EVS26
Los Angeles, California, May 6-9, 2012

Smart Charging Systems for Plug-in Electric Vehicles

Abe Shocket
TE Connectivity
Fuquay-Varina, NC
ashocket@te.com

Abstract

This paper describes "smart charging" systems for plug-in hybrid electric vehicles (PHEVs). The principal design feature is that the system uses gathered information to adaptively control PHEV charging, and does so in a way that allows customer PHEVs to still be charged at a preferred rate (cost). This paper reviews the drivers for smart charging, including electric grid readiness for large adoption rates of PHEVs, and considers national, regional and local distribution level issues. At the distribution level, the effect of increased PHEV charging loads on transformers is considered. The current state of standardization is reviewed with emphasis on communication messages and use cases that reflect smart charging attributes. Centralized system approaches are described, such as integrating electric vehicle supply equipment (EVSE), i.e. chargers, into Advanced Metering Infrastructure (AMI) networks, and treating EVSEs as controllable loads for Demand Response programs. Metering and monitoring the transformers that feed EVSEs can drive a control scheme that is either centralized or distributed. Alternatives to AMI-integration for centralized networks are also reviewed, including commercially available systems. Additionally, smart charging is considered from the billing perspective, where system approaches are described that allow for identification and association between connected PHEVs, EVSEs, premise meters and other smart devices.

Keywords: charging, load management, PHEV (plug in hybrid electric vehicle), smart grid, standardization

1 Introduction

The effect of plug-in hybrid electric vehicles (PHEVs) on the electric grid infrastructure has been the subject of a number of studies. Utilities, government entities, automobile manufacturers and consumers are interested to know if the existing grid can handle a large amount of PHEVs, and if PHEVs can reduce overall emissions. Now that a range of PHEVs choices have arrived in the market, and with promises from the automobile manufactures for many more, real-world experience can be monitored to validate the conclusions of the previous studies. In this paper, PHEV is used to cover all-electric battery EVs (BEVs) also.

Projections for ever-increasing demand for electricity have led to concerns that future demand cannot be met by continuing to build more fossil-fuel power plants. Therefore if large numbers of PHEVs cannot be charged with existing generation capacity, the results could be slower adoption of PHEVs, higher costs to charge batteries, consumer and environmentalist backlash, and more emissions.

Studies have shown that PHEVs could replace a large number of the existing vehicle fleet, and be adequately charged by existing excess generation capacity [1, 2]. Hadley and Tsvetkova [1] concluded that most US regions will need to add generation capacity by 2030, or implement demand response programs, to accommodate evening charging (5:00 PM), whereas night charging (10:00 PM) will have little effect. The authors note that consumers cannot be counted on to charge when utilities prefer.

Kintner-Meyer et al [2] concluded that up to 73% of the US light-duty fleet of cars, pick-up trucks, sport utility vehicles (SUVs) and vans could be supported by existing infrastructure.

Other studies have looked at electric utility capabilities further downstream from aggregate generation, i.e. the distribution networks [3, 4]. Ultimately, the PHEV owner will plug into the grid at the local level and will place a new demand on whatever transformer is feeding that grid connection. The author acknowledges that it is also possible to charge PHEVs from renewable sources that may be "off-grid", however the majority of charging points in the near future will be grid connected.

Even if adequate generation and transmission resources exist to handle high PHEV loads, the local distribution network may not be able to cope. [4] considers the effects of PHEV charging loads on oil-filled transformers at substations. [3] considers the effects of loading on 25kVA to 75kVA sized distribution transformers where all PHEVs start charging either at 6:00PM or all at off-peak hours, which vary by season in the Blacksburg, VA model area. Level 1 and 2 charging [9] are considered. [6] also looks at distribution transformers in the 15kVA and 25kVA range.

2 Smart Charging

High PHEV penetration rates with uncontrolled charging will lead to strain on the grid, from generation to the local distribution transformers. Today's initially slow PHEV penetration rate allows utilities to study the effects, try new strategies and accommodate the demand growth in a managed way. Consumers in the same neighborhoods may adopt PHEVs at the same rate, leading to a clustering of PHEVs. This may force utilities to address loading issues in spot areas, even if their overall "readiness" was adequate. Smart charging tools are needed to not only help utilities avoid costly and wholesale transformer replacements and distribution feeder upgrades, but also to avoid aggregate effects where PHEV charging loads are seen as leading to increased generation and more emissions.

Smart charging is a term that can be difficult to define, but for the purpose of this paper, smart charging is defined as any method of controlling charging to minimize costs (to consumers) or negative loading effects (to utilities or other electricity service providers).

