Topic Paper #20

Vehicle to Grid (V2G)

On August 1, 2012, The National Petroleum Council (NPC) in approving its report, *Advancing Technology for America's Transportation Future*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

V2G Whitepaper

National Petroleum Council
Future Transportation Fuels Study
Infrastructure Committee, Electricity Subgroup

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Introduction

To promote the broad adoption of electric vehicles in the U.S., the initial impact to the electric grid needs to be minimized; however, ultimately, the aim is to employ the unique attributes of the electric vehicle to benefit the electric grid. To truly realize the full benefit of PHEVs rather than simply swapping one set of increased emissions for another, we will need to ensure that there is smart charging of the vehicle with two way communications available between the vehicle and the grid."[1] Vehicle-to-Grid (V2G) is the provision of two-way electrical service from a vehicle to the electrical grid, under control of a grid operator's signal.[2] While V2G is not a necessity for the broad adoption of plug-in electric vehicles (PEVs)[3] envisioned by the current administration, it could aid in the deployment of PEVs by providing needed services to the grid, thus enabling additional incentives to the buyer. With vehicle battery packs having energy storage capacity between 5-35 kWh and a power interface between 1-19 kW AC, PEVs have the potential to provide valuable services to the electrical grid. These services not only help maintain grid reliability and reduce the cost of electricity, in some cases, they generate revenue for the owner of the vehicle.

In order to aid the understanding of how V2G could impact the electric system, the system or "grid," along with its various components, is reviewed below. Electricity markets are a focus in this review because their existence and particular structure will be major determinant in successful PEV integration, and ultimately V2G implementation.

Electricity Grid

In the U.S. the electricity infrastructure consists of three major elements: 1) Generation—the production of electricity from various resources such as fossil-fuels, nuclear, hydro, wind, and solar; 2) Transmission—the transportation of electricity along high voltage lines from the generator to the distributor; and 3) Distribution—the transportation of lower voltage electricity to the consumer. Approximately two-thirds of the electricity consumers in the U.S. are served by an Independent System Operator (ISO)[4] or a Regional Transmission Organization (RTO)[5] (Figure 1). These entities operate the system to ensure reliability in terms of adequacy: ensuring that there are sufficient electric generating resources to meet demand during extreme conditions, and security: operating the system in a way that anticipates possible failure of key system elements. This type of system management guards against a cascading failure of the electric system and ultimately minimizes the loss of service to large groups of customers.

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[1] Testimony of Kenneth Huber on Behalf of PJM Interconnection to the United States Senate Energy and Natural Resources Committee, December 10, 2009.

[2] Kempton, W., Udo, V., Huber, K., Komara, K., Letendre, S., Baker, S., Brunner, D. & Pearre, N. (2008). *A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System.*

[3] Plug-in electric vehicles or PEVs is used in this document to describe vehicles that contain a battery pack that can be charged externally from the vehicle, such as Battery Electric Vehicles or Plug-in Hybrid Electric Vehicles.

[4] FERC Orders 888 and 889 put forth the concept of an Independent System Operator to provide non-discriminatory access to electricity transmission. Information on Order 888 is available at: http://www.ferc.gov/legal/maj-ord-reg/land-docs/order888.asp and Order 889 is available at: http://www.ferc.gov/legal/maj-ord-reg/land-docs/order889.asp

[5] FERC Order 2000 addressed the formation of regional entities to administer the transmission grid, and presented twelve characteristics and functions that define a Regional Transmission Organization. Order 2000 is available at: http://www.ferc.gov/legal/maj-ord-reg/land-docs/RM99-2A.pdf

