Impact of EV Parking Lot on Distribution System Reliability

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***Abstract*—Due to the aggregating feature of the parking lot, it can be served as a distributed energy resource (DER) for distribution grid. This study presents the impact of electric vehicle parking lot (EV PL) on distribution system reliability level for an intended operation period. Stochastic storage capacity model of a sample EV PL that was recently proposed is used for the assessment of the aforementioned impacts on the reliability level of a distribution feeder located at the Thrace part of Istanbul distribution system. Reliability improvement of distribution system through EV PL is evaluated using SAIFI, SAIDI, and ENS indices. Moreover, impacts of EV PL on load point reliability indices are also evaluated and discussed.**

Keywords—distributed energy resources, electric vehicle, parking lots, energy storage capacity, reliability assessment, distribution system.

I. Introduction

In recent years, power generation from renewable energy sources (RES) and electric vehicles (EVs) have been the most popular actors of the evolving smart power grid because of their technical and economic benefits as well as because of increasing awareness of the community on environmental concerns. Several countries have already announced their road maps to generate more clean electricity and to minimize fossil fuel usage in transportation. One of the consequences of this awareness has resulted in merging the two large infrastructures; namely, electrical transportation systems and electric power systems. Furthermore, when EV is used as an energy storage unit, it has an important advantage through the lack of intermitted behavior of RES.

On the other hand, there are several technical operational challenges of the electricity grid which includes huge number of electric vehicle, EV, penetration. Bi-directional behavior of EVs can be assigned as the main reason of several problems. They are non-stationary loads during the charging phase (Grid to Vehicle operation mode, G2V) and require more flexible distribution grid. On the other hand, they are distributed storage sources during discharging phase (Vehicle to Grid operation modes, V2G) requiring again some additional attentions during the design phase.

One of the main aims of power system planning and operation efforts is to provide reliable and economic electrical energy to the customers [1]. In traditional power system, distribution system had taken less attention on reliability issues than generation and transmission system since the outages had localized effect in distribution system. However, with the new smart electrical grid environment, distributed supply and storage units have been participating the grid operation at distribution system level. Hence, new challenges about the improvement of end users' supply reliability have been raised. In response, distributed generations (DGs) and distributed energy resources (DERs) give opportunities to cope with these challenges [2].

EVs spend most of the daytime at parking position in parking decks or parking lots (PLs). Although, even a single EV can be used as an emergency supply by vehicle to building/home operations, this type of small-scale applications is not feasible for medium voltage distribution networks. At this point, parking lots play a crucial rule by aggregating a number of EVs. If their stored energy is injected at peak-load durations or in case of distribution grid outage conditions as well as feeder component outages, it facilitates to improve distribution system reliability.

The first step of V2G application involves assessment of available storage capacity, ASC, of the parking lots taking into account uncertain behavior of the drivers and some other probabilistic parameters like the travel distances of the cars before arriving at the PL, state of the charge (SoC) of EV batteries, etc. In [3], ASC model of an existing EV PL is proposed using real car arrival/departure data. It was also shown that car arriving/departing patterns had significant impact on the ASC of EV PL [4-5]. The results of these papers indicated that EV PLs have a considerable storage capacity during the midday hours. Remembering that there are several public and private PLs which have 100 or more car capacity in metropolitan cities, and penetration of EVs is increasing day by day, PLs will be important distributed storage assets of the grid in the near future.

On the other hand, many countries have announced the future plan passing from internal combustion engine vehicles to EVs. This situation has provided increasing the attention on assessing impacts of EVs and EV PLs on distribution system reliability. Because of intermittent behavior of RESs such as wind and solar generation systems, integrating EVs or other energy storage systems with RESs is an efficient means of improving distribution system reliability [2]. Due to the cheaper energy price, EVs usually charge at night times, hence more wind energy can be consumed for this charging action. In [2], reliability performance indices Annual Expected Energy Not Served, AENS, and System Average Interruption Duration Index, SAIDI were used to assess the reliability level improvement of EV PL integrated with renewable generation systems. Also, reliability assessment of EV PL is used to determine ancillary benefits like finding optimum allocation of

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PL or proposing stochastic–probabilistic energy and reserve market clearing scheme [6], [7], [8]. Furthermore, EV based reliability studies were proposed in [9] [10], [11].

Reliability improvement on distribution system by using EVs also provides several economic benefits. To increase spinning reserve capacity improves the reliability of power system, but also increase the total cost. In [12], EV aggregator which helped to minimum price and reduced the prices of spinning reserve was proposed and this provided reliability improvement. In literature, other models which showed reliability/cost relation in V2G mode were presented [12], [13].

