21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2022 Grid of the Future Symposium

Planning for Fleet Electrification on Electric Distribution Systems

J. DEBOEVER, R. SHERIDAN, J. DUNCKLEY, J. KWONG, D. TRINKO
Electric Power Research Institute
USA

SUMMARY

The electrification of the transportation sector is a key element of many corporate, state and federal decarbonization plans. While the initial transition towards electrified transportation has already begun, there remains tremendous uncertainties with respect to when, where and to what scale the necessary charging infrastructure will be connected to electric utility distribution systems. This is particularly true with regards to commercial vehicles and fleets, where freight and delivery companies, bus and taxi operators, service stations, and many other fleet entities have locational choices and the potential to transform their fleets in a rapid manner.

Although electric distribution companies are aware that fleet electrification is imminent, there is still a significant level of uncertainty around where on the grid these fleets will likely emerge, what their needs will be, and how a utility can help enable the transition. This paper discusses a planning framework to help electric distribution companies accommodate for fleet electrification on the electrical grid. The proposed planning framework focuses on four broad industry needs: (i) fleet identification, (ii) fleet demand characterization, (iii) distribution system impact analysis, and (iv) integrated solutions evaluation. The challenges associated to each step of the framework are discussed and new planning methods, tools, and metrics – including load hosting capacity and energy deliverability metric – are presented to anticipate fleet electric vehicle adoptions more effectively. This paper aims to highlight the challenges that the industry faces to encourage and facilitate discussions with external stakeholders (customers, regulators, energy providers, EV stakeholders, etc.).

KEYWORDS

Distribution Systems, Electric Vehicles, Hosting Capacity, Electrification Opportunity

jdeboever@epri.com

INTRODUCTION

The electrification of the transportation sector is a key element of governmental, corporate, and individual sustainability plans, and the maturity of electric vehicle (EV) technology is progressing such that widespread adoption is imminent. The discussion surrounding electric vehicles and the necessary infrastructure needs has often been directed towards accommodating residential vehicles because of the larger market share of EV adopters and current federal and local incentives. However, the number of new EV models suitable for commercial operations that are available in the market is expanding every year as shown in Figure 1. As production of these commercial vehicles grow, freight and delivery companies, bus and taxi operators, and many other fleet entities have the potential to transition their fleet very quickly, simultaneously increasing electric power demands on the distribution system to accommodate the necessary charging infrastructure. Moreover, unlike residential vehicles, fleet electrification will have more concentrated impacts on the grid even with one customer making the transition due to the larger number of vehicles charging at a central location.

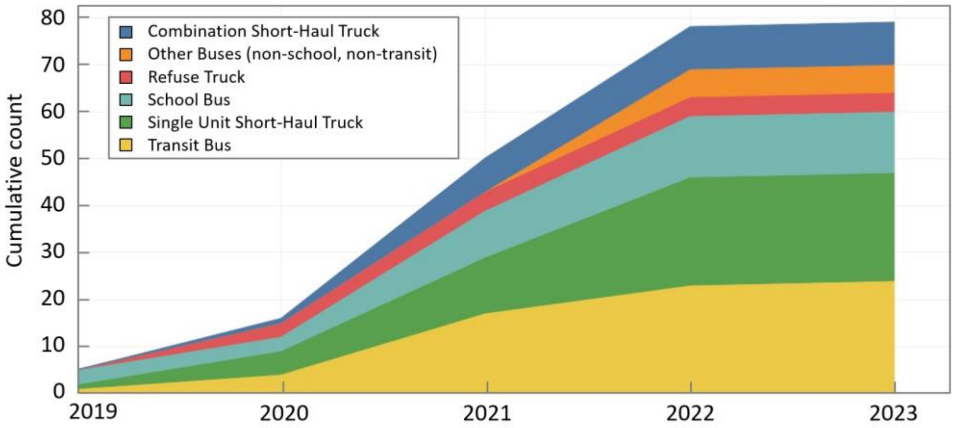

Figure 1. Total number of available medium- and heavy-duty vehicle models by MOVES category [1]

The electrification transition is a major opportunity and an immense challenge for electric distribution companies. To ensure a smoother transition, it is imperative for distribution companies to anticipate and proactively plan for this new demand. By proactively and strategically planning for electrification, electric utilities will become a key enabler for the achievement of broad electrification and sustainability targets. Although electric distribution companies are recognizing that commercial fleet electrification is coming, there is significant uncertainty as to where fleets will locate, where on the grid charging equipment will be connected, and what the real time power needs will be at each charging location. This uncertainty in forecasting load growth from this new type of demand creates a major challenge for distribution companies to justify infrastructure investment within the current regulatory framework. Moreover, the lead times for major utility infrastructure upgrades can be significant (1 to 5 years depending on the upgrade) and is longer than the time required for some fleets to transition to EVs. Therefore, proactive system planning is essential to ensure that distribution capacity constraints are not an unmanageable barrier to electrification.

