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Charge the North: findings from the complete data set of the world's largest electric vehicle study

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Summary

Charge the North is an electric vehicle (EV) study aimed at identifying the opportunities and challenges in EV load management through the collection of vehicle-side charging and driving data. Over the course of the project, FleetCarma, with the support of Natural Resources Canada and 10 Canadian electric utilities, collected driving data equivalent to a total of 12.4 million miles and 4,700 megawatt hours (MWh) of charging data through 1,000 EV owners across the nation. The report expands on findings from Charge North with data from 3,944 electric vehicles. This includes 40 EV makes and models, 10,010,535 charging slices grouped into 761,096 charging windows, 2.3 million hours of charging representing 8,576 MWh, and 28.9 million miles of driving data, making this the largest and most comprehensive up-to-date data set on EV charging. EVs on the road today are vastly different than they were as recently as five years ago. Long-range Battery Electric Vehicles (LR BEV), the most unpredictable and demanding class of electric vehicles, represented over 66% of all new EV sales in the US for 2019. These vehicles present a need for service territory-specific profiling studies on account of the changes in charging and driving behaviour they have incited. Service territory-specific load profiles and driving data will provide utilities with more insight into the areas where these risks are most likely. The increasing level of electric vehicle (EV) adoption and the advances in EV battery and charging technology are estimated to impact the distribution infrastructure.

Keywords: electric vehicle, EV, charging, utility, telematics

1 Introduction

Beginning in June 2017, a ground-breaking research project was launched by FleetCarma, with support from Natural Resources Canada, to identify and address the impact of electric vehicles (EVs). The "Charge the North" project aimed to help the Canadian government and electric utilities better understand how EVs are being charged and driven, as well as their impact on the electric grid. Since then FleetCarma has been helping electric utility companies prepare for the integration of electric vehicles (EVs) with the grid. Through regional EV charging load profiling studies such as "Charge the North" [1], FleetCarma has compiled data from thousands of EVs. This paper expands on the initial 2017 Charge the North findings from 1,000 EVs by leveraging data from over 3,900 vehicles participating in charging studies across Canada and the United States, making this the largest and most comprehensive up-to-date data set on EV charging. This data allows utilities to identify areas susceptible to infrastructural damage caused by asymmetrical vehicle density (EV clustering), and enables them to effectively mitigate its impact by incorporating customer-controlled load shifting programs. This study will identify the risks to the grid associated with the increase of EV adoption and the increased market share of Battery Electric Vehicles (BEV), as well as advocate the need for up-to-date data in a rapidly changing market.

1.1 Study highlights

This project is one of the largest studies of EV charging load that has ever been conducted. The findings of this report were compiled from the initial Charge the North project, which includes 1,000 electric vehicles, which began in early 2017 and ended on March 31, 2019. The up-to-date charging analysis includes data from 3,944 electric vehicles located across North America. The data set includes 40 EV makes and models, 10,010,535 charging sessions that were grouped into 761,096 charging windows, 2.3 million hours of charging representing 8,576 MWh, and 28.9 million miles of driven data, over 2019.

2 Technology and application

To gain the most accurate insight into EV charging and driving behavior, data was collected through a connected IoT device installed into the vehicle's on-board diagnostics (OBD II) port. All data was transmitted through a secure cellular data connection to a cloud-based storage system where it was aggregated and analyzed. FleetCarma's cloud platform, paired with the C2 telematics device, has the unique capability of collecting vehicle-side data from EVs. The C2 device connects to the vehicle through the onboard diagnostics (OBD II) port, and can send battery, charging and driving information. FleetCarma's platform enables vehicle and charging station (EVSE) agnostic data collection, regardless of the charging location or vehicle type. This in-vehicle technology also collected driving and regional climate information, which provided additional data points and insights into seasonal vehicle performance and driver behavior.

3 Methodology

To showcase the evolution of EVs, two vehicle groups were created representing electric vehicles that would have been on the road in 2014 and are currently on the road 2019. All data analyzed was collected in 2019. Due to a marked difference in technology and use patterns, data from models produced in 2014 or earlier was weighted by market share to facilitate per-vehicle comparisons with 2019-model vehicles.

