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Electrification Opportunity on Distribution Systems: A Case Study

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SUMMARY

Rapid growth of electric vehicles adoption will inevitably have an impact on electric distribution systems. Unlike traditional load growth, there are uncertainties related to electric vehicles – location where they would charge, the quantity of vehicles, the transition timeline – and planning for this growth can be challenging. Hence, it is important to assess the current capabilities of the system to understand where capacity is limited, new infrastructure that would be necessary, and locations where existing capacity could be leveraged for early electrification transition. This paper discusses a case study based on Dominion Energy distribution feeders assessing their electrification opportunity. The study discusses not only the hosting capacity at peak load but also presents time-series hosting capacity based on the specific load behaviour of the feeder to assess overnight and off-peak capacity. Finally, a wide-area distribution assessment study is presented to provide a more holistic overview of electrification opportunity.

KEYWORDS

power distribution, electric vehicles, power system planning.

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INTRODUCTION

Electric vehicles (EV) adoption has continued to increase in the recent years, whereas new EV sales has surpassed the 5% threshold that some economists have defined as the tipping point for mass adoption [1]. The U.S. nationwide-average new EV market share reached 6.7% from January to July 2022 compared to 4.4% in 2021 while some counties already experiencing market shares above 25% despite supply chain issues [2]. This rapid growth in technology adoption demonstrates the importance and urgency for grid planners to proactively plan for the new demand to anticipate these pockets of loads and to evaluate strategic investments to accommodate it [3].

Electric distribution companies (EDCs) are not foreign to load growth and how to accommodate it (e.g. air conditioning units in the 1970s). However, the timeline of EV adoption and the magnitude of the potential demand that could manifest itself on the grid can be concerning especially in areas where the grid is already at near capacity. Unlike air conditioning, the behavior of the demand from EVs is not fully understood, whereas air conditioning demand would manifest itself proportionally to the temperature.

While residential vehicles account for a larger share of the total energy consumed by the transportation sector [4], commercial fleets are arguably a much more imminent load for grid planners to plan for. Unlike residential vehicles, fleet vehicles are 'spread-sheet' purchased, where economics is the main driving factor to electrification, whereas residential vehicles may be emotionally purchased. Moreover, for the grid to experience significant impacts from EVs, multiple residential customers would need to purchase EVs whereas a single fleet owner could electrify dozens or even hundreds of vehicles at a location. Lastly, residential vehicles are more likely to have a distributed impact on the system, while fleet EVs would have a much more concentrated impact based on the number of vehicles charging and their size. Although both vehicle segments will impact the grid, the impact of fleet EVs could be observed earlier than residential EVs.

Grid planning for load growth is an on-going effort for EDCs planners. However, planning for EVs is especially challenging because of the uncertainty around the location, timeline and magnitude of the new load [3]. Hence, it is critical for distribution planners to first assess the capability of the current system to identify areas with available capacity to incentivize EV adoption or areas with limited capacity to prioritize infrastructure investments. This paper discusses a case study performed on Dominion Energy distribution feeders to assess their electrification opportunity. This includes quantifying the available capacity to accommodate new demand during peak load conditions, as well as performing a time-series hosting capacity analysis to capture the daily and seasonal variation in the capacity based on the existing load on the feeder. An integration assessment is also presented to identify the type of constraint that a feeder could experience (voltage or thermal), the severity of the constraint, and the frequency at which the constraint occurs. Finally, the hosting capacity analysis is conducted on multiple distribution feeders to provide a more holistic understand of the capability of the system as part of a wide-area distribution assessment.

This paper is organized as follows. Section 2 discusses the background of the work. The modeling and simulation assumptions are presented in Section 3. Section 4 discusses the hosting capacity results at both peak and off-peak load conditions. The time-series hosting capacity analysis is discussed in Section 5. Section 6 discusses the electrification opportunity and integration assessment. A wide-area distribution assessment is presented in Section 7. Finally, key learnings from the study are summarized in Section 8.

