily jammed traffic. The driving habits in this city are so different from other places, so the fossil fuel consumption of the Tehran transportation system in comparison with the international standards is very high. Considering this fact, an efficiency coefficient applicable to Tehran is suggested. Afterwards, the charging profile of the PEVs and accordingly the power consumption model of the parking lot are achieved. Eventually, the appropriate point of connection is determined according to the power generated by the PVs as well as conforming to the power quality indices.

The remainder of this paper is organized as follows. At first, the employed datasets are reviewed and modeled by fitting appropriate pdfs. Then, the suggested demand modeling methodology is described. Afterwards, the simulation results are presented and discussed. Finally, the paper is summarized.

DATASETS OF THE ICE VEHICLES

The employed datasets have been gathered using questionnaires filled-out by the randomly selected owners of the commuter light duty ICE vehicles in Tehran. The owners were asked to give merely the commuting data. The datasets include parking lot arrival time ($\mathbf{a}_t$), daily travelled distance ($\mathbf{tr}_d$) and parking lot departure time ($\mathbf{d}_t$) of the vehicles during weekdays. The datasets can be seen in Fig. 1.

To generate random samples required in the Monte Carlo simulation, it is essential to fit pdfs to the datasets. Most of the earlier researches have used the Gaussian (Normal) probability density function (pdf) as a straightforward distribution [3]. However, the Normal pdf did not match with those datasets and this led to inaccurate results. It is suggested in this paper to fit appropriate non-Gaussian pdfs to the three mentioned random variables (RVs). In fact, a number of pdfs are tested on them and then, the best is selected.

As may be seen in Fig. 1(a), the Weibull pdf ($f_{\mathbf{at}}(t)$) is suggested as the most appropriate function to be fitted to the arrival time RV as below:

$$f_{\mathbf{a}_t}(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{(\beta-1)} e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \quad , t > 0 \tag{1}$$

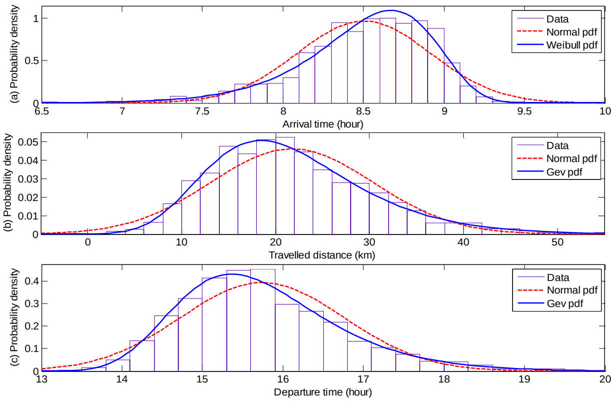

Fig 1: The data and pdfs of (a) parking lot arrival time, (b) daily travelled distance and (c) parking lot departure time

To model the daily travelled distance a type III Generalized expected value (Gev) pdf is derived as (2). The result is illustrated in Fig. 1(b).

$$f_{\mathbf{tr}_d}(d)=\frac{1}{\sigma_{\mathbf{tr}_d}}\left(1+k_{\mathbf{tr}_d}\frac{(d-\mu_{\mathbf{tr}_d})}{\sigma_{\mathbf{tr}_d}}\right)^{-(1+\frac{1}{k_{\mathbf{tr}_d}})} e^{-\left(1+k_{\mathbf{tr}_d}\frac{(d-\mu_{\mathbf{tr}_d})}{\sigma_{\mathbf{tr}_d}}\right)^{-\frac{1}{k_{\mathbf{tr}_d}}}} \qquad (2)$$

