Appendix G. PGE Whitepaper on V2G

Utility Experience with Vehicle-to-Grid Regulatory and Technology Challenges, and the Final Hurdles to Large-Scale V2G Deployment

Ian Beil[1], Luke Whittemore[1], and Anik Shrestha[2]
[1]*Grid Edge Engineering,* [2]*Transportation Electrification*
Portland General Electric, Portland, Oregon
{ian.beil, luke.whittemore, anik.shrestha}@pgn.com

***Abstract*—Advancements in electric vehicle charging equipment, vehicle battery improvements, and technical standards updates have led to a recent proliferation of vehicle-to-grid (V2G) demonstration projects that presages a dramatic increase in V2G deployments worldwide. This paper discusses one utility's initial experiences in developing a regulatory framework for customer participation in V2G. It also covers the technical barriers encountered when implementing several V2G demonstration projects, and considers the final barriers that remain before V2G chargers are widely installed across the power system.**

***Index Terms*—Electric Vehicles, Vehicle-to-Grid, Distributed Energy Resources**

I. INTRODUCTION

Motivated by carbon reduction goals and improved product performance, consumers and businesses are adopting electric vehicles (EVs) at a rapid pace. The exponential growth of EVs and their accompanying electrical infrastructure requirements has compelled system planners to think deeply about how these resources will be integrated into the power grid in a way that is convenient to the user, avoids malignant impacts to the electric provider, and is cost effective for all parties involved. One avenue that has the potential to reduce costs for consumers and provide flexibility to the utility is vehicle-to-grid (V2G) technology, in which the EV's on-board energy storage can be utilized to send power back to the grid through the EV's associated Electric Vehicle Supply Equipment (EVSE).

While V2G technology has existed since the early 2000's [1], it has taken many years for EVSE vendors to commercialize products that offer bi-directional charging. There are a number of reasons for this - initial technology limitations, firming up standards to include V2G capability, and a lack of obvious revenue streams - that will be discussed throughout the paper. Nonetheless, breakthroughs in these areas have led to recent V2G demonstration projects, and the time is ripe for much wider deployments of V2G-capable EVSE in a number of applications.

This paper briefly discusses some of the early efforts involving V2G charging and more recent commercial deployments. It then pivots to discuss some of the last hurdles that must be overcome before wide-scale V2G adoption, including regulatory and policy considerations as well as technological challenges. Finally, it covers the experiences that Portland General Electric (PGE) has had installing two separate V2G chargers - one a passenger vehicle charger located at a PGE facility, and the second a larger V2G-capable electric bus charger located at a customer's school bus depot.

II. PAST V2G EFFORTS

The possibility of using EVs to provide V2G services has existed since Kempton and Tomić [1] first proposed and patented the technology in the early 2000's. Since then, considerable research has gone into understanding how V2G resources could be integrated into the grid, including discussions of the possible transmission impacts of large fleets of V2G vehicles [2], considerations of the required communication and control infrastructure [3], as well as analysis of both the technical and social barriers preventing early adoptions [4]. A recently published textbook [5] provides a comprehensive overview of many of these issues.

The economics of V2G have also gained considerable attention. Previous research analyzing how V2G revenue could affect vehicle purchase economics [6, 7] indicates that the technology can pencil out provided that the correct compensatory structures are put in place. Using V2G to provide ancillary services [8], participate in energy markets [9], and offer reactive power support [10] has also been considered, and these options are likely to become more viable in the United States as FERC Order 2222 is fully integrated across ISO/RTO environments.

Managed charging of electric vehicle fleets employing V2G has also been studied extensively, both to provide energy to the grid at times of peak system demand [2, 4, 11] and to relieve more local distribution system bottlenecks [12, 13]. These analyses indicate that V2G could provide substantial benefits over uni-directional charging by offering increased system flexibility. Indeed, a review of past EV research [3] indicates that the total amount of energy stored in V2G-capable EVs could match or even exceed the amount of stationary battery energy storage deployed on many power systems in the near future. If managed in a coordinated fashion, the potential for V2G as a dispatchable resources is quite large.