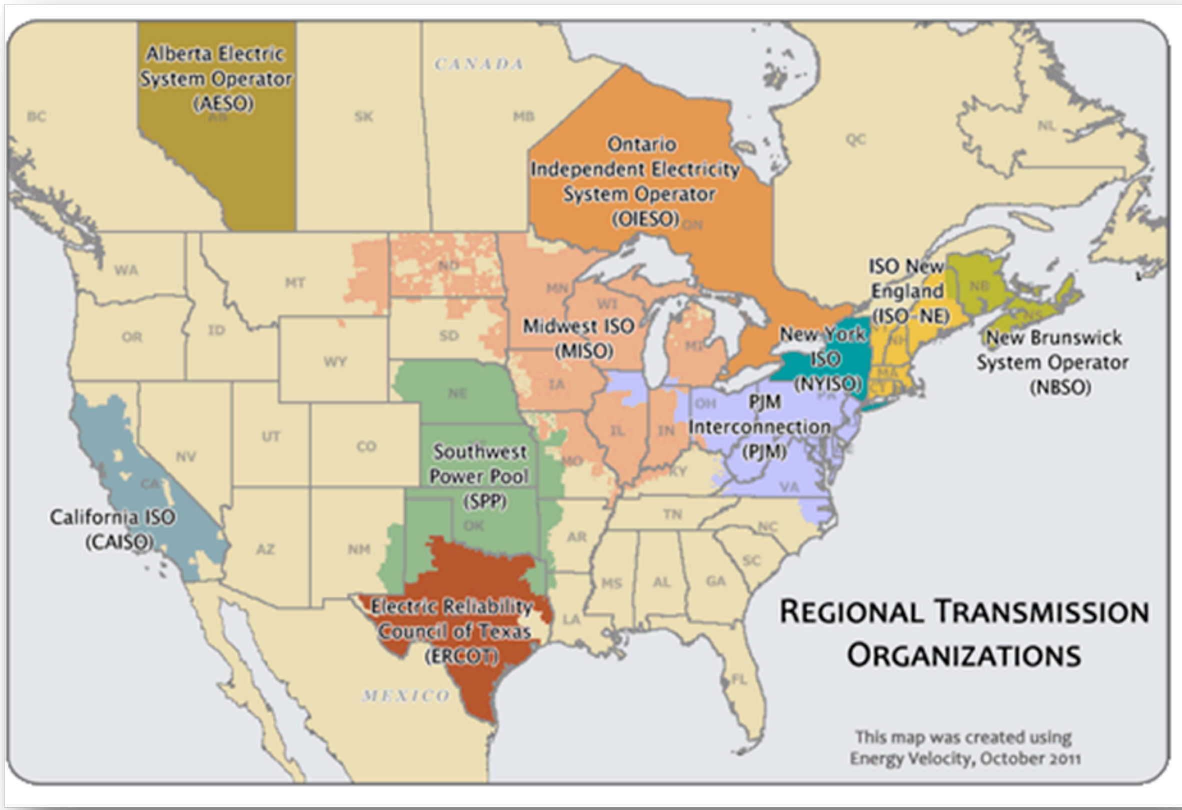


Figure 1: Independent System Operators and Regional Transmission Organizations in the U.S. and Canada

Security-Constrained Economic Dispatch

ISOs and RTOs ensure reliability by keeping the system in balance via continuous monitoring of the system, and reacting to changes in demand, equipment problems, weather conditions and other factors. They direct how much energy should be supplied and request adjustments to the production of generating plants and the consumption of demand side resources[6] to accommodate demand and to make sure that no transmission lines or facilities are overloaded. This balancing for reliability is done at the lowest cost possible, and is known as "security-constrained economic dispatch." Security-constrained economic dispatch influences electricity market structure.

Electricity Markets

Energy Markets

In order to obtain the lowest cost operation of the system, ISOs/RTOs make use of competitive markets, such as energy, capacity and ancillary services. Energy markets consist of real-time and day-ahead markets. Real-time markets are instantaneous, in which participants can buy or sell power on an hourly (or shorter) frequency, with prices being set in real-time, the moment energy is generated and consumed. Day-ahead markets are forward markets in which the participants

[6] A demand side resource is defined by FERC as a resource capable of providing a reduction in the consumption of electric energy by customers from their expected consumption in response to an increase in the price of electric energy or to incentive payments designed to induce lower consumption of electric energy. 18 CFR 35.28(b)(4) and (b)(5).

may submit bids to buy or sell a defined amount of electricity that are settled a day prior to delivery. Additionally, participants may use bilateral contracts, outside of the structured energy markets to buy and sell electricity directly with another party for periods ranging from hours to years, as well as self-scheduling their own generation facilities to serve their customer loads. ISOs/RTOs accommodate these self schedules and contractual arrangements as they arrange real-time operations, while using the spot markets to allow parties to cover any imbalances or differences between their announced self schedules and forward contracts and their actual production or consumption in real time. For this reason, the RTO real-time spot markets are sometimes called “balancing markets.”[7] These competitive energy markets, in conjunction with capacity and ancillary service markets send price signals that not only promote efficient, least cost operation of the grid, but help maintain grid reliability.

Capacity Markets

In addition to energy markets, a few ISO/RTOs also operate capacity markets to ensure the adequacy of resources such as generation, demand response and energy efficiency. These are forward markets from a few months (short term) to a few years in advance (long term) used to secure capacity to meet forecast load. In order to address any transmission congestion, capacity markets are designed for prices to signal where capacity is needed through locational features. Long term capacity markets have been successful in attracting and retaining needed capacity, including large amounts of demand response resources.[8]

Ancillary Services

ISOs/RTOs also operate markets for ancillary services in order to support the reliable, lowest cost operation of the transmission system. The North American Electric Reliability Corporation (NERC) defines ancillary services as “those services necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practices.”[9] In Order 888, the United States Federal Energy Regulatory Commission (FERC) defined six ancillary services that must be included in an open access transmission tariff:

1. scheduling, system control and dispatch service;
2. reactive supply and voltage control from generation sources service;
3. regulation and frequency response service;
4. energy imbalance service;
5. operating reserve – spinning (synchronized) reserve service; and
6. operating reserve – supplemental reserve service.[10]

Of the services listed above, the ones in which PEVs are most likely to participate in the near-term are regulation and frequency response, and operating reserves. Technically speaking, PEVs enabled with V2G have the capability to provide all of the services listed above.

[7] Ott, Andy. How RTOs Establish Spot Market Prices. September, 2007. Available at: http://www.pjm.com/~/media/documents/reports/spot-market-prices-j-chandley.ashx

[8] The Brattle Group, Cross RTO Survey of Capacity Markets: What is Working and What is Not. Presented at EUCI Conference on “Smart” Capacity Markets. November 9, 2009. Available at: http://www.brattle.com/_documents/UploadLibrary/Upload834.pdf

[9] NERC Glossary of Terms Used in Reliability Standards. February 12, 2008. Available at: http://www.nerc.com/files/Glossary_12Feb08.pdf

[10] 75 FERC ¶ 61,080 (1996).