This paper explores key challenges for distribution companies to strategically plan for fleet electrification. The planning framework proposed in this paper focuses on four broad industry needs: (i) fleet identification, (ii) fleet demand characterization, (iii) distribution system impact analysis, and (iv) integrated solutions evaluation. The paper discusses the challenges with each step and proposes new metrics and analytics to help electric distribution companies plan for fleet electrification. Finally, this paper aims to highlight the challenges that the industry faces to encourage and facilitate discussions with external stakeholders (customers, regulators, energy providers, EV stakeholders, etc.).

BACKGROUND / MOTIVATION

Not all electric vehicle types, nor fleets, will have the same impact on the electrical grid. In some ways, electric vehicles can be segmented in a similar fashion as distributed solar generation: distributed residential connections and centralized large-scale connections. While the transition of a few residential vehicles (low-duty vehicles) at an existing home can have very localized impacts, major infrastructure needs on the backbone of distribution systems will likely only be necessary with large adoption levels of residential vehicles. On the other hand, vehicle fleets (medium- and heavy-duty vehicles) can have a larger more immediate impacts on distribution system over residential vehicles because of the number of vehicles dwelling at the same location and the increased amount of power and energy needed at that location. Furthermore, electrification can develop quite rapidly for fleets with only one customer making the transition for many vehicles. Long-term planning of the distribution system must consider the impacts of both high adoption residential EV and the electrification of commercial fleets, but the necessary planning capabilities will be different for residential EVs versus fleet EVs due to the following considerations:

Table 1. Comparison of planning considerations between residential EVs and commercial fleet EVs.

	Issue	Residential Vehicles	Commercial Fleet
When	**Vehicle Availability**	Widely available	Rapidly developing
	Customer Adoption Propensity	Customer adoptions underway	Pilot/Demonstration level implementations
	Potential transition speed	Needing multiple customers to adopt before major Dx impacts	Potential major impacts from a single customer
Where	**Primary Charging**	Existing Home Locations	Workplace or new remote Depot
	Alternative Charging	Workplace and Public	Depot and Public
How Much	**Installed capacity of charging equipment**	L1 and L2 chargers (1-19.2kW each)	Large L2 and DCFC chargers (<20 to >150kW each)
	Charging Load Profile	Evaluated in aggregate for feeder-level impacts	Evaluated individually and in aggregate
	Charging Flexibility	Broad customer programs	Customized program design
	Grid impacts	Localized (low adoption levels) Feeder-level (high adoption levels)	Feeder-level even with few customers electrifying

As part of cyclical distribution system planning studies, new infrastructure investments are identified to accommodate forecasted load growth. While other industries may shy away from capital investment, the electric industry often perceives new infrastructure as an attractive investment. This is because of the regulatory framework defining the electric rates where electricity prices are mainly driven by energy costs and return on investment of installed capacity. Electric distribution companies are required to justify new infrastructure through forecasted load growth to avoid unnecessary investments. The challenge with fleet electrification is the uncertainty on where that demand will appear on the system and the timeline at which it could occur. Hence, there is a growing need for better forecasts to justify infrastructure investment even though the existing regulatory framework may still need to adapt to allow pre-emptive grid hardening measures to be deployed before there is a pressing need for it by fleet customers making the transition.

In addition to forecasting fleet electrification, assessing the available capacity on the existing electrical grid is also imperative to understand the current capability of the system to accommodate this new load. A recent study assessed the available capacity across Seattle City Light's territory to host electrification technologies and the study found that available capacity varied from one distribution circuit to another and from one hour to another [2]. The study found that some areas of the utility territory had sufficient capacity to accommodate significant load growth while other areas didn’t. These findings would enable distribution planners to prioritize infrastructure investments in areas with limited capacity or to incentivize early electrification adopters in areas where distribution capacity existed. The study also found that significant capacity was available during off-peak hours and more specifically overnight suggesting the potential opportunity for charge management programs. Thus, forecasting for fleet electrification is especially important to anticipate the new demand but assessing the current capability of the electrical grid can also provide valuable insights to distribution planners and other stakeholders.