Portions of this work were funded through the Oregon Clean Fuels Program

Given these insights into the potential benefits of bi-directional EV charging, a number of V2G demonstrations have been conducted over the years. In the US, this includes early efforts to integrate a V2G-capable vehicle into the California ISO [14] and at an Air Force base [15]. There are also several incidents where V2G chargers were incorporated into microgrid environments [16, 17]. While all notable efforts, these tended to contain one-off prototype technology that was not yet fit for large-scale commercialization. Of particular interest to this paper are the more recent deployments of V2G technology, all within the last two years, and all utilizing commercial off-the-shelf EVSE chargers. These include an electric school bus and charger deployed at Pekin, Illinois [18], a five bus V2G testing site deployed in White Plains, New York [19], and a larger-scale project involving both passenger vehicles and electric buses employing V2G technology within Southern California Edison service territory [20]. Together, these projects seem to represent the start of a much larger push for V2G adoption within the US.

PGE has also recently deployed a pair of V2G projects within its service territory, which are discussed in Section V. First though, Sections III and IV discuss some of the barriers that were encountered during project execution. The lessons learned during these endeavors may be of use to other industry participants as they navigate their own V2G deployments.

III. REGULATORY AND POLICY BARRIERS TO V2G ADOPTION

The potential for V2G - or “batteries on wheels” - presents a challenge for regulatory and policy analysts. Should these resources be treated the same as stationary energy storage assets? Can they deliver the same level of reliability? And what are the implications of a utility or third-party aggregator directly controlling both charging and discharging of a customer’s vehicle?

A. *Tariffs and Rate Design*

As of publication, there were few, if any, widescale V2G electricity tariffs available within the US. Several pilot tariffs have been or are in development for the projects mentioned above, but these tend to be available to only a select few participants. As previously mentioned, without the ability to compensate vehicle owners that provide power back to the grid, it is difficult to justify the added project costs of V2G-equipped EVSEs.

General considerations for designing a V2G electric rate structure include:

- **Lack of Precedents** - While V2G tariffs do exist in EU and UK markets, there is a paucity of existing examples in the United States. This puts increased pressure and visibility on any initial V2G tariffs from a US electricity provider.
- **Comparison to Stationary Storage** - There are tariffs available for instances where US utilities directly control and dispatch stationary battery energy storage assets. Of course, since a V2G battery can drive off at any moment, it begs the question of how these resources should be compensated compared to an asset that is generally available 24/7.
- **General Rate Design** Special consideration must be given to the implications that a rate structure will have on V2G operations at scale. Particular approaches could include net-metering, time-of-use rates, or more dynamic pricing structures. Poor rate design could have the unintended effect of causing vehicles to dispatch at off-peak times rather than aligning V2G discharge to the grid at peak times when the energy is most valuable.
- **Demand Charges** An EVSE that can charge and discharge at a high rate may be more valuable to the power system than a lower-powered model; however, demand charges could inadvertently punish an EV customer that is providing this higher degree of flexibility by charging a flat rate for the peak energy used during a billing cycle. For instance, a customer providing ±50 kW of bi-directional charging is more useful than a customer providing ±25 kW, but the former customer could potentially see much higher demand charges, therefore disincentivizing them from providing the full range of their EVSE power capability to the grid. Care must be taken to avoid this type of misaligned incentive.
- **Equity Considerations** Policy makers and electricity providers have a duty to design rates in a way that promotes equity among ratepayers. For instance, the Oregon Public Utility Commission (PUC) has stated [21] that distribution system planning must “identifying grid needs, implemented in partnership with communities and community-based organizations” that “create value-adding investments for communities, and align the energy system with community priorities.” Discussions around V2G rate structures must consider how they will impact low-income customers and those for whom EV adoption may be more difficult to attain. Early research in this space [22] indicates that additional studies and consideration are warranted to better understand the social dimension of V2G charging.
- **Control of Customer Assets** Any form of managed charging, whether uni-directional or V2G, must contemplate the implications of a utility or third-party aggregator gaining control over a customers asset, especially one as critical to daily life as an automobile.

All of these consideration make designing V2G tariffs a challenging process. It is anticipated that the ongoing discourse between electricity providers and PUCs across the country on this subject will lead to more widely-available V2G rates in the very near horizon.

B. *Interconnection Agreements*

Typically in the US, any resource that backfeeds onto the distribution system is required to file an Interconnection Request and eventually sign an Interconnection Agreement that specifies how the asset can operate. These agreements legally bind the customer’s resource to provide features such as anti-islanding control during outages, and may specify compliance with standards such as IEEE 1547-2018.

The Interconnection Agreement process tends to be highly regimented and specific to each state. The necessary adjustments to this process to include V2G-capable resources are not considered particularly onerous. Nonetheless, it does require coordination between electricity providers, state regulators, and relevant stakeholders to make the changes necessary to allow V2G resources to file such Interconnection Requests.