Reactive Supply and Voltage Control Service

Reactive Supply and Voltage Control, also known as voltage support, is used to maintain transmission system voltages within acceptable limits. Voltage support involves the injection (capacitance) or absorption (inductance) of reactive power11 in order to keep voltage and current in phase and to maintain transmission-system voltages within required ranges. Reactive power must be provided in close proximity to where it is needed because at high loadings, relative losses of reactive power on transmission lines are often significantly greater than relative real power losses, and these losses increase with distance traveled.12 NERC standards ensure voltage levels, reactive flows, and reactive resources are monitored, controlled, and maintained within limits in real time to protect equipment and the reliable operation of the system. Voltage-control equipment can be reactive, such as: motors, shunt reactors, loaded transmission lines, static VAR compensators, transformers, underexcited generators; or capacitive, such as: shunt capacitors, synchronous condensers, unloaded, overexcited generators, static VAR compensators, lightly loaded transmission lines. Both the speed and magnitude at which reactive power demands can change on a system makes providing reactive power services a good fit for the rapid response of batteries, such as those contained in PEVs. Additionally, batteries are capable of providing both capacitance and inductance used in voltage support.

Regulation and Frequency Response Service

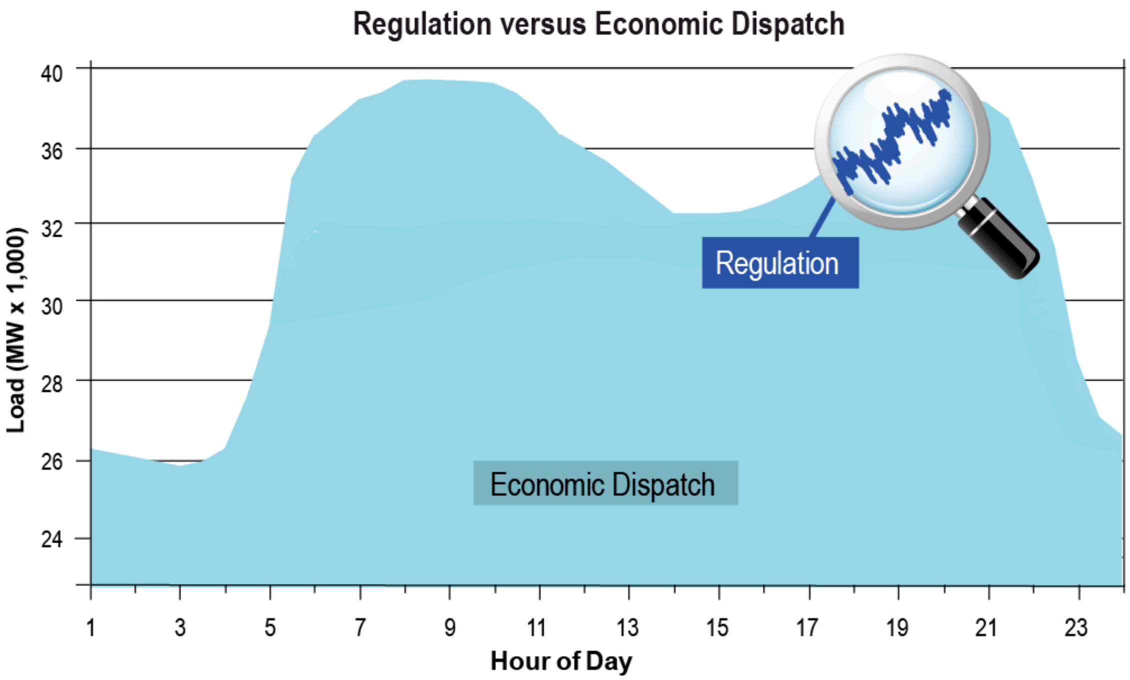
PEV batteries will also be able to provide regulation service, which corrects for short-term imbalances in supply and demand that might affect the stability of the power system. Regulation helps match generation and load in an effort to constantly maintain the desired frequency of 60Hz in the U.S. Regulation can be required up, if the frequency is too low (generation is less than load) or down, if the frequency is too high (generation is more than load). Load-serving entities13 (LSEs) can meet their obligation to provide regulation to the grid by using their own generation, by purchasing the required regulation under contract with another party or by buying it through the Regulation Market. In the case of PEVs, they can provide regulation up by discharging the battery to the grid (or ceasing charging), or regulation down by charging.

[11] In alternating current (AC) systems there are two types of power: real power (measured in watts) and reactive power (measured in volt-amperes reactive, or var). Real power accomplishes useful work, while reactive power supports the voltages necessary to transport real power. Additionally, reactive power does not travel far due to significant transmission losses, so it must be procured close to where it is needed.

[12] FERC. Principles for Efficient and Reliable Reactive Power Supply and Consumption. February 4, 2005.

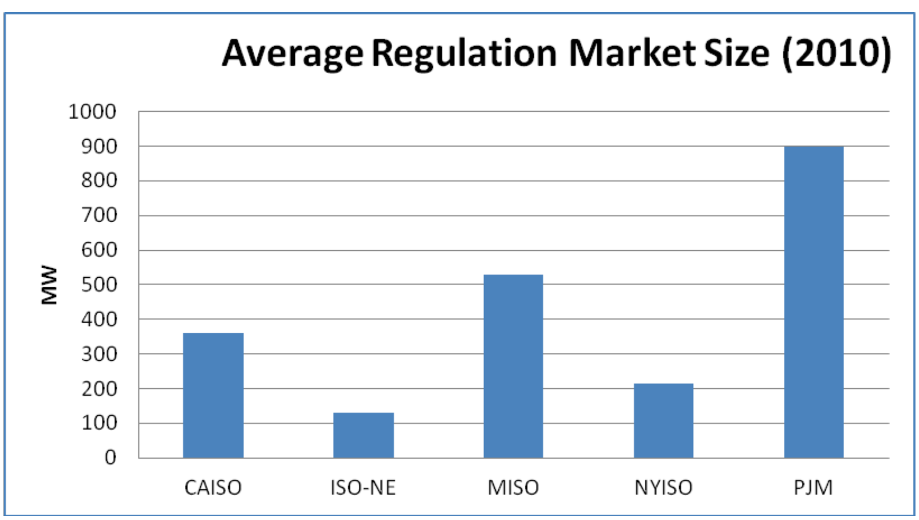
[13] A load-serving entity is defined by NERC as “Secures energy and transmission service (and related Interconnected Operations Services) to serve the electrical demand and energy requirements of its end use customers.”

