International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 837

A Case Study of EV Charging Behaviors and Electricity Demand of a Public Car Park in England

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ABSTRACT

This work analyzes a real-life dataset of charging records to understand charging behaviors at public charging stations. Data analytics were carried out to understand the statistical distribution of EV charging time, peak charging period, charging duration, seasonal and yearly effects, etc. The study was carried out with charger-centric data of a public car park in England, containing more than 12,000 charging records from 2016 to 2020. The results found that rapid charger (up to 50kW DC) is 3 times more popular than the fast charger (single-phase 7kW) and delivers 4 times more energy than the fast charger. This work will greatly help Charge Point Operators and Power Distribution Networks Operators for EV charging infrastructures planning and operations.

Keywords: electric vehicles, EV charging, EV charging behavior

1. INTRODUCTION

Electric Vehicles (EVs) have been widely recognized as one of the most credible technologies to achieve zero emission road transport. In recent years, the number of EVs has been growing exponentially and becoming mainstream green transportations. The UK Government is going to decarbonize transport further and faster by phasing out the sale of new petrol and diesel cars and vans by 2030, with all new cars and vans to be zero emissions at the tailpipe by 2035 [1].

Along with the increase in EV numbers and the development of battery technologies, the EV charging behavior has drawn a lot of attention. An earlier study about EV driving and charging behavior was conducted in [2], analyzing the statistical data of 2,903 in-use vehicles. These data include the distance driven per day, charging locations, the charging event frequency and the State-of-Charge (SoC) at the start and end of charging events. The work provided some understanding of public charging behaviors. A statistical analysis of EV charging behaviors in the UK was carried out in [3]. The data analyzed came from 221 residential EVs (NISSAN LEAF with battery capacity of 24 kWh). A few charging features were discussed, such as the connections per day, start charging time, initial SoC, final SoC, weekday and weekend charging. By using the Gaussian Mixture Models (GMMs), the probability density function of charging behavior was produced along with a statistical charging profile, but the results were restricted to one EV model. An open-source EV charging dataset of ACN-Data were released and studied in [4]. User behaviors, e.g., the arrival and departure time, charging duration and energy obtained from chargers were illustrated and learned by using GMMs. Arrival time-based predictions were conducted for the EV charging stations to forecast the user's departure time and energy consumption. Survey data of individuals' travel habits were used to anticipate EV charging behaviors in [5]-[7]. Survey data can provide some generic estimations of charging behaviors and predictions of charging demands, but they are not realistic representations of real-life scenarios.

Accordingly, this paper analyses a real-life dataset of charging records to understand charging behaviors. The data analyzed are charger-centric data of a public car park in England, containing more than 12,000 charging records from 2016 to 2020. Statistical analysis was carried out considering the start and end charging time of a day, peak charging time of a day, charging duration,

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

seasonal and yearly effects, etc. This work particularly observes EV charging behaviors from the perspective of public charging stations and presents an early study of the electricity demand forecasting. It will greatly help the Charge Point Operators for their charging infrastructure planning and operations and allow the Distribution Network Operators to plan well in providing sufficient grid capacity for EV charging.

2. EV CHARGERS & HISTORICAL EV CHARGING DATA

The charging power rating of an EV depends on the type of connectors and charging stations. In the UK, the most common categories of charging stations are rapid, fast and standard [8]. The key attributes of chargers are demonstrated in Table I.

Table 1. EV charger types in the UK

Type	***Rated Power***	***Power Supply***	***Location***
Rapid	43 kW	AC	Service stations, etc.
	50 kW	DC	
	100 kW	DC	
	150 kW	DC	
	350 kW	DC	
Fast	7 kW	AC	Shopping centres, etc.
	22 kW	AC	
	25 kW	DC	
Standard	3.5-7 kW	AC	Home, etc.