3.1 Definitions of vehicle categories

For the purpose of this study, vehicles were placed into one of three categories: Plug-in Hybrid (PHEV), Short-range Battery Electric (SR BEV) and Long-range Battery Electric (LR BEV). A PHEV is an electric vehicle which has both an internal combustion engine and an electric engine. A BEV is a fully electric vehicle which is then further classified by the capacity of its battery, which defines its range: the distance it can travel on a single charge. A short-range BEV (SR BEV) has a battery capacity below 50 kWh, whereas a long-range BEV (LR BEV) has a battery capacity of 50 kWh or more.

3.2 Vehicle selection and group composition

The single largest differentiating factor between the 2014 and 2019 vehicle groups is the market share of long-range BEVs. In 2014, this vehicle type represented 14% of new EV sales [2]. In 2019, the market share of this vehicle type increased to 66% [3]. After reviewing the data from all participating vehicles and creating per-vehicle averaged data sets for each vehicle category, market share data was used to simulate an accurate composition of the vehicles being driven in each time period from the available sample set. EVs in the 2014 group were drawn from those whose manufacturing data was from 2014 or earlier as determined through VIN verification.

3.3 Representing EV charging as a "charge window"

EV charging is often seen as a charging session, which begins when the battery starts drawing energy and ends once it stops. During this analysis, it was discovered there were multiple occasions where a session occurred that lasted for a few seconds. It is hypothesized that these small sessions are a result of battery conditioning within the vehicle. The concept of a "charge window" was introduced in order to avoid skewing the data, which would result in misrepresented average charging peak power, total energy drawn and charge event durations. A charging window is the grouping of all charging sessions that occur between consecutive trips. The total amount of time and energy for all of the sessions within each charge window are added together and used to calculate more representational mean results.

3.4 Calculating charging power (kW) for charge window statistics

Calculating charging power for the per charge window statistics was achieved by measuring the total amount of energy (kWh) provided by the charging station during charging events within a given charge window, and then dividing that sum by the total time spent charging.

3.5 Calculating maximum power in load curves utilizing charge slices

Charge slices are charging events that are broken into 15-minute intervals. For each charge slice, the maximum power, which is the highest power from the 15-minute interval, is measured. Each data point on a load curve is the average maximum power across charge slices for every 15-minute interval per day.

3.6 Removing away charging, including DCFC charging, from load curves

Charging events that occurred away from home, including the use of public Direct Current Fast Charging (DCFC) stations, have been removed from the road curves in this study in order to better represent the impact EV charging has on utilities' local distribution assets. Public charging stations often have upgraded infrastructure to handle the high demands of EV charging and DCFC charging stations are extremely unlikely to appear in the homes of EV owners due to their industrial-level power requirements.

3.7 Identifying home versus away charging

In order to define what charging occurs at home, geofences were created around the areas where EVs spend the most time charging at night, as those areas most likely represent the residence of the EV owner.

3.8 Identifying Direct Current Fast Charging (DCFC)

Charging sessions with power greater than 20 kW were classified as Direct Current Fast Charging (DCFC) as those levels of power output are beyond the capabilities of a Level 1 or Level 2 charging station.

3.9 Other considerations

When reviewing this study, there are a few considerations that need to be addressed. Firstly, none of the energy calculations consider any electricity transmission and distribution (T&D) losses, which could add an average of about 5% to the overall demand [4].

Secondly, this data was collected from EV drivers across North America. This means there could be multiple factors that influence charging and driving behavior such as climate or utility TOU rate programs.

Lastly, the impact of battery degradation could influence charging behavior, particularly in older EVs. Battery degradation is a natural process that permanently reduces the amount of energy a battery can store and EVs, on average, experience a capacity loss of 2.3% per year [5].

4 The expiration of EV charging load data

The electric vehicle ecosystem is going through significant changes and existing data, much of which is based on the needs of older vehicles, is quickly becoming obsolete. The rate of EV adoption is growing exponentially on account of both public desire and government mandates to reduce greenhouse gas emissions through transportation electrification. This desire has driven product innovation, and as a result there have been significant changes in EV technology.

