Distributed Storage Capacity Modelling of EV Parking Lots

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***Abstract*— As the power grids have been evolved to be more smarter, distributed energy resources (DER) and Electric vehicles (EVs) provide a new and effective storage capacity during peak loading times. EVs are the new and upcoming technology to electrify the transportation sector. EVs refer many advantages which one of them is expected to be an effective distributed energy capacity for future power systems. Furthermore, they give an opportunity to store the excess of generation from renewable energy in off-peak periods. It is clear that an effective storage can be achieved by aggregating the single EVs. Commercial car parks and parking lots (PL) of several public and private companies can be used for these purposes. The objective of this paper is to develop a probabilistic available capacity model of an EV PL by sequential Monte Carlo simulations that will in turn supply the distribution network.**

***Keywords:* Distributed Energy Resources, Electric Vehicle, Electric Vehicle Parking Lot, Monte-Carlo Simulation**

1. Introduction

The two large scale sectors; namely transportation system and electric power industry have already merged for electrical transportation era. Electric vehicles, EVs, are probably the newest member of electrical transportation system. The prevalent use of EVs may be an option for the emission reduction as in other electrical transportation systems. Moreover, EVs have some additional functionalities in the system when compared with the other electrical transportation systems.

EVs operate either at charging mode or discharging mode. Charging mode is named as grid-to-vehicle (G2V) mode. Discharging mode comprises both the transportation of an EV where the stored energy is converted to mechanical energy and supply the electric network through appropriate devices as a distributed energy resource, DER. The second one is named as vehicle-to-grid (V2G) mode. Finally, EVs can be at an idle phase where they do not perform any charging or discharging work. According to [1], private vehicles are averagely driven only one hour in a day and charged for a couple of hours; hence, they are parked at an idle phase during most of the day time.

Since EVs are parked most of the time during a day, it is always probable to operate at G2V and V2G modes in accordance with the power needs of the grid. However, the latter operation mode requires the installation of V2G technology. At this point, parking lots (PLs) play a crucial role in aggregating the EVs to reach high distributed energy storage capacity for longer periods. Modern electric power systems will face new challenges due to integration of EVs and EV operational management will be of great importance for distribution system operation due to their mobile and highly dispersed character.

One of the most important features of EVs is their large-scale distributed energy capacity usage for future power systems. Furthermore, they give an opportunity to store the excess of generation from renewable energy sources in off-peak periods. In literature, there are many studies regarding V2G technologies for integration of renewable energy resources (RESs) to the power grid [2 - 6]. EVs are generally charged at off-peak (night) times. They do not only play an important role in valley-filling of the load duration curve but also increase the chance of participation of wind power, which is more efficient during the night times. This idea is promoted in [5], that EVs during night charging improves the ability and efficiency of integration of wind power.

The stored energy of EV batteries can be injected to the distribution network by means of parking lots during the peak-load durations. Actually, total peak load period in a year is almost thousand hours corresponding to one eighth of total annual duration. In metropolitan cities, like Istanbul, due to high population density, there are many challenging tasks during peak-load periods for the grid management [7]. In order to consume the peak loads, PLs can be used as cheaper and more reliable sources than the power plants having high installation costs. The usage of car parking lots as a peak shaving DGs was purposed in [8 - 10]. Furthermore, several technical and environmental restrictions for renewable generations at metropolitan areas, increase both the necessity and the probability of using EV parking lots as effective DERs.

In recent years, decreases in installation costs of photovoltaic (PV) systems have provided fast increase in PV generation. In order to increase the utilization of V2G concept and enhance the penetration level of PV generation, the coupled system integrating EVs and PV rooftops would be designed. The physical areas of PLs can be used for this coupled system [4]. Also, intelligent PL models are offered to maximize the integration EVs and RESs [2, 3, 11]. In this type of PLs, the stochastic optimization algorithms are used to determine the appropriate time intervals by selling stored energy in EVs with the best prices.

The studies about smart grids (SGs) have been accelerated all around the world. One of the main objectives of the SGs is to provide the integration of small scale distributed generations and storage facilities with the distribution system. In the grown, developed, and deregulated power systems, DERs provide positive contributions such as decreasing the uncertainty of renewable energy sources, providing frequency regulation services and increasing the end user reliability [12, 13].

