International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Special Issue: | Apr 2023 www.irjet.net p-ISSN: 2395-0072
International Conference on Recent Trends in Engineering & Technology- 2023 (ICRTET-3)
Organised by: VSM College of Engineering, Ramachandrapuram

Expectation study of Plug-In EVs Impact on Power Grid through Houses and Parking Garages

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ABSTRACT:

Plug- in electric vehicles in the future will conceivably crop extensively in megacity areas. Lines of similar vehicles in large figures could be regarded as considerable stochastic loads in view of the electrical grid. Also, they aren't encamped in unique positions to define their impact on the grid. External parking lots could be considered as important aggregators letting these vehicles interact with the mileage grid in certain positions. A bidirectional power interface in a parking lot could link electric vehicles with the mileage grid or any storehouse and dispersed generation. similar vehicles, depending on their need, could distribute power with parking lots. Considering parking lots equipped with power interfaces, in more general terms, parking- to- vehicle and vehicle- to- parking are propose then rather of conventional grid- to- vehicle and vehicle- to- grid generalities. Grounded on statistical data and espousing general regulations on vehicles(dis) charging, a new stochastic methodology is presented to estimate total diurnal impact of vehicles added up in parking lots on the grid. Different scripts of draw-in vehicles ’ penetration are suggested in this paper and eventually, the scripts are dissembled on standard grids that include several parking lots. The results show respectable penetration position perimeters in terms of machine voltages and grid power loss

***Index Terms*—Central electric power interface, daily travel profile, grid-to-vehicle-mode, parking-to-vehicle mode, penetration level, plug-in electric vehicle, power transaction, probability density function, vehicle-to-grid mode, vehicle-to-parking mode.**

NOMENCLATURE

C_N	*Plug-in electric vehicle (PEV) battery averagenominal capacity [in kilowatt hours (kWh)].*
C_S	*PEV battery charge at the beginning of travel (in kWh).*
C_P	*PEV battery charge when entering a parking lot (in kWh).*
C_R	*Required charge for driving the rest of travel afterparking stop (in kWh).*
l_1–l_3	*Daily length of travel parts (in miles).*
l_b	*Daily length of travel passed before entering aparking lot.*
l_a	*Daily length of travel remaining after entering aparking lot*
r	*PEV average energy consumption (in kWh/mile).*
t_{pi}	*Time when a PEV plugs into electric power interface(EPI) of a parking lot (in hours).*
t_{po}	*Time when a PEV unplugs from EPI of a parkinglot (in hours).*
Δt_P	*Parking stop duration for a vehicle (in hours).*
Δt_R	*Required parking stop duration for PEV powertransaction (in hours).*
Δt_{eff}	*Actual parking transaction duration for a vehicle(in hours).*
t_{hi}	*Time when a PEV plugs into charger at home (inhours).*

t_{ho} *Time when a PEV unplugs from charger at homebefore start of daily travel (in hours).*

ΔE_P *Energy transaction of a PEV via parking lot EPI (inkWh).*

ΔE_H *Energy transaction of a PEV via charger home (inkWh).*

P_P *Charging or discharging rate of central EPI in aparking lot (in kW).*

P_H *Charging rate of home charger (in kW).*

Power conversion efficiency at parking lot. Power conversion efficiency of home charger.

INTRODUCTION:

Moment, there are several suggested. Druthers to fossil energies that are being well delved in order to replace fossil energies in numerous aspects of mortal life and diligence. Several provident, ecological, and political intentions lie behind this relief, one of which is hothouse gas pollution leading to global warming. One of the effected aspects of mortal life from this issue is the transportation sector and the result is to make it incompletely to fully galvanized by replacing a number of conventional internal combustion machine (ICE) vehicles with electric vehicles (EVs). EVs use battery storehouse to give power for their electric motors. They're substantiall*y divided in to three orders:* 1) battery electric vehicles (BEVs); 2) hybrid electric vehicles (HEVs); 3) fuel-cell electric vehicles (FCVs). Plug-in EVs (PEVs) have the capability of connecting to the utility grid via power outlet for power delivery. Among the current PEV technologies, PHEVs due to the advantage of using both ICE and electrical motors are probably the most promising option until more advanced BEVs become technically mature [2]. Ac- cording to [3], three market scenarios are drawn for the future of PHEVs. Based on that, the car market peak share of PHEVs varies from 20% to 80% of the whole in 2050, depending on the density of penetration. In medium scenario according to [3], by 2015, this share would be 8% and by 2025, this value would be 50% of the whole sale. The emergence of new BEVs, especially Tesla Roadster [4] and Nissan Leaf [5], with 1) com- parable specifications compared to conventional vehicles like speed and driving range (100 to 300 miles) and considerable small recharging time (0.5 to 3 hours in fast charging mode) and 2) the advantage of zero emission operation over their conventional counterparts, suggests the possibly pervasive role of these newly arrived green vehicles in the transportation system of cities in the near future. Therefore, the occurrence of these vehicles in urban areas in addition to PHEVs is included in this paper.

When plugged into a power outlet, PEVs could operate in two modes: a) charging or grid-to-vehicle (G2V) mode, and b) dis- charging or vehicle-to-grid (V2G) mode. In the former, the PEV is considered as a load for the utility grid, while in the latter, PEV could provide the grid with injected energy. Therefore, PEV in the view of the utility grid is considered as probable load or generation. High level penetration of PHEV without consideration of V2G mode would reduce system-wide reliability as a result of a reduction in system reserve capacity. In addition, the absence of low load periods adds additional constraints on the delivery limits since cooling periods of transformers and lines would significantly be reduced [6]. Therefore, the appearance of PEVs on the road draws the attention of designers to grid reinforcement. Many works, in relation to the G2V deployment of large numbers of PEVs, have suggested smart, coordinated, or optimal charging instead of dumb or uncontrolled charging scenarios, i.e., the charging profiles of PEVs are shifted to the off-peak periods of a daily load, especially charging over night when the electricity price is low [2] and [7]–[13].

However, any controlled charging scenario needs both official incentives/regulations for PEVs' owners and the provision of smart technologies and advance metering infrastructure [14]. Therefore, the uncontrolled charging scenario is the most probable option and the most likely initial case before market penetration of smart technologies and the advanced metering infra- structure [7].

The V2G concept could be applicable in several ancillary services [13]. Economic issues about the V2G concept for integration of PEVs in the grid and the hardware cost is well discussed in [6], [8], and [13]–[21].