Five years ago, 4 out of the 5 top selling plug-in electric vehicles (PEV) in the US were not in production. The introduction of long-range BEV models such as the Tesla Model 3 and the Chevrolet Bolt, have redefined not only the industry standard for vehicle electric range, but also vehicle battery capacities and charging capabilities. The Tesla Model 3, which now represents 47% of all 2019 EV sales to date in the US [3], did not come into production until 2017. This drastic change in vehicle sales signifies that previous data is no longer an accurate representation of today's vehicle composition.

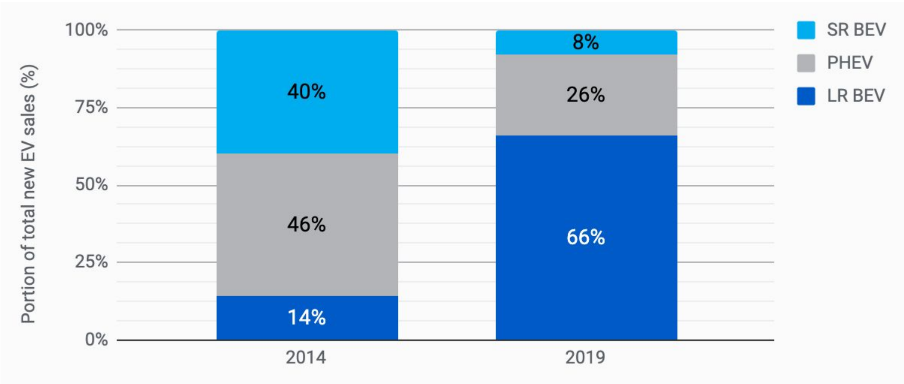

Figure 1: Annual eElectric vehicle composition, 2014 & 2019

4.1 The characteristics of a long-range BEV that define its unique behavior

The fundamental distinction of a long-range BEV is that it has a battery with a larger capacity. This allows the vehicle to travel further on a single charge and is referred to as its range. The EPA-rated range of a current long-range BEV could be up to 335 miles, a short-range BEV has a range of about 150 miles and a PHEV has an electric range of about 53 miles [6]. The increased range of long-range BEVs alters driver behavior, because drivers are now able to use the vehicle more frequently and travel further between charges.

When comparing the average monthly driving distance per vehicle, a long-range BEV will drive 53% more miles than a short-range BEV and 19% more than a PHEV. It should be noted that on average 40.3% of the miles driven by the PHEVs observed were powered by gasoline, meaning they are less relevant to electric utilities.

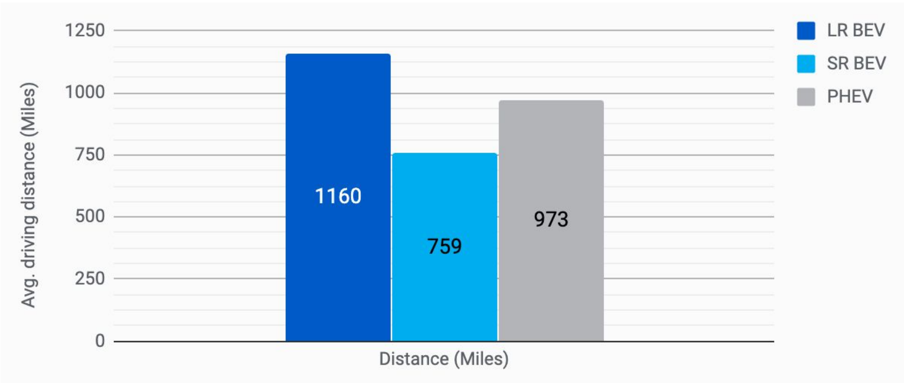

Figure 2: 2019 average monthly driving distance per vehicle.

While the increased range of a long-range BEV is beneficial for the driver, it creates multiple issues for utility companies. Firstly, the charging behavior of a long-range BEV is less predictable. On average, a US vehicle owner will drive 27 miles daily [7], meaning a driver of a long-range BEV does not need to charge every day. This makes predicting EV charging load more difficult. Secondly, larger batteries need to be charged either for a longer period of time or at a higher power level. Finally, since these vehicles are not as limited in range as earlier EV models, they can be used for out-of-town trips. Consequently, long-range BEVs are more likely to utilize public charging stations, and they are relying on utilities or other partners to provide this infrastructure.