Figure 2: Dispatch of regulation services compared to the economic dispatch of energy, where economic dispatch is the larger movement of energy over the day, and regulation is the smaller movement, usually minute by minute, used to balance load and demand.



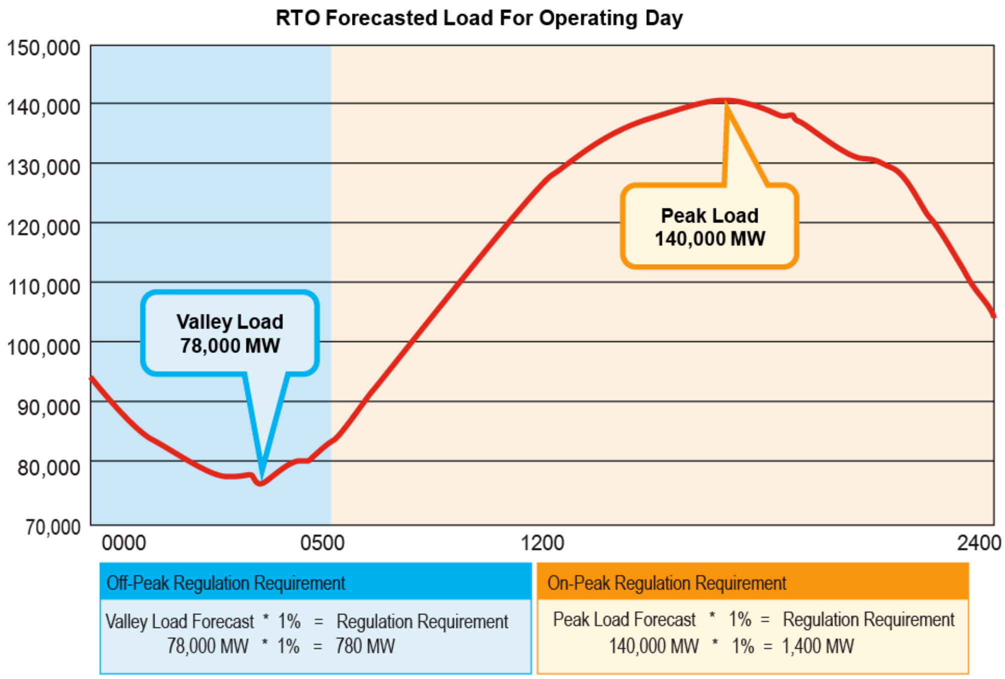
In practice, regulation services are contracted by the ISO/RTO on an hourly basis as needed throughout the day. The actual dispatch of the contracted regulation varies between ISO/RTO markets, but is normally a few minutes in one direction (up or down) at a time (Figure 2). Payment is typically made for the contracted amount of capacity for a given hour ($/MW per hour). This price is set hourly through the market clearing process. This market could make use of a PEV's quick response time and flexibility.

Figure 3: Average regulation market size in specific ISO/RTOs for 2010.



The capacity of PEVs to participate in the regulation market will depend on the market size in each ISO/RTO, as shown above in Figure 3. PJM's regulation market is 1 percent of the daily forecasted peak load and off-peak load, as illustrated in the example below in Figure 4. The 900 MW referenced in Figure 3 represents the average regulation market size in PJM, while the 780 MW and 1400 MW shown below represent an example of how the regulation requirement is calculated each day.

Figure 4: Example of the amount of regulation necessary in PJM to meet the one percent of peak demand requirement.



ISO/RTO Experience with Vehicle to Grid: Electric Vehicles Participating in the PJM Ancillary Services Market

PJM conducted a technology demonstration with industry and academic partners in which a one MW stationary battery array was aggregated with three 19 kW PEVs. The resources were then bid into the PJM Regulation Market. The batteries in the array and in the PEVs charged and discharged in response to a regulation signal that was sent every four seconds from PJM. These resources were paid for providing this frequency regulation. The PEV batteries became a source of regulation service that was more distributed but provided the same, and in some cases superior, regulation service to what is provided today by central station generation assets.[14]

Figure 5: AC Propulsion eBox and AES 1 MW battery trailer array used to aggregate electric vehicles and bid their collective capacity into the market during V2G demonstration.