PLANNING FRAMEWORK FOR FLEET ELECTRIFICATION

The electrification of the transportation sector presents new opportunities for the electric utility’s to proactively work with their customers, regulators, and other stakeholders for a smooth transition. To facilitate the more complex forecasting and grid assessments, several new tools and processes will need to be leveraged by distribution planners. The need for advanced planning tools and capabilities for fleet electrification can be categorized into 4 core objectives (Figure 2) to facilitate fleet electrification:

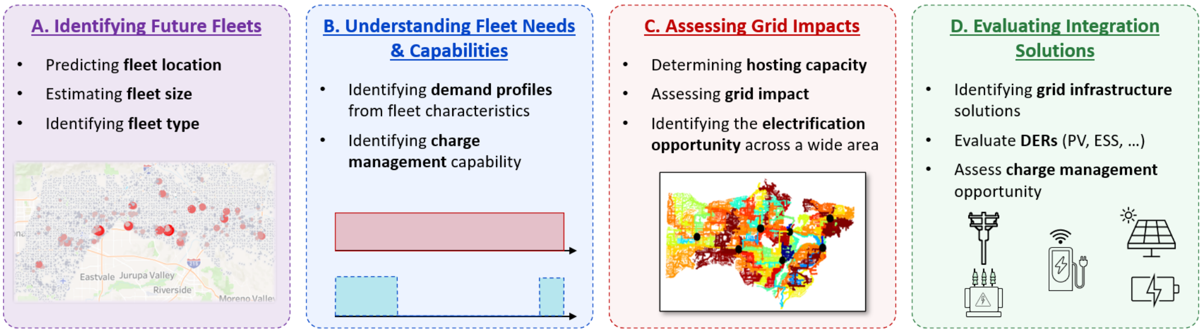

Figure 2. Process for a streamlined fleet electrification

A. Identifying future fleets

The first step in planning for fleet electrification is to understand the where, when, and how much EV charging infrastructure will be connected to the distribution system. Without estimating fleet characteristics, forecasting the power and energy needs that will manifest on the grid is extremely challenging because of the number of factors that affect the charging demand: number of vehicles, types of vehicles, miles driven, dwell time, charging behavior, etc. The most accurate source of information for fleet characteristics is to directly interact with fleet managers / owners that are likely already customers to their local electric distribution company. While customer outreach on a large scale could create its own challenges, some fleet managers may be reluctant in sharing characteristics about their fleet operation as they could see that information as sensitive or to lose their competitive advantage in the marketplace (e.g. last mile delivery companies). Hence, there is an industry need for new analytics to predict fleet characteristics.

WHERE – Predicting the location of residential vehicles is relatively straight forward because residential vehicles tend to be registered at the same address that they dwell. On the other hand, predicting the location of commercial vehicles is significantly more challenging because they are often registered at a headquarter and operated out of another location. While electric utilities have customer databases, it can be challenging to know which customers have fleets and how many vehicles would charge at that location. Furthermore, it is challenging to know if the vehicles would charge at those locations or if they would charge in a different location (i.e., en-route charging vs depot charging). Aside from directly asking a customer, there isn't a perfect database providing the number of vehicles at a location. Hence, an accurate prediction of fleet locations will require multiple datasets to identify likely charging locations and help planners evaluate potential grid impacts at these locations.

Potential datasets may include:

- Customer engagement database: Enhanced engagement between utilities and its commercial customers with fleets will be critical for the efficient planning of the distribution system. Distribution planners should have access to and leverage information and insights with regard to customer development.
- Vehicle telematics: telematics data is collected by some fleet companies. Because data is not available for all vehicles, additional statistical analysis will be necessary to make conclusions from these representative sample datasets.
- Vehicle registrations: unlike residential vehicles, it is less common for commercial vehicles to operate where they are registered making this dataset less than ideal for locating fleets.
- Aerial Imagery: aerial image processing is one method to locate fleet vehicles, however there are challenges associated with image processing and having images collected at a time where vehicles are dwelling, as well as potential customer privacy concerns as data is aggregated.
- Commercial building size and location: While the size of a commercial building is not indicative of fleet size or of a fleet at all, knowing the location or owner of a large commercial building can be the starting point for future discussions on vehicle numbers and driving patterns.

WHEN – Predicting the timeline that customers will electrify is arguably one of the more challenging aspects of assessing future fleet electrification. Again, customer outreach should provide the most accurate timeline estimates but doing so on a large scale is challenging especially for national companies with multiple fleets [3]. That said, there are some indicators to which fleet segments or industries are more likely to electrify first. Namely, technology maturity as well as state and federal regulations will influence manufacturing and customer adoption. Technology maturity must consider maturity of the vehicles themselves as well as the state of supportive infrastructure. For instance, box trucks are already being manufactured while tractor trailers are still early in the pilot project phase [1]. Moreover, high power DC fast chargers – necessary infrastructure for charging tractor trailers – may not be readily available to enable interstate commerce with electric vehicles.

Another factor considered in assessing the timeline of fleet electrification is the state and federal programs along with corporate commitments. For instance, the recent announcement of the National Electric Vehicle Infrastructure (NEVI) Formula Program funding has garnered considerable attention as an accelerator of zero-emission vehicle charging infrastructure [4]. Governmental programs such as this one may not provide a specific timeline to when national and local companies will electrify but they can be indicators as to which fleet segments is more likely to electrify first. Hence, monitoring these type of announcements – governmental programs, corporate commitments, or even from original equipment manufacturers (OEMs) – can help inform the electric industry of an general electrification timeline.