On the other hand, they have also some negative impacts on the system, such as harmonic distortions, stability and security problems. Therefore, the framework of SG will strengthen the integration of V2G to the power grids. In order to enhance of V2G operations, intelligent energy management systems for energy scheduling in SGs proposed in [3, 13, 14].

Available storage capacity of EV PLs depends on some uncertain parameters such as EV users' behavior, arrival/departure times of the cars, the distance transported prior to arriving the parking lot, state of charge of the batteries, and charging rate of the system. Therefore, statistical data is the indispensable requirement to assess a proper stochastic modeling of the diversity of EVs in the PL. It was already shown that the travel data (distance) of EVs are similar to those of internal combustion engine (ICE) vehicles'. In order to simulate the statistical behavior of the EV drivers, most of the previous researches have used the normal distribution [13, 15, 16]. However, but it is actually case dependent and do not generally show a symmetry with respect to corresponding mean value. A typical probability density function for car arrival time to a PL is shown in Fig. 1, where the drivers arrive at around 8 a.m. Hence, Weibull distribution is more appropriate fitting function representing the arrival time of EVs to the PL during the morning time of a weekday [17].

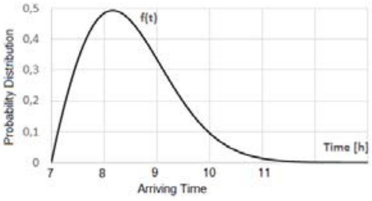

Fig. 1: Weibull Probability density Function to represent the Arrival Time of an EV to the parking lot.

There are several studies on optimum allocation and sizing of EV PLs in literature which can be used as a starting point of new PL construction attempts. However, existing PLs have already been built according to urban planning issues and aim to provide a community service without any economic benefit expectations. Therefore, use of existing PLs to increase the service quality of the power grid is another important task. This paper presents an initial study for this secondary aim of existing parking lots. It presents a probabilistic distributed energy capacity model of EV PLs that will in turn be used for reliability analysis of associated distribution grid. The model is based on the past arrival/departure time statistics provided by The Chief Management of Istanbul Car Parking Corporation (ISPARK) as well as mean length prior to arrival of the cars and some expected technical parameters. The real-time data of an existing PL in Istanbul is used and available storage capacity of a sample PL is determined for each day hour using sequential Monte-Carlo simulations. The results of this study will also provide an information for power system operators to assess the contribution of PLs during peak-load times.

2. Parking Lots

EVs are the new and upcoming assets to electrify the transportation sector. They refer many advantages. Among them, contribution to future distribution grids as an effective distributed energy capacity is of crucial importance. Hence, they enable using their distributed storage facilities as peak shaving generations. However, it is clear that an individual impact of an EV is limited due to its small scale battery storage capacity. Therefore, PLs, aggregating the single EVs serve as efficient storage facilities.

Istanbul is a huge metropolitan city and population density is very high. Almost seventeen million people lives in Istanbul [18]. Its electric distribution network is divided into two regions as European site and Asia site and each side has its separate administration utility. This study is focused on the power distribution system of European site of Istanbul which is under the responsibility of Bosphorus Electric Distribution Corporation (BEDAS). In order to assess storage capacity of EV PLs, the arrival/departure time data of a PL in this region is used.

In BEDAS region, energy supply from distributed generation resources is around 1.5 percent of overall regional consumption [19]. Most of the existing DGs in the region are natural gas based cogeneration units; wind and PV based generation is almost negligible. Moreover, there is not any expectation of increased wind and PV based distributed generations in the future. The most important reason for the lack of wind and PV based DGs is the high price of terrains in the region. Therefore, the only remaining DERs for the region is waste based biogas units and storage capacity of EVs.

