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Based on Smart Grid Regional Demonstration Project – Los Angeles

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***Abstract*—In order to evaluate the impact of electric vehicles (EVs) on the distribution grid and assess their potential benefits to the future smart grid, it is crucial to study the EV charging patterns and the usage charging station. Though EVs are not yet widely adopted nationwide, a valuable methodology to conduct such studies is the statistical analysis of real-world charging data. This paper presents actual EV charging behavior of 64 EVs (5 brands, 8 models) from EV users and charging stations at Los Angeles Department of Water and Power for more than one year. Twenty-four-hour EV charging load curves have been generated and studied for various load periods: daily, monthly, seasonally and yearly. Finally, the effect and impact of EV load on the California distribution network are evaluated at different EV penetration rates.**

***Index Terms*—Electric Vehicles, Smart Grid, Statistical Analysis, Charging Station, Grid Impact**

I. Introduction

The increasing penetration rate of electric vehicles (EVs) in the U.S. is expected to bring great contribution to reduce greenhouse gases (GHG) and the need to use traditional fuels. It has been studied that the integration of EV charging on the grid may have significant potential impact on the grid [1]-[3]. However, if EVs can be effectively integrated, they will also play a crucial role to reduce other system impacts and become great resources for smart grid infrastructure [4], [5]. In order to understand the corresponding quantitative impacts, it is important to study and analyze how EVs are being used and how EV owners are interacting with their EVs including their charging patterns.

This research paper is based on the Los Angeles Department of Water and Power (LADWP) Smart Grid Regional Demonstration Project (SGRDP), which is a five-year leading edge demonstration project that encompasses installation of smart-grid equipment, collection of system data, construction of equipment models, performing power system studies, formulation of operating strategies, and development of software and techniques related to the above-mentioned areas of smart grid. University of California, Los Angeles (UCLA), Jet Proportion Lab (JPL), and University of Southern California (USC) are partnering with LADWP in this project.

The objective of this paper is to present some results of the EV demonstration project, specifically the charging station and EV usage in Los Angeles, CA. The usage of EVs and charging stations, as well as the charging patterns were recorded and analyzed by LADWP for 64 EVs. 7,334 charging events have been recorded for a time period of one year, from February 2015 to February 2016. The results will be used to provide information and practical insights for LADWP and other similar utility companies for planning and design of EV infrastructure as well as providing policy makers data for implementation of policies and future infrastructure such as wireless charging for EV.

The data requirement for the analysis is collected by each EV charging station that collects and sends utilization data to a main server. Data transfer will occurs primarily through the Advanced Metering Infrastructure (AMI) network with additional communications. Power consumption data is stored using timestamp information. In addition, the miles driven between each charging session are collected for statistical analysis and EV driving characterization. Once enough power consumption data is collected to determine usage patterns and load curve shapes, analysis will be performed to investigate the feasibility of using EV chargers to levelize load curve shapes by removing/reducing peaks and valleys. Another benefit of charger monitoring will be the ability to detect a charger failure in timely manner.

This paper first gives an overview of the EV demonstration project activities and describes the methodology used (Section II). Section III presents statistics of EV charging record, while Section IV analyzes the EV usage. Section V describes the results and analysis of the charging station usage. Section VI discusses the potential impacts and suggestions of EV charging on the grid. Finally, the conclusions based on this analysis and future work are presented in Section VII.

The research work was conducted under ARRA Smart Grid Regional Demonstration Project (Federal Grant Number DE-OE0000192) and funded by the US Department of Energy and Los Angeles Department of Water and Power.

II. Methodology

A. *EV Status*

For this study, 64 EVs in 5 brands and 8 different models were used in LADWP. The specific model and battery size are shown in Table I.

TABLE I. EV Model and Battery Size

Brand	Model	Number of Vehicles	Battery Size (kWh)
Chevrolet	Volt	14	16
Ford	C-Max Energi	2	7.6
	Focus	3	23
	Fusion Energi	2	7.6
Mitsubishi	i-MiEV ES	3	16
Nissan	Leaf	27	24
Toyota	RAV4	10	42
	Prius	3	4.4

B. *Charging Stations and Data Collection*

Multiple EV charging stations are available in LADWP consisting of Level 2 and 3 chargers [6]. In total, 251 chargers are available, including 14 DC fast chargers and 237 level 2 chargers. These chargers are available in Parking Levels 1, 2 and 3 of the John Ferraro Building (JFB) for the LADWP workers and visitors to charge their EVs. Parking Level 3 arrangement is shown in Figure 1.