BACKGROUND

The challenge with demand projections from electric vehicles is that not all vehicles are created equal. Residential vehicles (class 1-2) will have a significantly different impact from commercial vehicles (class 3-8), both in the magnitude of the demand but also when it will occur within a 24hr period [5]. For example, school buses will have a different loadshape compared to transit buses, and food delivery will have a different demand compared to last-mile delivery fleets. Moreover, significant differences in demand could be experienced within the same segment of vehicles depending on the application. Residential vehicles will have a different power and energy needs whether they are used for daily commutes, weekend trips, or extended road trips. This demonstrates the challenges for electric companies to forecast this new demand and proactively plan for the system to be able to accommodate it.

Electric vehicles are an active research topic discussed in the literature whether it is investigating charging load curves [6, 7], adoption models [8], or electrification forecasts [9]. The integration of EVs and their impact on electrical systems is also a growing research area given that impacts will depend on the type of EVs, the specific location on the grid, or even the number of EVs being integrated. For example, a case study discussing the impacts of electric vehicles on a New Mexico utility's urban distribution infrastructure identifying short-term and long-term impacts is presented in [10]. Lastly, some publications discuss methodologies to assess the grid's ability to accommodate EVs [11] or electrification technologies [3, 12].

Distribution planners typically have forecasting models to assess the new load on the system over the next ~5-10 years where load growth conventionally exacerbate the peak load conditions. However, EV demand may not necessarily manifest itself during peak load conditions due to several characteristics such as: dwell time, dwell duration, miles driven, and others [3]. Moreover, the load profile may also vary based on external factors designed to impact the load shape such as smart charging technologies, customer incentive programs, or even rate structures (e.g. time-of-use rates). Hence, the work presented in this paper investigates not only the peak load capacity to accommodate new load but also the time-series hosting capacity to assess the daily and seasonal patterns in available capacity.

MODELING AND SIMULATION

One of the challenges that the industry faces when performing any types of grid assessments is the quality of the models and dataset used for the analysis. Some feeder verification and data cleaning processes are necessary to ensure accuracy in the simulation results. Model validation consisted of verifying characteristics of power delivery equipment to ensure impedance and equipment rating represents the physical property of the system. The second step is to verify power flow conditions (voltage profile and equipment loading) to guarantee the model is properly representing the feeders at their normal operating conditions.

To perform any types of time-series simulation, one of the most effective approaches in modeling the temporal behavior of the load is to leverage SCADA measurement at the feeder head [13]. However, data integrity may become a challenge due to typical data measurement artifacts. As shown in Figure 1, time-series data may contain noise, random spikes (due to switching events), zero values due to power outages or data dropouts, sudden shifts in the load data (feeder reconfiguration or load transfer), or simply missing values. Although some may be the actual power flow behavior, they may not properly model the temporal behavior of the load in the model of the feeder (e.g. load transfers). Hence, it is especially important to address these data quality issues before utilizing the time-series load data to perform studies such as time-series hosting capacity.

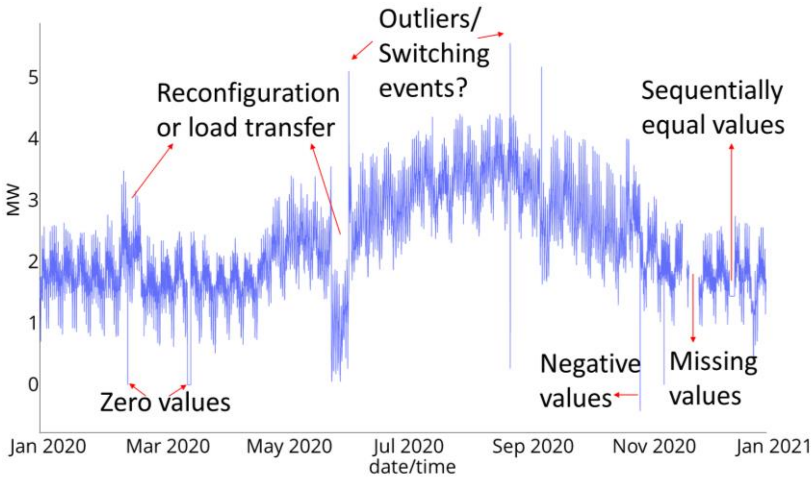

Figure 1: Time-series measurement data demonstrating zero values and missing data.