This paper focuses on the impact of EV PL on distribution system reliability level. We have already proposed a storage model of EV PL in previous studies [3-5]. Car arrival/departure statistics of a sample PL, which was provided by Istanbul Car Parking Corporation (ISPARK) was used in these studies. The capacity of this sample PL was 500 cars and with an optimistic assumption, it was assumed that half of the parking places were equipped with V2G facilities. The storage model was developed using Sequential Monte-Carlo (MC) simulations.

Impact of this sample EV PL on the reliability of a distribution system was evaluated for different operational modes of the network. Simulations are conducted for a part of Istanbul-Thrace part distribution grid, whose data was provided by Bosphorus Electric Distribution Corporation (BEDAS). This study is limited with the improvement of distribution system reliability during noon peaks of the grid (peak shaving operation). Therefore, V2G operation is considered for the time range of 11:00 to 14:00, whenever required.

The remaining part of the paper is organized as follows. ASC model of the EV-PL developed in [3-5] is summarized in the second chapter. The information regarding a part of distribution grid of Istanbul is given in the third chapter. The fourth chapter is devoted to the reliability assessment of the distribution network. Finally, discussion of the results and the conclusions are presented in Chapter 5.

II. Energy Storage Capacity of EV PL

With smart grid development, small scale renewable generations and storage units come forward owing to giving an economic and reliable solution for peak-load durations. As in other metropolitan cities, high prices of terrains are the most important barriers against high penetration level of renewable based DGs in Istanbul. Therefore, the share of DGs is around 1.5 percent of all consumption BEDAS region. As mentioned before, PLs of 400-500 car capacity are expected to be important distributed storage facilities in Istanbul. Therefore, determining the ASC the EV PL is a vital assessment for future distribution system planning.

In our previous studies [3,4, and 5], stochastic storage capacity of a sample EV PL was developed using real data of a PL which was a closed park and ride area by a subway station. The first aim of these studies was to determine the ASC of the PL and to assess the impact of the PL on distribution system reliability. Target time interval was selected between 07:00 and 00:00 in this study. It was shown in [4] that the car arrival/departure pattern had a decisive role to obtain realistic storage capacity of the PL. Therefore, modeling of the car arrival/departure patterns had to be done as accurate as possible. To fit more appropriate probabilistic distribution functions for car arriving times and departing times was crucial for obtaining storage capacity of the PL.

Car arriving times of this PL in a weekday for the sample period are given in Fig. 1. Note that each cluster shows number of cars which arrive to the PL in a 15 minute interval. Several probability density functions were tried to model the arrival time pattern of the cars. Simulations showed that, two-parameter Weibull distribution function was best one for modeling arrival car pattern. Details about this process were given in [4-5].

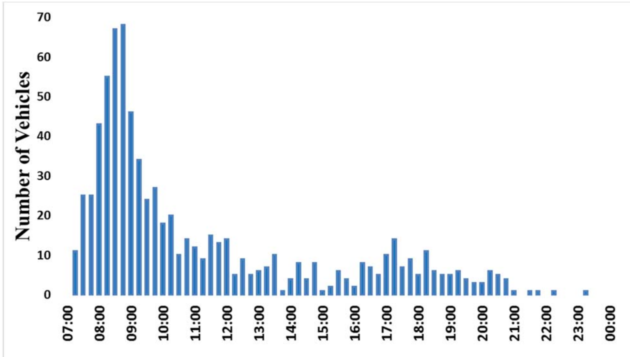

Fig. 1: Arrival times of the cars in a weekday for the sample period.

Modeling of car departing times could be done using departure time statistics directly or more precisely, using the car park durations together with the correlation between the arrival time and the parking durations. We preferred the latter one. Statistics of car departure times were more complicated than arrival time statistics as seen from Fig. 2. It was mainly because of the impacts of several different purposes of the drivers on the parking durations. For example, cars arriving at the PL early in the morning were usually parking all the day up to evening times. However, drivers arriving after 09:00 had so many different purposes and it was difficult to simulate their parking behavior by using one dimensional probability density functions. Hence, it was decided to use two-dimensional statistics for parking duration of these cars. Moreover, non-parametric Kernel density estimation (KDE) is used for smoothing the statistics of car departure times. The details of the process were explained in [5].