A PEV is designed to perform transportation and therefore the primary duty of battery storage in a PEV is to provide enough power for the vehicle to drive. Consequently, the final impact of PEVs on the utility grid is high-level loading. However, this undesired impact in case of a large number of PEV fleets could be considerably lessened in terms of charging and discharging planning or scheduling. Previous works have paid attention to this issue by adopting regulations or limitations on charging time, charging duration, and charging level of PEVs during 24 hours [2], [8], [9], [13]. In [9], a good coverage of previous works is presented while insisting on the lack of addressing the determination of the aggregated PHEVs daily load profile in previous works. However, in [9], the V2G concept is not addressed and it is assumed that PHEV are charged at homes at the end of daily travel. A comprehensive integrated method in [22] is presented to study the impact of EVs considering the transport and power networks and vehicle technology. Although the models and mathematical process used in the framework are intricate considering many issues about vehicles such as energy price, power consumption, transportation, and traffic jams, the method consumes a considerably large amount of data as inputs that may not be available. Moreover, V2G opportunity for PEVs is neglected in the simulations.

Two charging points could be envisioned for (dis)charging of PEVs [2]: individual charging points which are located in residential or parking areas designed for normal or slow charging rates (0.2'C rate) and charging stations similar to gas stations comprising several connection points for fast charging (1 and 2'C rate) [2]. Parking lots and garages [10], [12], [23], [24] are suitable places for implementing the V2G concept as vehicles spend several hours per day parked in them [10], [11]. A vehicle spends 23 hours per day parked [1] and 90% of vehicles are parked even during peak traffic hours [25].

In this work, PEVs are assumed to drive daily travels in a city just like current conventional ICE vehicles. The goal is to bring the availability of a PEV for the vehicle driver as close to ICE vehicles as possible by providing enough charge for PEV and minimizing any delay time due to charging procedure at the same time, while benefiting from PEV excessive energy, if any, for reducing PEVs loading impact on the future grid. The study involves PEVs charging at home and (dis)charging in parking lots which are equipped with central (dis)charging infrastructure proposed previously by the authors. A unique stochastic methodology is then presented to assess a PEV impact.

The rest of the paper is partitioned as follows. Section II introduces the central infrastructure in a parking lot to establish power delivery via PEVs. Section III presents the study frame- work including databases used, assumptions, and model formulation to set up the idea of the work. In Section IV, modeling of a PEV power transaction is carried out. In Section V, the average impact of a PEV is determined. In Section VI, simulation of the work on different defined scenarios is done. The conclusion of the work is drawn in Section VII.

II. PARKING LOT CENTRAL POWER INTERFACE AND MODESOF OPERATION:

A central electric power interface (EPI) in a parking lot could integrate several PEVs without occupying too much space (Fig. 1). Moreover, in terms of power efficiency and control, it has superiority over other possible topologies. PEVs resident in a parking lot may either deliver power to the EPI of the parking lot or absorb power from it depending on the state-of-charge (SOC) of their batteries, upcoming travel length, and the drivers' willingness. If this power transaction occurs between PEVs and the utility grid via the EPI, then the aforementioned G2V or V2G mode of operations would be established. The realization of centralized topology in Fig. 1 is fulfilled in the authors' previous work [26], where a power electronic converter comprising of a dc–ac converter and two similar multiport (MP) converters are proposed as a bidirectional EPI in a parking lot. The MP capability of dc–dc EPIs allows for responding to different voltage levels and SOCs of PEVs batteries. Therefore, PEVs interfaced by dc–dc MP-EPIs and utility grid interfaced by dc–ac EPI form a new high-power micro-grid that is worthy of studying.

The proposed EPI of a parking lot has a higher power level compared to home chargers, thus, the dc-bus has a high level of voltage to guaranty high efficiency. Therefore, fast charging and discharging of PEVs could be applied in a parking lot as connections at a higher voltage level in this regard are indispensable [13].

Regarding Fig. 1, a new way to transfer power between PEVs is possible in which, PEVs connected to dc–dc EPI provide the power demanded by PE$_1$Vs connected to dc–dc EPI . Therefore, a fleet of PEVs in a parking lot equipped with such a central EPI could be isolated from the utility grid and able to transact power as standalone loads and generations. Moreover, the application of renewable energies or storages as dispersed generations (DGs) that operate on dc form when connected to the dc-bus could outweigh the power provision role of the grid in such a micro-grid in some cases. Therefore, in this paper, more general terms, vehicle-to-parking (V2P) and parking-to-vehicle (P2V) are proposed instead of V2G and G2V acronyms to include any possible kind of power transaction in a parking lot, though dc-bus connection of DGs is neglected and left for future follow-ups. The proposed dc–dc MP-EPI in [26] has more than 90% efficiency in either mode of operation. Thus, 90% value is applied as power conversionefficiency (η_P) in a parking lot compared with home chargers 85% efficiency [8].

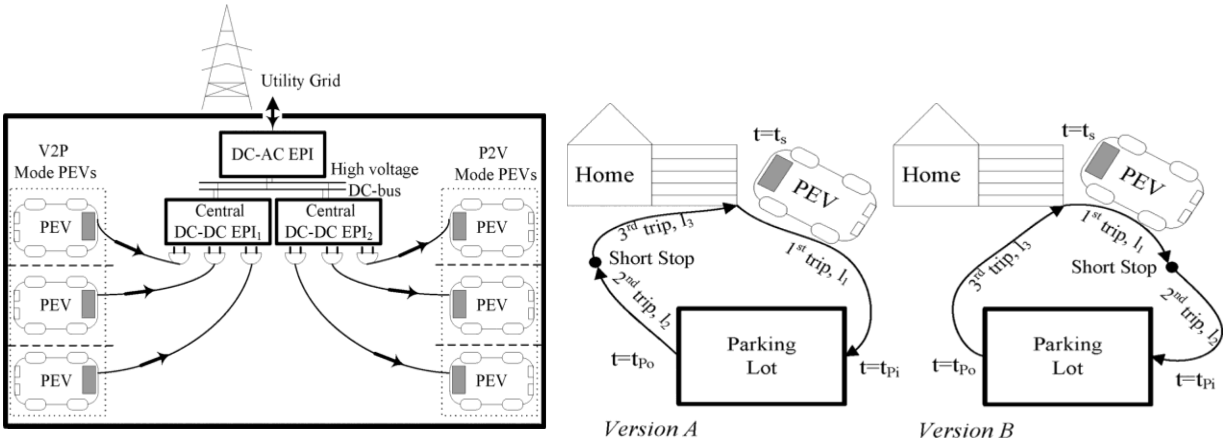

Fig . 2 PEV directly travel map for version A interfacing PEVs in V2P and P2V modes of and B.operation with unity grid.