HOSTING CAPACITY ANALYSIS

Hosting capacity analysis quantifies the amount of resources (either load or generation) that can be accommodated on a distribution feeder while maintaining power quality and reliability in the system [14]. Within the scope of this case study, the hosting capacity analysis allows planners to assess how much additional load (EVs or other electrification technologies) can be accommodated at different locations across a distribution feeder while considering the specific characteristics of the feeder and the loading on the backbone or laterals. This analysis is performed in the EPRI DRIVE tool [14]. In this study, the hosting capacity analysis takes into consideration voltage and thermal constrains, and current feeder loading.

Figure 2 shows the centralized hosting capacity results of a distribution system at peak load. The hosting capacity varies throughout the feeder from 8MW (location A) to 0MW (location C) demonstrating that hosting capacity can vary drastically even within a single feeder.

Figure 2: Hosting capacity analysis: peak load

As expected, hosting capacity for additional load is higher near the substation and lower at the edge of the grid. However, an interesting behavior in the results shows a significant step down from 8MW to ~2.5 MW then to ~0MW. This is due to the specific characteristics of the feeder and more specifically the conductor’s rating. Figure 3 shows the feeder schematic colored by the conductors rating. Note that the step down in hosting capacity correlates to the step down in line ratings. With the load center closer to location C, the backbone feeding that area is rated for 200-300 amps which creates a bottleneck when adding new load downstream.

Figure 3: Element rating

While the hosting capacity analysis in Figure 2 shows the hosting capacity at peak load, there might exist additional capacity at different loading conditions even if the feeder is constrained by its element ratings show in Figure 3. The hosting capacity results during the off-peak load scenario are shown in Figure 4. Because the demand on the feeder is lower during off-peak conditions, the power flow throughout the feeder will be lower allowing for additional capacity (e.g., locations B and C). While distribution engineers plan for the worst-case condition (i.e., peak load condition), it is important to capture this variability in the hosting capacity given the feeder's loading conditions, due to the different behaviors of EV charging demand. Therefore, the time-series hosting capacity is necessary to assess the feeder's capacity considering the behavior of its load throughout the year.

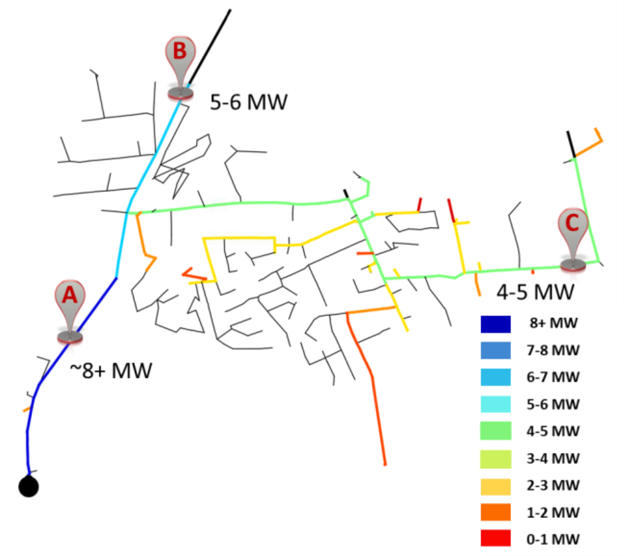

Figure 4: Hosting capacity analysis: off-peak load

TIME-SERIES HOSTING CAPACITY ANALYSIS

Time-series hosting capacity is performed by considering the load 8760-hour profile, thus, providing the range of hosting capacity available at specific locations throughout the feeder instead of at static load conditions such as peak and off-peak load. The time-series hosting capacity results for locations B and C of Figure 2 can be observed in Figure 5. The range of available capacity for each hour of the day at both locations can be observed in the box plots. It can be observed that while the minimum capacity (corresponding to peak load) occurs a handful of times, the average daily capacity throughout the day resides between 5-7MW and