Rapid chargers supply high-power Direct Current (DC) or Alternating Current (AC) to charge vehicles. Typical power ratings are 50 kW DC (or 43 kW AC), 100 kW DC, 150 kW DC and 350 kW DC, differing by EV models and connector types. The 150 kW DC rapid chargers will become very common, but across the UK most are still 50 kW DC (or 43 kW AC) charging stations [9]. Rapid chargers can provide at least about 100 miles of range in half an hour, so that they are often used for en-route charging. In addition, to keep EV batteries healthy, rapid chargers do not consistently charge at their typical power ratings. Fast chargers provide AC charging with a rated power of either 7 kW (single-phase) or 22 kW (three-phase). Rare fast chargers supply DC power. By far most public charging stations in the UK are single-phase 7 kW devices, which can provide around 23 miles of range per hour. Thus, fast chargers are common in places where EVs might be parked for several hours, such as shopping centers. Slow chargers are rated up to 7 kW AC, and the common available power ratings are 3.5-3.7 kW [9]. The slow charger is typically used for top-up charging at home and workplaces. The approximate range per hour charging is 12 miles.

The data analyzed in the paper were collected from 8 chargers in a public car park in England. It contains more than 12,000 records over 5 years from 2016 to 2020. Each record has the start charging time, end charging time, consumed energy in kWh and vehicle tag serial. Each vehicle has an identical 'tag serial' and the chargers can recognize the same vehicle by the vehicle's tag serial. It is found that there were 490 vehicles charged in the car park (with 8 charge points) in the 5-year period, 30 of which charged more regularly, i.e., having more than 100 charging records.

The specifications and usages of the 8 charge points are shown in Table II. There are 6 single-phase fast chargers with power rate of 7 kW. The total electricity consumption for the 5-year period was 25,500 kWh with an average number of uses per day of 2.3. There is 1 fast charger with power rate of 22 kW (3-phase). The total energy consumption was 1,264 kWh and it was used 0.4 times per day on average. There is 1 rapid charger with power rate of 43 kW AC or 50kW DC. The total electricity consumption was 120,094 kWh, and the average number of uses per day was 6.6. It is found that the rapid charger was two times more frequently used than the single-phase fast charger. The rapid charger delivered 4 times more energy than the single-phase fast charger. The differences are even more significant when comparing with the three-phase fast charger. Therefore, it is clearly shown that the rapid charger was more popular and more effective in providing charging services to EV drivers than the fast chargers.

Table 2 Comparison of different types of EV chargers

Type	***Rated Power***	***No.***	***Total Consumption***	***No. of Uses***
Single-phase Fast charger	7 kW	6	25,500 kWh	2.3/day
Three-phase Fast charger	22 kW	1	1,264 kWh	0.4/day
Rapid charger	43 kW AC	1	120,094 kWh	6.6/day
	50 kW DC			

3. CHARGING BEHAVIOR ANALYSIS

Charging records collected from 6 single-phase fast chargers were statistically analyzed in this section to find charging characteristics. Yearly and seasonal effects on charging behaviors were analyzed through average daily profiles. The real speed of chargers was obtained by clustering. In addition, the probability distributions of the charging speed, charging amount, and start/end charging time of all charging records were analyzed and presented.

3.1 Yearly demand profiles

Average daily demand profiles from 2016 to 2020 are shown in Fig. 1. There are many similarities among these profiles. First, there were very little demands from 0am to 6am, then the charging demands increased sharply and remained high values until 6 pm. After that, the charging demands decreased gradually toward midnight. Due to the location of the public car park, there were few cars charging in early mornings, and most of charging events happened during daytime from 9 am to 6 pm. This behavior can be understood because the analyzed car park is located near working places and public transportation hubs.

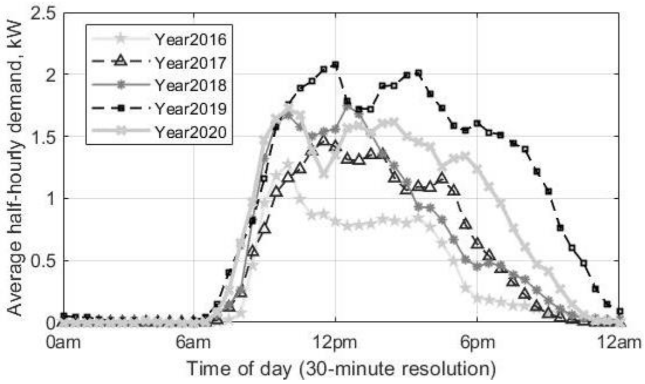

Fig. 1. Daily EV charging demand profiles from 2016 to 2020

3.2 Seasonal demand profiles

Average daily demand profiles in each season are statistically analyzed as shown in Fig. 2. It reveals that the EV charging demands in autumn and winter were greater than that in spring and summer. The peak of the power demand was 2.5 kW in autumn, compared with that of 1.2 kW in spring. Moreover, the average daily energy consumption was 19.17 kWh in winter and 18.99 kWh in autumn, while the consumption was 11.65 kWh in spring and 11.97 kWh in summer. This shows that the demand in spring was similar to that in summer but different from autumn and winter.