III STUDY FRAMEWORK:

As PEVs in an urban area are independently dispersed probabilistic loads or generations, there have to be some assumptions to make it possible to assess the impact of a large number of PEVs on the distribution grid.

A. Physical Characteristics of PEVs

The study covers a one-day period of urban transportation during which PEVs begin their travel commuting between several points in a city. Meanwhile, they stop for some time in a parking lot. Although it is required to scan a vehicle movement for more than one day in order to achieve the real periodic position of it, but for the sake of simplicity, it is assumed that PEVs have 24-hour periodic behaviors that are not changing from one day to another. Based on statistics re- ported about U.S. household vehicles' characteristics in 2009 [27] and a one-year study conducted with the aim of characterizing driving habits of average drivers in the city of Winnipeg in Canada [11], the following data are extracted leading to realistic assumptions on which the probabilistic study is based:

1) The average driver makes three trips per day; 2) daily vehicle average length of travel is 29 miles per driver; 3) the average vehicle speed is 32 mile/h; 4) the average vehicleshort stop is 10 min.

To simplify the process of study on a large number of PEVs in a city, these assumptions are adopted on the whole EV daily travels; therefore, the study covers three-trip travel in 24 hours of a day. Each PEV starts daily traveling from a start point such as a house or parking garage, etc., in a city and ends its travel inan ending point at the same city.

The start points of PEVs are usually homes. Other possible locations are rare and hence insignificant. Condominium complexes and apartment buildings are equal to several homes which have the same position and the same number of PEVs asthe apartment and complexes accommodate.

As shown in Fig. 2, a PEV daily travel consists of three parts (trips). The first part is originating from home (mile), the second part is between the first and second parts (mile), and the third part is leading to the ending point (l_3 mile). Two stop points are considered between these three parts. One of them is a parking lot equipped with EPI, where the PEV stays for a long period and is plugged into a power outlet for transacting power. The other is a short stop point off the parking lot for any purpose (assumed 10 min). In other words, a long stop with any purposehappens in a parking lot exactly once a day.

As shown in Fig. 2, the starting and ending points of a travel coincide exactly. There are two possible travel versions for a PEV: Version A, in which the PEV enters a parking lot at the end of the first trip and Version B, in which the PEV enters a parking lot at the end of the second trip before the start of the third trip. In an urban area, there are several parking lots. To have a more realistic assessment, the number of parking lots and weekly distribution of PEVs among these parking lots along with more complicated travel plans (more stops and more travel parts) have to be defined that is a generalization of what is presented here. Here, the objective is to present the methodology. In this paper, in order to have a simple study on the effect of PEVs, it is assumed that PEVs travel plans are determined at the beginning of the travel. Additionally, a constant average value is considered for the PEV's speed during the whole travel path despite naturalior unexpected phenomena that may cause the vehicle to speed up or slow down.

B. Electrical Characteristics of PEVs

1) PHEVs: PHEVs are mainly characterized based on their all-electric range (AER) to [2], [3], [9]: PHEV-20, PHEV-30, PHEV-40, and PHEV-60, in which the numerical subscript represent the vehicle AER in miles. Over time, the new vehicle market shares of PHEV-20 and PHEV-40 increase [3]. The study of this paper considers PHEV-20 [9], while the methodology is general and other types of PHEV could be involved. An average PHEV has a battery with nominal capacity $C_N=7.4\ kWh$ and electrical energy consumption of r=0.37KWh/mile [9]. For PHEV, it is preferred to begin its travel on the base of electrical energy until its battery capacity hits the lower limit. Therefore, the whole or initial part of a PHEV daily travel is assumed to be purely electric depending on whether AER of PHEV covers the whole daily travel lengthor a portion of it.

2) BEVs: A long list of BEV brands and their specifications is presented in [1]. Based on that, the average capacity and the average energy consumption of BEVs are calculated as $C_N = 24.33\ kWh$ and $r = 0.23\ KWh/mile$, respectively.

3) Charging and Discharging Profile of a PEV From a Home With Charger: A PEV could be charged during the night at a home that has a charger. As there is adequate time for charging, it is assumed in this case that a PEV begins its daily travel with 100% SOC. When the PEV arrives at a parking lot equipped with EPI, depending on its need and considering maximum depth-of-discharge (DOD) limit, it may transact power with the parking lot in either V2P or P2V modes of operation. To gain the maximum advantage of PEVs in both modes for the vehicle owner and the grid, it is assumed that a PEV transact with the parking lot to the extent that the charge left after leaving the parking lot would suffice the rest of its daily travel plus some extra amount due to maximum DOD (reported 20% SOC in [7], [13], and [25]). Thus, the power transaction between the PEV and the parking lot will let the vehicle finish its travel with a final 20% SOC. As for PHEV, power transaction duration is limited to the vehicle parking duration (Δt_P) regardless of its operation mode since it can operate based on its ICE. Considering BEV in V2P mode, power transaction duration must not exceed the vehicle parking duration while in the P2V mode, the vehicle has to stay for Δt_R until its battery receives the minimum required charge regardless of Δt_P value.

4) Charging and Discharging Profile of a PEV From a Home Without Charger A PEV beginning its trip from a home without a coliseum has an original battery charge of lower than 100 that is left from the last quotidian trip. Hence, its value is dependent on the former operation of the vehicle. In the appendix, a system predicated on fine expectation is explained for determining the average value of original charge in this case. As a PEV in this case is deprived of home charging, it has to reach a coliseum down from home in order to charge its battery. Furthermore, the process of charging a battery is rather time-consuming. therefore, a parking lot with a central EPI is the swish charging position for a PEV in this case. As a PEV quotidian trip is assumed to have exactly one parking stop, therefore, the power trade of a PEV in a parking lot in this case is in P2V mode. Anyhow of PEV type, its battery SOC, and parking duration, it has to stay connected in this case until the 100 SOC battery condition. still, in reality, the PEV auto mobilist's amenability is a necessary condition; also, any premature exit of the vehicle will cancel the power trade procedure. This work disregards this matter. 5) expression of Daily Power Transaction

As depicted in Fig. 2, a PEV begins its quotidian trip with original battery charge at. After passing the first or alternate trip part (in Fig. 2 interpretation or), at, the vehicle connects to a parking lot EPI with charge to begin a power trade. The power trade lasts for after which, the vehicle disconnects from EPI at and ultimately finishes the quotidian trip returning to home with charge left equal to.