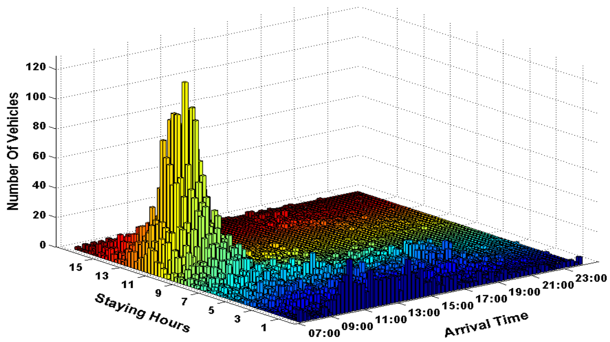

Fig. 2: Two dimensional arrival time-parking duration patterns of the cars

Sequential MC simulations are performed to assess the hourly ASC of the PL. The resulting average storage capacity of the EV PL during the daytime is given in Fig. 3. Note that the storage capacity is expressed as a percent of rated storage capacity of the PL, where the rated capacity is the uppermost value obtained for 250 EVs each having a capacity of 25 kWh; i.e. 250*25 = 6250 kWh.

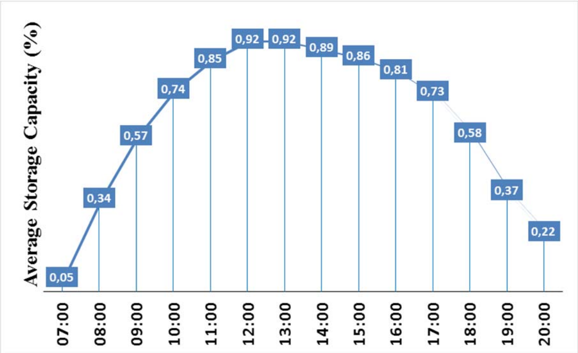

Fig. 3: ASC of the PL during the day time

The results show that the ASC of the EV PL is 90% or higher during midday hours. Assuming that each car should have at least 50% storage capacity at its corresponding departure time, almost 40% of its rated capacity can be transferred to the power grid during peak-loads in midday (peak-shaving operation). On the other hand, again for the same 50% capacity constraint, the PL can be used as a redundant supply at least part of the distribution grid for limited durations during all the day in case of an outage of grid supply as well as outage of feeder components.

III. Distribution System

In this study, real distribution system data of the PL region provided by BEDAS staff is used. Single-line diagram of the distribution feeder where the presumed PL can be connected is given in Fig. 4. This data includes failure and repair statistics of each feeder component and the load duration curve of this distribution system. There are nine load points on the feeder, each having different consumption capacities (transformers). There are 3785 consumers supplied from the feeder. In average, 60% of overall consumers are commercial ones and the remaining 40% is residential at each load point.

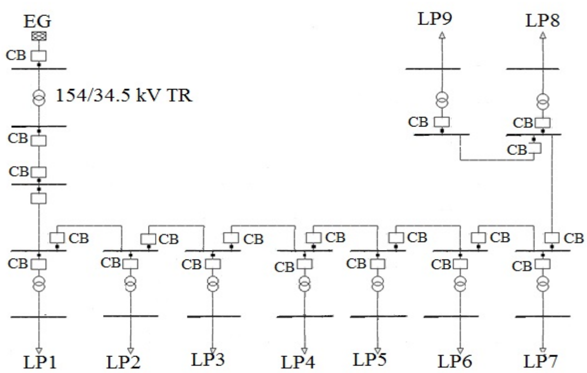

Fig. 4: Single-line diagram of the distribution system

The load duration curve of the feeder for a representative weekday is given in Fig. 5. Note that consumption is expressed as percentage of the peak load, where the feeder peak load is 3.71 MVA.

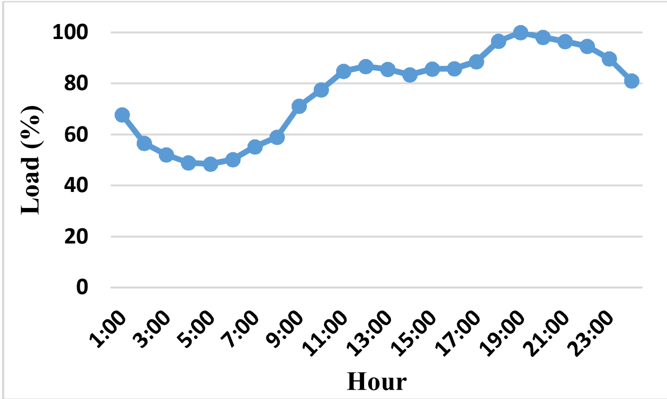

Fig. 5: Load duration curve

Before reliability assessment, failure rates and average repair durations of feeder components are calculated using raw BEDAS data. The results are illustrated in Table 1. The failure rate and average repair time of busbar are expressed aggregation of circuit breakers and busbar's. Because, reliability information of circuit breaker cannot be entered in DigSILENT PowerFactory.

