SAND2019-13042R

I Grid and Charging Infrastructure [Use Heading 1]

I.1 Fast Charging Enabling Technologies [Use Heading 2]

I.1.1 Smart Electric Vehicle Charging for a Reliable and Resilient Grid (Sandia National Laboratories)

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Project Introduction

Adoption of plug-in electric vehicles (PEVs) has expanded over the last few years, yet introduction of PEV smart charging has been stalled due to barriers in communication, controls, and an unclear method for determining the value PEVs will bring to the grid. This project will consider the grid impact of a variety of future scenarios, including adoption of different vehicle types, proliferation of extreme fast charging (xFC), expanded adoption of distributed energy resources (DER), and multiple smart charge management approaches. This project will determine how PEV charging at scale should be managed to avoid negative grid impacts, allow for critical strategies and technologies to be developed, and increase the value for PEV owners, building managers, charge network operators, grid services aggregators, and utilities.

Sandia National Laboratories (Sandia) is a team member on this project, which also includes the National Renewable Energy Laboratory (NREL) and Idaho National Laboratory (INL). Sandia will 1) focus on the grid integration impacts of EV smart charge management, 2) model the interplay of multiple DER to understand how EV smart charging will interact with other grid resources and 3) leverage its electric grid resiliency analysis framework to understand the impact and possible benefits of smart charging during extreme events.

Objectives

This project will address benefits and barriers of smart charge management for PEVs at scale through multi-lab collaboration. Taking advantage of their combined cutting-edge facilities, capabilities, and access to data, the team will develop technology for real-world implementation of smart charging. The team will investigate grid

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resilience and reliability challenges and opportunities presented by mass adoption of PEVs through detailed simulation. Team research will:

1) Quantify the effects of uncontrolled charging to understand how increased PEV adoption may negatively impact the grid
2) Analyze the effectiveness of multiple control strategies in mitigating negative grid impacts introduced by PEVs at scale
3) Rank the benefits and costs of the control strategies in avoiding grid upgrades, providing grid services, and improving resilience, and
4) Overcome technical barriers to implementing high-value control strategies.

Approach

The project is separated into nine tasks to accomplish the four objectives listed above. Sandia is involved in the following tasks:

Task 1: Scoping, requirements, and industry engagement
Identification of regions for the PEVs at scale analysis will be performed to engage utility partners willing to support and provide distribution feeder models, load data, and other analysis or insight into the operation of their distribution system.

Task 3: PEV charging and distribution system modeling
Detailed distribution grid models will be implemented to understand the locational impact of PEV charging on distribution grid operations and identify voltage or thermal constraints. This modeling will take place in OpenDSS, a powerful open-source software conducive to both translating results to commercial software and to releasing developed tools and models to the research community.

Task 4: Quantifying the impact of uncontrolled charging
Sandia will apply existing hosting capacity analysis tools to possible PEV charger connections. For each node on the distribution feeder, the maximum charging capacity will be identified. Hosting capacity also resolves the limiting factor (e.g., voltage violations or current limits), which can be used to understand the sensitivity of the feeder.

Task 5: Refining smart charge control strategies
This task will study the potential of multiple control approaches to mitigate negative impacts of PEV charging at scale and provide grid services. New functionality will be added to control PEVs across multiple distribution feeders and to include bulk grid impacts in the objective function. A series of simulations will be run to compare the efficacy of each control's approach in delivering multiple grid services in various future scenarios.

Task 6: Value of smart charging
The value of implementing smart charging will be quantified using the same process as in Task 4. The hosting capacity with various methods of smart charging (including controlled ramps up in charging, smart temporal charging, etc.) will be compared to the hosting capacity for uncontrolled charging. The increase in hosting capacity will be compared against the "cost" of smart charging (e.g., slower charging, charge not available when needed, etc.) to determine the value and tradeoff of smart charging.

Task 7: Resilience Impact
PEV impacts to grid operations during resilience events may be fundamentally different than impacts during normal operations. This task will investigate how smart charging can adapt to a "coherence of load," a significant increase in PEV load that happens very rarely. The team will investigate how the power and charging infrastructure and controls can support these extreme scenarios without "gold-plating" the power system.

Results

Results by task are listed below.

Task 1: Utility Engagement

Sandia has partnered with utilities interested in EV integration. Through these partnerships, Sandia has obtained insights and data related to PEV integration. Sandia has had regular communications with utility employees in power delivery, electric transportation, and distribution systems operations.

Task 3: Distribution System Modeling

Through partnerships with distribution utilities, Sandia has received and analyzed distribution system models for 10 feeders. These feeders were converted to OpenDSS format [OpenDSS 2019], as OpenDSS suited to research-level analysis due to its ability to interface with data analysis programs through a COM interface. An overview of the feeders is shown in Table I.1.1.1.

Table I.1.1.1 Feeder descriptions

	Description
Feeder 1	Residential
Feeder 2	Residential, some Commercial
Feeder 3	Industrial
Feder 4	Commercial and Residential
Feeder 5	Commercial, some Residential
Feeder 6	Industrial
Feeder 7	Residential and Commercial
Feeder 8	Residentail and Commerical
Feeder 9	Commerical
Feeder 10	Commercial, some Residntial

Task 4: Impact of Uncontrolled Charging

On each of the 10 feeders, Sandia performed hosting capacity analysis. Hosting capacity cycles through each node on the feeder (i.e., each location where a PEV might possibly be connected), adds a new PEV load, and incrementally increases the size of this load until a violation is detected. Violations include excessive loading of lines and under- or over-voltage situations. When a violation is reached, that size of PEV load is recorded as the hosting capacity at that node, the PEV load is removed from the circuit (to return the circuit to the base state with no PEV loads), and the process repeats at the next node.