TABLE I
REQUIRED PARAMETERS FOR PROFILES OF PEV

PEV profile type	Battery initial charge [%], C_S/C_N		l_b	l_a	Δt_{eff}	
	BEV	PHEV			BEV	PHEV
1	100	100	l_1	l_2+l_3	Δt_P for V2P Δt_R for P2V	Δt_P
2	100	100	l_1+l_2	l_3	Δt_P for V2P Δt_R for P2V	Δt_P
3	88	36	l_1	l_2+l_3	Δt_R	Δt_R
4	88	36	l_1+l_2	l_3	Δt_R	Δt_R

In the condition of the presence of a coliseum at home, charging is carried out during. For home dishes, slow charging is espoused while for parking lots, due to a advanced position of EPI voltage, fast charging is espoused. Considering the vacuity to coliseum at home and interpretation of a quotidian trip, four types of PEV trip lives could be imaged as tabulated in Table I. As shown, type 1 & 2 in the first column relate to the case of a home with a coliseum and thus the corresponding entries in the alternate and third columns are each 100. Types 3 & 4 in the first column relate to the case of a home without a coliseum and thus the corresponding entries in the column of original SOC have average values less than 100. The system of calculating these average values s explained subsequently. The fourth and fifth columns of Table I show the interpretation of trip profile.

Based on what set forth so far, a mathematical model of power transaction could be written as follows.

$$C_P = C_8 - l_b \text{ x } r \quad (1)$$

$$C_R = l_a \text{ x } r + 20\% \text{ x } C_N \quad \text{With home charger}$$
$$= C_N \quad \text{Without home charger} \quad (2)$$

$$\Delta E_P = (C_P - C_R) \text{ X } \eta_P \quad \text{V2P mode} \quad (3)$$
$$= (C_P - C_R) \text{ X } \eta^{-1}{}_P \quad \text{P2V mode}$$

$$\Delta t_R = |\Delta E_P| \text{ X } P_p{}^{-1} \quad (4)$$

$$t_{PO} = t_{pi} + \Delta t_{\text{eff}} \quad (5)$$

$$\Delta E_H = -80\% \text{ X } C_N \text{ X } \eta^{-1}{}_H \quad (6)$$

$$t_{ho} = t_{hi} + |\Delta E_H| \text{ X } P_H{}^{-1} \quad (7)$$

Equations (1)–(5) relate to a power transaction in a parking lot and (6) and (7) relate to home charging. In (3), positive and negative values of ΔE_P show, respectively, V2P and P2V modes of operation. In (4), required power transaction duration (Δt_R) is calculated. PEV parking duration (Δt_P) may not be long enough to include Δt_R totally. Therefore, actual power trans- action duration (Δt_{eff}) is equal to either Δt_R or Δt_P.

Based on what was expressed in Sections III-B3 and III-B4, in Table I, the values of Δt_{eff} for different travel profiles are presented. As said before, a PEV finishes its daily travel with 20% SOC. Therefore, (6) and (7) describe the electrical characteristic of a PEV of types 3 & 4 when connected to a charger athome.

C. Stochastic Model of a PEV Daily Travel Profile:

1) Daily Travel Starting Time (t_S): This study focuses on urban vehicle travels which repeat daily. The probability daily travel start time $(P_S(t_s))$ is assumed to be a Rayleigh-type probability density function (pdf) and the time interval of 6–7 is the most possible occasion an EV to begin its daily travel and near 24 is the most unlikely occasion to start a daily travel.

2) Total Length of Daily Travel Path *(l)*: In [9], the daily travel profile is reflected in a bar graph showing percentage of vehicles versus daily miles driven. These data are used as the pdf of a PEV daily travel mileage $(P_T(l))$.

3) Length of Daily Travel Parts $(l_1\text{-}l_3)$: As mentioned, a daily vehicle travel is assumed to have three parts on average. The assumption is continued considering that the first two parts are random variables with normal distributions $(P_{T1}(l_1))$ and $(P_{T2}(l_2))$, as depicted in Fig. 3. The length of first trip ranges from 0% to 100% of the whole (l) and the length of second trip (l_2) ranges from 0% to 100% of the rest of the travel (l_T). Therefore, the pdf of the second trip is dependent to the first trip. The length of the third trip is no longer a variable when thefirst two parts are determined $(l_3=l-l_1-l_2)$.

4) Parking Stop Duration (Δt_P): Driving habits of PEV drivers will probably have to change to cope with charging restrictions of near-term PEVs. In case of conventional ICE vehicles, each vehicle parking duration is determined solely by the driver's future plan, but assuming a PEV in a parking lot with EPI, SOC of the PEV battery is also a determining factor. The goal of this paper is to offer a charging or discharging profile for a PEV such that the vehicle owner feels minimum influence from using a PEV instead of conventional ICE. Here, pdf function of a PEV parking stop duration $(P_P(\Delta t_P))$ is generated according to the accessible average general data for vehicles [11] to simulate the parking stop duration of PEVs.

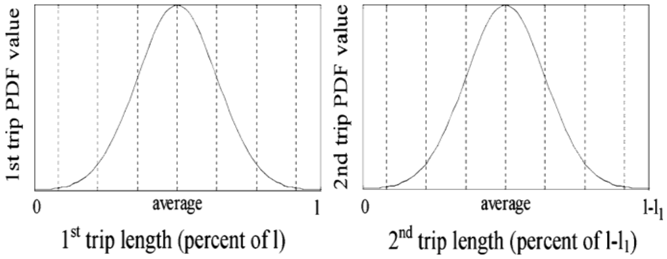

Fig .3 PDFs of a PEV for first and second trip length

IV. STOCHASTIC MODEL OF A PEV DAILY POWERTRANSACTION

A PEV could begin to travel at a random moment of the day in a city. Its daily travel length and time of its parking lot stop are random variables. Therefore, a PEV power transaction through a parking lot (and a home charger) has a stochastic model. Applying stochastic curves of Section III in mathematical model of daily power transaction established in the same section, a PEV daily power transaction model could be defined.

A PEV daily travel profile needs seven parameters to be specified: 1) initial charge of a PEV battery (C_S); 2) travel version (A) or (B); 3) parking stop duration (Δt_P); 4) time of beginning a daily travel (t_s) ; 5) total length of a daily travel (l) ; 6) length of first trip, l_1 ; 7) length of second trip (l_2).