5 Comparison of the 2014 and 2019 vehicle groups

Compared to the vehicles available in 2014, the period analyzed in the most substantive previous studies, the 2019 cohort of consumer EVs have vastly different predictable effects on driving behavior, charging behavior, and grid impact. To showcase these differences, multiple metrics were measured for both vehicle groups.

5.1 Comparing battery state-of-charge percentages

In order to better understand the charging behavior of both vehicle groups, a comparison was made between the change in the battery's state-of-charge (SOC). Observations of a battery's SOC% allows for the determination of how "full" the battery was when charging started and when charging ended.

Both the 2014 and 2019 vehicles were subject to similar charging patterns. Owners would begin charging events at an SOC% in the 40s, and would end charge events at an SOC% in the 80s. This data shows that regardless of the battery capacity, drivers don't let their vehicles go much below half empty and don't fill it completely. The former would suggest owners do not want to risk running out of charge on the road. The latter is based upon the fact that most EVs have adjustable charge ceilings designed to limit battery operation in areas of higher degradation [5].

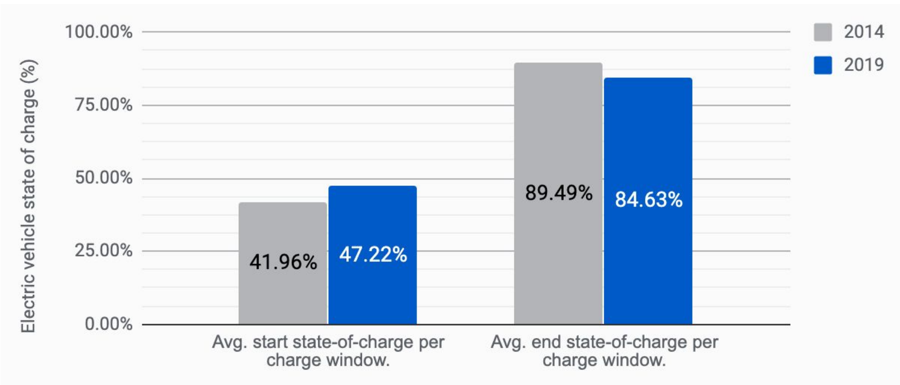

Figure 3: Average starting and ending SOC% per charge window, 2014 & 2019.

5.2 Average energy consumption per charging window

When comparing the per vehicle average amount of energy for a charging window, the 2019 vehicles consumed almost exactly double the amount of electricity. This is the direct result of the higher proportion of long-range BEVs, as they simply require more energy.

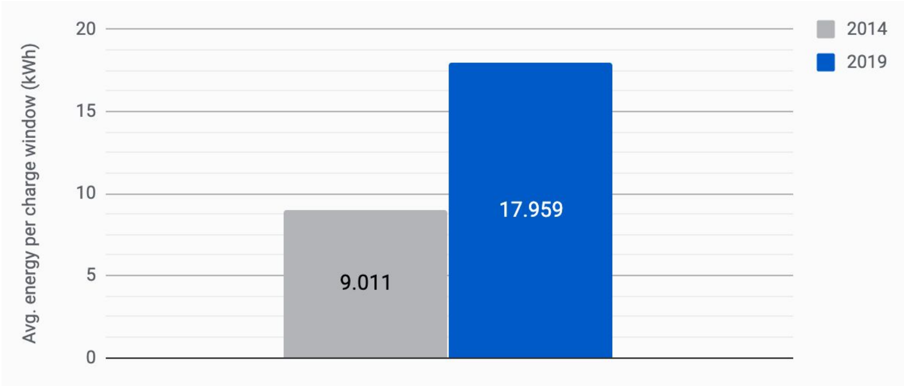

Figure 4: Average energy consumption per charge window, 2014 & 2019.

5.3 Average charging time per charging window

The total amount of time spent charging for both vehicle groups was also the same, averaging between 3-3.5 hours. This means that although the 2019 vehicle group consumed twice as much power, it did so in the same amount of time. The only way this is possible is that the power level (kW) was higher as a result of the use of more advanced charging equipment.

5.4 Average power per charging window

When comparing the two data sets, the most significant finding was that the 2019 group used more than twice the amount of average power per vehicle. As the long-range BEV category continues to become more popular, this average will continue to grow.