C. *Market Participation of V2G Resources*

Besides direct payment from the utility to a customer providing V2G services, there is also the possibility of an EVSE or aggregation of EVSEs to engage in an energy or ancillary services market in order to receive compensation. In the US, this process is currently being overhauled to comply with FERC Order 2222, which will impact the value proposition of V2G resources in ISO/RTO environments. In more vertically-integrated environments such as the West's Energy Imbalance Market outside of California, it remains to be seen how V2G-capable chargers and related distributed energy resources will be engaged with market operations.

IV. TECHNOLOGICAL BARRIERS TO V2G ADOPTION

The past twenty years have seen considerable advancements in both EV charging equipment and battery technology that has made V2G a more viable economic proposition.

A. *Battery Degradation*

The earliest and most daunting issue facing V2G operation was the prospect of increased battery degradation over time. All chemical batteries experience a waning of their power and energy capacity as they experience charge/discharge cycles. For the lithium-ion batteries installed in most EVs, the implication used to be that battery life did not extend past the 7-10 year range (under uni-directional charging and normal driving patterns). V2G charging inherently increases the number of charge/discharge cycles that a battery endures, and thus may shorten its life and decrease the value proposition of V2G participation. Indeed, early research indicated that V2G charging would require multiple battery replacements over the life of an EV [23].

More recent studies, however, suggests that these concerns may be overstated (for a review, see [24]). While V2G operation does have a measurable impact on battery life, at least one empirical study [25] has demonstrated that the effect on battery capacity is not much more impactful than standard uni-directional charging. There is evidence [26] that keeping the battery within a 30-90% state-of-charge, for instance while providing frequency regulation services, tends to minimize degradation under V2G charge/discharge cycles.

Adding to these observations is the increasing prevalence of V2G-capable vehicles on the commercial market. Anecdotely, several electric bus manufacturers now offer V2G capability standard. This is indicative of reduced concerns over V2G-induced battery degradation that manufacturers now have.

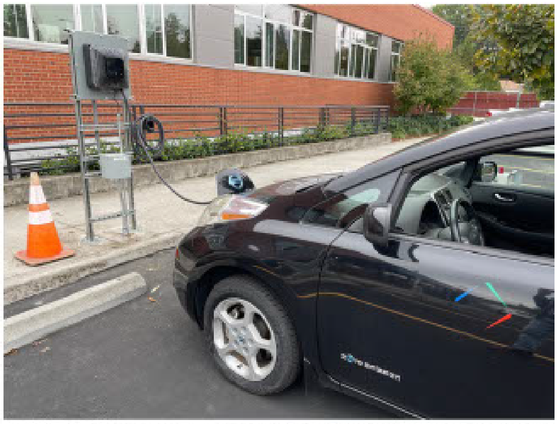

Fig. 1. A Nissan LEAF undergoing V2G testing at PGE's Portland Service Center with a Quasar Wallbox charger. The 240 V, 32 A bi-directional charger can provide up to 7.2 kW of power from the vehicle battery to the grid. Successful testing of the charger's V2G capability was conducted in October 2021, with ongoing efforts underway to study the efficiency and reliability of the charge/discharge process.

B. *Ongoing ISO 15118 Standard Update*

One issue that, as of publication, is still being resolved is the ongoing revision process of the ISO-15118 standard. This standard specifies how vehicles and EVSEs communicate under V2G conditions. While several V2G charger manufacturers have been able to find near-term workarounds for this issue, once the revisions are officially in place, they will prevent the need for these type of "bootstrapped" solutions and make it easier for EVSE vendors to manufacture V2G-capable equipment.

C. *Integration with Utility Control Infrastructure*

Another ongoing integration challenge revolves around how electricity providers and third parties interact with distributed energy resources on the grid. This will require coordination with both utility-owned advanced distribution management systems and third-party operated distributed energy resource management systems.

The IEEE 2030.5 standard is anticipated to aid in the communication between EVs and other entities. Increased deployment of IEEE 2030.5-compatible equipment, both by the customer and the electricity provider, should aid this transition and enable managed charging of both uni-directional and V2G resources.

V. EXPERIENCE WITH V2G DEMONSTRATIONS AT PGE

PGE installed and operated two separate examples of V2G technology in the 2021 timeframe - one a passenger vehicle charger, the other an electric school bus charger. Both are discussed below.

