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Can Plug-in Electric Vehicles in a Smart Grid Improve Resiliency?

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Issue

While the impact of plug-in electric vehicles (PEVs) on electricity generation and transmission has been studied extensively, the impact of PEVs on the resiliency of the local electricity distribution system has not been addressed in detail. Understanding resiliency impacts is important as the increased use of PEVs, and especially the clustering of PEVs in one area (such as a neighborhood), place additional pressures on already aging power grid infrastructure. As an example, charging a large population of PEVs during normal operations can stress system components (such as transformers) resulting in accelerated aging or even failure, which reduces resiliency of the system. On the other hand, PEVs can also increase system resiliency. When connected to the grid, PEVs are an energy resource that can provide electricity for critical services (such as community shelters) during grid outages and facilitate grid restoration by providing electricity to support the restart of transformers and other utility assets.

To identify the management and control systems needed to achieve positive outcomes (and mitigate the negative impacts) of large-scale PEV deployment, researchers at the University of California Irvine created detailed models that can simulate the dynamics of the electricity distribution system, assess the effects of PEV charging on the aging of transformers, and help evaluate smart charging strategies for grid-connected ("normal") operations as well as for grid outages.

Key Research Findings

PEVs can be used as energy storage to serve critical loads with minimal system upgrades. PEVs can be used in vehicle-to-home (V2H) applications to provide household electricity (such as during periods of high demand) and avoid service interruptions. This will require a few upgrades, including PEV electric chargers that allow electricity to flow in both directions and installation of a smart home energy management systems. Additionally, PEVs plugged in at parking lots can be aggregated to serve larger nearby critical loads such as emergency shelters. The switching needed to route electricity from PEVs to the critical facility is minimal in this case, and only a handful of switches would need to be upgraded to smart or remote-controlled switches in order to automate the process. This approach could potentially help avoid significant investment in infrastructure upgrades to achieve same level of resiliency. Alternatively, a field crew can manually implement the required switching.

Clustered PEVs in a parking lot are more suitable to facilitate grid restoration compared to scattered PEVs. While PEVs plugged into homes scattered across the distribution system have sufficient power and energy to support the restart of substation transformers, substantial upgrades would be required including: (1) replacing older switches with new smart switches to ensure that all inverters (devices that convert DC to AC) across the system are capable of operation without the grid, and (2) establishing communication links between the substation central controller and the multiple individual home chargers. In contrast, using PEVs clustered in a parking lot would only require upgrading the switches in the specific route between the parking lot and the substation, and the substation central controller would only need to communicate with the inverter that connects all the PEVs at the parking structure. Furthermore, to allow for bi-directional flow, fewer chargers would need to be upgraded and only the parking lot inverter would be required in the absence of the grid.

Smart charging strategies significantly mitigate the negative impact of increased PEV demands on local grid infrastructure. During the study's simulation of normal operations without smart charging implementation to reduce the peaks of energy use, the stress on system components from high PEV demand resulted in accelerated aging and possible transformer failures, which increases system operation and upgrade costs. However, in a well-designed smart (i.e., "controlled") grid, high PEV use with smart charging results in neither residential transformer failure nor high hot spot temperatures (HSTs). In all scenarios and circuit configurations simulated, smart charging reduced the negative impact of PEVs on transformers by reducing the average equivalent aging factor (EAF) up to 20 percent and reducing the maximum EAF up to 45 percent.

A combination of local distributed energy resources (DERs), energy efficiency measures, and smart charging provides the best results in terms of fewer infrastructure impacts and lower greenhouse gas emissions. The study showed that adding DERs that can generate and/or store electricity locally (often from renewable energy sources) and energy efficiency measures to smart charging further mitigates the negative impact of PEVs on grid infrastructure.

Smart charging can increase renewable penetration in the distribution system. Smart charging facilitates the use of available renewable electricity generation, resulting in increased renewable penetration in the distribution system without any required infrastructure upgrades.

Flexible travel plans and additional charging stations increase the effectiveness of charging strategies. Simultaneous departure times of PEVs (such as at rush hour) limit the effectiveness of smart charging strategies even with renewable resources. Flexible travel times and the provision of additional charging opportunities at workplaces and other destinations, increase the effectiveness of smart charging strategies.

More Information

This policy brief is drawn from the final project report entitled "Resiliency Impacts of Plug-in Electric Vehicles in a Smart Grid" written by Ghazal Razeghi and Scott Samuelsen at the University of California Irvine. The report can be found on the UC ITS website at www.ucits.org/research-project/2020-64.

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