Among the above parameters, 3–7 could be estimated using the pdfs of daily travel profiles presented in Section III. A *stochastic case* (SC) is defined as a daily incident for a PEV, during which it begins a travel at a specific time with a specific total, first trip and second trip lengths. Therefore, an SC defines a complete daily travel profile of a PEV. The pdfs of Section III, if continuous, could be quantized to several discrete bars. Thus, a finite number of SCs could be determined where each describes specific daily travel. Due to large a number of travel profiles that a PEV can take and regarding statistical data at hand, it could be inferred that any correlation between random variables of daily travel pdfs is very weak and thus they are assumed independent. Therefore, based on the *product rule* in probability, the following equation could be expressed for the incidence probability of an SC:

$$P(i) = \frac{1}{2} P_S(t_S) \times P_P(\Delta t_P) \times P_T(l) \times P_{T1}(l_1) \times P_{T2}(l_2) \qquad (8)$$

Where P(i) is the probability of the ith SC and coefficient ½ suggests the same probability for a PEV entering a parking lot at the end of either the first or second trip.

Obviously SCs' probabilities must satisfy the following equation:

$$\sum_{i=1}^{N} P(i) = 1 \qquad (9)$$

Where N is the number of SCs.

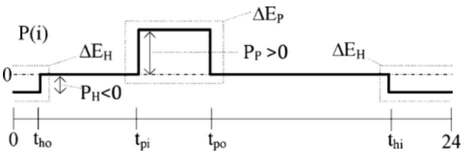

Fig. 4. Twenty-four-hour PTF of a PEV for SC .

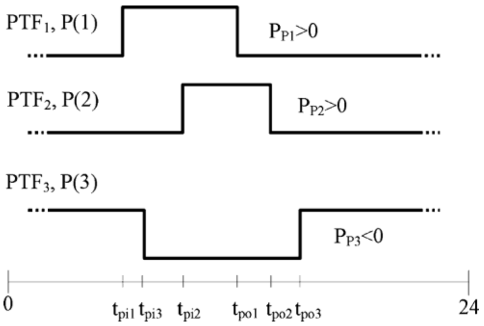

Fig. 5. Three different PTFs relating to three SCs of a PEV

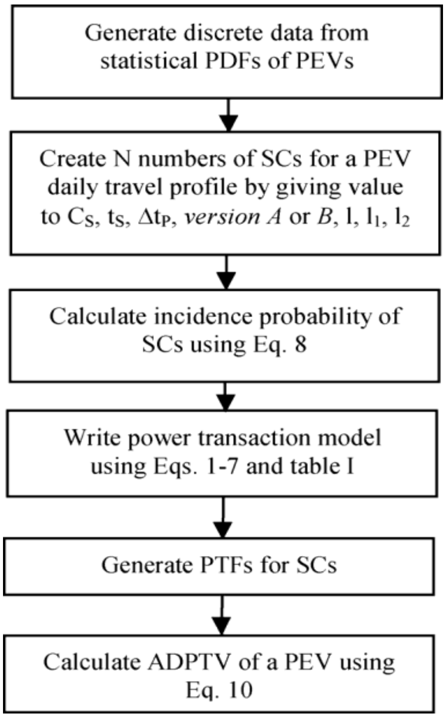

Fig. 6. Flowchart of building ADPTV for a basic case

Power transaction function (PTF) is a mathematical description of a PEV daily power transaction in a 24-hour time domain. In Fig. 4, PTF relating to SC is illustrated. As shown, the SC has a probability of incidence equal to $P(i)$. This value will be used later as weighting coefficient for averaging on total PTFs. In Fig. 4, during periods t_{hi}-t_{ho} and t_{pi}-t_{po} home charging and parking lots (dis)charging transactions take place, respectively, during which, PTF has constant values equal to parking lot EPI and home charger powers, i.e., respectively,P_p and P_H. During t_{pi}-t_{po} , PTF could be positive or negative depending on if V2P or P2V mode of operation is executed but during t_{pi}-t_{po} , PTF is negative as home charging takes place. Out of these periods,PTF is zero implying no power transaction happens.

In real conditions, PEVs enter different parking lots spontaneously. Therefore, PEVs are not distributed necessarily in a uniform pattern among parking lots of a city. Thus, there are different spatial points of concentration for power transaction. Fig. 5 shows three PTFs relating to three desired SCs. These SCs represent options of daily travel profile which a PEV could ac- cept (home charging parts are not shown). As shown, in PTF ± 2 a PEV delivers power in V2P mode (positive value of PTFs)

wh$_3$ile in PTF , PEV accepts power in P2V mode (negative value of PTF). The travel profiles of PTF – in Fig. 5 do not necessarily inclu$_1$de$_3$ a shared parking lot. Therefore, power transactions may happen otherwise in three different parking lots.

V. AVERAGING POWER TRANSACTION OF A PEV

A. *Definition of the Average Power Transaction Criterion*

Parking lots equipped with central EPIs and homes with chargers are regarded as power transaction terminals, where PEVs have interaction with the utility grid (and possible DGs or storages connected EPIs). In order to assess a PEV average power transaction for too many SCs, using the definition of expected value, the average daily power transaction variation (ADPTV) index is given as a criterion to describe the average impact of aPEV

$$\mathrm{ADPTV} = \sum_{i=1}^{N} P_i \times \mathrm{PTF}_i. \qquad (10)$$

Ignoring DGs or storages connected to the dc-bus of parking lots EPIs, total daily power transaction between PEVs and the grid via homes and parking lots is equal to ADPTV$\times N_V$, where N_V is the number of PEVs.

B. *Calculation of ADPTV for Four Basic Cases*

ADPTVs are determined for four basic average cases of 1) BEV from home with charger; 2) PHEV from home with charger; 3) BEV from home without charger; and 4) PHEV from home with charger. A flowchart is shown in Fig. 6 to il- lustrate the whole procedure carried out to produce ADPTV for these cases. By a combination of quantized data points of pdfs, 10^3 SCs are generated for BEVs and HEVs separately.