TABLE 1: FAILURE RATE AND AVERAGE REPAIR DURATIIONS OF FEEDER COMPONENTS

	Substation Transformer 154/34.5 kV	**Distribution Transformers 34.5/0.4 kV**	**Busbar** (Circuit Breaker+Busbar)	**Cable**
Failure Rate (1/year) [for cables: 1/year.km]	1	0.1	0.05	0.15
Average Repair Time (hour)	7	3	4	4

IV. Reliability Assesment

Due to failure probability of some system components, distribution system operators (DSOs) try to prevent interruptions which affect all consumers in the area, by means of switching equipment. However, it is very difficult to minimize the effected costumers in radial distribution systems. Even in some cases, DSOs have to disconnect all the loads [9]. At this point, a DER of an appropriate size can be connected to an appropriate point of the feeder as an alternative source to minimize the amount of load interruption. In practice, DER connection points are generally limited because of some other aspects and it is out of the scope of this paper.

There are many reliability indices that can be used to evaluate the reliability level of distribution system. Among them, system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) energy not supplied (ENS) are the most commonly used reliability indices. These common indices will be evaluated using DigSILENT PowerFactory and MATLAB as computation tools. Furthermore, load point interruption frequency (LPIF), load point interruption duration (LPID) and load point energy not supplied (LPENS) are computed and used to determine the impact of EV PLs on load point reliability indices.

In order to determine the impact of EV PL on distribution system reliability, time interval of G2V and V2G of the PL has to be specified. This study is concentrated on midday hours of operation. EVs are charged from 07:00 to 11:00 and their ASC is determined for the following hours. Then, the stored energy is discharged to the distribution grid during 11:00 to 14:00 whenever a failure occurs in this time interval.

For this operational scenario, both the costumer loads and PL load is taken into account together with the charging and discharging characteristics of the EV batteries. Typical characteristic charging curves of a Li-ion battery are shown in Fig. 6 [14].

Maximum charging power of the PL for each hour for the given charging interval is calculated by sequential MC simulations using car arrival/departure times and the charging characteristics. The resulting PL load for the specified charging interval is illustrated in Table 2.

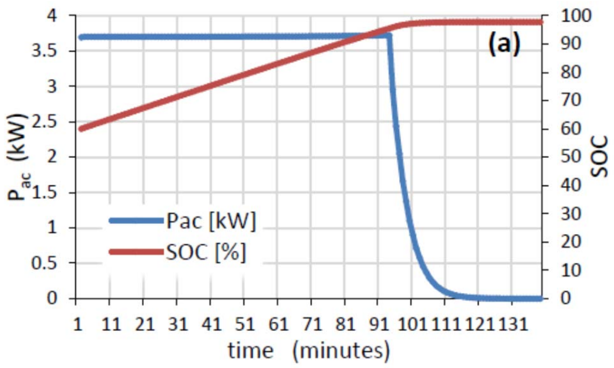

Fig.6: The power Pac and the SOC profile of the EV [14]

TABLE 2: LOAD DURATION OF THE PL

	08:00	09:00	10:00	11:00
Power (kW)	297	242.5	238.5	195

The PL is connected to the distribution system on L9, since it is the closest busbar of the feeder. In order to obtain the impact of the PL on distribution system reliability, firstly, reliability indices and load point indices are calculated using DigSILENT PowerFactory software. The PL is included in the system as a variable load at bus L9 that follows the pattern given in Fig. 6. The results of reliability analysis of this distribution system is given in Table 3, Table 4-a, and Table 4-b as base case values.