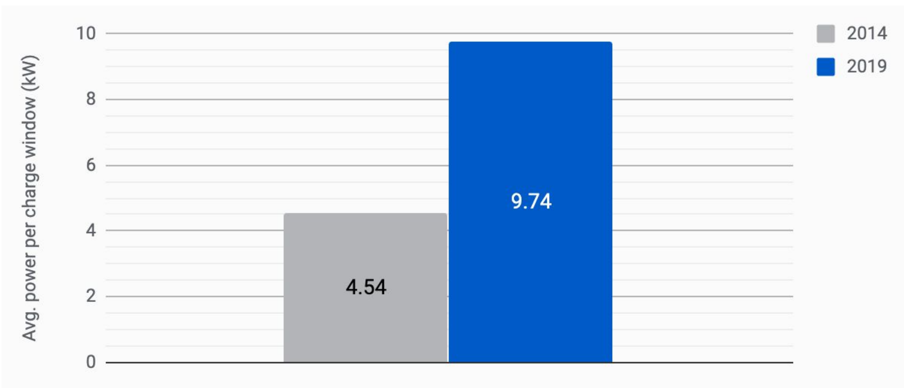

Figure 5: Average power per charge window, 2014 & 2019.

5.5 Average hours charging per month

From a load-management perspective, the most challenging aspect of long-range BEVs is trying to predict when charging will occur. As mentioned previously, long-range BEVs do not need to be charged every day. To show this, the number of hours spent charging per month was analyzed. The data below shows that vehicles spent more time charging per month in 2014 than they did in 2019. Considering in light of the fact that the charge window lengths for both vehicle groups were approximately the same and the total amount of energy collected in 2019 was higher than it was in 2014, this finding indicates that long-range BEVs can go a few days without having to charge.

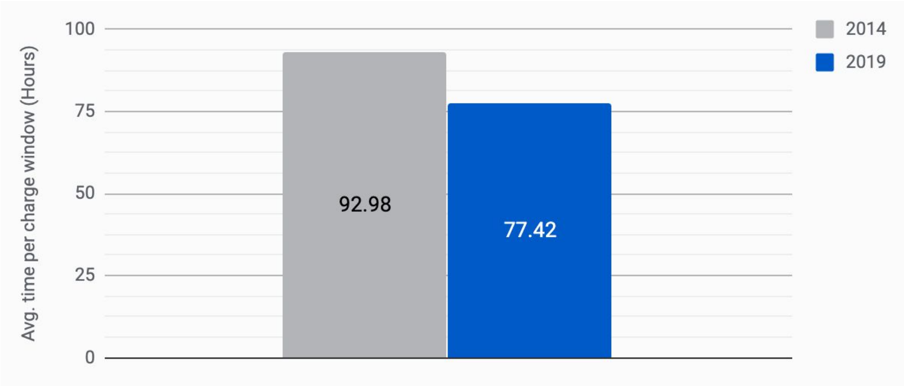

Figure 6: Average monthly time spent charging, 2014 & 2019.

5.6 Home versus away charging

While the majority of EV charging still occurs at home, the 2019 data shows a significant increase in the frequency of charging events that occur away from home. Away charging could include workplace charging, charging at stations in public areas such as malls, or charging at dedicated charging areas like the Tesla Supercharger. The common adage was that 90% of charging occurred at home, however the data shown in the table below shows that in 2019 it was closer to 60%. Considering the amount of emphasis placed on creating public infrastructure in recent years, this number was not surprising. The majority of away charging is attributed to Level 2 charging and not DCFC fast charging. Because these vehicles were charged for extended periods, we infer these events were likely workplace charging.

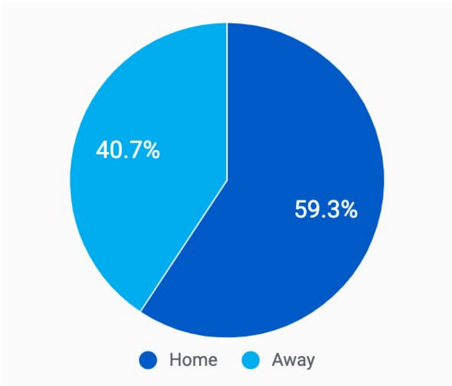

Figure 7: Home versus Away charging, 2019.