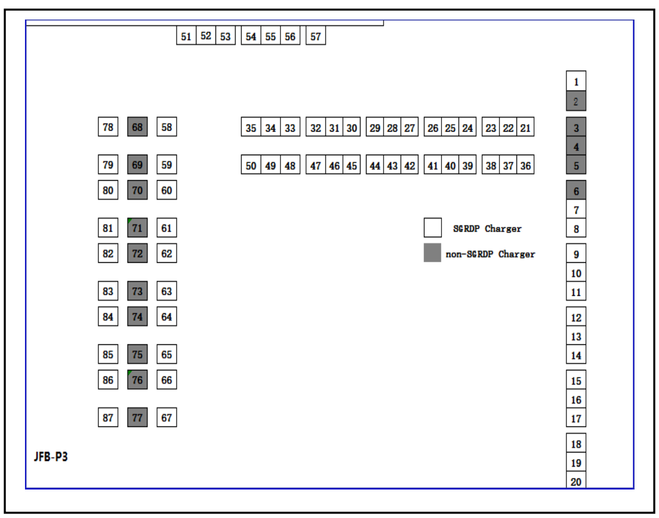

Figure 1. LADWP JFB Parking Level 3 Charging Station Arrangement

All level 2 chargers were using US/Japan standard type J1772, level 3 chargers were installed and complied with CHAdeMO standard connector [7]. The output power for level 1, 2 and 3 were 1.9 kW, 6.6 kW and 24 kW, respectively.

C. *Charging Events and Data Interpretation*

EV charging records received from FleetCarma have start time, duration, charging level, charging energy (kWh), charging loss (kWh), starting and ending state-of-charge (SOC) (%). A charging record is defined as a session that starts when an EV's charging hatch is opened and ends when the hatch is closed. 7,334 charging events have been filtered and analyzed in this paper for a time period of one year, from February 11st, 2015 to February 12th, 2016. All data were recorded and updated in FleetCarma.

III. EV Charging Pattern

Charging data were obtained from the receivers in all of the EVs. Charging patterns were analyzed based on charging plug-in time, and total energy transferred per charging event.

Figure 2 shows the energy delivery for every EV charging at LADWP from February 11th, 2015 to February 12th, 2016. It can be noticed that 90% of charging events transferred less than 9.1 kWh. Because of the Christmas and New Year holiday, very few charging events took place during these two time periods. Also, there were few charging happen between February 2015 and May 2015. This was because not many EVs were equipped with data receivers and only few charging events were recorded during that time period.

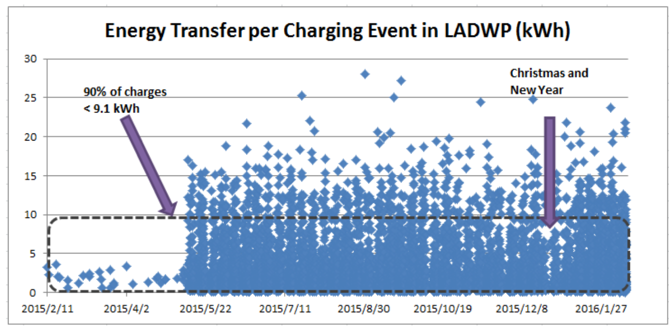

Figure 2. Energy Delivery per Charging Event in LADWP from February 2015 to February 2016

In Figure 2, no adjustments were made for the type of charger used or the type of vehicles. As outlined in Section II above, the three types of chargers used have different energy transfer rate capacities. Furthermore, the various classes of vehicles in the study have different battery sizes and thus different energy storage capacity. Data analysis with adjustments for each charger type and vehicle class is not useful as this time due to the sample size of the data. As we have more data and more vehicles in each class in the future, we will provide a more refined analysis.

The histogram of the charging plug-in time intervals over the whole 7,334 charging events is plotted in Figure 3. Out of all charging events, 80% (5867/7334 events) of EV users parked and plugged in their EVs for less than 2 hours. Less than 1% (51/7334 events) of the time EV users would plug in their EVs for more than 5 hours.

Included in the plug-in time data of Figure 3 is the actual charging time of the EVs. This is a function of the battery SOC at the time of plug-in, the level of charger used, the vehicle battery size, and the SOC at the time of disconnection. The data collection devices don't have these data to make adjustments to accurately describe the charging time. Other indirect methods such as the miles driven between charges, the charger type used and the battery size can be used to make approximations for the actual charging time. This analysis is still undergoing and will be reported in future publications.

