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Integrating Electric Vehicles with Energy Storage and Grids

New technology and specific capabilities spur numerous applications.



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THE EFFECTIVE INTEGRATION OF ELECTRIC vehicles (EVs) with grid and energy-storage systems (ESSs) is an important undertaking that speaks to new technology and specific capabilities in machine learning, optimization, prediction, and model-based control. As more vehicle manufacturers turn to electric drivetrains and the ranges for these vehicles extend due to larger energy-storage capabilities, EVs are becoming an important distributed energy resource (DER) that utilities, microgrids, and other industry service providers can use to help efficiently balance grid supply and demand, provide ancillary services, produce economic benefits, and support critical energy needs during outages.

State of the Industry

With 2017 sales increasing 24% in the United States from the previous year, annual plug-in EV (PEV) sales are growing rapidly. These vehicles—including both battery EVs that drive exclusively on electric power and plug-in hybrid EVs that offer electric and include internal combustion

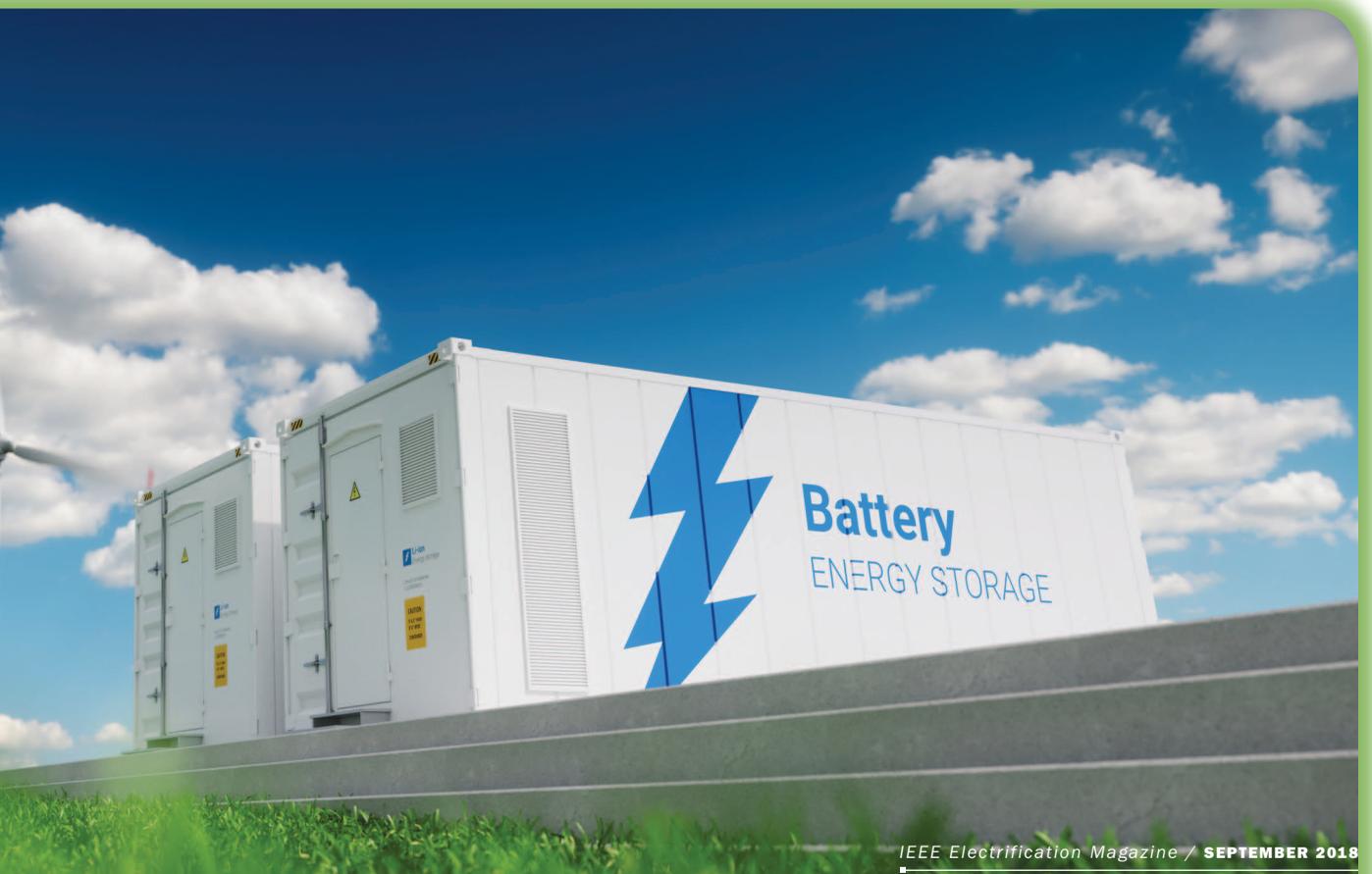
engine power trains—contain battery packs with storage capacities of between 4 and 100 kWh. If managed and optimized by grid operators, these mobile “storage-on-wheels” systems provide significant potential to increase overall energy demand while providing services that make the grid more resilient and robust.