EV PLs is an expected DG sources in BEDAS area to create a flexible source option to the grid operators. As of June 2015, 44 PLs are being operated by ISPARK in BEDAS territory and construction of 215 additional lots until 2019 are already planned. Existing and planned PLs in the region have an average size of 400 cars. On the other hand, EV sales mainly depend on oil prices and on some regulatory specifications of the administrations from economic and environmental points of view, respectively. Although, expected EV penetration by 2019 is 9% [20], this study is based on half of the cars in PLs are EVs to account expected dominancy of environmental cares. If an EV has an average energy capacity of 30 kWh, and 60 % of this energy is assumed to be injected to the grid; one PL may serve as a temporary storage unit of 1.2 MW along 2-3 hours. In addition, both the increasing percentage of EVs among all cars and increasing storage facilities show that parking lots will be more effective DG sources in the future. Furthermore, these PLs are generally close to Park and Ride (P/R) regions or intensive working areas which increases the importance of PL support to the distribution grid.

Due to uncertain behavior of drivers, two important parameters are need to determine the available storage capacity of a PL; namely, state of the charge (SoC) and charging/discharging rate of EV batteries. The SoC of the battery for an EV arriving at a PL depends on the travelled distance. The travelled distance, battery capacity, and energy expenditure of an EV directly affect the amount of energy consumption. Battery capacity, and energy expenditure of an EV depends on the type of an EV. Today, battery capacity and energy expenditure of EVs are between 12 kWh to 65 kWh and 0.18-0.25 kWh/km. In this study, battery capacity and energy expenditure of an EV is assumed to be 25 kWh and 0.23 kWh/km, respectively [6]. On the other hand, all EVs are assumed to be fully charged at night before starting their travel..

The travelled distance of an EV prior to arriving a PL is modeled by a random variable. In literature, some studies have been used the data based on travel pattern provided by the 2009 National Household Travel Survey (NHTS) [16, 21, 22, 23]. According to the survey in [20], daily average drive in Istanbul is 50 km/day. In addition, travelled distance is assumed mostly normally distributed in earlier studies [7, 16, 24].

There are three types of chargers for EVs. These are named as Level 1, Level 2 and Level 3 chargers. Their specifications are illustrated in Table 2 [25]. Level 1 type chargers are used at homes, Level 2 type chargers are installed at working places, PLs, and shopping malls. Level 3 type chargers are fast chargers; hence they affect the life of battery and the distribution network. They are not generally installed at PLs, due to their disadvantages. Consequently, Level 2 type chargers are considered and maximum charger power is assumed to be 12.5 kW in this study.

Table 2: Charging Power Levels

Level Types	**Description**	**Power Level**
Level 1	Opportunity charger (any available outlet)	1.4 kW (12A) 1.9 kW (20A)
Level 2	Primary dedicated charger	4 kW (17A) 19.2 kW (80A)
Level 3	Commercial fast charger	Up to 100kW

This study is based on the statistical data of a PL with a total capacity of 500 cars. Half of the cars are assumed to be EVs equipped with V2G hardware. ISPARK statistics for 22 weekdays in December 2014 is used to model the arrival/departure times of the cars. Data format is given in Table 3, and arrival/departure tines are sketched in Fig. 2. Note that, instead of single car representation, the figure is sketched for a time step of 15 minutes. On the other hand, this data comprises all the cars in the PL and much better arrival/departure patterns are expected for EVs due to possible incentives for EVs in the future. Finally, at this initial phase, PL is assumed to be capable of charging all the cars with a maximum charging power value of 12.5 kW.

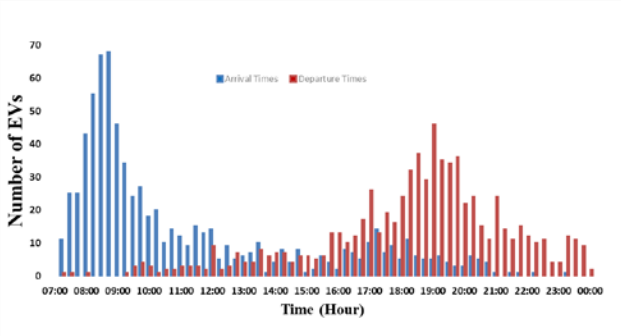

Fig. 2: Arrival/departure times of the cars in weekdays for the sample period.