HOW MUCH –The operational characteristics of a given fleet is a key variable for planners to understand. The number of vehicles, miles driven, dwell time, vehicle type/efficiency, amongst other will affect the power and energy need from a customer and identifying these characteristics on an aggregated basis can be challenging. The number of miles driven and vehicle efficiency will impact the energy needed to recharge vehicles while the dwell time will dictate the power needed to ensure the vehicles are able to recharge while dwelling at a location. Hence, the charger size (and power need from the grid) will depend on both the trip distance and the dwell time as shown below. Figure 3 shows an example distribution of the charging power needed for different vehicle dwell times and trip distance based on telematics data. For vehicles with a short dwell time and a high number of miles, they will have to charge at higher power whereas vehicles with lower mileage and a long dwell time will charge at lower power. Some preliminary analysis of conventional MDHD data also shows that a majority vehicles that returns to the same depot every day can charge at lower power due to mileages less than 100 miles and long dwell times.

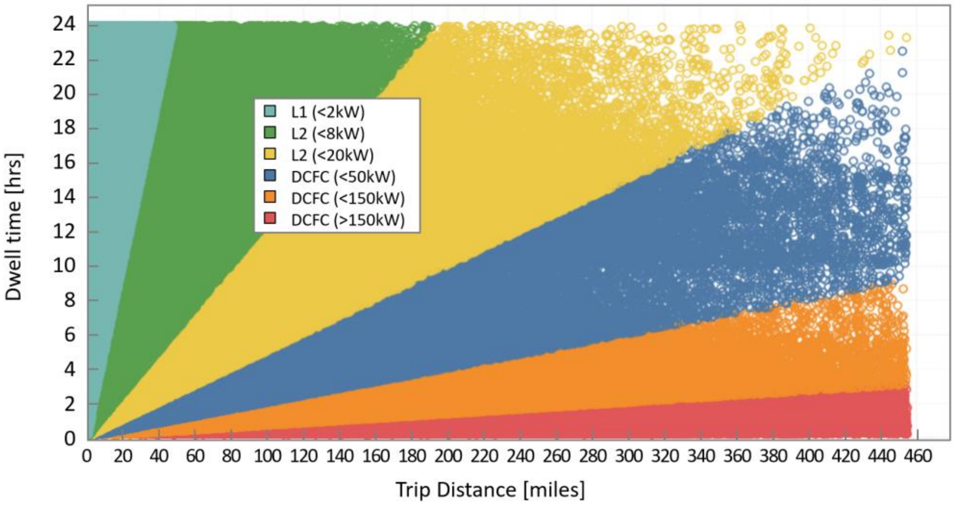

Figure 3. Scatter plot of vehicle trips based on their dwell time and trip distances based on telematics data assuming a vehicle efficiency of 1mi/kWh.

B. Understanding fleet needs and capabilities

The operating characteristics of fleets must be transformed into power system metrics that can be integrated into distribution planning analysis to assess their grid impacts. There are a number of factors that may affect the load shape and peak demand from a fleet customer, whether it is related to the magnitude of the peak demand or when that peak demand occurs in a 24hr period. Figure 4 illustrates the variability of the load shape from a large fleet customer when assuming different charging sizes, load management strategies, or scheduling variability. Note that the latter two are fleet operational characteristics that *could* be influenced by fleet managers whereas the first one is a fleet hardware characteristic.