However, this additional electricity demand has thus far proven to be unevenly distributed in its impact on the 8760 load profile. The majority of PEV owners recharge their vehicles at the conclusion of the work day, with charging sessions commencing between 6:00 and 8:00 p.m. and concluding between midnight and the early morning hours. To more positively shape this load, utilities are beginning to assert managed charging programs and pricing schedules to shift the load away from peak demand and more evenly distribute charging to provide a more beneficial load shape that levels out the impacts on the peaks while filling in the valley of underutilized demand.

V1G

Vehicle grid integration (VGI) includes both unidirectional power management by modulating the rate of power at which the vehicle battery is charged (also known as V1G)

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or by providing power back to the grid, known as *bidirectional grid integration* or *vehicle to grid (V2G)*. While V1G does not require additional equipment for vehicles, V2G provides greater flexibility in providing grid services; however, it can require the addition of bidirectional converter capability to the vehicle as well as the charging station. The vast majority of VGI pilot programs conducted so far have been unidirectional grid services due to concerns about the potential of frequent bidirectional charging to degrade the vehicle's battery capacity.

Active smart charge management via VGI offers the benefits of reducing electricity costs and preventing infrastructure upgrade costs; when optimized, it can suppress general costs because of the more effective utilization of assets. Similar to stationary storage, PEV batteries have the distinction of being more responsive to grid signals than peaker natural gas plants, which provides utilities with an effective tool for compensating for the inherent ramping of intermittent renewable wind and solar generating resources.

For example, the 100-MW Hornsdale Power Reserve plant in Australia, built with Tesla EV energy-storage technology, has markedly and positively impacted grid performance and met the widespread need for frequency-controlled ancillary services in its national electricity market. Notably, markets with a lower percentage of renewable generation resources often have equally lower demand and compensation for grid service and are thus less likely to be target markets for VGI.

Currently, VGI activities have focused on fleets rather than individual PEV owners because of the need to aggregate vehicle battery storage capacity and power demand to volumes that are meaningful for utilities to enable grid services. There have been examples of pilot trials in which personal PEVs have been combined with stationary storage or other grid resources, such as the Charge Forward program in the San Francisco Bay Area with Bavarian Motor Works and utility company Pacific Gas and Electric Company (PG&E).

Due to the current lack of concentrated numbers of PEVs in most service territories, in the short term, the pooling of vehicles in VGI programs will often be combined with other grid resources until the volume of PEVs scales to sufficient size. Fleet PEVs are generally easier to manage for aggregators because they can be combined and managed more efficiently and their driving schedules (and, therefore, availability to provide grid services) are more consistent. VGI is currently being explored by utilities, automakers, energy aggregators, and fleet managers.

While the theoretical aggregated capability of all PEVs today may appear to be significant, the vast majority

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of PEVs are unable to provide grid services at a given moment, since many are not plugged in at a charging station for most of the day. Certainly, this will improve as workplace charging programs, fleet programs, and public EV service equipment (EVSE) penetration increases. While the future overall theoretical capability of PEVs to provide grid services will be larger than today's market, the current realistic potential to provide grid services based on availability is less than 3% of the market, according to data from Navigant Research.