As it is shown in Fig. 1(c), a type III Generalized expected value (Gev) pdf is fitted to the parking lot departure time RV as well. The Gev pdf is described as:

$$f_{\mathbf{d}_t}(t)=\frac{1}{\sigma_{\mathbf{d}_t}}\left(1+k_{\mathbf{d}_t}\frac{(t-\mu_{\mathbf{d}_t})}{\sigma_{\mathbf{d}_t}}\right)^{-(1+\frac{1}{k_{\mathbf{d}_t}})} e^{-\left(1+k_{\mathbf{d}_t}\frac{(t-\mu_{\mathbf{d}_t})}{\sigma_{\mathbf{d}_t}}\right)^{-\frac{1}{k_{\mathbf{d}_t}}}} \qquad (3)$$

Moreover, the extracted distribution of each RV is compared with the Normal pdf fitted to the same dataset in order to verify the mentioned claim (Fig. 1). It is seen that fitted non-Gaussian pdfs provide a better approximation of the original datasets. The parameters of the fitted pdfs are given in TABLE I.

TABLE I: THE PARAMETERS OF THE FITTED PDFS

Datasets	The Normal PDF	The suggested PDF
$\mathbf{a}_t$	$\mu_{N\mathbf{a}_t}=8.5027$ $\sigma_{N\mathbf{a}_t}=0.4129$	$\alpha=8.6851$ $\beta=25.7705$
$\mathbf{tr}_d$	$\mu_{N\mathbf{tr}_d}=21.7504$ $\sigma_{N\mathbf{tr}_d}=8.6369$	$k_{\mathbf{tr}_d}=-0.062626$ $\mu_{\mathbf{tr}_d}=17.9875$ $\sigma_{\mathbf{tr}_d}=7.2669$
$\mathbf{d}_t$	$\mu_{N\mathbf{d}_t}=15.7432$ $\sigma_{N\mathbf{d}_t}=1.0116$	$k_{\mathbf{d}_t}=-0.06884$ $\mu_{\mathbf{d}_t}=15.3057$ $\sigma_{\mathbf{d}_t}=0.8542$

In the next section, the extracted pdfs are utilized to generate the random samples.

MODELING METHODOLOGY

The proposed methodology

In order to achieve the main aim of this paper, it is necessary to efficiently derive the hourly load consumption of the parking lot with uncoordinated charging. The overall procedure of the proposed approach is visible in Fig 2.

At first, the random samples of $\mathbf{a}_t$ (a_n), $\mathbf{tr}_d$ (tr_n) and $\mathbf{d}_t$ (d_n) are generated by using the extracted pdfs. The available charging time (t_{avi}) for each of the PEVs is calculated by subtracting the arrival time (a_n) from the departure time (d_n). The battery capacity (Cap_{bat}), SOC_{init}, power rating (P_{rat}) and efficiency (C_{chr}) of the battery chargers determine the necessary time to fully charge the battery (t_{full}). In case t_{full} would be less than t_{avi}, the full charging of the battery can be accomplished. Otherwise, it is impossible to fully charge the battery. The bigger the battery capacity and the lesser the power rating of the charger, the longer time is necessary to fully charge the battery. In each iteration, extraction of the demand profile of the individual PEVs ($DPIP_n$) is fulfilled in order to estimate the demand profile of the parking lot (DPP_m).

Given the IN as the iteration number of the Monte Carlo simulation, the explained procedure is carried out for IN times in order to derive the distribution of the aggregated power consumption of the PEVs within each hour ($DAPF_h$). Next, the expected values of the hourly load demand of the PEVs can be calculated regarding the $DAPF_h$. Eventually, demand profile of the parking lot (DPP) is estimated by employing the extracted hourly expected values.

Sizing and siting of the parking lot should be accomplished through minimizing *the power loss* of the grid as well as *maximum voltage deviation*.