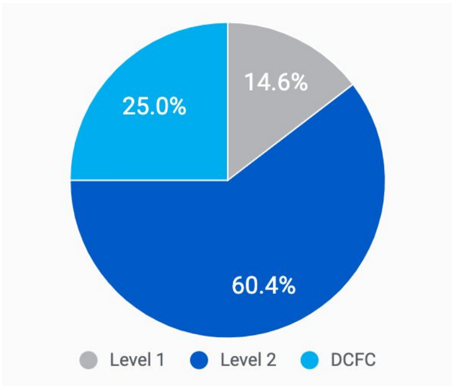

Figure 8: Away charging by level, 2019.

5.7 Impact of free workplace charging

Findings from the original Charge the North program had found that while the majority of charging happens at the EV owners' residence, the proportion of home charging had decreased over the previous five years until March of 2019. Previous studies had suggested that home charging accounts for about 90% of the total charging energy. Charge the North found that residential charging accounted for 72% of the total charging energy. This trend has continued and for 2019 59.3% of charging events occurred at a residence. Of the 40.7% of charging which occurred away from home, Level 2 charging accounted for 60.4%. We can assume that this change is attributable to the increase in workplace charging availability.

5.8 Growth in charging technology

Charging of EV batteries has evolved to accommodate the needs of newer vehicles with larger battery capacities, and to improve the user experience. There are three classifications of charging levels: Level 1, Level 2, and Level 3 or direct current fast charging (DCFC).

Level 1 charging utilizes a standard 110/120 V plug which can provide up to 1.9 kW of charging power. These chargers provide approximately 4.5 miles of range per hour [8]. As a long-range BEV can have a range of over 300 miles, drivers of these vehicles prefer to use Level 2 chargers.

Level 2 charging utilizes a 208-240 V plug and can provide between 2.5 and 19.2 kW of charging power, the maximum power level will often be determined by the vehicle's on-board charging system. Level 2 chargers provide up over 40 miles of range per hour [9]. They are becoming increasingly popular for both home and public charging.

The chart below (Figure 9) shows that Level 2 charging accounted for 63.4% of charging at home in 2014, whereas in 2019 it accounted for 79.7%. This is a result of owners wanting their vehicles to charge faster, specifically if their EV has a larger battery capacity and it has the capability. In 2014, the most sold EV in the US was the Nissan Leaf [2], which has a maximum charging capability of 6.6kW [10]. In comparison, the most sold EV in 2019 was the Tesla Model 3 [3], which has a maximum charging capability of 11.5 kW [9].

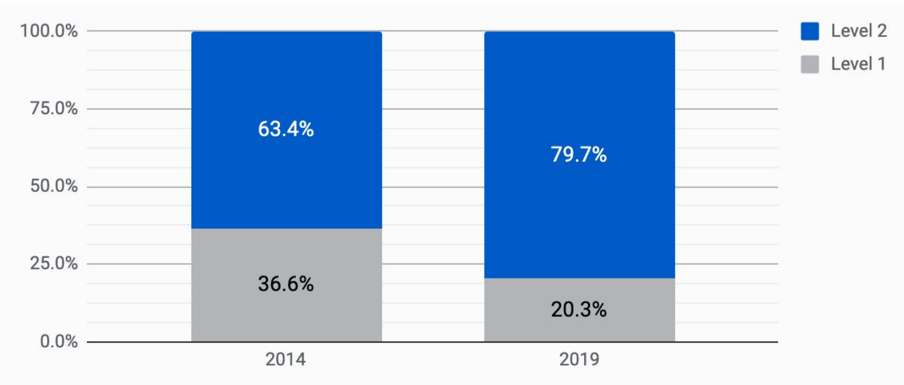

Figure 9: Electric vehicle home charging by level, 2014 & 2019.

5.9 Conclusions for the comparison of 2014 vs. 2019 charging and driving behavior

Data shows that vehicle type composition can have a significant impact on overall charging and driving behavior. The implications presented by the increase of long-range BEVs are clear, as is the fact that older data is no longer relevant when planning for EV charging load.

The vehicle category is still growing and evolving. More powerful new vehicles, including light-duty trucks, are entering the market. Some of these vehicles feature a 180 kWh battery [11], which is almost double the capacity of a current long-range BEV. Much like battery capacity growth has driven EV behavior changes over the last five years, this new increase will also fundamentally alter the impact EVs have on the grid.