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V2G

During the next few years, bidirectional V2G is expected to be evaluated more through programs with fleets due to the high cost of the enabling technologies to individual PEV owners. Using vehicle batteries as storage to provide grid services has the advantage over stationary storage because the storage is effectively paid for by the vehicle owner with little to no upfront cost; utilities pay for access to the storage that already exists. However, V2G commercialization will take several years as automakers will continue to monitor the impact on the battery life before committing to putting the necessary power and communications technologies in the vehicles at the factory.

Fast Charging and Stationary Storage

Most PEV charging today occurs at lower power rates through ac charging at 1.3–7.2 kW. Residences and workplaces are the most frequent charging locations, and by smart charging PEVs, these smaller loads can be useful in regulation services by slightly increasing or decreasing the power flow. DC fast-charging ranges primarily from 25 to 50 kW today, but the auto industry recently began shifting to much higher power charging between 100 and 400 kW. These charging sessions are focused on minimizing the charge time and returning vehicles to the road and have much less flexibility and value in grid services.

Due to the higher power, several EV charging station operators, including Tesla, are combining fast-charging stations with stationary storage. The batteries are charged at slower rates and then deliver power to the vehicles at higher levels to minimize the grid impacts and, more importantly, for the operator to avoid demand charges. When not providing power to PEVs, the stationary resources, if sufficiently sized, can provide grid services, which diversifies and increases their value and potential revenue streams.

For instances in which charging stations are remote and have much higher installation costs due to the distance from a distribution point, adding solar panels to

charge stationary storage can be more cost-effective. The batteries are slow charged via the solar grid and provide power for charging via ac or dc without the need to be grid tied. This configuration can also be used with microgrids, which can be islanded as needed to increase resiliency and avoid power outages.

Integration, Technologies, and Infrastructure Use Case

Regions with high PES adoption rates are currently looking beyond vehicles to VGI use cases to support utility and customer needs. In California, a recent study by PG&E assessed the technical feasibility and potential benefits to individual customers and ratepayers of vehicle-to-home (V2H) technology, which can be used for resiliency and reliability. The assessment found that V2H is technically capable of islanding and supporting household load in outage and demand response events.

The following key findings and insights were sourced from the final project report:

- ▶ V2H commercialization is challenged by multiple barriers.
 - 1) V2H is technically feasible but not currently commercially available.
 - 2) Customer willingness to pay was lower than the estimated V2H system cost.
 - 3) There is a high customer interest in emergency preparedness; however, costs outweigh perceived benefits.
- ▶ Once V2H/V2G technology is commercially available, early adoption is likely to be motivated by V2H resiliency and reliability benefits.
- ▶ After a V2H system is adopted by a customer for personal resiliency and reliability benefits, utilizing an EV and V2H system for a demand response event is cost-effective from a program administrator cost-test perspective.
- ▶ **Key question:** Home energy storage or EV?
 - **Answer:** A V2H system may be able to substitute for stationary storage, depending on customer mobility and home electricity needs.
- ▶ **Key question:** Home energy storage and EV?
 - **Answer:** A V2H system with solar PV and stationary storage can provide significant resiliency benefits in the case of sustained outages.

Ultimately, PG&E concluded that the “V2H market is nascent and requires further investigation ahead of PG&E commercialization activities.” (For more information, see the “For Further Reading” section.) Nevertheless, PG&E found that its work to “validate the feasibility and potential

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value of V2H technology has significance for the entire industry—in particular, for utilities that are experiencing customer interest in using the same technology.”

This case study provides a robust and in-depth view of how utilities in high-adoption regions are thinking through the value streams associated with VGI before the enabling technologies for V2H and V2G become attractive and viable from a customer willingness-to-pay standpoint.

Standards and Regulations at Work

The integration of EVs with energy systems requires many layers of systems interaction including informa-

tion, i.e., requires data and technology integration services as well as applications utilizing such integration, along with contractual components, thus enabling the financial aspects of services and markets. This integration is also an important pursuit in the web of development for the Internet of Things (IoT) and smart cities, as billions of devices are integrated through cloud, fog, and other edge-computing approaches. This will allow for new optimization approaches and opportunities for progress across many different application domains. There are numerous standards development and regulatory efforts underway worldwide. The following overview highlights a slice of the global interest in this application space:

- 1) Local jurisdictions may have special permissions in place for EVSE equipment as well as local utility standards for integration with grid services, and both vary greatly by jurisdiction worldwide. For example, in California, Assembly Bill 1236 requires cities and counties with a population of more than 200,000 to adopt specific governance processes to accelerate EVSE installation.
- 2) More broadly, industry bodies and standards development consortiums are advancing the agenda on the integration of electric transportation concerning many aspects of smart cities including public transportation, commercial fleets, workplace charging, and autonomous and shared mobility applications. For example, in the IEEE IoT consortium (iot.ieee.org), the Smart Cities Working Group (WG) is tackling applications for use in the transportation, energy, social good, public service, and many other domains drawing on development effort from IEEE P2413, *Standard for an Architectural Framework for the Internet of Things*.
- 3) Transportation electrification efforts and DER growth worldwide are also driving regulatory approval of V2G and are subsequently increasing utility investment in EV and energy-storage integration with grid resources,

accelerated markets, and program adoption. Reflecting these interests, standards efforts are now underway to advance energy system capability maturity for EV and ESS integration.

- 4) Specific to vehicle charging safety, Underwriters Laboratories (UL) 2594 and UL 2202, *Standard for Electric Vehicle Supply Equipment and Standard for Electric Vehicle Charging System Equipment*, cover level 1, 2, and dc fast-charging applications, while UL 9741, *Outline of Investigation for Bidirectional Electric Vehicle Charging System Equipment*, covers the export of power-to-power systems and the safety of bidirectional EV charging systems and equipment.
- 5) Vehicle plug standards are also key to effective integration, with significant work underway in standards such as International Electrotechnical Commission (IEC) 62196, *Plugs, Socket Outlets, Vehicle Connectors, and Vehicle Inlets—Conductive Charging of Electric Vehicles*, the Society of Automotive Engineers (SAE) International J2954 standards for wireless power transfer (up to 11 kW), *Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology*, and J1772 standard for plug connections, *Electric Vehicle and Plug-In Hybrid Electric Vehicle Conductive Charge Coupler*, and Japan EV Association Standard G105 (called CHAdeMO), *Connectors Applicable to Quick-Charging System at Eco-Station for EVs*. SAE J2954, released in December 2017, also has techniques for testing vehicle systems and automating the commercial transaction with a wireless charging station (i.e., without operator involvement).

Within the IEEE Power & Energy Society (PES), two different committees are also acting today with efforts underway through task forces, WGs, and standards development activities:

- ▶ *The IEEE PES Energy Storage and Stationary Battery (ESSB) Committee*: This committee is working along with Standards Coordinating Committee 21 to develop guides and best practices (i.e., IEEE standards) that provide information to users implementing various energy-storage technologies as well as address applications and interconnection to the grid requirements. The IEEE PES ESSB Committee has also released guides on lithium-ion and sodium battery ESS technologies and is beginning work on a flow battery guide as part of the IEEE 1679 series of standards, *Recommended Practice for the Characterization and Evaluation*

of Emerging Energy Storage Technologies in Stationary Applications.

- ▶ *The IEEE PES Smart Buildings, Loads, and Customer Systems (SBLC) Committee*: This committee is working alongside contributors from IEEE Standard 2030, *Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System*, and *End-Use Applications and Loads*, and IEEE Standard 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems*, to develop IEEE P825, *Guide for Interoperability of Transactive Energy Systems with Electric Power Infrastructure*. The IEEE P825 standard addresses the application, design, deployment, and operation of energy services behind the meter. The IEEE PES SBLC Committee is also working

on developing *Recommended Practices for Evaluation of Power Quality Impacts by Electrified Railway Loads* and a *Guide for the Application of Quick Response Systems of Customer-Side Loads*, including applications for EVs and ESSs providing ancillary services. Both efforts are being accomplished through sponsorship by the IEEE PES SBLC Loads subcommittee and in coordination with the IEEE PES SBLC Asia-Pacific WG.

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Emerging Markets and Transactive Energy

With the integration of energy storage and EVs across distribution grids, we predict new market systems will emerge in the distribution grid as the proliferation of ESSs within residential and commercial sectors accelerates. Markets are an important aspect of effective integration, driving both adop-

tion and capability maturity. One of the most important aspects of this future growth is transactive energy (TE). The Transactive Energy Framework, developed by the GridWise Architecture Council, defines TE as follows:

TE refers to the use of a combination of economic and control techniques to improve grid reliability and efficiency. These techniques may also be used to optimize operations within a customer's facility.