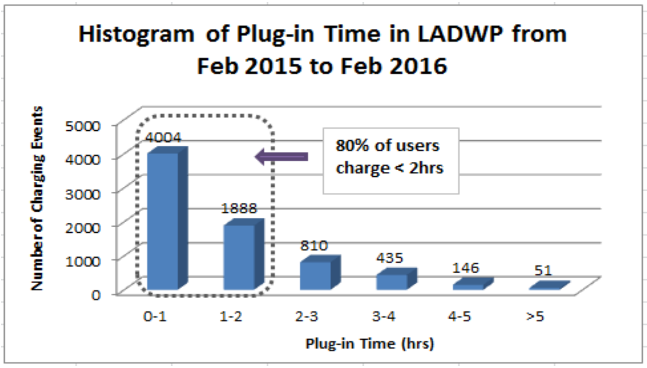

Figure 3. Histogram of Charging Plug-in Time in LADWP from February 2015 to February 2016

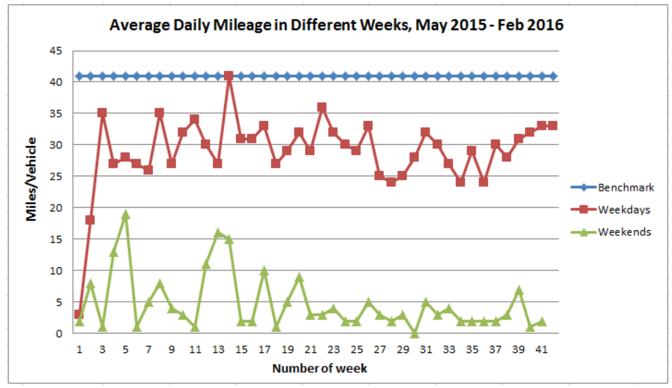

Figure 4. Average Daily Mileage in Different Weeks in LADWP from May 2015 to February 2016

IV. EV Usage Analysis

The EV usage information will be presented and analyzed in this section, including average trip details, equivalent MPG, electricity usage and etc. Since only limited EV usage data were logged during February 2015 through April 2015, the study analysis in this section will only focus on data recorded from May 1st 2015 until February 12th 2016.

Tables II and III list detailed information on LADWP EV usage by brand and type, respectively.

TABLE II. EV Usage By Brand

Brand	Model	Average Total Distance (mi)	Average Daily Distance (mi)	MPG eq	Idle (%)	Electricity Usage (kWh)	Electric Distance (%)
Chevrolet	Volt	3686	39	67	34	479	75
Nissan	Leaf	1536	11	128	45	395	100
Toyota	RAV4	2911	27	93	28	1057	100
	Prius	3707	43	53	22	61	27
Ford	C-Max Energi	6193	55	52	15	500	31
	Focus	7825	75	49	24	385	19
	Fusion Energi	204	8	84	63	63	100
Mitsubishi	i-MiEV	706	5	88	62	325	100

TABLE III. EV Usage By Type

Type	Total Distance (mi)	Average Daily Distance (mi)	MPG eq	Idle (%)	Electricity Usage (kWh)	Electric Distance (%)
Plug-in Hybrid Electric Vehicle (PHEV)	4584	46	60	28	415	54
Battery Electric Vehicle (BEV)	1662	14	112	44	507	100

There were 42 weeks in the time period of the analysis. The average EV usage in these 42 weekdays and weekends were described in Table IV and Figure 4 below.

TABLE IV. Average EV Usage in Weekday and Weekend

	Vehicles #	Total mi	Daily mi	Benchmark-Daily mi/Veh	Daily On hours	Ave Start SOC%	Ave End SOC%
Weekday	54	5,647	29	41	1	81	65
Weekend	19	96	5	41	0	81	77

V. Charging Station Usage

The data of charging station were obtained primarily through the AMI network with additional communication of all chargers. Power consumption data are stored using timestamp information. Twenty-four-hour energy distribution were plotted and analyzed to obtain daily, monthly, quarterly, and yearly load curves.

A. Weekday vs Weekend Energy Distribution

Figure 5 is a comparison of 24-hour average energy distribution between weekday and weekend. It can be seen that there was almost no energy transferred to all EVs in the weekends, compared to weekdays. The reason is because the EVs would only be used and charged in the weekdays.