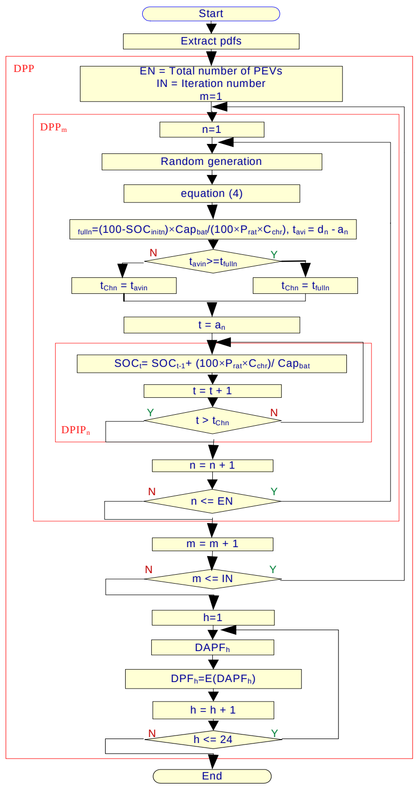

Fig 2: Flowchart of the proposed approach.

Battery initial SOC

The SOC_{init} is determined based on the daily travelled distances. It is supposed that the home charging is available. Thus, it is rational to assume that the battery SOC of the PEVs is 100% at the home departure time. Hence, the SOC_{init} of the PEV can be derived as follow:

$$SOC_{initn} = 100 - \frac{tr_{dn}/2}{C_{eff} \times Cap_{bat}} \times 100 \qquad (4)$$

where C_{eff} is the efficiency coefficient of the PEVs during driving which is depended on the driving patterns and traffic conditions as well as driver efficiency of the electric motors.

SIMULATIONS AND DISCUSSIONS

Figure 3 represents a 20kV distribution system within an official center area. Regarding some spatial reasons, nodes 3, 4, 5, 7 and 8 can be the connection point candidates. A typical official load profile is used to model load variations (Fig. 4). High penetration of PV generation is modeled as aggregated generations with a 250kW power rating at nodes 4, 6, 8 and 9. Figure 5 illustrates generation profile of the PVs attained based on actual recordings.
The simulation parameters can be found in TABLE II.

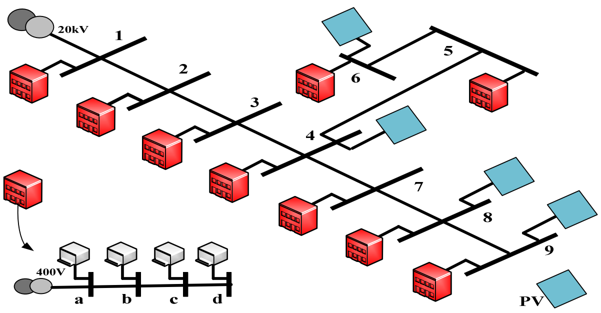

Fig 3: A 20 kV distribution feeder with several 4 node 400V official networks and high penetration of PVs.

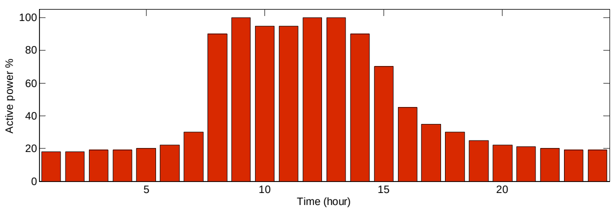

Fig 4: Load profile of the official centers (400V, 50kW, PF=0.85).

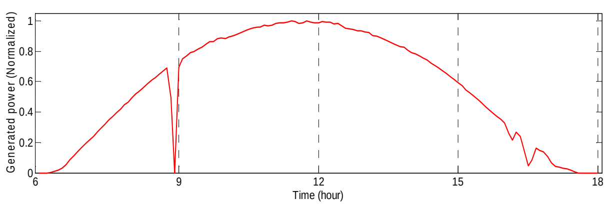

Fig 5: Generation profile of the PVs.