$480 \times$

Two types of (dis)charging are assumed in this study: slow charging at home (0.2'C rate equal to 4.87 and 1.48 kW for BEV and PHEV, respectively) and fast (dis)charging at parking lots with central EPI (1'C rate equal to 24.33 and 7.4 kW for BEV and PHEV, respectively). For a PEV with 20% SOC battery, it takes, respectively, 1 and 4 hours for its battery to be charged fully using fast and slow charging. These values seem adequate as per the vehicles' average stops in home garages and parking lots [11]. Slow charging begins when a PEV ends its daily travel at a home and the grid is in light load condition (here, light load period is assumed to begin at 23:45 P.M.); otherwise, PEV waits until the light load condition.

A computer code is written to do the summation in (10) on a scale of a minute to gain maximum accuracy (1440 points for 24-hour duration). Figs. 7 and 8 show the outputs of the code. For clarification, average home charging is separated from (dis)charging in parking lots and id shown in Fig. 8.

Fig. 7 shows four different ADPTV curves relating to the above-mentioned basic cases. As shown for the ADPTV of case 1, the curve is always above zero (V2P mode of operation) meaning that a BEV beginning daily travel with 100% SOC, on average could be regarded as a storage out of home with a maximum power of 1.14 kW at . For cases 2, 3, and 4, unlike case 1, a PEV has an ADPTV value below zero (P2V mode of operation) which makes it an active load out of home with maximum values equal to 0.64, 0.96, and 1.07 kW, respectively (between 8:47 and 11). Case 2, which relates to PHEV, has the lowest ADPTV value because PHEVs have batteries with usually small capacities, therefore, to maximize the all-electric-driven portion of the PHEVs daily travels; they often have to be charged during parking lot stops. In Fig. 8, home charging in basic cases 1 and 2 is depicted. As shown, ADPTV of cases 1 and 2 have nonzero values between 23:50–6:40 and 23:50–5, respectively.

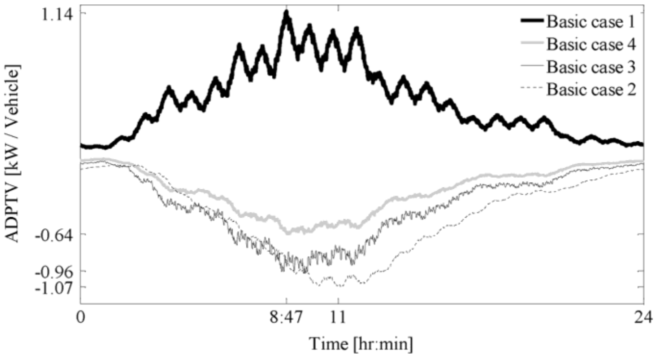

Fig. 7. ADPTV of a PEV through parking lot EPI in basic cases 1–4.

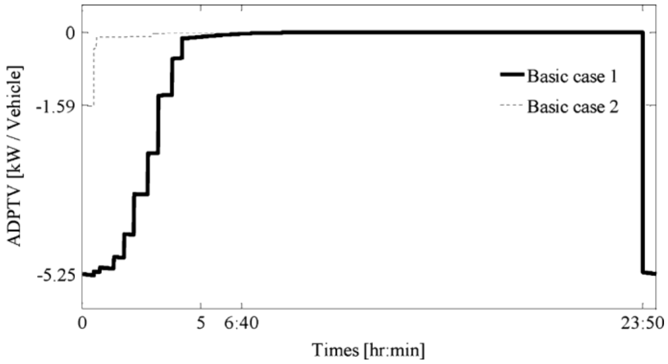

Fig. 8. ADPTV of a PEV through home charger in basic cases 1–2.

TABLE II
SUMMARY OF ADPTV CALCULATIONS FOR 480×10^3 SC

Basic case	Avg. energy transaction via parking lot [kWh/vehicle]	Avg. energy transaction via home [kWh/vehicle]	Parking lot charging delay [min/vehicle]		
			Min.	Max.	Avg.
1	10.14	-17.96	0	0	0
2	-11.8	-1.88	0	0	0
3	-9.87	–	0	36	0.432
4	-6.82	–	0	18	1.8

Considering several numbers of PEVs, ADPTV curves of cases 1–4 could be multiplied by the number of PEVs (N_v) showing aggregated impact of PEVs to assess the grid load change due to large-scale penetration of PEVs. By summation over 24 hours, a total average value of energy transaction for cases 1–4 could be determined as arranged in Table II. As shown in the first column of Table II, for basic case 1, an extra amount of energy equal to 10.14 kWh/vehicle (in average) could be absorbed by parking lots. Therefore, in this case, PEV V2P mode operation dominates P2V mode. But, for other basic cases, entries of the first column of Table II are negative showcasing P2V mode operation is dominant. Regarding this column, for cases 2 and 3, it is revealed that a BEV beginning from a start point without a charger needs less energy on average compared to a PHEV beginning from a start point with a charger in order to maximize AER of PHEV. The second column of Table II shows the average home charging impact of a PEV for cases 1 and 2. The third column of Table II shows the delayed time a PEV owner feels on average for each case due to participation in power transaction in parking lots. As shown, for cases 1 and 2, zero delay time is achieved while in cases 3 and 4, as charging to 100% SOC is obligatory, 0.432- and 1.8-min delay, respectively, is calculated.

TABLE III
AVERAGE ABSOLUTE DEVIATION (%)

Basic case	**PDF replaced by its average value**		
	$P_S(t_S)$	$P_T(l)$	$P_P(\Delta t_P)$
1	130%	27%	1.5%
2	135%	131%	74%
3	128%	80%	–
4	146%	50%	–

C. Sensitivity of ADPTV to PDFs of PEVs

As set out so far, ADPTV criteria is based on pdf functions de- scribing the stochastic habit of PEVs during daily travels in a city. Therefore, pdf forms and number of discrete points of pdfs may have significant impact on resulted ADPTV and consequently the final conclusion. Table III shows the sensitivity of ADPTV criteria to a pdf of PEVs. Average absolute deviation of ADPTV is determined by replacing one of original pdfs value with its average value for the whole SCs and differentiating the resulting ADPTV from the original ADPTV. From Table III, it is apparent that pdf forms have significant impact on the resulting ADPTV as their difference with the original ADPTV is considerable for all cases except for case one where parking lot duration pdf is re- placed by its average value (1.5% deviation). This shows high sensitivity of resulting ADPTV to main pdfs. Therefore, pdfs have to be produced with maximum resolution from adequatelylarge data base of vehicles physical characteristics in a city.