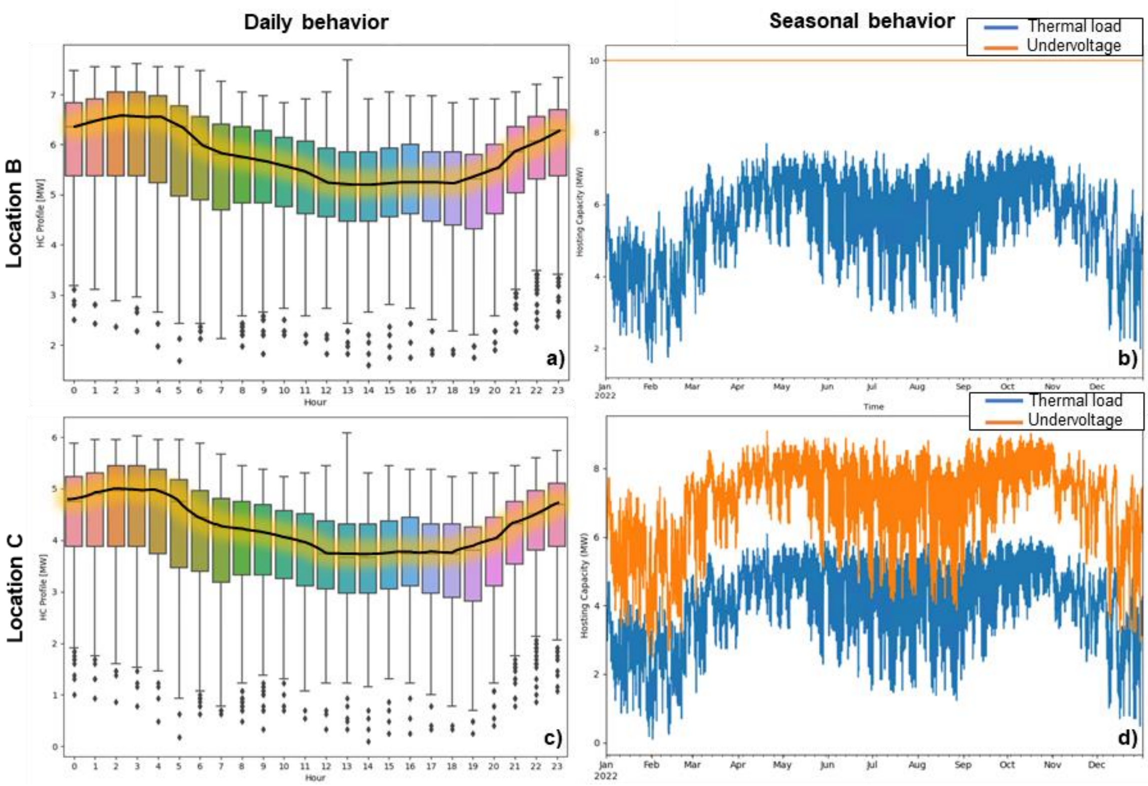

Figure 5: Hosting capacity analysis results at Location B & C. Sub-plot a) and b) are hourly box plots of sub-plot b) and d) are time-series plots.

3.5-5MW for locations B and C, respectively. The line plots show the time-series hosting capacity for the full 8760 for constraints such as the thermal loading and undervoltage. Note that when evaluating the voltage constraint separately from the thermal hosting capacity, location C showed lower available capacity as expected since locations further from the substation will see more voltage drop and as a result, under voltage conditions.