6 Long-Range BEVs pose a risk on the distribution assets

When analyzing macro level EV charging data based on the average load over each hour of the day, it was found that EV charging load is unlikely to impact the electric utility generation and transmission assets. However, the data suggested that there may be significant risks to the distribution of assets moving forward. This was further supported by charging data that showed EVs not being distributed evenly across the electric utility service territory, but rather clustering in certain neighbourhoods. Data from Charge the

North has shown, in Figure 10, a clustering of vehicles that on average charge at 6 kW may overload the residential transformer very easily.

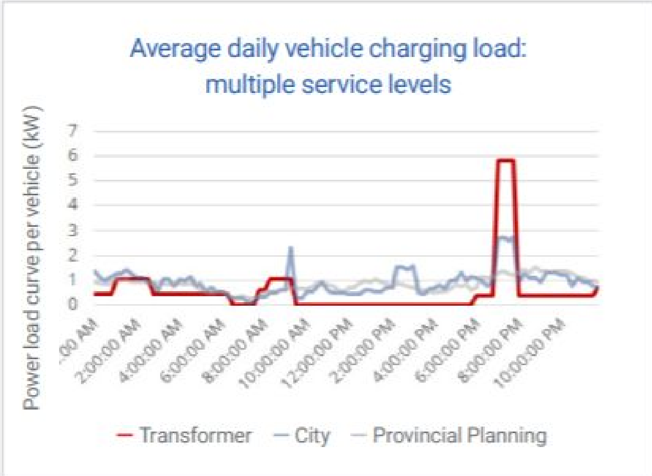

Figure 10. Average daily vehicle charging load at multiple service levels

To highlight the impact that long-range BEVs have on the grid at multiple levels, data from an expanded number of vehicles across North America was used to generate load curves for different vehicle groups. As with previous findings, this data has been treated with vehicle-type market share percentages to showcase the difference between 2014 and 2019. It should be noted that this data includes vehicles that are being influenced by different load management initiatives, including TOU rates. This results in EV charging being shifted to off-peak time periods for both 2014 and 2019 vehicle groups. The purpose of these load curves is to show the difference in peaks, as a result of the increased number of long-range BEVs, and not as a way to validate the need for load management solutions. As other studies have shown, most EV owners who are not being influenced by a TOU program will plug in and charge their vehicle as soon as they get home from work, coinciding with standard residential peaks [1]. It should be noted that these load curves strictly represent EV charging load and do not include any additional household load.

6.1 Change in system level average load per vehicle

To visualize the average maximum power per vehicle, load curves were generated for both vehicle groups, during weekdays, for a one-month period. To show the potential impact colder weather has on charging behavior, curves were made in January and July to represent winter and summer. For the month of January, shown in Figure 11 below, the highest average power per vehicle in 2014 was 0.69 kW. In 2019 the highest power was 0.96 kW. This aligns with previous findings that long-range BEVs charge at a higher power level. This load curve suggests that long-range BEVs are more likely to be shifted using a solution like a TOU rate because drivers are using more powerful Level 2 chargers. Drivers are thus more likely to delay charging until a time when energy costs are lower, or to a time when they are receiving an incentive.

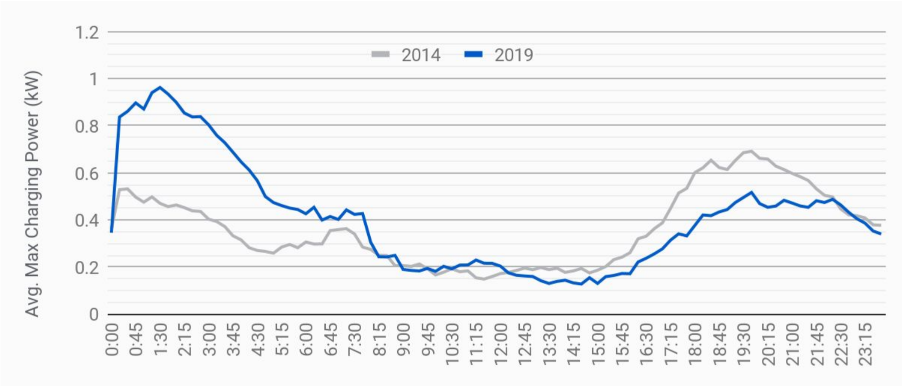

Figure 11: Average daily weekday max power per vehicle in January, 2014 & 2019.