Figure I.1.1.1 shows an example hosting capacity result. Feeder nodes along the three-phase backbone of this feeder have large hosting capacities: at least 7MW as indicated by the blue color in Figure I.1.1.1. Feeder nodes along single-phase laterals of the feeder had much lower hosting capacities, as indicated by the red colors in Figure I.1.1.1. In some of these areas, the hosting capacity limit was due to larger PEV charge loads exceeding the line rating – single-phase lines typically have smaller capacities. Other areas were affected by undervoltage violations, especially as loads connected to single-phase systems can increase load imbalance between the three phases and quickly reduce the voltage to below the ANSI Range A of within +/- 5% of nominal voltage (i.e., 114-126V for a residential 120V system) [Kersting 2019].

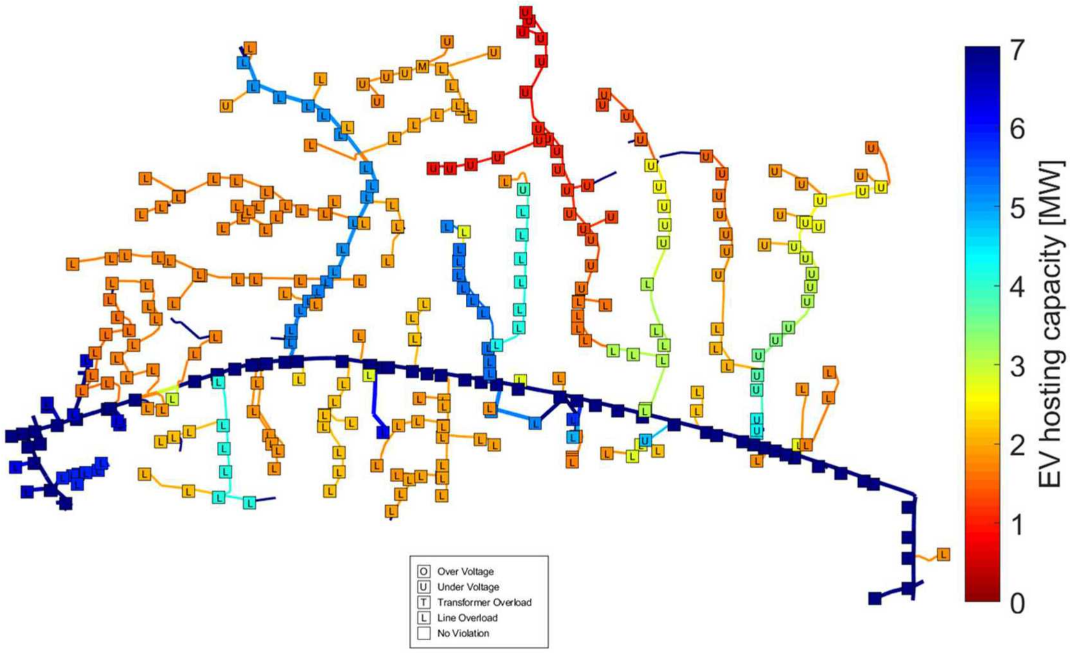

Figure I.1.1.1 Hosting capacity result for a residential feeder.

Task 5: Smart Charge Control Strategies

The uncontrolled charging hosting capacity is a worst-case scenario, where all chargers that exist on the feeder are assumed to be in-use at full capacity. In this task, we have begun to look at the impact that smart charging can have to reduce or eliminate the hosting capacity limits seen in the uncontrolled charging case. For example, when undervoltage violations are the limiting factor, we are looking to introduce control strategies which reduce real power draw during low-voltage times, such as delaying charging slightly to avoid feeder peak demand. Similar controls are being explored to alleviate line-loading concerns – limiting simultaneous charging to ensure that power flow through a particular line never exceeds the line's rating. Geographic controls shifting charger locations to areas with high hosting capacity are also being explored.

Task 6: Impact of Smart Charging

Sandia has started to implement the control strategies considered in Task 5 into the hosting capacity analysis to understand the impact. This work will be continued throughout project year two.

Task 7: Resilience Impact

This task is planned for project year three and work has not yet started.

Conclusions

While this work is still ongoing (two project years remain), work so far has highlighted the possible challenges in PEV integration if PEV charging is uncontrolled. With the distribution feeder data obtained, hosting capacity analysis was used to identify grid vulnerabilities. Across all feeders, limits were either line loading or undervoltage, though the size of PEV charge load at which that limit occurred depended on both the feeder and the location of the PEV charger on the feeder. This has highlighted opportunities for controlled charging: controls can both reduce or mitigate line loading and voltage problems by limiting charging during times when the feeder is stressed, and by encouraging geographic movement of charge events to areas without line loading or voltage limitations. The impact of controlling charging in these ways will be explored in project years two and three.

Key Publications

Lave, M. "Towards High Fidelity Modeling of DER Integration to Distribution Grids." *Smart Grid Edge Analytics Workshop*,Atlanta, GA, June 2019. Available: https://smartgridedgeworkshop.ece.gatech.edu/wp-content/uploads/sites/995/2019/06/S32_MattLave_SANDIA.pdf.

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- Kersting, W. H. "Distribution feeder voltage regulation control." *2009 IEEE Rural Electric Power Conference*. IEEE, 2009.

Acknowledgements

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