[14] Testimony of Kenneth Huber on Behalf of PJM Interconnection to the United States Senate Energy and Natural Resources Committee, December 10, 2009

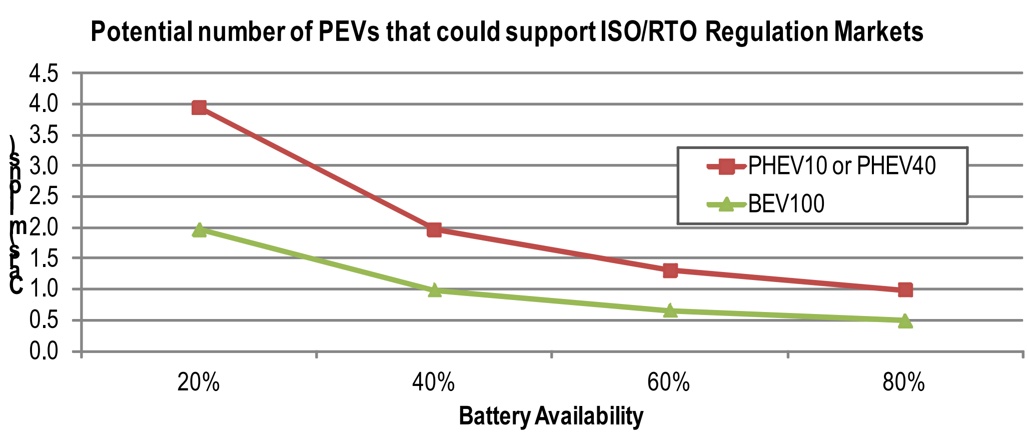
Estimate of PEVs Needed to Support ISO/RTO Electric Regulation Market

It is possible to estimate the size of PJM's Regulation Market in terms of number of vehicles, which will vary widely depending on each vehicle's charging characteristics, availability to provide the service, and whether or not they have bi-directional power flow capabilities. Here, we provide a matrix of vehicles that have bi-directional power flow, but at differing power levels and with varying availability to provide Regulation (in terms of hours available). For example, looking at the table below, if 12 kW per vehicle was available for approximately five hours per day (20 percent), then roughly 375,000 vehicles would be needed to serve the entire 900 MW regulation market in PJM. This example may be used to estimate the potential number of PEVs that could participate in the existing regulation markets in the U.S. Figure 6 below shows this estimate, which is based on the 2010 regulation market size, and assumes that both PHEV10 and PHEV40 vehicles have a 3.3 kW battery and BEV100 vehicles have a 6.6 kW battery, and that the entire regulation market would be served by one vehicle type to the exclusion of all other regulation resources. In practice, PEVs will be competing with other regulation resources such as generators, pumped-hydro facilities, grid-scale battery systems, and even water heaters. Also, to put the potential PEV regulation market participation in perspective, approximately 8,000 Volts and 10,000 Leafs were sold in the U.S. in 2011, amongst a total U.S. light duty vehicle sales of 153 million.[15]

Table 1: Number of vehicles, with bi-directional power flow ability, needed to satisfy the average PJM Regulation Market requirement in 2010 (900 MW). It should be noted that availability percentage may be tied to the size of the battery, among other things.

Availability/Power per Vehicle	1.5 kW	3 kW	6 kW	12 kW
20%	3,000,000	1,500,000	750,000	375,000
40%	1,500,000	750,000	375,000	187,500
60%	1,000,000	500,000	250,000	125,000
80%	750,000	375,000	187,500	93,750

Figure 6: Potential number of vehicles that could be supported by the US regulation market.



[15] Total U.S. Light Vehicle Retail Sales (SAAR). See at: http://www.motorintelligence.com/m_frameset.html

Operating Reserve Services

Another market in which PEVs could participate is the Operating Reserves market. A core service of this market Synchronized Reserve, also known as spinning reserve[16], supplies electricity if the grid has an unexpected need for more power on short notice, such as an unplanned generator outage. It is called synchronized because the resource's alternating current output must be the same phase sequence, voltage, and frequency as that of the alternating current of the grid. The power output of generating units supplying synchronized reserve can be increased quickly to supply the needed energy to balance supply and demand; demand resources also can supply synchronized reserve by reducing their energy use on short notice. PEVs could provide this service by either discharging or ceasing to charge their batteries. Like the Regulation Market, synchronized reserve resources are paid for both their ability to provide energy and the actual energy that is provided. Load serving entities can meet their obligation to provide synchronized reserve to the grid by using their own generation, by purchasing it under contract with another party or by buying it in the Synchronized Reserve Market.

Synchronized Reserve has traditionally been provided by generating units; however, FERC Order 890[17], finalized in 2007, allows non-generation sources such as storage and demand response resources to also provide these services, as evidenced by participants in PJM's Synchronized Reserve market in recent years, and detailed below in an excerpt from a recent PJM white paper on market design.[18]

"The PJM Synchronized Reserve market is an hourly market in which PJM secures resources to provide a 10-minute response to a system event.[19] The Synchronized Reserve market has provided opportunity for competitive development of demand reduction response through investment in demand response infrastructure. The payments to resources that clear in the Synchronized Reserve market are compensation for the demand reduction resource capability to respond within ten minutes. Although demand reduction resources must install infrastructure to allow them to curtail their consumption of electricity within ten minutes, they will only be requested to curtail when system conditions require the 10-minute response. Since 2006 the participation by customers in the Synchronized Reserve market has grown steadily. In 2011, on average, 9 percent of synchronized reserve supply is demand based. In some hours, as much as 16.3 percent of the synchronized reserve requirement has been met by demand-based resources. The deployment of Smart Response technology has enabled aggregated demand resources to provide synchronized reserves."

Figure 7, below illustrates the curtailed load response of an aggregated retail demand resource consisting of over 13,000 residential customers. This resource was offered into the market as a 9 MW synchronized reserve resource. PEVs, which may be included with these non-traditional (demand) resources, have the potential to provide retail customers with the ability (through an aggregator) to participate in the Operating Reserves markets, thus providing additional flexibility to manage their energy needs.