Smart charging is covered in the standards specification [8] that deals with communications between electric vehicle supply equipment (EVSE), i.e. chargers and the electric power grid. The intent of this standard is "grid optimized energy transfer for plug-in electric vehicles", that ensures adequate energy for vehicles and minimal stress for grids. Smart charging requires either smart EVSEs or smart PHEVs or both, to enable communications of specific messages under various use cases. Use cases are covered in [7], which offers further definitions of smart charging as "The ability for the utility to 'load shape' and therefore optimize vehicle charging or discharging with grid capacity," and "a system in which PEVs communicate with the power grid in an effort to optimize vehicle charging or discharging rate with grid capacity and time of use cost rates."

Smart charging can also extend beyond the domain of EVSEs and PHEVs. Control schemes that (1) monitor utility loading at various points from generation to the end user, and (2) broadcast signals that may indicate a high price period or a demand response event, or (3) remotely control on/off functionality of utility or consumer devices can effectively minimize consumer costs and reduce grid loading without directly communicating with an EVSE or PHEV.

3 Standards

Standards play a critical role in adoption of new technologies. Standardized interfaces between equipment, such as the EVSE and the PHEV, allow for faster commercial availability, more choices and lower costs to consumers, and minimal operational problems.

EVSEs are covered by SAE J1772™ [9] which defines the coupler of the EVSE and the outlet on the vehicle. Also defined in this specification is a

control and data scheme that while not traditionally considered "smart charging", is actually smart in the sense that it provides for a range of charge control features. When the coupler is connected to the PHEV, the EVSE control pilot detects a specified resistance level that confirms that it is indeed connected to a PHEV. The EVSE oscillates the control signal to communicate it is ready to supply and at what level. The PHEV interprets the duty cycle from the EVSE as what current will be supplied and adjusts the current drawn into the battery charger appropriately.

The five use cases in the standard [7] cover (U1) time-of-use (TOU) rates, (U2) direct load control for demand response (DR) programs, (U3) real time pricing, (U4) critical peak pricing and (U5) optimized energy transfer programs. All of the use cases are designed to encourage consumers to charge in ways to optimize grid capacity and rates, however the rate plans in U1, U3 and U4 are more passive in that consumers will respond to price signals and may charge or not according to their particular needs at the time. If a driver needs to get somewhere in his PHEV, and needs a charge to get there, then he will charge regardless of the price signal. For all cases, the user can typically override the utility load shed request or command.

U2 and U5 lend themselves to allow utilities to play a more overt role in effecting charge time efficiency. U5 allows for both load control that is on/off as well as reduced amperage. A utility may even compare the state of charge (SOC) of a number of PHEVs connected and queued for charging and allocate to PHEVs with lower SOC first. PHEVs can request a charge schedule and the utility may respond with availability information, including alternate scheduling. Detailed messages are specified that cover Energy Available, Power Available, Time Charge is Needed, Power Schedule, and Energy Delivered, among others.

For the U2 use case, messaging contains start time, duration, criticality and load reduction request; therefore, charging can be both curtailed or throttled, based on need. Another message type concerns the availability of green energy (energy from renewable sources such as wind, solar or hydro, e.g.). A customer may select to accept green energy if available, and may be supplied more energy than requested. This could aid a utility that has significant wind resources connected to its grid. When the wind is blowing strong at night, there may not be sufficient load available, nor any storage means (other than PHEVs).

4 Smart Grid

Previously referenced studies on the effects of PHEV loading on distribution transformers [3, 4, 5, 6] lead us to consider mitigation schemes that leverage monitoring, communications and control technologies that are utilized in smart grid applications. These schemes may take the form of edge control networks or centralized control networks.

4.1 Centralized Control vs. Edge Control

Centralized networks can leverage a utility's existing systems and large network deployment investments. All critical data must traverse the entire network, from end-user connected devices to a centralized data management system. Data management software must be adapted to correctly identify, store, and act upon the additional data. Proper prioritization of data and messaging over the network needs to be established. Edge networks can be designed with greater simplicity to act only on the much smaller set of devices and attributes. Initially, utilities will weigh the need for access to data and control, in order to understand the issues surrounding EVSE/PHEV deployment and charging, against the convenience of partitioning a new application relegated to niche areas.

Two schemes proposed in [3] are Stagger Charge Control (SCC) and Household Load Control HLC). Both schemes require an advanced metering infrastructure (AMI) network and on/off controls for the EVSE and additionally, other household loads.

AMI is a centralized control network where each household has a smart meter that communicates back to a central data management system at the utility head office. AMI implies two-way communications. Utilities may need to read meters off cycle, do remote turn off/on, send price information to customers or control loads. Load control typically covers shedding AC units or pool pumps, or adjusting smart thermostats up or down.