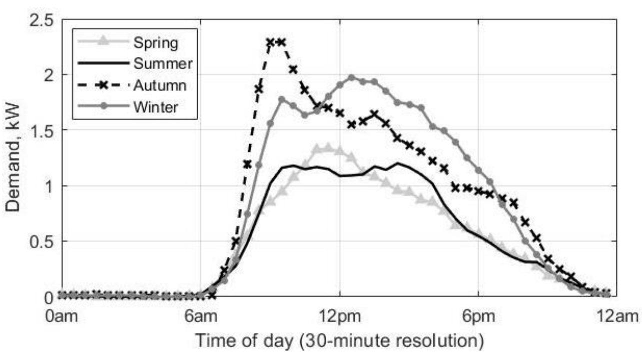

Fig. 2. Daily EV charging demand profiles in different season

3.3 Charging slop – the speed of charging

Fig. 3 plots charging records of all vehicles with charging duration shorter than 200 minutes for simplicity. Each dot represents one charging record. Based on slops of the dots, these charging records were divided into two groups by using the un-supervised K-means clustering algorithm. The centroid of the largest cluster is at 85 minutes, 5 kWh (slop 3.5 kW).

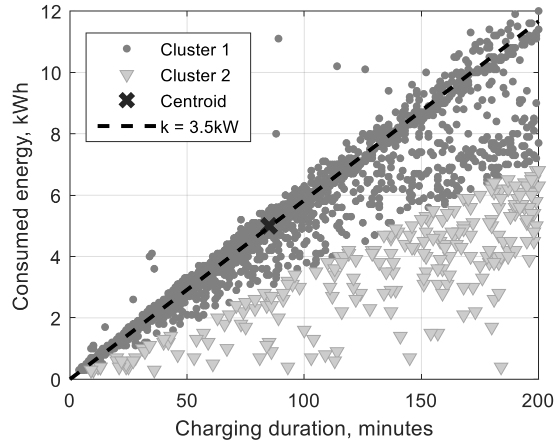

Fig. 3. Consumed energy versus charging duration for all charging records

The probability distribution of the value of charging slopes for all records is presented in Fig. 4. According to Fig. 4, around 43% of charging records had their charging slope greater than 3 kW, which is close to the power rating of the single-phase fast charger. This indicates that almost half of vehicles used the parking sessions at the public car park for charging, i.e. these vehicles did not, or just, get fully charged when finishing the parking sessions. In the contrast, there are 12% of charging records having a charging slope under 0.5 kW. These vehicles either parked for a long period of time or required a small amount of energy to be fully charged.

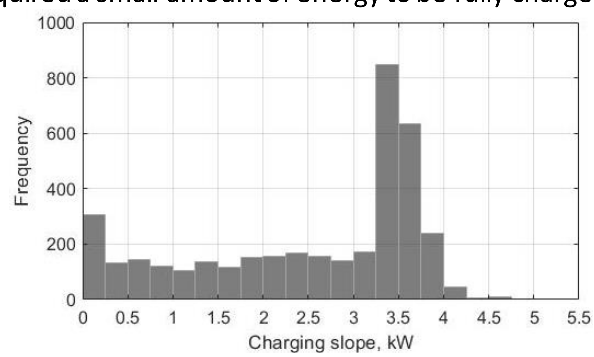

Fig. 4. Probability distribution of the charging speed

3.4 Charging amount

The probability distribution of the electricity consumption of all charging records is shown in Fig. 5. It found that the distribution was concentrated around 5 kWh. Assuming the fuel economy is 30 kWh/100 miles for new EVs [10], the 5 kWh energy consumption equals to a travel distance of 17 miles, which is in line with the statistics of that cars in the UK drive an average of 20 miles a day.