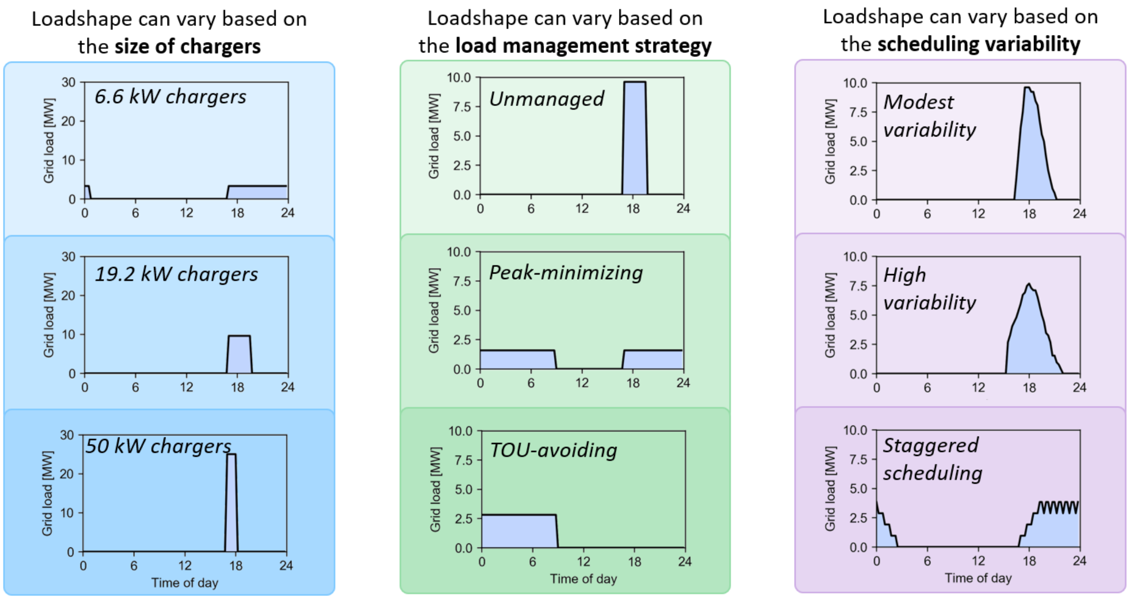

Figure 4. Example of variation in the demand loadshape of large fleet highlighting various factors affecting the general shape of the demand.

This uncertainty in the load shape that would result from fleet electrification is a significant challenge for electric distribution planners even when fleet characteristics (vehicle count, type, miles drive, dwell time) are known. Thus, another important aspect to estimating their demand load shape is to understand how susceptible to change certain fleet segments/industries are with their operational characteristics. For instance, last-mile delivery companies might be more responsive to different rate structures than school and transit buses agencies. Uncertainty in fleet operation is a significant challenge but operational flexibility could be an opportunity for distribution planners to minimize their impact on the grid.

Planning for fleet electrification at the distribution level will require not one but multiple load shapes to consider the uncertainty of fleet operational characteristics. To illustrate this point, the same telematics data used in Figure 3 can be analyzed to assess the number of vehicles charging simultaneously at any hours of the day to estimate the general load shape across an area. Figure 5 shows two load shapes of the same sets of vehicles assuming two different charging strategies: (i) charging as soon as possible, and (ii) charging as late as possible. The assumption is that the vehicle would charge at the rated power of the charger until fully charged either starting at the beginning of its dwell time or as late as possible to still allow the vehicle to be fully charged. Note the difference in the time when the peak demand occurs between them. These are two extreme scenarios, but it provides some boundaries to the type of load shape that an area of the system could experience based on the current fleet operation.

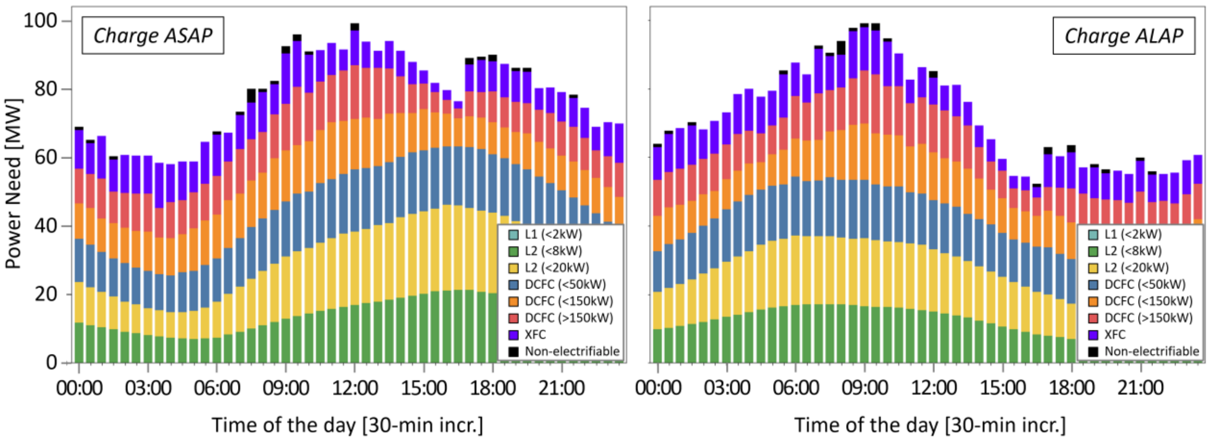

Figure 5. Aggregated 24-hr load shapes under two charging strategies: charge as soon as possible (LEFT), and charge as late as possible (RIGHT). This includes 19,500 MDHD vehicles recorded in a geographical region segmented by charging needs.

C. <u>Assessing grid impacts</u>

Hosting capacity analysis has commonly been used to assess how much solar PV the distribution system can accommodate while maintaining power quality across the network [5]. Some state regulators have started requiring utilities in their states to publish hosting capacity maps (e.g., NY [6], CA [7]) to help inform project developer understand the capability of the grid during their facilities siting analysis. The same concept can be applied to understand how much additional load can be accommodated at specific locations on distribution system (i.e., near the substation or at the end of the feeder). This information can also provide useful insights for distribution planners to help identify areas of the system with more, or less, capacity to accommodate load growth especially since fleet electrification will be more or less concentrated in certain areas of their territory.