When reviewing the load curve for the month of July, the overall difference between the vehicle groups is increasing by 2.46 times at the peak, 0.41 kW in 2014 and 1.01 kW in 2019.

Figure 12: Average daily weekday max power per vehicle in July, 2014 & 2019.

6.2 Impact to a street level transformer

The biggest risk posed by EVs is at the distribution level of the grid. EV clustering is a trend that shows that EVs may not be distributed evenly across the utility service territory, with the high likelihood of EV owner concentration on a specific street or neighborhood. To simulate this, five vehicles from each vehicle type were selected at random and their load was combined for a randomly selected day. This would represent the vehicles being charged on the same residential transformer. The load curve below shows the difference between each vehicle type and that the long-range BEV group had a peak of 7.34 kW.

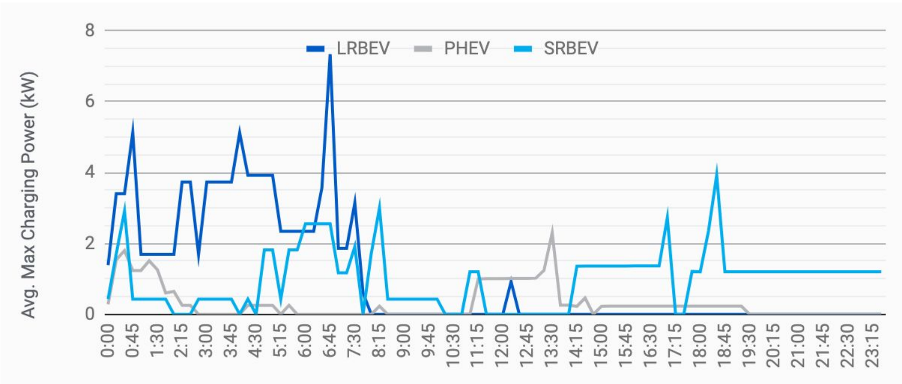

Figure 13: Average daily max power for 5 vehicles on a single transformer in 2019 by vehicle-type.

6.3 Conclusions from load curves

The load curves shown above showcase multiple details about EV adoption that utility companies need to take into consideration when studying EV charging load. Firstly, long-range BEVs create considerably higher peaks, and this average will continue to rise as long-range BEV market share increases. Secondly, long-range BEVs are more likely to have their load be managed, and the loadshifting program will be more impactful if it is EV specific. Lastly, temperature and climate play a significant role in charging characteristics, meaning territory-specific data should be used when preparing load management solutions.

7 Evolving destructive potential of Battery Electric Vehicles (BEV)

Charge the North played an important role in identifying the trends in EV driving and charging in Canada. With this latest EV data set, FleetCarma was able to recreate charging profiles relating to infrastructure risks, public charging, TOU rates and many more. The results of this study suggest that utilities need to continuously monitor the growth of EV load, and considerations need to be made to the rapidly growing EV adoption rates for better risk management.

The impact EVs have on the grid, particularly the risk they pose to damaging distribution assets, has changed dramatically over the last 5 years. Long-range BEVs are very different from older electric vehicles: they are driven more, they consume more energy, they draw power at a higher level and they are less predictable. As the fastest-growing vehicle type, long-range BEVs continue to represent a larger proportion of new EV sales. Moreover, EV charging has a potentially destructive effect on local transformers; by 2030, up to 17% are likely to need to be replaced [12]. The severity of this finding is compounded by the fact that the EVs observed during that study were not an accurate representation of what is being sold today. With the popularity of EVs increasing, along with the expansion of models being offered with much higher battery capacities, their destructive potential on distribution assets will continue to grow. Utility providers can prepare for this eventuality using up-to-date, accurate data. They need an ongoing source of information specific to their service territory, that can incorporate new vehicles as they enter the market.

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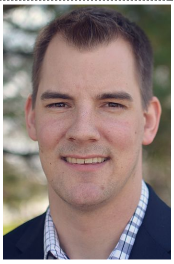

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