A. *Utility-owned passenger vehicle charger*

In an effort to gain access to early V2G technology, PGE purchased a European model residential charger, the Quasar

Fig. 2. The (very shiny) display of the V2G-equipped passenger vehicle charger. The negative sign convention on the -6.1 kW reading indicates that the vehicle is engaged in V2G discharging to the grid. The display also shows the vehicle's current state-of-charge (71%).

Wallbox, in 2021. The charger was installed at a PGE-owned facility, obviating the need for an Interconnection Agreement and related complexities. Installing the charger came with a few key challenges:

1) The charger uses the ChadeMO connection, and thus a Nissan LEAF is the only compatible US vehicle that can be used to test it. PGE had several LEAFs in its fleet and was able to assign one for testing. It also required a trip to the dealership to have the vehicle configured to allow for V2G operation (this functionality is typically disabled for customers).
2) As a European model, the charger expected a 240 V connection via one hot and one neutral wire. Since the US distribution system configuration requires two hots to provide 240 V service, a specialized ground fault current interrupting circuit breaker was required for the installation. Testing by the electrical contractor ensured that the breaker correctly operated during faulted system conditions.
3) In order to avoid additional service upgrades to the distribution equipment at the site, the charger had to be installed at a location where there was significant background load to prevent net backfeed to the grid. PGE's Portland Service Center was chosen as the hosting site, given its higher ambient loading and its general accessibility for fleet vehicles.

The Wallbox model was successfully installed in October 2021, and initial testing demonstrated the ability of the EVSE to discharge power back to the grid as well as charge the vehicle. The listed bi-direction power capacity of the model is ±7.68 kW (at 240V, 32 A), and these levels were achieved in both directions. During initial trials, the battery of the vehicle has been successfully discharged from 90% state-of-charge down to 65% and back to 90%.

Additional testing is underway at the site. The research plan for the charger includes assessment of its round-trip efficiency during a discharge/charge cycle and its ability to perform several charge/discharge events back-to-back. Efforts are also underway to tie the resource to existing PGE control systems and allow for remote dispatch. If achieved, this would allow the parked vehicle to discharge power back to the grid during peak loading conditions, thus integrating it into a nascent virtual power plant.

B. Electric School Bus V2G Charger

The PGE Electric School Bus initiative, with funding provided through Oregon Clean Fuels Program, give school districts access to capital that can be used to purchase electric school buses and associated charging infrastructure. One local customer, the Newberg School District, in conjunction with their transportation provider First Student, applied for and received funding for a V2G-capable vehicle and charger to be installed in 2021. This project featured a 155 kWh Blue Bird bus and a 60 kW bi-directional Nuvve charger.

As a customer-owned endeavor, this project presented additional challenges during implementation compared to the PGE-owned charger. For instance, this was the first V2G resource to go through PGE's Interconnection Agreement process, and required some adjustments to the pro forma language included in the attendant documents.

It was also necessary to determine the required electrical infrastructure for the V2G charger. Eventually, the PGE Electrical Service Requirements for PV generation were utilized by the distribution engineers studying the project. These include stipulations that a utility-accessible manual disconnect switch be located adjacent to the customer-owned switchgear. The EVSE was also required to comply with the IEEE 1547-2018 standard and have gained full UL-certification.

The charger will also be integrated into PGE control systems via an IEEE 2030.5-compatible server. Similar to the passenger vehicle charger, this integration will allow the electric school bus to be dispatched as part of a larger virtual power plant operation.

There is ongoing dialogue in the state of Oregon with a number of stakeholders around potential V2G tariffs, and PGE looks forward to being able to offer compensation to customers who provide this valuable service.

VI. CONCLUSION

While vehicle-to-grid (V2G) technology was original developed decades ago, it seems poised to finally reach a level of large-scale commercial success in the near future. As discussed throughout this paper, the barriers to mass adoption include regulatory and legal hurdles such as updates to interconnection processes, questions about appropriate electricity rate structures, and considerations for how a customer's vehicles can and should be controlled. There are also a few technical bottlenecks related to standards updates and integration with utility and third-party control systems that need to be resolved.

Still, the big picture outlook is bright. Two recent demonstration projects by PGE are discussed in this paper, which together may foster larger-scale tests and help to visibly promote the technology. Ongoing cooperation by electricity providers, equipment manufactures, and a range of customers will be required to make broad V2G deployments a reality.

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