Impact of EV Charging Schedule on Storage Requirements for a Renewable-driven Grid in California

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***Abstract*—California is going through a transition towards electric vehicles (EVs) as a pathway to its decarbonization goals. As the number of EVs on the road increases, the load profile will shift, and will affect the role of energy storage in a renewable-driven grid depending on whether the charging infrastructure enables EV charging to be a flexible or inflexible load. This paper considers daytime and nighttime EV charging profiles assuming the anticipated number of EVs and investigates the impact on different types of storage in a renewable-driven grid in California. A hierarchical-storage technique is used to understand the role of different charging profiles on the minimum number of cycles and size of energy storage required in a zero-carbon grid.**

***Index Terms*—electric vehicle, charging profile, load, storage, solar, renewables**

I. INTRODUCTION

Many countries are setting policy targets to reach zero-carbon emission by mid-century. According to data from 2020, the power industry and transportation sector emissions are around 36.5% and 20% of the global emissions, respectively [1]. Decarbonizing these two sectors could make the transition towards renewable energy easier and fast achievable. As defined by the Environmental Protection Agency (EPA), transportation (29%) is the largest sector of GHG emission in the US followed by electricity (28%) [2]. To decarbonize the transportation part, we need to put more effort on vehicle electrification, EV charging infrastructure, and demand flexibility. To guide those efforts, it is useful to analyze the effects of a large number of EVs on a decarbonized grid.

California is largely affected by emissions from the transportation sector. It was reported that 41% of the total CO2eq emissions in 2021 comes from transportation [3]. California Air Resources Board is planning to phase out the sale of any gasoline-powered light-duty vehicles by 2035 [4]. More EVs on the road will need more expanded charging infrastructure and the associated load profile will depend on the type of infrastructure that is installed. The resulting load profile will be sensitive to the EV charging pattern and will impact the energy storage requirements of a decarbonized grid. Majidpour, et al [5] show the methodology of how to model and analyze the load demand due to battery charging of the electric vehicles in a distribution system. However, they do not investigate the potential change in load profile for large scale of EVs with varying charging schedules in the future and associated impact on the storage system in a decarbonized grid. For changes in demand profile due to introduction of more EVs, a capacity expansion model with multistage distribution is presented in [6]. They show the model to help the manufacturers on their investment decisions in energy storage systems. They also conclude that the energy storage could minimize investment and operational costs without expanding existing substations for increasing EV charging demand. Mowry, et al [7] show that the annual operational cost increases by 8% for grid and highway-fast-charging interaction, especially due to transmission congestion. Longer duration energy storage could be highly effective in those stations, and it might mitigate the overall cost increase as suggested by the analysis. Both studies provide useful answers to the extent that the costs are known, but do not give the complete picture of the required energy storage, especially when the results are dependent on the specifics of the cost assumptions that are used. They discuss more on the overall system cost rather than the requirements for cycling the storage. In this work, we estimate the minimum requirements for the amount and frequency of use of energy storage for a given set of load and generation profiles considering anticipated charging of EVs in the future.

II. DATA AND METHODOLOGY

This study analyzes the impact of EV charging schedule on energy storage requirements in a decarbonized grid in California using energy balance approach. We focus on the mismatch between load and generation and how that affects the diurnal as well as seasonal needs of storage. For this analysis, we consider two potential EV charging schedules: (i) daytime charging and (ii) nighttime charging as shown in Figure 1. Daytime charging is based on the EV owners who might charge it just after reaching their workplace. Long-haul freight trucks run by electricity may be charged primarily during the

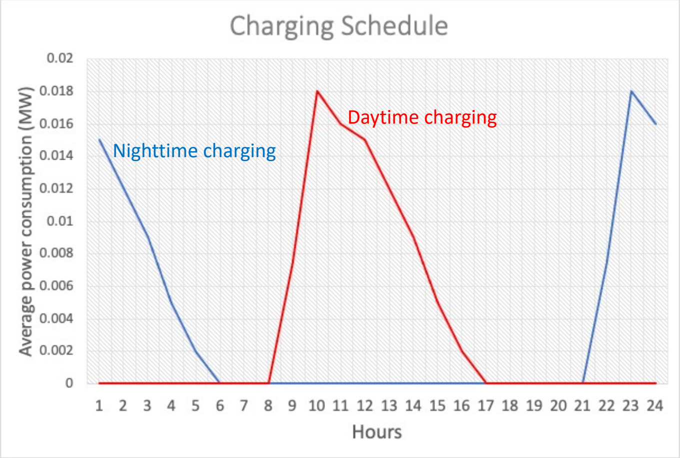

Fig. 1. Charging schedule used in this analysis.

day. Alternatively, nighttime charging is based on the people who charge their EVs after returning home at night.