The hosting capacity generally describes how much additional resource/load that feeder can host before experiencing any issues at any time of the year by capturing the worst-case conditions: peak and minimum load conditions. For EVs, limiting conditions would align with peak load periods which likely occurs in the summer afternoon/evening hours or in the winter morning hours depending on the geographical location of the feeder. However, these load constrained conditions may only occur a few hours per year and significantly more capacity may be available the majority of hours during the day/year. Since fleets can have very predictable behavior, this nuance in the hosting capacity to capture time-varying load conditions can be insightful for understanding the capability of the system to accommodate these loads where peak demand may not coincide with system peak.

Time-series hosting capacity (TSHC) analysis can provide an estimate of the available capacity throughout the day / year capturing the daily and seasonal variability. This variability is caused by the varying load on the feeder and the available capacity at a specific location on a feeder will depend on how much downstream load there is. In the figure below, the time-series hosting capacity analysis results for three locations on a feeder demonstrates the temporal and geographical variation in available capacity. Note that the available capacity across the feeder ranged from 0.5 and 2MW during the peak load hour (lowest value). However, depending on the location of interconnection, the capacity could vary greatly during off-peak hours (2-8MW near the substation) or insignificantly (0.5-0.6MW on the red branch).

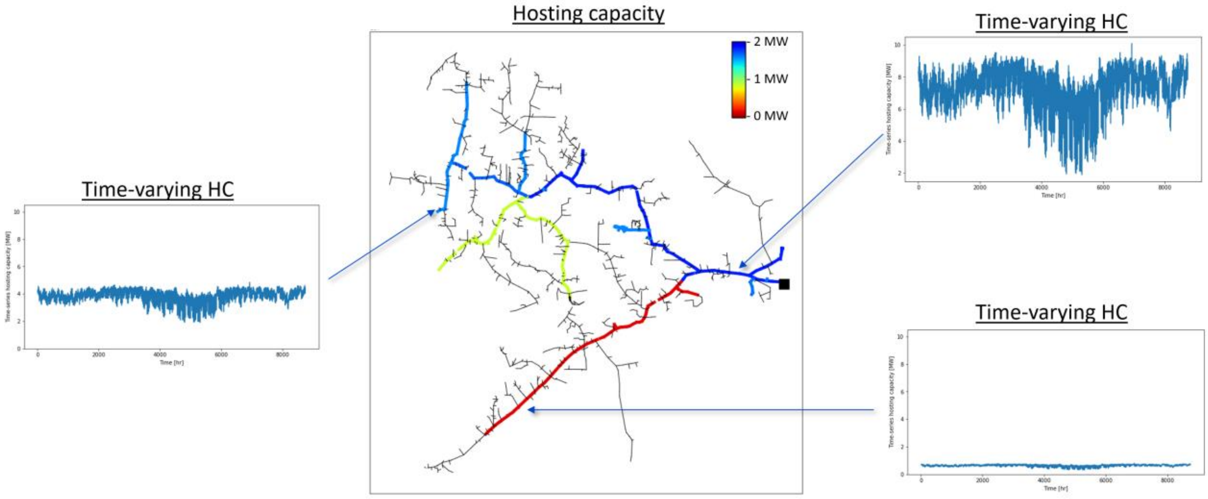

Figure 6. Hosting capacity map of a distribution circuit demonstrating temporal and geographical variation in the available capacity using EPRI's DRIVE tool [5].

Because electric distribution companies are required to minimize any downtime by regulators, distribution planners will always plan for the worst-case condition. However, considering that EVs could have more predictable behaviors and potentially some built-in flexibility, it is important to recognize the range of hosting capacities to capture the daily and seasonal variation in available capacity. More specifically, a box plot of the time-series hosting capacity can provide a better understanding of the available capacity overnight. For instance, using the TSHC results above, Figure 7 shows a worst-case hosting capacity of 2 MW but at least 5 MW overnight between 10pm and 7am regardless of the day of the year. In contrast, the locations further down the feeder might not show a large range of hosting capacity limiting the value of overnight charging. While distribution planners still need to plan for the worst-case condition, evaluating the available capacity overnight can be insightful electric distribution companies to determine if some type of incentive programs for overnight charging would be beneficial for the system.