EVSEs can be considered as candidates for load control or load management. A utility can monitor total loading on a feeder cable, or a transformer and compare this to individual household loads that are fed from the transformer and feeder. When EVSEs come on-line, their incremental load demand can be compared to the aggregate and in the event of an overload, the utility can send control signals to the EVSEs to turn down or off. SCC implies that the transformer is monitored continuously in a PHEV Charge Control Unit (CCU). The CCU either allows charging or staggers charging through a randomly generated delay, depending on whether or not a pre-programmed threshold load for the transformer is crossed.

HLC is similar to a DR program, where other lower priority household devices may be shed in order to allow the higher priority EVSE to charge, based on the transformer loading. As in the SCC case, HLC also uses the CCU to continuously monitor the transformer loading, and when the measured load crossed the threshold, the CCU tries to shed other house loads first, in order to reduce the measured transformer load sufficiently to allow for EVSE charging to begin.

Note that the above described systems that use a CCU could also be configured as an Edge Control Network. The CCU can be pre-programmed to act on a certain load value and then communicate directly with the EVSEs or the other household loads through a Home Area Network (HAN). Communications could be wireless or power line carrier (PLC), each with it advantages and disadvantages. One advantage for PLC is that the CCU at the transformer is always, and only, talking to EVSEs that it is feeding.

The SAE standard [8] broadly describes an Energy Management System (EMS) that could control a charging session in use case U5. This EMS can take different forms including the utility itself, or a transformer-mounted meter. An EMS can be part of a centralized network, edge control network, or both, where it might receive critical peak price information over an AMI network, but then work locally with the connected loads.

4.2 Commercial AMI Solutions

Over the last few years, a large number of AMI networks have been deployed. Initial use cases focused on two-way communications, metering and DR programs. Some of the vendors who supply these networks have expanded their value propositions to include smart charging [10, 11], and compare connectivity options for EVSE/PHEVs over HANs vs. Neighborhood Area Networks (NANs). NANs offer redundant paths, high security, remote firmware upgrades, longer range and better signal propagation (needed to reach into garages). While [10] explores the advantages of integrating smart charging into AMI networks, i.e. a centralized control scheme, [10] does acknowledge that transformers with monitoring and communications capabilities could directly control the attached EVSE/PHEVs, i.e., an edge control network.

EVSE vendors have also shown possible integration with AMI networks [12], but also offer the possibilities of communicating directly to the Internet via a HAN or a dedicated direct link. [13] describes a novel solution for charging that addresses security and billing concerns associated with public charging in multitenant dwelling units (MDUs), public garages and workplace charging. The system is comprised of two components; a standards compliant level one charge cordset and a smart outlet. The cordset can be used by itself in any 120V outlet and provide basic charging functions. Additionally, the cordset can be supplied with a smart socket, with wired or wireless communications capabilities to allow communications to the local utility directly through the Internet, or into an AMI network, or into a HAN.

Communications can be used for security to authenticate the module owner, and then enable grid energy to be available at the outlet. This association of cordset owner and premise location for the grid connection are necessary for proper billing in public charging where the vehicle may charge at various locations each session. The cordset includes metering to provide usage data back to the utility at the close of each charging session. Note that the charger can also receive communications from the energy provider. Users may program schedules, rate preferences, acceptance in load shedding DR programs, etc.

The smart socket can also provide energy theft prevention. The authentication feature allows the

utility to ensure that the connection is actually to a PHEV and not to some other loads that want to take advantage of preferred rates. Permanently mounted smart sockets in public parking areas allow site operator / owners to control charging and billing, by being able to throttle sockets on and off as well as recording authorized user identification and billing information.

5 Metering and Billing

One critical aspect of smart charging relates to the proper metering and billing of electricity. Utilities have complete metering coverage of the grid at all customer (legal) connections today. However, in order to provide additional rate choices such as TOU, or PHEV subsidized rates, a utility would have to install a separate meter wired directly to the EVSE circuit. The separate meter records EVSE usage and the amount recorded is subtracted from the total house load. This is happening today, but it is not the best solution. Utilities have to send out a crew, add the extra meter and socket, and coordinate with an electrical contractor to run wiring from the outside of the house to the inside of the garage to the EVSE.

An alternative is to sub-meter the EVSE inside the premise. The customer or the EVSE owner would own the sub-meter, which could be embedded into the EVSE, leading to a more cost-effective solution. A coalition of EVSE manufactures promoted submetering as a way to provide consumer choice, cost-effectiveness, ease of implementation, accurate and reliable measurement, and billing enablement for loads to facilitate load management and non-utility EV services [14].