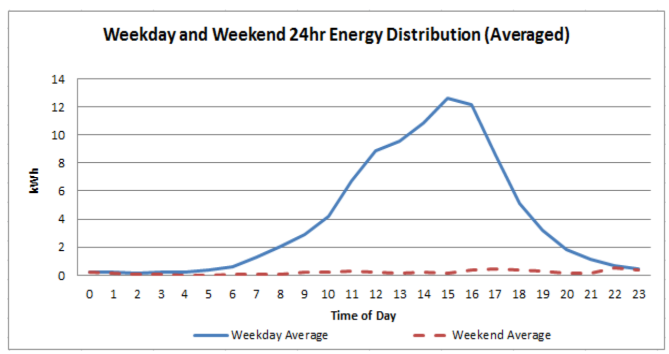

Figure 5. Comparison of Normalized Weekday and Weekend 24 hour Energy Distribution in LADWP from February 2015 to February 2016

B. Energy Distribution in Different Seasons

Figure 6 is a comparison of 24 hour normalized energy distribution in four seasons in 2015. Each curve represents an averaged one day energy distribution in different season.

In summer and winter 2015, the charging energy consumed was more than the other two seasons. One reason was EV users tend to turn on the air conditioner more often to feel comfortable when driving their EVs. Another possible reason was the high heat would cause the EV battery run out of electricity sooner than other conditions. It can be noticed that the charging energy distribution are almost identical in the summer and winter season except the slight difference in the morning time from 6-10 am (hour-ending 07 to hour-ending 11). This is probably because more EV users would turn on their air conditioner in the winter due to the low temperature in the morning when they started to drive the EV. Therefore, the electricity remained in the battery would be less, compared with summer season, when they arrived at work and started charging.

The spring season energy distribution curve was much lower compared with other seasons because only few EVs were used and very few charging events were logged in those three months.

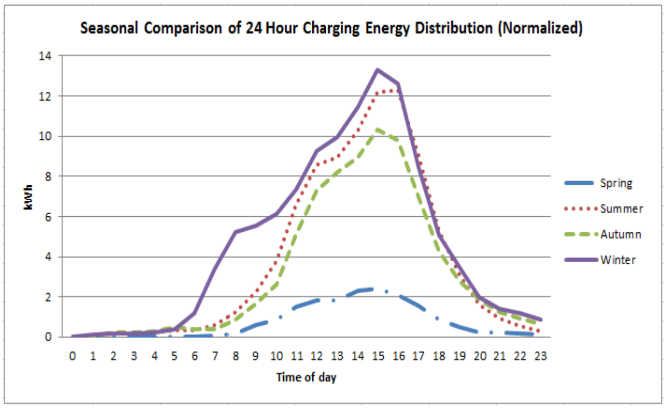

Figure 6. 2015 Seasonal Comparison of 24 Hour Cumulative Charging Energy Distribution in LADWP

C. 1 Year Cumulative Energy Distribution

Figure 7 is the cumulative 24 hour energy distribution for all charging in one year, from February 2015 to February 2016. It can be seen from the figure that the cumulative load curve has one peak, between 3-4pm. The cumulative peak value of all testing EVs charging in LADWP reached 3200 kWh. This EV charging load curve looks pretty similar to the summer daily load profile in California [8].

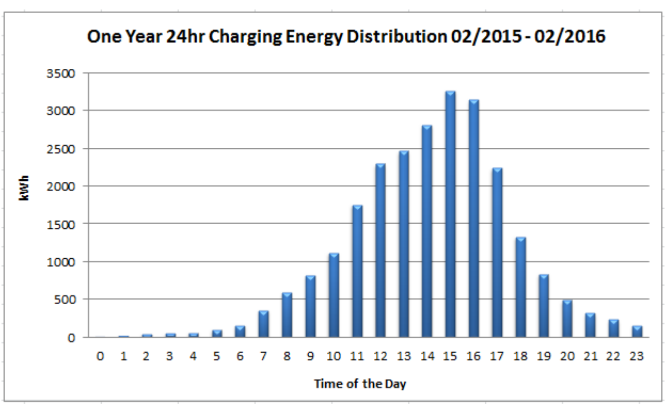

Figure 7. One year Cumulative 24 hour Energy Distribution in LADWP from February 2015 to February 2016

VI. Discussion

A typical daily load variation in California in different seasons is shown in Figure 8 below [8]. It can be seen that the daily peak time occurred in the afternoon from 2-6pm, while off-peak hours were in the early morning, between 2-6 am.