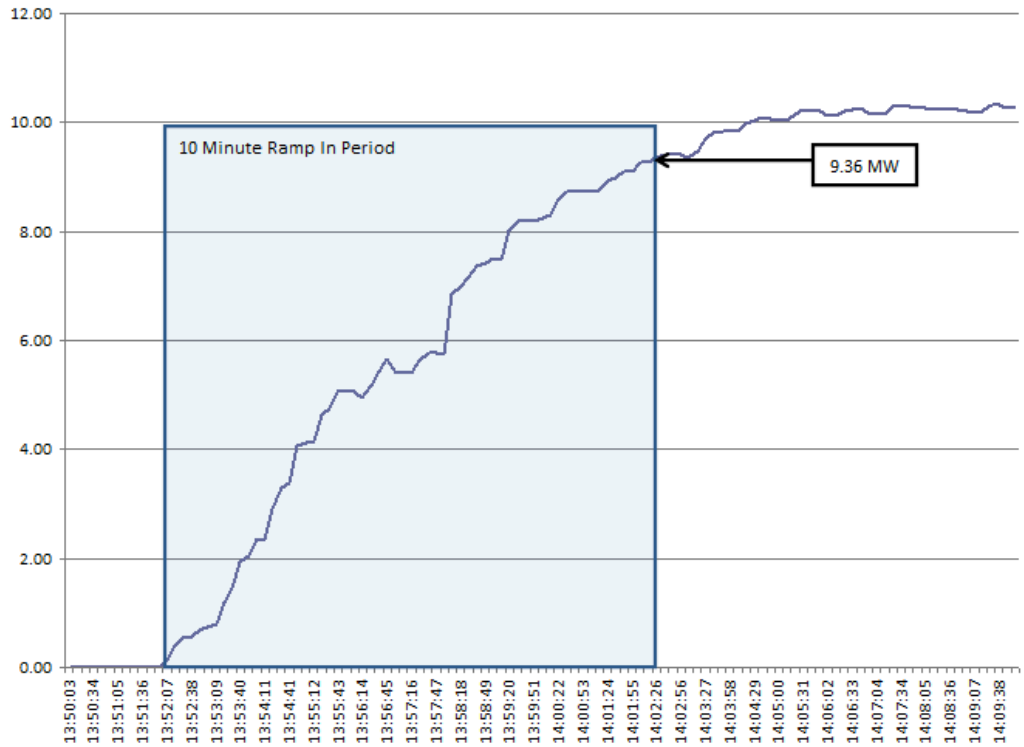
[16] Reserve requirements are values of reserve which enable the system to operate reliably and economically while providing protection against load variations, forecast error and equipment failure.

[17] FERC Order No. 890. Preventing Undue Discrimination and Preference in Transmission Service. February 16, 2007. See at: http://www.ferc.gov/whats-new/comm-meet/2007/021507/E-1.pdf

[18] PJM. Evolution of the US Power Grid and Market Operations through 2030. November 2011.

[19] Section 1.3.33B.01 of the PJM Operating Agreement defines Synchronized Reserves as the reserve capability of generation resources that can be converted fully into energy or Demand Resources whose demand can be reduced within ten minutes from the request of the Office of the Interconnection dispatcher, and is provided by equipment that is electrically synchronized to the Transmission System. Synchronized Reserves are supplied from 10 minute synchronized generating resources (i.e., Synchronous Reserves) and 10-minute demand side response resources.

Figure 7 – Curtailed load event ramp, 10-minute response.



Market enhancements for non-traditional resources

Non-traditional (non-generation) resources may have different, unique characteristics compared to typical generation assets, such as faster ramp[20] speeds, limited energy, and, in some cases, the ability to both inject energy into the grid as well as absorb energy from the grid. In order to accommodate some of these different characteristics and improve the efficiency and stability of the grid, FERC issued a final rule on performance-based regulation[21] in October 2011. This rule requires ISOs/RTOs to compensate frequency regulation resources for both capacity, which includes the marginal unit's opportunity costs[22], and performance that reflects the quantity and quality of frequency regulation service provided. This rule is intended to enable all resources to compete to receive compensation based on the speed and accuracy of their response to ISO/RTO control signals. PJM filed a tariff change with FERC on March 5, 2012, to implement pay-for-performance beginning in October of 2012.[23]

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[20] Ramp is the increase or decrease of a service such as energy or regulation, and ramping ability is the speed and accuracy of a service response.

[21] FERC Order No. 755. Frequency Regulation Compensation in the Organized Wholesale Power Markets. October 20, 2011. See at: http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

[22] In an auction that uses a uniform clearing price, such as that used in capacity markets, the lowest offer (or price) that clears the auction sets the price received for all suppliers that have cleared the auction. The provider of this offer that sets the market clearing price is known as the marginal unit. The marginal unit's opportunity costs are the revenues the marginal unit foregoes because it may not participate in the energy market while it is participating in the regulation market.

[23] PJM Interconnection LLC Docket No. ER12-1204-000 Order No. 755 Compliance Filing. See at: http://pjm.com/~/media/documents/ferc/2012-filings/20120305-er12-1204-000.ashx

A study issued last year found that ISO/RTO rule changes that allow electricity storage to compete on an equal basis with traditional generation assets appear to be a significant factor in driving investment of fast-response storage.[24] ISOs/RTOs also are moving to improve the granularity of their systems in an effort to improve performance. On October 21, 2011, FERC approved PJM's request to reduce the threshold for Regulation, Synchronized Reserve and Day-Ahead Scheduling Reserve markets from 0.5 MW to 0.1 MW, this includes the aggregation of demand response resources.[25] On November 21, 2011, PJM began receiving regulation services from small sources.[26] This allows PJM to more accurately and efficiently balance its system, as well as promote the use of smaller resources such as PEVs (0.1 MW could be made up by aggregating approximately 15 vehicles)[27].