VI. SIMULATION OF THE STUDY

A. Simulation Grid

A 34-bus 24.9-kV IEEE network [28], as shown in Fig. 9, is selected as the residential test grid for this study. Three parking lots are assumed in connection with the grid at arbitrary nodes 5, 15, and 28, where PEVs could interact with the grid out of home $(N_P = 3)$. The base load of the grid (excluding PEVs loading effect), as depicted in Fig. 10, is assumed to be 830 kW on average and its peak is 1030 kW at $t = 20:30$.

B. PEV Distribution Scenarios and Loading Effect

The average U.S. household power demand is reported to be about 1.5 kW/year [29]. Furthermore, an average number of 1.87 vehicles per household is reported in 2009 in the U.S. [27]. Taking these two statistics into account, the number of homes could be equal to 830 / 1.5 = 553 and number of household vehicles is 533 X 1.87 = 1034 vehicles. Assuming that each household possesses a maximum one PEV, it is possible to approximate the number of PEVs in the residential grid area (N_v) via multiplying 1034 by the PEVs' penetration level.

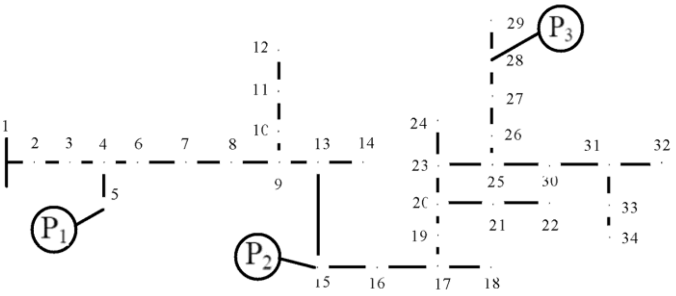

Fig. 9. Test grid with three parking lots.

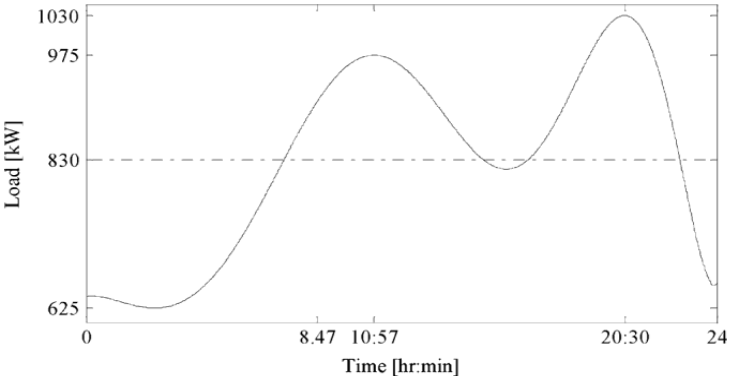

Fig. 10. Grid base load curve.

A different compilation of the introduced four basic cases of PEVs could be combined to form distribution scenarios of PEVs in a city. Table IV introduces four scenarios of distribution for fleets of PEVs that are used in this work. Each entry of the table shows the percent of the corresponding basic case among the total number of PEVs. For example, scenario 1 relates to the condition that there is an equal number of PEVs from each basic case. Regarding Table IV, scenario 2 is the worst-case scenario among all the scenarios as a percent of basic case 1, of which the provided extra power (see Fig. 7) is zero. Therefore, no V2P operation takes place and no energy is available for injection into the grid. Thus, the loading impact of the PEVs' penetration on the grid is at its highest compared to the other scenarios. Scenario 3 seems to be more near term in relation to the other scenarios as PHEVs have been mass produced so far and a majority of predictions about the future market share of other alternatives to ICE vehicles involves HEVs, whereas comparable BEV are newcomers to this area and still under development. Moreover, a small portion of households could afford to equip their homes with a charger in the very near future. Therefore, basic case 4 has the largest coefficient among other cases in scenario 3 and the total percent of basic cases 3 and 4 relating to homes without a charger is twice the percent of cases 1 and 2 relating to homes without a charger.

The PEVs' impact on the grid loading has two parts: home charging load and parking lot charging load. According to the distribution scenario, the parking lot charging and home charging loads are calculated using the ADPTVs of Figs. 7 and 8. The home charging load is added evenly to the nodes of the grid whilethe parking lot load is added to buses 5, 15, and 28.

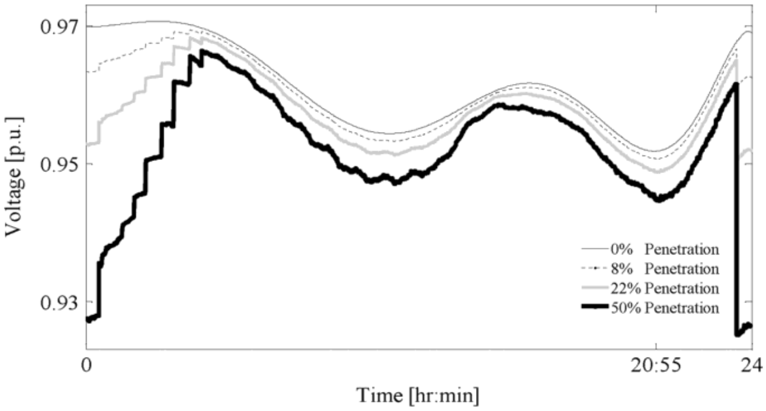

Fig. 11. Voltage profile of Bus 29 in scenario 1.

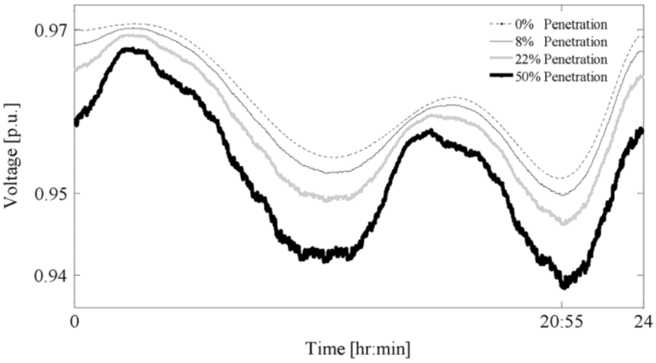

Fig. 12. Voltage profile of Bus 29 in scenario 2.