TE systems will be viewed as an extension of the existing wholesale paradigm with new retail and managed peer-demand-side attributes and characteristics. To provide context for effectively integrating EVs with the grid and ESSs, TE systems refer to specific information distribution techniques that implement and improve grid services, reliability, and efficiency, while also providing decision support for customer energy system-operations optimization. In the wholesale markets, transactions or exchanges have been among agents (traders, curtailment

service providers, load-serving entities, utility distribution companies, and so on), whereas the emerging TE paradigm extends the transactive agents to retail and grid-edge domains, including EV mobile resources and ESSs.

Notably, the agents or actors facilitating wholesale transactions are wholesale market operators and balancing areas, whereas the retail and end-use transactions primarily impact distribution operations, to which traditional market operators have limited or no visibility. In this, it is clear that consumer-side and grid-edge transactions between mobile systems need to be monitored and, where needed, facilitated [i.e., by a new distribution system operator (DSO) construct or similar energy service provider (ESP) role]. The facilitation of these services may occur through the exchange of information, including location-based energy price, or, alternately, through the exchange of financial contracts and grid data, such as in the wholesale markets.

One of the most important aspects of the effective integration of EVs and ESSs is distribution constraint management, in which a task is delegated to the distribution system operator and, more recently, to autonomous agents acting with safety and system protection objectives. Like wholesale markets, the DSO or ESP can facilitate grid-edge transactions in a number of ways, including matching voluntary bids and offers for energy and ancillary services submitted by transactive participants or influencing behavior in some other prescribed way. One other such way could be a communication containing the local marginal price or even a simple request to manage demand from an EV in some way (i.e., without a control, such as a behavioral distributed resource program). Each has its benefits and potential pitfalls in terms of reliability; however, the model of interaction is clear.

For all transactions in the grid between mobile and grid assets (i.e., the exchange of energy, information, and ancillary services), the DSO or agent will issue a control based on the extent of imminent or potential constraint violation determined in near real time. Controls can also be accomplished through distributed intelligence. When no action is taken by distributed agents to remedy a distribution grid constraint, the DSO would use priority schemes based on various preestablished criteria, such as the impact on constraint relief, similar to practices prevalent in bulk power operations and wholesale markets. From this emerges a framework that supports, at a minimum, the following:

- 1) transactive systems that exchange information between EVs, EVSEs, ESSs, and other behind-the-meter or IoT resources to elicit a response or control or otherwise improve a value proposition related to participation in the grid system

- 2) transactive systems that may exchange contracts and financial instruments to manage the financial aspects of these services
- 3) linked transactive systems for the exchange of goods and services.

Next Steps in Industry

To enable the broad use of EVs as flexible, cost-effective grid assets, innovation must occur across the hardware, software, and communications platforms that follows acceptable technical standards enabling the coordination, control, and maintenance of grid reliability. Automakers need to develop onboard chargers with bidirectional power flow capabilities that protect the integrity of the battery's lifespan. To reduce the consumer cost of participating in V2G programs, charging equipment needs to be developed that seamlessly communicates vehicle availability and state of charge and shares meter-quality electricity flow data to utilities without requiring a second dedicated meter.

Utilities must build on the data collected from the successful V2G and V2H trials and develop programs that factor in the multiple potential grid services necessary to justify the additional utility and consumer costs of exploiting EVs as grid resources. As EVs begin to penetrate regions in sufficient numbers to provide meaningful capacity, they can be employed as the lowest capital cost option for integrating EVs into DER programs. In taking a holistic view that anticipates the increasing needs to balance solar and

wind ramping, DER integration and the value of V2G services can be maximized, with that value ultimately being distributed among the pool of EV prosumers and other grid participants.

For Further Reading

Electric Program Investment Charge. (2018, Feb. 27). EPIC 2.03b—Test smart inverter enhanced capabilities—Vehicle to home. Pacific Gas and Electric Co. San Francisco, CA. [Online]. Available: https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/PGE-EPIC-Project-2.03.pdf

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