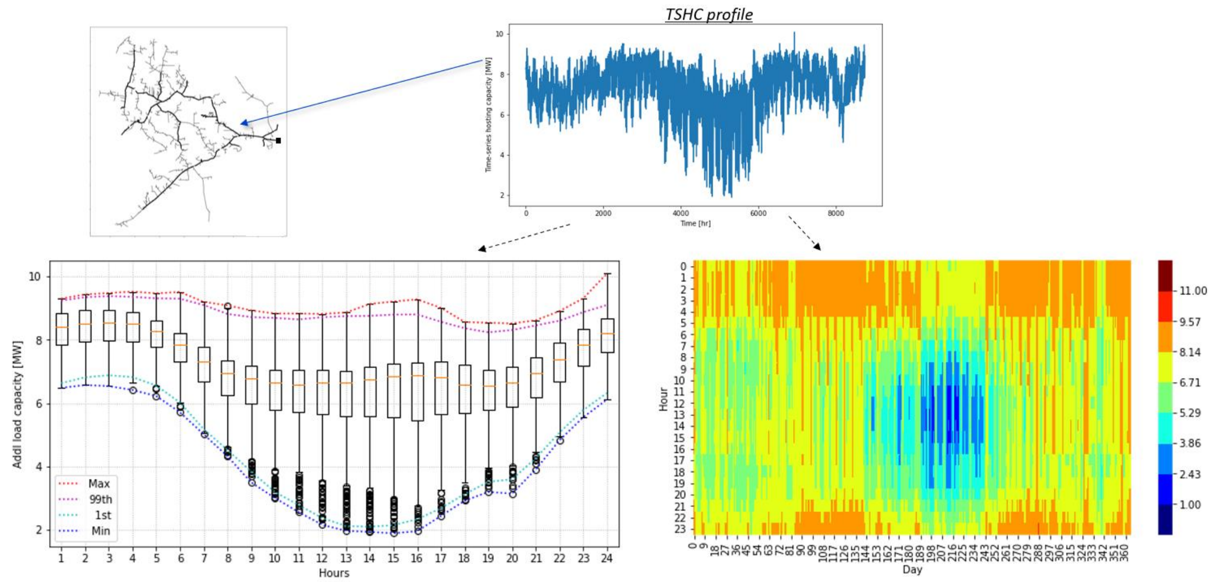

Figure 7. Hourly box plot and heat plot demonstrating the daily and seasonal behavior of the available capacity at a location on a distribution circuit using the time-series hosting capacity analysis in EPRI's DRIVE tool [5].

An important metric derived from time-series hosting capacity results is the energy deliverability at a location on a feeder. Quantifying the energy availability can provide valuable insights to summarize time-series hosting capacity results in a single metric. Specifically, fleet managers will often be aware of the total number of miles driven by their fleet or their operational costs in terms of fuel consumed. These metrics can be translated into a kWh / day value to assess their energy demand from a site if they were to electrify. Thus, quantifying the energy deliverability would enable planners to compare the same metrics not necessarily to determine if a customer can electrify its fleet but rather to assess if there is sufficient energy deliverability at a site even before looking into managed charging or behind-the-meter charging solutions (discussed in detail in the next subsection).

Using the box plot above, one could quantify how much deliverable energy is available to a customer. The foremost approach would be to quantify the deliverable energy assuming un-managed charging. This would assume the customer can charge up to a certain power level regardless of the time of the day (i.e., worst-case hosting capacity). From the example above, with 2 MW hosting capacity all day charging could consume up to 48 MWh/day. If time-varying hosting capacity is leveraged, between 10pm and 7am when there is 5 MW of available capacity 45 MWh/day can be consumed during this 9-hour period. Note that these two scenarios almost resulted in the same amount of deliverable energy available to the customer assuming the worst-day of the year in both cases.

D. Evaluating integration solutions

Whether it is for electrification requests or for distribution planning studies, the first step to evaluating integration solutions is to understand the type of constraints limiting the opportunity for electrification. In the previous section, the hosting capacity was discussed as the maximum amount of additional load that can be connected without causing operational issues, whether it is a voltage or thermal constraint or both. However, the most limiting constraint might vary from one distribution feeder to another or even within the same feeder between different laterals. Figure 8 demonstrates the most limiting constraint at each node on the distribution feeder discussed earlier. Note that the hosting capacity is most constrained by under-voltage issues on the grid-edge. Thus, depending on which feeder or even location on a feeder, the type of integration solutions needed to accommodate a fleet customer may vary based on the constraint(s) it creates.

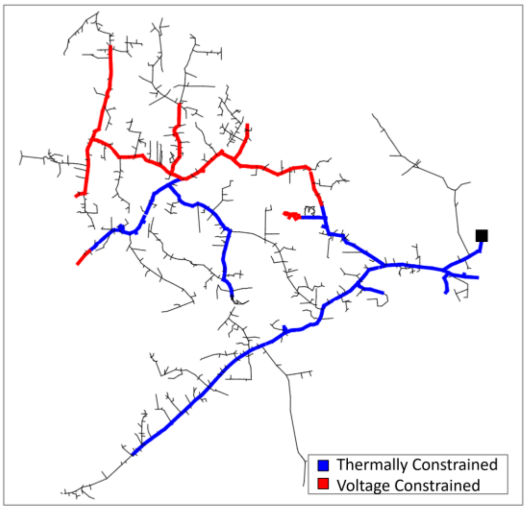

Figure 8. Minimum hosting capacity over a 24-hr period when considering each type of constraint separately: UVHC – Under-voltage hosting capacity, TLHC – Thermal Load Hosting Capacity.