In 2014, California had the most Plug-in Electric Vehicles (PEV) registrations of all states with 126,283 PEV registrations among 38 million residents, 3.25 PEVs/1000 people [9]. With continuing rapid growth of the adoption rate of EV, the demand in distribution networks is expected to increase. Data analyzed in the previous sections represents a group of 64 EVS and more than 1000 EV daily commuters, and it can be used to estimate the potential demand increments brought by EV charging. Figure 9 compares the total daily load curve of different EV penetration rate at 10%, 20% and 30%, respectively, in California summer season.

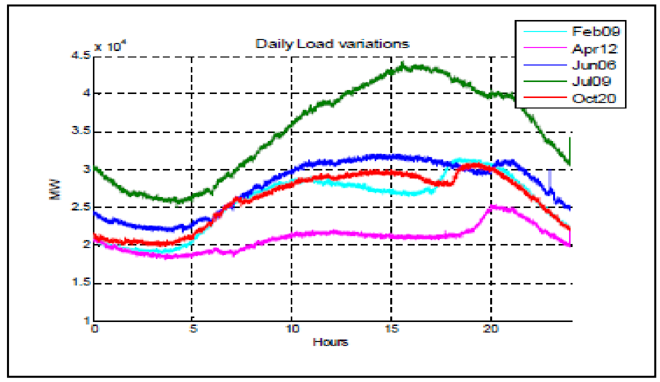

Figure 8. Daily Load Variation in California by CAISO

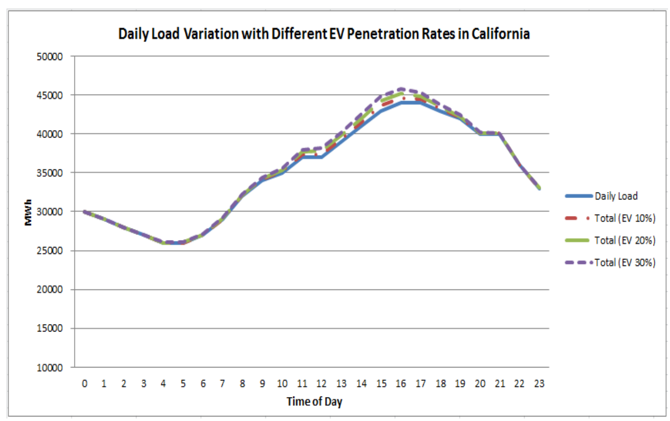

Figure 9. Daily Load Variation with Different EV Penetration Rates

Figure 9 suggests that EVs have the potential to increase the demand in the daytime when EV users arrive at work and start connecting the EVs to the charging station. If coupled with renewable energies, such as installing PV panels and wind turbines, the EV charging increments could be offset.

VII. Conclusion

This paper presents a detailed analysis based on SGRDP to evaluate the impact of EV charging patterns as well as the charging station usage on the grid. 64 EVs on 5 brands and 8 models, and multiple chargers at level 1, 2 and 3 were selected and tested in LADWP. EV charging events were recorded from February 11th, 2015 to February 12th, 2016. Energy transferred for all 7,334 charging events were studied and the plug-in time per charging were examined. As for charging station usage, 24 hour energy distribution were plotted and analyzed daily, monthly, seasonally, and yearly. The statistic results will be used to provide information and practical insights for utility companies to make city planning and future installations of the EV charging infrastructures [10]-[12].

The result from EV charging events implement that 90% of charging events transferred less than 9.1 kWh. Regarding the EV plug-in time, 80% of the time EV was connected for less than 2 hours, while less than 1% of the time EV users plugged in their EVs for more than 5 hours.

From the charging station usage, it can be concluded that energy peak brought by EV charging from the grid was between 3-5 pm. The 24 hour charging energy distribution curve is pretty similar to the daily load curve in California. Charging stations delivered most of the energy to all EVs during daytime, which could be offset by installing PV panels and solar systems [13].

The next step in this project is to continue collecting EV charging and station usage data to keep updating the current conclusions. PV panels have been installed at the charging stations to serve EV charging and vehicle to grid (V2G) experiments have been done to reduce the daily peak [14], [15]. A thorough analysis will be made based on the real data logged when charging stations coupled with these two technologies.

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