TABLE II: THE SIMULATION PARAMETERS

IN	1000
DOD	70%
P_{rat}	3kW
Cap_{bat}	20kWh
C_{eff}	3km/kWh
C_{chr}	0.9

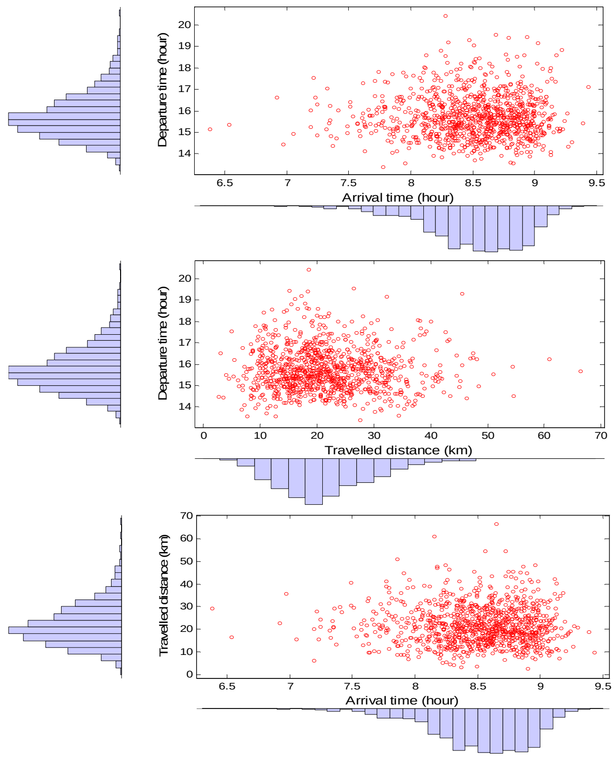

Fig 6: The randomly generated samples to be employed in the proposed Mont Carlo procedure.

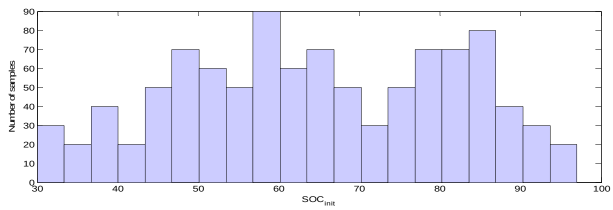

Fig 7: the synthetic initial SOCs.

Synthetic dataset

Figure 6 presents distribution of the randomly generated samples (the synthetic data) for PEVs by using the three suggested pdfs. Each generated set includes 1000 samples.

Battery initial SOC

The SOC_{init} is determined based on the daily travelled distances. According to (4), the SOC_{initn} is depended on the travelled distance (tr_{dn}), the battery capacity (Cap_{bat}) and the efficiency coefficient of PEVs during driving (C_{eff}). The distribution of the synthetic initial SOCs of the PEVs is shown in Fig. 7.

The power consumption of the parking lot

Regarding the fact that the sizing of the parking lot is one of the main targets of this paper, it is required to estimate hourly power demand of the parking considering several scenarios of the vehicle numbers. The following strategy is carried out for each of the scenarios:
The demand profile of the parking lot (DPP_m) is achieved by estimating the demand profile of the individual PEVs ($DPIP_n$) in each iteration of the devised procedure. According to Fig. 2, the procedure is repeated for 1000 times (the iteration number) in order to derive the distribution of the aggregated power consumption of the parking lot within each hour ($DAPP_h$). Afterwards, the demand profile of the parking lot (DPP) consisted by the expected values of the $DAPP_h$ is estimated.
For the sake of the limited space, merely the extracted DPP related to 50 PEVs is shown in Fig. 8. As above-explained, DPPs of 40, 60, 70, 80, 90 and 100 PEVs are estimated as well.