Table 3: Arrival/departure Data Format of the Data provided by ISPARK

Arrival Date	Arrival Time	Departure Date	Departure Time
8.12.2014	08:55:20	8.12.2014	18:46:18
8.12.2014	08:54:51	8.12.2014	21:16:44
8.12.2014	08:52:34	8.12.2014	18:24:18

3. Simulation Methodology

At first, the raw arrival/departure data of the PL is processed. Among several alternatives, separate modeling of arrival and departure times was found to be more appropriate for distribution function representation. A time scale of 15 minutes from 7:00 a.m. to 00:00 am was found to be reasonable since the distributed capacity of the PL was not assumed to be used during night time. In order to obtain the average number of cars arriving to and departing from the PL at each time step of the weekdays, the data given in Figure 1 is sorted and aggregated. Consequently, a data cluster representing the stochastic characteristic of the car arrival/departure was obtained.

Second stage of the study is devoted to obtain the appropriate probability distribution function for the random arrival and departure times of the cars for 07:00 a.m.-11:59 p.m. period. To do this, various type of distributions in MATLAB to fit arrival and departure times of the cars are used and the results of the fitting performance of each distribution function is compared for both of arriving/departing data sets of the cars. Sum square error (SSE), R-squared, and root-mean squared error (RMSE) is used for fitting performance indices. For arriving data set, two-parameter Weibull distribution function and exponential distribution function give more appropriate fitting performance as seen in Table 4-a. For departing data set, two-parameter Weibull distribution function and normal distribution function give more appropriate fitting performance as seen in Table 4-b.

Table 4-a: Fitting performance for arrival data set

Performance→ **PDF↓**	SSE	R-squared	RMSE
Weibull Dist.	0.0967	0.9783	0.0383
Exponential Dist.	0.0972	0.9782	0.0381
Normal Dist.	0.3268	0.9267	0.0704
Lognormal Dist.	0.0959	0.9785	0.0381

Table 4-b: Fitting performance for departing data set

Performance→ **PDF↓**	SSE	R-squared	RMSE
Weibull Dist.	0.0579	0.9932	0.0296
Exponential Dist.	3.0460	0.6429	0.2132
Normal Dist.	0.0713	0.9916	0.0329
Lognormal Dist.	0.1442	0.9831	0.0468

Consequently, two-parameter Weibull distribution function is selected in order to use similar probability distribution functions for arriving/departing data sets of the cars. Weibull distribution is a 2-parameter probability density function (PDF) as given in Eq.(1), where α and β denote the shape and the scale parameters, respectively.

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(x/\beta\right)^{\alpha}} \qquad (1)$$

For the random arrival and departure times of the cars, the most appropriate α and β values are given in Table 5.

Table 5: Weibull parameters for the probability density function of arriving and departing data sets of the cars.

	α	β
Arriving data set	0.9831	16.8
Departing data set	50	4.665

The last stage of the study is to obtain the stochastic storage capacity of the PL with the following deterministic and stochastic parameters:

- Arrival time: Weibull (α =0.9831, β = 16.8),
- Departure time: Weibull (α =50.0, β = 4.665),
- Battery capacity of an EV = 25 kWh, energy expenditure of each EV per km is assumed 0.23 kWh,
- Maximum charging power = 12.5 kW,
- Travelled distance of an EV before arriving to PL: Normal(η=30 kms, σ= 15 kms)
- SoC of EVs when arrived to the PL: Normal(η=70 %, σ= %15)
- SoC of EVs when departing from PL: Fully charged(100 %),
- Each arriving EV to PL is charged immediately: Exponential (α= 1.956 1/h),
- Car capacity of the parking lot= 500 cars,
- Average number of daily arriving cars to the PL=710,
- Half of the cars are EVs,
- The cars depart from PL until midnight.
- The number of initial cars at 7:00 a.m. (either stayed at the park or come before 7 a.m.): Normal (η=10 cars, σ= 1 cars); those cars are assumed to be fully charged during the night time..

4. Simulation Results

A probabilistic approach based on MC simulation was developed for the storage capacity of a PL. The model is valid for the day time from 7:00 to 23:59.

Average available storage capacity of the PL at each day hour is illustrated in Fig. 3. Available capacity is expressed as a percentage of maximum capacity. Therefore, the model can easily be adopted for increased percentage of EVs as well as for improved storage capacities of the EVs. According to aforementioned operating conditions, average storage capacity of the PL is almost 100 % after midday hours. Furthermore, average storage capacity is still greater than 70% at 6 p.m., which enables the PL to supply the grid not only for noon times but also during the peak-load at the evening. It is clear that the distributed storage capacity of the park can be used during 10.00 a.m.- 07 p.m. with respect to power market conditions, whenever required.