PEV Interaction with the Electric Grid

PEV interaction with grid was the subject of a 2010 ISO/RTO study entitled "Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems." This study was conducted by the ISO/RTO Council (IRC), and identified product and services that PEVs could provide under existing market and structures of the North American ISO/RTOs.[28] It first identified the following traditional services and products that are currently available in ISO/RTO markets, in which PEVs could potentially participate:

Scheduled Energy – In this case, a PEV owner could work through an aggregator to schedule charging, interrupting charging when called upon for a specified period of time.

Regulation – A PEV would act through an aggregator and provide an adjustment in the PEV charging rate by a specified amount, in a specified response time (6-30 seconds), for a specified period of time (currently 15-60 minutes). The aggregator's rate of change, percent/second, must meet the requirements of the regulation agreement, as well as maintain the modulation within the constraints of each vehicle's battery pack.

Reserves – In this case the aggregation of PEVs would be required to alter its charge level to the required level immediately. The aggregator will need to have sufficient resources to be able to reduce load by the reserve amount offered for the required time period.

Emergency Load Curtailment – In this case the aggregation of PEVs would be able to shed load in emergency situations by stopping charging in a specified period of time. This is similar to emergency demand response.

Balancing Energy – An aggregator capable of altering PEV charging on a real-time basis could adjust charging load down to sell energy or adjust charging load up to buy energy in response to ISO/RTO control signals. This could be a valuable service to provide for hourly schedule transitions, where energy is balanced and movement is small in either direction (up or down).

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[24] Innovation in Competitive Electricity Markets. February 24, 2011

[25] Federal Energy Regulatory Commission. Frequency Regulation Compensation in the Organized Wholesale Energy Markets. October 20, 2011. See at: http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

[26] First Small Scale Demand-Side Projects in PJM Begin Providing Frequency Regulation. November 21, 2011. See at: http://wired.pjm.com/~/media/about-pjm/newsroom/2011-releases/20111122-news-release-dr-firms-participate-regulation-service.ashx

[27] Erica Gies, The Cash-Back Car: Monetizing Electric Vehicles. Forbes. June 6, 2011.

[28] ISO/RTO Council. Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems. March 2010. See at: http://www.isorto.org/atf/cf/%7B5B4E85C6-7EAC-40A0-8DC3-003829518EBD%7D/IRC_Report_Assessment_of_Plug-in_Electric_Vehicle_Integration_with_ISO-RTO_Systems_03232010.pdf

Important to the ability to provide these services is the ability of the aggregator to communicate with the PEVs and charging equipment, and the ability of both PEV and charging equipment to either adjust charging, or provide electricity flow back through the charging equipment to the electricity supply.

Potential Areas for Future Development

The aforementioned IRC study also identified the following two areas where ISO/RTOs could expand their interaction with PEVs: 1) Enhanced Aggregation, which would allow the ISO/RTOs to provide price signals to aggregators so that they may determine their energy response similar to a conventional generator, determining the amount of charging that occurs each hour; and 2) Dynamic Pricing, in which the PEV would receive retail electricity pricing information direct from the local utility and determine when to charge. A number of dynamic price pilot studies have been conducted, and a few utilities are offering those services. Dominion Virginia Power is running a pilot program that offers variable rates to customers who use electric vehicles, in order to encourage charging at times of lower demand (off peak).[29] PJM is working on incorporating "price responsive demand" into its market construct, in order to account for the impact of retail customers responding to price signals, and thus maintain and improve reliability of the electric grid.[30]

Role of PEVs in the PRD construct

The current wave of smart meter installations taking place nationwide appears to be a nice precursor for the coming adoption of PEVs, and a means to not just reduce the impacts PEVs may have on the electric system, but to actually use PEVs to help the system operate more efficiently. There are three key factors that can make this a reality: 1) the inherent flexibility that most PEVs will have in *when* they charge, 2) a retail rate structure that reflects the actual (or real-time) price of electricity, and 3) the seamless communications infrastructure to signal charging events to the PEV. The first item is in place today. The second item is yet to be implemented on a broad scale (pilot demonstrations are currently taking place). The third item is in the early stages of demonstration, with a foundation of standards in place or under development to support it. If these three factors come together in a utility's service territory, then customers, including owners of PEVs, will be able to make informed decisions about their electricity usage based on prices revealed by ISO/RTO administered markets.

Consider, for example, Smart Home that has central air-conditioning and a new PEV. Consider further the impact on the electric grid of a decision by Smart Home Owner to cool the house and charge the PEV (requiring an additional 3.3 kW) on a very hot summer afternoon.

Price Responsive Demand would enable Smart Home Owner and her local utility, known as the load serving entity (LSE), to reduce usage by programming the PEV charger to automatically stop charging when an agreed upon retail (dynamic) rate is triggered by a real-time wholesale energy price. The LSE would in turn tell PJM that Smart Home Owner will not consume additional electricity to charge the PEV when the triggering real-time wholesale price occurs.