Siting and sizing

Regarding some spatial reasons, nodes 3, 4, 5, 7 and 8 in Fig. 2 can be the connection point candidates. Sizing and siting of the parking lot is accomplished through minimizing the power loss of the grid as well as maximum voltage deviation. Figure 9 illustrates the power loss of the grid after connecting the parking lot with 40, 50, 60, 70, 80, 90 and 100 PEVs at nodes 3, 4, 5, 7 and 8. As it is clear, embedding the parking lot with 80 PEVs at node number 4 results in the least power loss of the grid.
The maximum voltage deviation of the grid after connecting the parking lot with mentioned sizes at the candidate nodes is shown in Fig. 10. It is obvious that embedding the parking lot with 40 and 80 PEVs at nodes number 3 and 4 respectively leads to the least deviations. Considering the simulation results, connecting a parking lot with 80 PEVs at node number 4 would be the most appropriate answer.

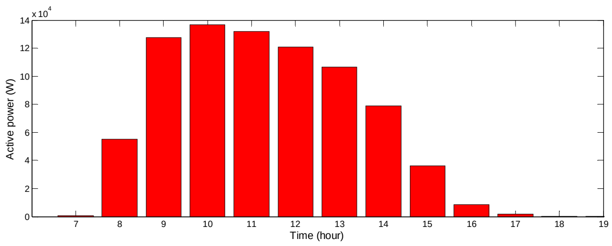

Fig 8: Demand profile of the parking lot considering 50 PEVs.

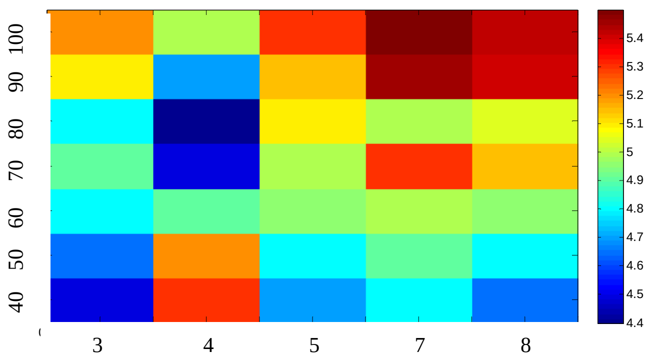

Fig 9: Power loss (%) of the grid after connecting the parking lot with 40, 50, 60, 70, 80, 90 and 100 PEVs at nodes 3, 4, 5, 7 and 8.

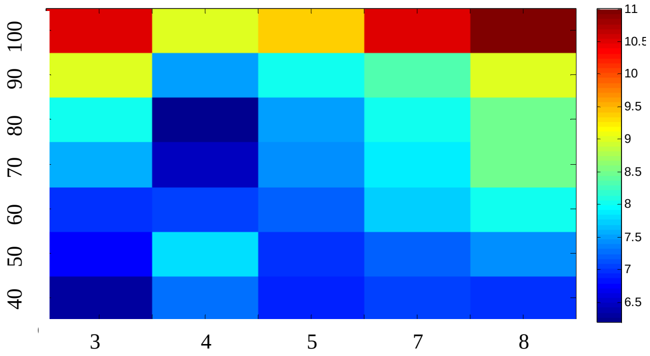

Fig 10: Maximum voltage deviation (%) of the grid after connecting the parking lot with 40, 50, 60, 70, 80, 90 and 100 PEVs at nodes 3, 4, 5, 7 and 8.

CONCLUSIONS

In this contribution, a stochastic approach based on Monte Carlo simulation to place a parking lot of plug-in electric vehicles as well as to determine the size of the parking is proposed. A series of datasets, including parking lot arrival time, daily travelled distance and parking lot departure time of randomly selected private ICE vehicles have been employed. To avoid any mismatching between the original dataset and their probabilistic models, appropriate non-Gaussian probability density functions has been fitted to them. Probability density function of the aggregated load of the PEVs within each hour has been derived by applying the Monte Carlo simulation. Then, expected value of the hourly load demand has finally been calculated regarding the achieved power distributions. Finally, the sizing and siting procedure has been carried out with the aim of minimizing the power loss of the grid as well as the maximum voltage deviation of the nodes.

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