Integration solutions could be categorized into two objectives: (i) reducing grid impacts, and (ii) mitigating grid impacts. This nuance is relevant when considering fleet electrification because of the nature of the new load. More specifically, charge management or behind-the-meter distributed energy resources can help the customer manage the demand that the grid will serve, hence reducing their grid impacts. On the other hand, if load managemenet is not a viable solution, mitigating the impact might be the only solution to enabling fleet electrification. In this case, the goal isn't to manipulate the demand to avoid grid constraints but rather increase the capability of the grid to accommodate it. Both approaches – reducing and mitigation grid impacts – will be necessary to accommodate high-adoptions levels of electric vehicles especially considering the potential flexibility that these new loads could offer to the electric grid.

CONCLUSION

In this paper, a planning framework is presented to help electric distribution companies accommodate for fleet electrification on electric distribution feeder. Unlike residential electric vehicles where the transition is more gradual, customers with fleet vehicles can create significant impacts onto the grid from a single customer electrifying their fleets. The challenge with the electrification of fleet vehicles is the uncertainty around where on the grid these fleets will likely emerge, what their needs will be, and how a utility can help enable the transition. On the other hand, electric distribution companies have a huge opportunity in this electrification transition from meeting broad electrification and sustainability targets to downward pressure on electricity rates. Hence, proactive planning for fleet electrification on electric distribution systems is necessary for a smooth transition.

The proposed planning framework focuses on four broad industry needs: (i) fleet identification, (ii) fleet demand characterization, (iii) distribution system impact analysis, and (iv) integrated solutions evaluation. Before estimating their electrical need, it is important to identify where, when, and how many fleet vehicles will electrify. The paper discusses the challenges with locating and identifying fleet characteristics that would impact their power and energy needs. Because there isn't a perfect database, multiple databases (e.g. vehicle registration, telematics, etc.) are necessary to provide a more accurate prediction of fleet characteristics and their location and their benefit and limitations are presented. The second step discussed in this paper is to understand fleet needs and capabilities. More specifically, the demand and load shape from fleet electrification will also depend on how these fleets are managed and operated. The paper elaborates on the different factors that would affect the load shape to better understand how this new type of load will impact distribution circuits. Explicitly, fleet vehicles can have distinct and relatively predictable behavior that may not impact the grid in a similar fashion as traditional load growth. Hence, new studies and metrics are discussed to nuance current planning practices including: time-series hosting capacity analysis, electrification opportunity assessments, energy deliverability, etc. Lastly, the paper discusses integration solutions unique to the transportation sector including charge management.

Fleet electrification presents unique challenges and opportunities given the more concentrated impacts on the grid due to the larger number of vehicles charging at a central location. Proactively planning for this electrification transition not only helps identify strategic investments across a utility's territory but also identify underutilized areas and assets to incentivize early electrification adopters. Leveraging available capacity can also enable utility planners to better understand customer needs before investing into new infrastructure and help them develop charge management programs where it would provide the most benefits. By proactively planning for fleet electrification, electric distribution companies are better positioned for the transition and as a result, be able to streamline customer electrification requests to maintain customer satisfaction.

BIBLIOGRAPHY

[1] EPRI's Consumer Guide To Commercial and Industrial On-Road Electric Vehicles. EPRI, Palo Alto, CA: 2022. PID: 3002023381.

[2] Seattle City Light Electrification Assessment. EPRI, Palo Alto, CA: 2022. Available at: https://powerlines.seattle.gov/2022/01/20/planning-for-an-electrified-future/

[3] Electric Vehicle Fleets – The Distribution Planning Process. EPRI, Palo Alto, CA: 2021. 3002023019.

[4] Federal Highway Administration (FHWA), U.S. Department of Transportation (DOT). 87 Fed Reg 37262. Published on 06/22/22. Available at: https://www.federalregister.gov/documents/2022/06/22/2022-12704/national-electric-vehicle-infrastructure-formula-program

[5] M. Rylander, J. Smith and W. Sunderman, "Streamlined Method for Determining Distribution System Hosting Capacity," in *IEEE Transactions on Industry Applications*, vol. 52, no. 1, pp. 105-111, Jan.-Feb. 2016, doi: 10.1109/TIA.2015.2472357.

[6] Central Hudson Gas & Electric Hosting Capacity maps available at: https://www.cenhud.com/en/my-energy/distributed-generation/hosting-capacity-maps/

[7] Pacific Gas & Electric Integration Capacity Analysis maps available at: https://www.pge.com/en_US/for-our-business-partners/distribution-resource-planning/distribution-resource-planning-data-portal.page