While peak load conditions will yield the most constraining hosting capacity results for additional load, time-series hosting capacity analysis can provide valuable insights on the behavior of the feeder. This is especially important considering that EVs and electrification technologies in general may have a very different behavior and may not coincide with the existing feeder peak. Moreover, time-series hosting capacity can enable distribution planners to assess the value of load flexibility. Feeders with a significant difference in daytime and nighttime hosting capacity would be ideal candidate for customer programs (e.g., time-of-use, charge management, etc.) to shift the demand to times in the day where more capacity is available.

ELECTRIFICATION OPPORTUNITY AND INTEGRATION

The available capacity for electrification (electrification opportunity) can be obtained by examining each of the nodes minimum hosting capacity (peak load condition) constrained by either thermal limit or under-voltage with respect to a defined EV fleet charging profile. For each location on the feeder, the EV profile is compared to the hosting capacity to identify if the location can (1) host the new load without any further considerations, (2) host the new load with charge management since there is sufficient energy available at that location if power-constrained by a few hours, or (3) cannot host the new load without infrastructure investment. Figure 6 shows the feeder feasibility map to host charging EV load.

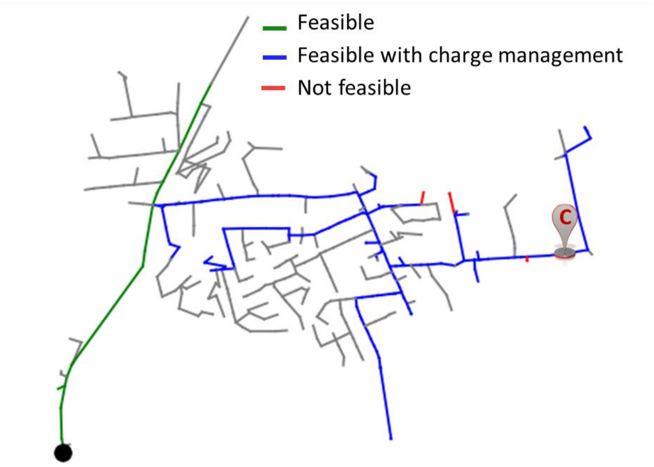

Figure 6: EV charging feasibility

Figure 7 takes a closer look at location C hosting capacity with respect to the EV charging profile, separated by voltage and thermal constraints. The EV charging profile exceeds the hosting capacity thermal limit constraint for the hours of 16-21. However, there exists additional capacity at different hours of the day, making it feasible to host the EV if charge management is available.

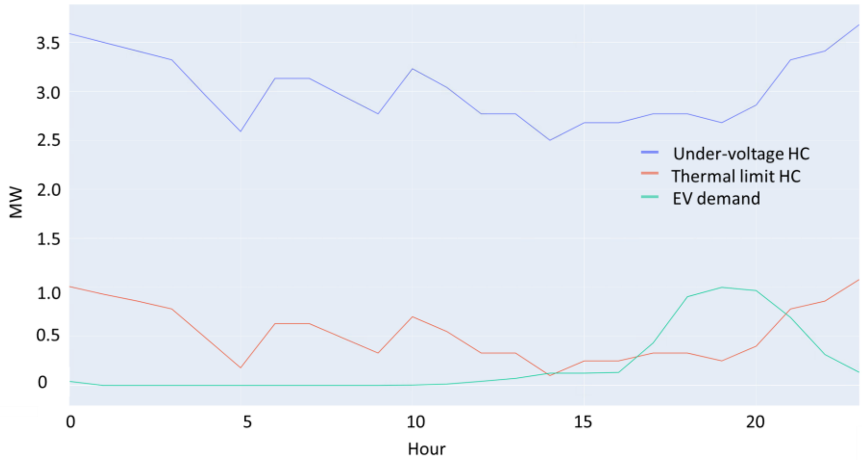

Figure 7: Location C HC constraints with respect to EV charging profile

WIDE-AREA DISTRIBUTION ASSESSMENTS

Analyzing a single distribution feeder can be insightful for electrification requests to understand the impact that a specific customer could have on the system. However, from a planning perspective, it may be valuable to do an assessment of the grid's capability across a utility's territory. A wide-area distribution assessment (WADA) studies the entire distribution grid to provide a holistic understanding of impacts and benefits from grid modernization, electrification, DER interconnection strategies, etc. The WADA study allows planners to identify feeders that should be prioritized for infrastructure investment due to increase/growth of fleet EV activity. Moreover, feeders with additional capacity could provide a great opportunity to incentivize early EV adopters.