This study proposes a probabilistic storage capacity model of EV PL. Following several runs of sequential MC simulations, cumulative probability of the parking lot (PL storage capacity ≥ k) for respective hours is depicted in Fig. 4. These curves show cumulative probability of the available storage capacity that can be injected to the power grid by the PL. Note that the PL reaches almost full capacity for a three hour interval between 1 p.m. and 4 p.m. This interval is shown by a representative curve named as 14:00 in the figure. Moreover, PL can supply significant amount of energy for 10:00 a.m., 12:00 a.m., 5:00 p.m. and 7:00 p.m.

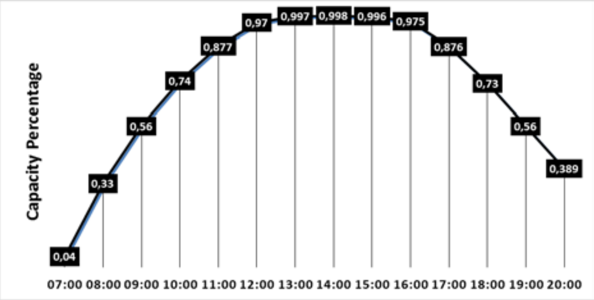

Fig. 3: Average available capacity of the PL

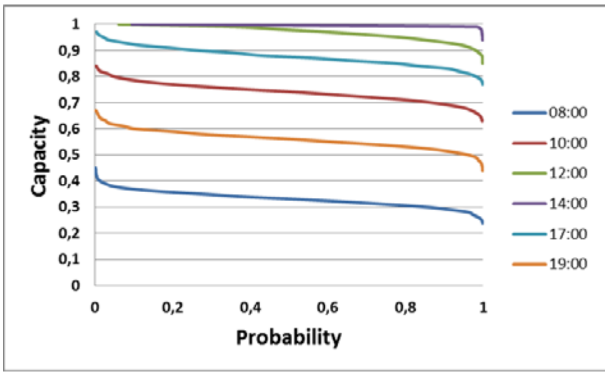

Fig. 4: Cumulative probability of storage capacity of the PL

Finally, Fig. 5 is given below to determine the period that the PL can be used as an effective supply of the grid. It is assumed that a capacity of 70% and higher is an effective supply, the probability of the PL having 70% or higher available capacity for several hours of the day. Note that, ±10% will not cause significant changes in the period.

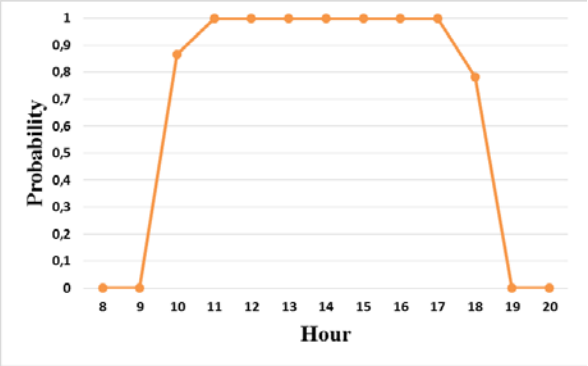

Fig. 5. The probability of the PL having 70% or higher available capacity for several hours of the day

5. Conclusions

EVs are a kind of load for power system (G2V), but they can be used a storage facility (V2G) at the same time. This paper presents an initial study for this secondary aim of existing PLs. PLs have a crucial task for aggregating EVs'. A probabilistic distributed energy capacity model of EV PLs is presented. The real-time data of an existing PL in Istanbul is used and available storage capacity of a sample PL is determined for each day hour using sequential Monte-Carlo simulations.

The results of this study shows that average storage capacity of the PL is almost 100 % after midday hours. Furthermore, average storage capacity is still greater than 70% at 6 p.m., which enables the PL to supply the grid not only for noon times but also during the peak-load at the evening. This also provides multiple options for the PL operators during 10.00 a.m.- 07 p.m. When the penetration level of EVs is increased and to possible incentives for EVs are set, the results of this study will also provide an information for power system operators to assess the contribution of PLs during peak-load times.

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