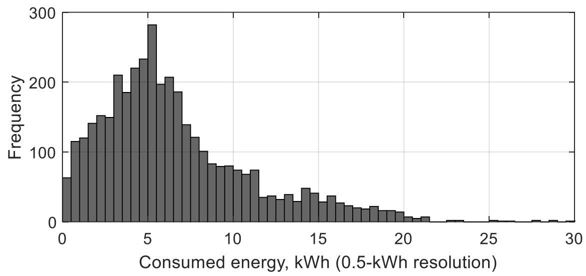

Fig. 5. Probability distribution of the charging amount

3.5 Start/end charging time

The probability distributions of the start and end charging time of charging records are shown in Fig. 6 and Fig. 7. Fig. 6. shows that 9 am was the most popular hour for the EV start charging time. Fig. 7 shows that the peak leaving time was at around 1 pm.

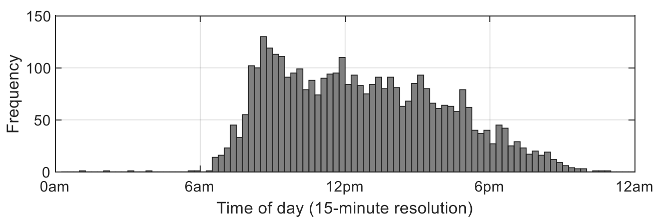

Fig. 6. Probability distribution of the start charging time

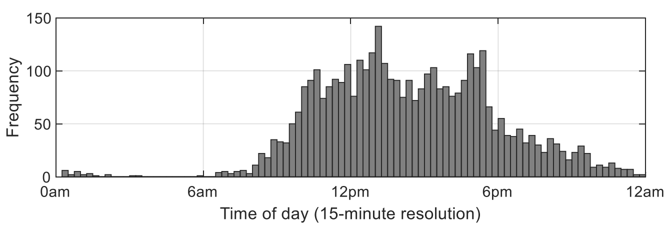

Fig. 7. Probability distribution of the end charging time

4. CONCLUSION

This paper analyses a real-life dataset of charging records to understand EV charging behaviors in public car parks. The data analyzed contained over 12,000 charging records at a public car park in England. This work provides some initial understanding of EV charging behaviors at public car parks, detailing the daily charging profiles with seasonal and yearly effect. The analysis results showed that the rapid charger is much more popular than the fast charger and 1 rapid charger provided 4 times more energy to EVs than 7 fast chargers all together for the same time period. This work will greatly help Charge Point Operators and power Distribution Networks Operators for EV charging infrastructures planning and operations.

ACKNOWLEDGEMENT

This work was supported in part by the Innovate UK, 'Advanced grid services provided by optimized EV community and fleet charging' project (ref 81425), and the EPSRC 'Mobility as a service: MAnaging Cyber Security Risks across Consumers, Organisations and Sectors (MACRO)' (EP/V039164/1).

REFERENCE

[1] Hirst D, Winnett J, Dempsey N, Hinson S. Electric Vehicles and Infrastructure. House of Commons Library; 2021.

[2] Smart J, Schey S. Battery Electric Vehicle Driving and Charging Behavior Observed Early in The EV Project. SAE International Journal of Alternative Powertrains. 2012;1;1:27-33.

[3] Quirós-Tortós J, Ochoa F L, Lees B. A statistical analysis of EV charging behavior in the UK. 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM). 2015:445-449.

[4] Lee J Z, Li T, Low H S. ACN-Data: Analysis and Applications of an Open EV Charging Dataset. In Proceedings of Proceedings of the Tenth ACM International Conference on Future Energy Systems (e-Energy '19). 2019:139-149.

[5] Shen Y, Fang W, Ye F, Kadoch M. EV Charging Behavior Analysis Using Hybrid Intelligence for 5G Smart Grid. Electronics, 2020;9;1:1-17.

[6] Sioshani R, Denholm P. Emissions Impacts and Benefits of Plug-In Hybrid Electric Vehicles and Vehicle-to-Grid Services. Environmental Science & Technology, 2009;43;4:1199-1204.

[7] Kang E J, Recker W W. An Activity-based Assessment of the Potential Impacts of Plug-in Hybrid Electric Vehicles on Energy and Emissions Using 1-day Travel Data. Transportation Research Part D: Transport and Environment, 2009;14;8:541-556.

[8] GOV.UK. Electric Vehicle Home Charge Scheme: minimum technical specification. 2020.

[9] Local Government Association. Electric vehicles: What are the different types of charge point? 2021.

[10] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. U.S. Environmental Protection Agency. Fuel Economy Guide 2021. 2021. [Online].