TABLE 3. BASE CASE RELIABILITY INDICES OF DISTRIBUTION SYSTEM

SAIFI (failure/customer-year)	**SAIDI** (hour/customer-year)	**ENS** (MWh/year)
2.34	12.27	30.93

TABLE 4-A. BASE CASE LOAD POINT RELIABILITY INDICES FOR L1-L5

Load Points→ **Indices↓**	**L1**	**L2**	**L3**	**L4**	**L5**
LPIF (1/year)	1.67	1.89	2.11	2.33	2.55
LPID (hour/year)	9.60	10.48	11.36	12.24	13.12
LPENS (MWh/year)	0.88	11.88	1.89	4.54	1.10

TABLE 4-B. BASE CASE LOAD POINT RELIABILITY INDICES FOR L6-L9

Load Points→ **Indices↓**	**L6**	**L7**	**L8**	**L9**
LPIF (1/year)	2.77	2.99	3.21	3.42
LPID (hour/year)	14.00	14.88	15.76	16.60
LPENS (MWh/year)	1.18	4.22	0.45	4.08

After base case calculation, storage capacity of the PL is embedded to the system model. As mentioned before, the storage capacity of the PL between 11:00 and 14:00 is almost 90% of its total capacity. It is assumed that each EV should have at least 50% of its battery SoC while departing from the PL so that it can safely get to intended destination. The remaining stored energy is injected to the distribution grid during the intended period. For this initial study, only technical requirements are considered and V2G operation is thought just for outage of the main supply and feeder components cases. If an outage occurs in given time interval, maximum 825 kW will be injected to the grid together with the relevant switching actions along the feeder.

TABLE 5: RELIABILITY INDICES OF DISTRIBUTION IYSTEM INCLUDING PL STORAGE CAPACITY

INDICES	**SAIFI** $[f/c-y]$	**SAIDI** $[h/c-y]$	**ENS** $[MWs/y]$
Value	2.22	11.64	29.49
Improvement [%]	5.13	5.13	4.66

Feeder and load point reliability indices are calculated for this operation philosophy using DigSILENT PowerFactory and an appropriate computation algorithm developed in MATLAB environment. Feeder reliability indices and corresponding improvements are given in Table 5. Load point reliability indices are illustrated in Table 6-a and Table 6-b.

TABLE 6-A. LOAD POINT RELIABILITY INDICES OF DISTRIBUTION SYSTEM INCLUDING PL STORAGE CAPACITY FOR L1-L5

Load Points→ **Indices↓**	**L1**	**L2**	**L3**	**L4**	**L5**
LPIF $[1/y]$	1.67	1.89	2.11	2.33	2.24
LPID $[h/y]$	9.60	10.48	11.36	12.24	11.48
LPENS $[MWs/y]$	0.88	11.88	1.89	4.54	0.95

TABLE 6-B. LOAD POINT RELIABILITY INDICES OF DISTRIBUTION SYSTEM INCLUDING PL STORAGE CAPACITY FOR L6-L9

Load Points→ **Indices↓**	**L6**	**L7**	**L8**	**L9**
LPIF $[1/y]$	2.43	2.62	2.81	3.00
LPID $[h/y]$	12.25	13.02	13.79	14.52
LPENS $[MWs/y]$	1.02	3.63	0.38	3.51

As seen from table 5, contribution of EV PL improves the system reliability indices by almost 5%. In this study we assumed that the load point priority is only related with the proximity to the PL injection point. Since the PL injection is limited with 825 kW, load points which are included in this power region are primarily affected from PL injection. Consequently, load point reliability indices of L5, L6, L7, L8, and L9 are improved up to almost 12.5%. However, the remaining loads which are connected far from the L9 are not affected from this PL injection. It is clear that, changing the connection point and the maximum power limit of the PL, reliability improvements of the load points will be different.

V. CONCLUSION

This paper has presented impact of EV PL on distribution system reliability indices. Firstly, real data of car arrival/departure pattern of a representative PL in Istanbul is used to obtain ASC of a sample EV PL in Istanbul. This model is then used to calculate the reliability indices of distribution feeder which is a part of BEDAS system. Existing connection of the PL at the end of the feeder is used as it is. For this initial phase of the study, it is assumed that the PL is used as an alternative DER for the grid during 11:00 am-2:00 pm time period. Moreover, PL injection is done whenever a failure occurs in the supply or in the components of the feeder. Finally, in order to ensure safe travel of the cars after departing from the PL, injection to the grid is done as far as the EV battery storage is greater than 50% of its rated values.

Feeder (system) reliability indices and load point reliability indices are determined under these operation conditions. The results have shown that the SAIFI, SAIDI and ENS of the system were almost improved by 5%, even for these limited operating conditions. Furthermore, load point indices were improved up to 12.5% depending upon the proximity of PL connection point.

The aim of this study is to show an EV PL which can be used as an effective DER and it will be developed using more realistic case studies to determine reliability improvement of the PL. Also we want to extend the study to obtain economic impact of the EV PL as a DER using dynamic pricing.

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