Submeters must satisfy utility requirements, which include accuracy and test requirements of ANSI C12. Form factor, sockets, dimensions, etc., as contained in the standard would have to be waived to allow manufacturers to embed meters into EVSEs. However, calibration concerns can be addressed by having removable modules and/ or test access.

Submeters can also be embedded into the PHEVs [15]. This solution provides the direct benefit of always being available to meter electricity into the PHEV, regardless of where it connects for charging. On-board telematics can communicate billing data directly to utilities. Modules could be either removable for 3rd party certification, or tested in the vehicle, similar to the way annual smog inspections are handled today.

6 Summary

This paper reviewed the need for smart charging in order to prevent additional peak loading problems with the existing electricity grid. Loading needs to be considered not just in the aggregate, but in the distribution network, and even to at the neighborhood transformers. Smart charging is defined in the current standards for EVSEs, and a number of use cases have been developed. Smart charging needs to be integrated into a wider network to allow for utilities, or other grid energy service providers, to communicate pricing information, and to control EVSEs for load shedding or throttling. The two-way communications capabilities of existing AMI infrastructure can be leveraged, as well as direct communication from EVSEs, or PHEVs to the Internet. Control schemes can also think and act locally, without taxing the centralized data management systems in place for AMI.

Standards have been written, with more coming, and technology solutions have been proposed. Commercialization of smart charging systems is also starting, and will address some of the proposed use cases. Cost effective architectures, including accurate and certifiable metering for billing are required to enable business models.

References

[1] S.W. Hadley, A. Tsvetkova, *Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation*, Oak Ridge National Laboratory, January 2008.

[2] Kintner-Meyer, M., K. Schneider, and R. Pratt, *Impact Assessments of Plug-in Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis*, Pacific Northwest National Laboratory, 2007.

[3] S. Shao, M. Pipattanasomporn, and S. Rahman, *Challenges of PHEV Penetration to the Residential Distribution Network.* IEEE/PES 2009 General Meeting, Calgary, AB, July 27th, 2009.

[4] S. Blumsack, C. Samaras, P. Hines, *Long-Term Electric System Investments to Support Plug-in Hybrid Electric Vehicles*, Proc. of the IEEE Power Engineering Society General Meeting. Pittsburgh, 2008.

[5] C. Farmer, P. Hines, J. Dowds, S. Blumsack, *Modeling the Impact of Increasing PHEV*

Loads on the Distribution Infrastructure, Proceedings of the 43rd Hawaii International Conference on System Sciences, Kauai, 2010.

[6] A. Hilshey, P. Hines, J. Dowds, *Estimating the Acceleration of Transformer Aging due to Electric Vehicle* Charging, Proc. of the IEEE Power and Energy Society General Meeting. Detroit, 2011.

[7] SAE J2836-1™ APR2010, *Use Cases for Communications Between Plug-In Vehicles and the Utility Grid.*

[8] SAE J2847-1 May2011, *Communications between Plug-In Vehicle and the Utility Grid.*

[9] SAE J1772™ JAN2010, *SAE Electric Vehicle and Plug In Hybrid Electric Vehicle Conductive Charge Coupler.*

[10] *How the Smart Grid Enables Utilities to Integrate Electric Vehicles*, http://www.silverspringnetworks.com, accessed on 2011-12-15.

[11] *Elster Showcases Electric Vehicle Infrastructure Technology at Plug-In 2011*, http://www.elster.com/en/press-releases/2011/1585875, accessed on 2011-12-16.

[12] A. Briones, *Submeter Protocol Public Workshop, CPUC OIR R09-08-009*, CPUC Submetering Workshop, San Francisco, Oct 27th, 2011.

[13] C.W. Chen, R. Peelle, V. Bhalodia, K. Yu, G. Gavrielides, T. Mohn, J.C. Martin, *Modularized Interface and Related Method for Connective Plug-In Electric Vehicles to the Energy Grid*, US Patent Application Publication US 2010/0045232 A1, Feb 25th, 2010.

[14] *EVSP Coalition Recommendations*, CPUC Submetering Workshop, San Francisco, Oct 27th, 2011.

[15] G. Bellino, *California Public Utilities Commission Sub Meter Protocol Workshop*, CPUC Submetering Workshop, San Francisco, Oct 27th, 2011.

Author

Abe Shocket is the Manager for Advanced Development at TE Connectivity, supporting xEV&I businesses. He received his BSEE from Carnegie-Mellon University, and is a member of the IEEE.