For load and generation, we use 2019 five-min resolution data reported by CAISO [8]. We estimate adding 0.8 million EVs to the amount of EVs in 2019 so the total number reaches around 1 million that aligns with the future approximation in [9]. After considering additional amount of EVs, total annual load increases by roughly 25 TWh which is equal to 12% of 2019 annual load. Average power consumption was considered as mentioned in [10]. For this work, we assume the total generation to be 120% of the total annual load. Current generation from 2019 CAISO data which includes solar, wind, biogas, geothermal, small hydropower, and large hydro sums up 35.5% of total annual load. We scale up the current (2019) solar generation to cover that additional 84.5% resulting in 120% of annual load. We assume scaling up existing solar generation with no change in profile might be one of the potential energy mixes in a future renewable-driven-grid in California. For both scenario, amount of total annual load (after EV addition) and generation (after scaling up) remains constant though the load profile varies for two different charging schedules. In this study, round-trip efficiency of the storage is assumed 80%. For daytime and nighttime charging, storage efficiency losses are different as storage is cycled more frequently for the nighttime charging. After including the losses in both cases, total generation also shows different numbers potentially leading to a difference in need of storage. To investigate the impact of total annual load on storage requirements, we adjust the amount of load from EV charging in a way that the added load contributes to 6%, 12% and 18% of total annual load for three different cases as we don't know the exact number of future EVs. We consider a grid with perfect transmission capability. Uncontrolled charging of EVs is considered for this paper. It is predictable that there will be potential resources like winter dominant wind, latitude tilted solar, offshore wind and some others with various generation profiles which might play a greater role in meeting the future load. We don't cover them in this study.

III. RESULTS AND DISCUSSION

We plot the minimum number of cycles in the y axis as a function of storage size in the x axis. We classify the storage types according to the definition used in this analysis, it might be different for any other study. We use log-log axis to show the details of diurnal and seasonal storage needs. Figure 2 represents the effects of shifting schedule of charging EVs. As we can see, nighttime charging needs more diurnal and seasonal storage than daytime charging. Regarding diurnal storage, the need increases from 0.21 TWh to 0.284 TWh. As the added generation is completely solar and it cannot support the nighttime charging directly, the rise in diurnal needs is expected. However, a wind-dominated grid (where the fraction of wind is more in the energy mix) might decrease the diurnal needs as wind blows high during the night. For required size of seasonal storage, it increases by 2 TWh shifting the need from 18 TWh to 20 TWh. When we add more nighttime load to the grid, more load is being added to the winter in a seasonal perspective. As solar resources are generating less in winter comparing to summer, we need to depend on more seasonal storage.

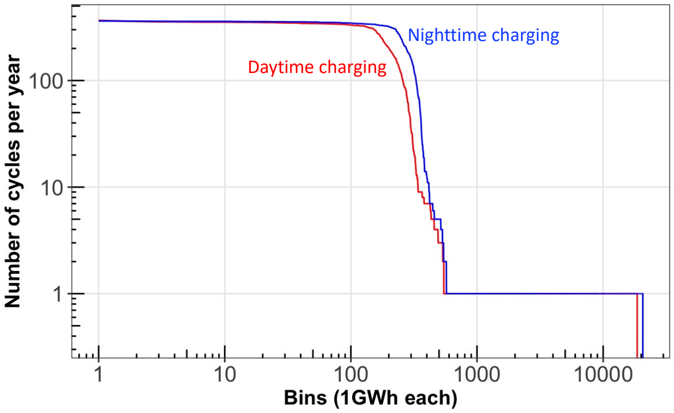

Fig. 2. Changes in number of cycles for shifting in charging timeline. Only solar scenario and same annual total load are maintained for all these cases.

Figure 3 explains how the frequency of use and minimum required size of different types of storage are changing when we increase the load by adding more EV charging to the grid. Through electrification, as we are heading towards higher demand of electricity, the need for all types of storage is expected to increase. To maintain the generation as 120% of the total annual load, we adjust scaling up the solar. For increasing the added load from 6% to 18% of the annual load, the need of diurnal storage changes in a small amount from 0.25 TWh to 0.317 TWh though the seasonal need shows a drastic rise of 5.5 TWh from 17.5 TWh to 23 TWh. These numbers might vary depending on the California grid energy mix as we are not certain of what fraction of solar and wind and other renewable resources will be used in future. We try to assess the impact on future storage requirements for different charging schedule and increasing amount of EVs on the road rather than providing solution to the storage problem.

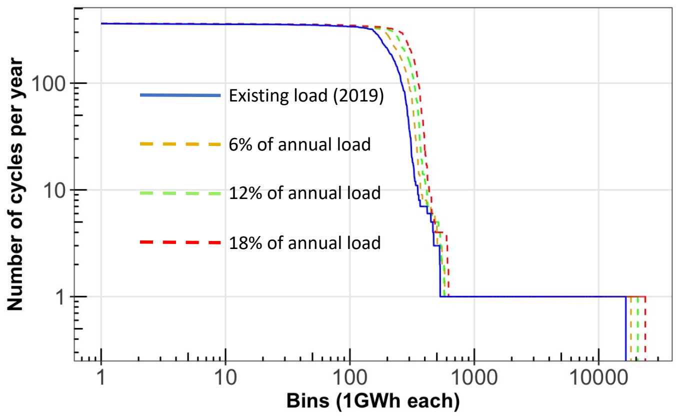

Fig. 3. Changes in number of cycles for variation in total annual load. 6% indicates that 6% of annual load is added to the existing load using EV charging profile. Total generation is equal to 120% of total annual load and nighttime charging is maintained for these cases.

IV. CONCLUSION

Electrifying the transportation sector can be accelerated by changes in major areas like regulations, technology improvement, consumer behavior etc. Charging of EVs results in additional load and depending on the charging profile it affects the needs for storage. Changes in daily charging schedule cause change in the minimum requirement of storage. Nighttime charging of EVs needs more diurnal and seasonal storage than daytime charging if we depend on mainly solar generation. The need for additional storage may be reduced if the infrastructure developed for EV charging is designed to allow for daytime charging (workplace, parking lots and shopping malls) enabling EV charging to become a flexible load. This paper could be helpful for the investors in making decisions on building more charging infrastructure and its flexibility.

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