C. Simulation Results

Considering the mentioned four scenarios, load flow calculations of the grid are performed for different PEV penetration levels during 24 hours based on the backward–forward sweep method [30]. Among 34 buses of the grid, bus 29 shows the maximum voltage fluctuations. Therefore, the voltage variations of this bus during four scenarios are selected to be shown. Figs. 11–14 show a variation of bus 29 voltage level, rated in per unit, for the mentioned scenarios and four penetration levels: 0%, 8%, 22%, & 50%. As shown, by increasing the penetration level, the voltage level falls due to the increase of PEVs in P2V mode as the dominant mode. This decrease is more sever at the beginning and ending parts of Figs. 11, 13, and 14, where home charging takes place. In fact, according to Table IV, the more home charging takes place, the more voltage drops at mar- gins of Figs. 11–14, and the less home charging takes place, the more voltage drops in the middle. In 8% penetration, the voltage level stays in the acceptable range (95%–105%) according to EN50160 standard in all the scenarios. By increasing the penetration level, the voltage level drops below the standard in scenario 2 (worst case) at 8%, in scenario 3 at 10%, and in all the scenarios in 50% penetration levels all at peak load instant, t = 20 : 55 Therefore, 8% is the marginal penetration for all scenarios. By removing V2P mode operation from power trans- action in parking lots in all scenarios (excluding scenario 2 and considering scenario 3 as worst case), current 10% penetration margin reduces to 8%. Therefore, V2P mode will be a great asset to reducing loading impact of PEVs on the grid.

In Table V total power loss of the grid, rated in per unit, is shown for four penetration levels in four scenarios. From the table, the grid power loss increase from base (0% penetration) is about 0.18% for 8% penetration level in all scenarios.

A marginal penetration level is in correspondence with the base load of the grid. Another set of load flow simulations is performed on 19-node grid [31], where three parking lots are connected to the nodes 3, 7, and 14. Two base load values equal to 183.5 and 359.3 kW are taken for the grid simulation. The results of load flow show 74% and 20% penetration margins for 183.5- and 359.3-kW grid base load such that no bus voltage would drop below 95%. Based on this, it is revealed that the PEVs' penetration margin is tightly associated to the grid base load.

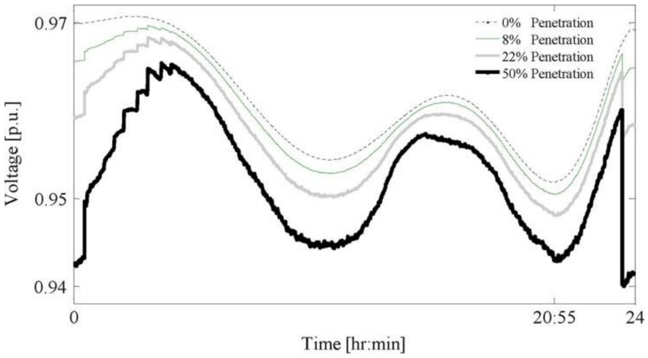

Fig. 13. Voltage profile of Bus 29 in scenario 3

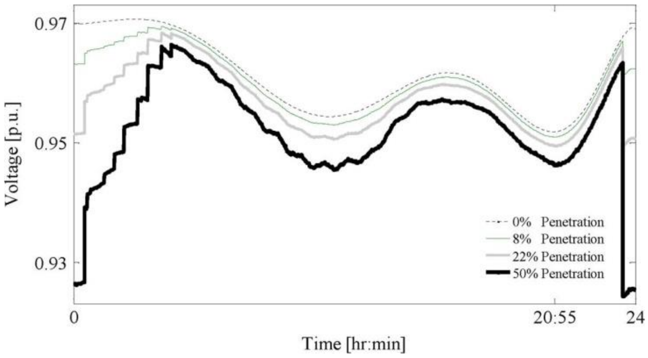

Fig. 14. Voltage profile of Bus 29 in scenario 4.

TABLE V
GRID POWER LOSS (p.u)

Penetration level [%]	Scenario			
	1	2	3	4
0	2.458	2.458	2.458	2.458
8	2.637	2.651	2.639	2.641
22	2.972	2.998	2.957	2.986
50	3.876	3.821	3.764	3.874

VII CONCLUSION

Considering a power electronic solution as central EPI in parking lots, the concepts of V2P and P2V were proposed. Several pdfs related to the PEVs' daily travel PEVs are presented that are based on statistics extracted from reality or assumptions made with regard to real conditions. (Dis)charging profiles of a PEV in a parking lot is based on minimal extra delayed time and minimal loading impact on the grid, both due to the charging process. Considering the parking lot stop in the middle of daily travel and the possibility of charging at home for a PEV, then the stochastic model of a PEV could be determined. Based on this model, the PTF model of a PEV is constructed. Four basic cases considering BEVs and PHEVs and the possibility of connection to a home charger are assumed. By quantization and combination of data points, 480 X 10^3 SCs are generated for each case. Considering the expected value concept, ADPTV criterion is suggested to assess the average daily power transaction of a PEV for each case. With a combination of the cases, four different scenarios of PEV distribution in a city are taken into account. IEEE 34-bus grid is selected to host PEVs, related homes, and three parking lots with EPI. The impact of PEVs on the grid is assessed using ADPTV criterion for different penetration levels. The results show that up to an 8% penetration level margin, for all scenarios, the voltage levels of the grid buses re- main in the standard range and the grid power loss is near the zero penetration condition. Similar simulation on 19 node grid shows even higher acceptable penetration levels.

The margin is dependent on the grid base load such that for two values of grid load, 20% and 74%, the penetration margin is seen. This suggests that even with deep penetration levels of PEVs emergence, facilitating city parking lots with central EPI and adopting proposed PEVs (dis)charging profiles in parking lots, will substantially decrease the severity of the charging problem of PEVs fleets previously emphasized and could significantly postpone any grid reinforcement.

APPENDIX

When a PEV adopts SC corresponding to a daily travel pro file of type 3 or 4 with probability $P(i)$, regardless of remaining travel length (l_a) at a parking lot, it gets fully charged, then

$$C_H(i) = C_N - l_b(i) \times r \tag{11}$$

$$\bar{C}_H = \frac{1}{C_N} \sum_{i=1}^{N_{\text{noch}}} P_i \times C_H(i). \tag{12}$$

In (11), C_H is charged left (or initial charge of next day) for PEV when finishing its daily travel at home. $\bar{C}_H$ in (12) is the aver- aged value over SCs and N_{noch} is the number of SCs relating to profiles of type 3 or 4. Although C_H is possibly changing from day to day, but its averaged value (C_H) is constant considering all possible SCs. Thus, C_H could serve as an estimate of initial charge C_S. Calculating (11) and (12) for 480 X 10^3 SCs, the av-erage values of C_S for BEVs and PHEVs divided by C_N are 88% and 36%, respectively.

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