This means that Smart Home Owner will instead charge the PEV in other hours when prices are lower. This also means that the electricity supplier will be able to offer Smart Home Owner a lower price for electricity. Finally, this means that PJM will dispatch resources needed to meet customers' needs more efficiently because the LSE has communicated in advance the limit of Smart Home Owner's usage at a specified real-time wholesale energy price.

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[29] Dominion Virginia Power Electric Vehicle Charging Pilot Program Begins. October 3, 2011. See at: http://dom.mediaroom.com/index.php?s=43&item=1037

[30] PJM PRD FERC Filing. September 23, 2011. See at: http://pjm.com/markets-and-operations/rpm/~/media/documents/ferc/2011-filings/20110923-er11-4628-000.ashx

As introduced above, jurisdictions are evolving dynamic pricing structures for PEVs to provide incentives for customers to modify consumption decisions in direct response to wholesale market conditions. Like traditional demand response that has historically responded to market events during peak conditions, PEVs, with the dynamic pricing structures and automated, two-way communication, can now respond to wholesale price signals and decide to avoid charging during high cost hours by limiting charging to lower cost hours as Price Responsive Demand (PRD). And like traditional demand response, the characteristics and expected consumption behavior of PEV load, can be aggregated, modeled and made visible to the ISO/RTO wholesale markets.

The primary benefit to the wholesale market from the incorporation of revised market rules for PRD is the increased operational efficiency that can be achieved through the recognition of price-sensitive retail load, such as PEV load, in real-time dispatch. With no visibility into how consumption patterns would change at the retail level at various price levels, the ISO/RTO would dispatch based on forecasts that don't take PRD into account and, as a result, dispatch too much generation resulting in decreased market efficiency.

Therefore, PJM's primary goal with respect to accounting for price-sensitive retail load, such as PEV load, is to provide a mechanism by which PJM can receive information regarding such load so that this information can be incorporated into the dispatch. Taking the above example, one step further, similar decisions by many PEV owners would reduce the grid's peak requirement, thereby delaying the need to build new generation.

The requirement for automation of PRD was discussed at the FERC's February 2012 Price Responsive Demand technical conference.[31] Recall that in the example discussed above the PEV charger was programmed to automatically stop charging in response to an agreed upon dynamic retail rate. During the technical conference, PJM representatives explained that more efficient dispatch and accurate real-time energy prices require automated response to price.

Implementation of V2G

The employment of actual two-way communications between a vehicle and the electric grid will be a response to market (consumer, producer, operator, regulator) needs. The Federal Energy Regulatory Commission has aided in the implementation of V2G by requiring the Regional Transmission Organizations that it regulates to provide comparable treatment to demand response[32], such as accepting bids from demand response resources if they are technically capable of providing the ancillary service, and submitting a bid under the generally-applicable bidding rules at or below market-clearing price, unless the laws or regulations of the relevant electric retail regulatory authority do not permit retail customers to participate.[33]

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[31] Notice of Staff Technical Conference, Docket No. ER11-4628-000, January 18, 2012.

[32] Demand Response is defined in the Federal Energy Regulatory Commission's 2010 Assessment of Demand Response and Advanced Metering as: Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. http://www.ferc.gov/legal/staff-reports/2010-dr-report.pdf

[33] Order No. 719, FERC Stats. & Regs. ¶ 31,281 at P 47. See at: http://www.ferc.gov/whats-new/comm-meet/2008/101608/E-1.pdf

Basic communication and infrastructure needs for V2G Implementation

The Energy Independence and Security Act of 2007 tasked the National Institute of Standards and Technology (NIST) with developing a framework regarding information management protocols and standards that will ensure interoperability[34] of Smart Grid devices and systems. The Draft NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0[35] includes, among other things, Smart Grid Interoperability Panel (SGIP) Priority Action Plans (PAP), which are used when there is a need for interoperability coordination on a critical issue. There are a number PAPs in place that will affect V2G such as plans dealing with wireless communications, common price and schedule communication models, energy storage interconnection guidelines, standard DR (demand response) and DER (Distributed Energy Resource) signals, and common object models for electric transportation. Additionally, the SGIP created the Distributed Renewables, Generators, and Storage Domain Expert Working Group to identify any interoperability issues related to grid integration of distributed generation, renewable energy and energy storage devices such as enabling the provision of ancillary services.

Complementary work is being done by the Electric Power Research Institute (EPRI) National Transportation Council PHEV Working Group, which is developing interoperability standards between the PEV and the electric company or aggregator. Also, the Institute of Electrical and Electronics Engineers (IEEE) published IEEE 2030 Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads. This guide provides a knowledge base addressing terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for smart grid interoperability of the electric power system with end-use applications and loads.

Conclusion

In the face of a rapidly changing electricity marketplace, PEVs may play a significant role as an energy/capacity resource. Evolution currently taking place in the industry include price responsive demand evolving out of demand-side participation; policy decisions including renewable portfolio standards that drive increased intermittent resources such as wind and solar, and environmental regulations that increase costs associated with coal-based generation driving the use of more natural gas generation, renewable resources and demand response; and technological advances such as hydraulic fracturing that enable the procurement of low cost natural gas. These are all transforming the grid into a system in which variable demand rather than variable generation will be relied upon to balance the grid. In a world of wide-spread PEV adoption, PEVs may be the largest and most flexible loads on the system.

[34] "Interoperability" as defined in the NIST Framework: refers to the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user.

[35] Draft NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0, October 17, 2011 Revision see at: http://collaborate.nist.gov/twiki-sggrid/pub/SmartGrid/IKBFramework/Draft_NIST_Framework_Release_2-0_10-17-2011.pdf