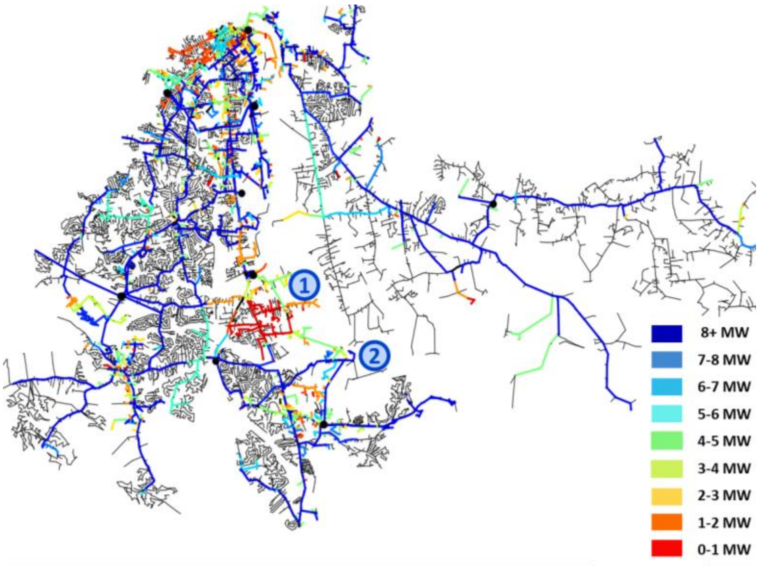

Figure 8: Wide-area hosting capacity at peak load

The feeder discussed in Figure 2 is part of a wide area network of circuits in the Dominion Energy territory. The WADA hosting capacity study for this network of circuits can be observed in Figure 8. The HC varies from feeder to feeder with the feeder demarked as 1 being one of the lowest. Furthermore, if load growth cannot be avoided for feeders with limited capacity, nearby feeders' capacity could be leveraged to support via tie-points, especially if neighboring feeders have excess capacity. For example, the feeder demarked as 2 has significantly higher capacity than feeder 1 which is directly adjacent. Through this WADA study, a distribution planner would be able to quickly identify opportunity to leverage existing assets to meet the new demand.

CONCLUSION

A case study assessing the electrification opportunity on Dominion Energy's distribution feeders is presented in this paper. Peak load hosting capacity to accommodate EVs and electrification technologies shows that capacity can vary from feeder-to-feeder but also within a distribution feeder depending on the specific topology and characteristics of the feeder. Off-peak hosting capacity and time-series hosting capacity are also discussed in the context of hosting EVs since additional capacity may be available when the demand would manifest itself on the system. Finally, a wide-area distribution assessment is presented to enable distribution planners to prioritize infrastructure investments wherever capacity is limited or incentivize early adopters on under-utilized feeders.

Electrification opportunity on distribution feeders is location-specific and will vary based on the characteristics of the system and the behavior of the existing loads. This paper presented a specific case study where the specific results may vary from one utility to another. Moreover, this paper presents a methodology to quantifying electrification opportunity that can be replicated to enable planners to better understand the capability of their system.

One consideration identified in the scope of this work is that this analysis focused on the capability of distribution feeders. However, it is important to recognize that substation capacity should also be considered for a more holistic assessment of the grid's capability. Finally, as additional resources are integrated onto the system, the transmission system may also be impacted and constrained in specific locations. This transmission and distribution electrification opportunity assessment is subject of on-going work.

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