Electric Vehicles as Grid Resources in ISO-NE and Vermont

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Executive Summary

In Vermont, the vast majority of transportation energy comes from petroleum products used to fuel internal combustion engines. Widespread use of plug-in electric vehicles (EVs) can greatly reduce transportation energy costs and pollution. The State's Comprehensive Energy Plan has established a goal of powering 25% of vehicles with renewable energy sources by 2030. A shift from fossil fuels to the electric grid as the primary supplier of energy for transportation will pose new challenges for utility providers with regards to peak power management but also new opportunities that, if properly managed, could result in net benefits to the grid.

GRID SERVICES

This paper explores various ways in which electric vehicles can serve as resources to the electric grid. Vehicle/Grid Integration should be approached in an incremental manner, with opportunities presenting the fewest barriers explored first. From this perspective, the benefits or grid resources examined include:

- Demand Side Management programs. Managing EV charging can provide an immediate opportunity.
- Aggregated EVs serving as resources in the wholesale level ancillary service markets through integration with the regional grid operator. This represents the next step in the strategic development of a Grid Integrated Vehicle (GIV) system.
- A fully integrated system in which aggregated EVs provide storage resources coupled with renewable energy sources providing distributed generation guarantees in capacity markets is a longer term vision.

Demand Side Management. Distributing energy demand such that it is evenly spread throughout the day enables utilities to use existing infrastructure more efficiently and meet increasing demand without needing system upgrades. The new controllable load introduced by smart electric vehicle charging presents utilities with the means to do this through demand side management strategies. Time of use rates and controlled charging help ensure charging occurs concurrent with low demand on the existing grid, saving ratepayers money and generating additional revenue for utilities. Studies of EV owners' charging behavior indicates that these programs are effective.

Wholesale Ancillary Service Regulation Market Resources. Regulation, managed by the regional grid operator, is the method by which proper balance is maintained on the electric grid. This balancing service is typically delivered by natural gas generators ramping up or down in response to a regional grid operator dispatch signal based on fluctuations in demand, but emerging research on grid integrated vehicle (GIV) technology suggests that electric vehicles are capable of serving in this resource capacity. Electric vehicle battery systems can provide near-instantaneous response to grid operator signals, while other generation technologies may require several minutes to hours to react to the dispatch signal. This use of EVs as resources in the ancillary service markets, specifically as a regulation resource, has been the focus of most GIV research to date. Regulation provides a good opportunity to establish EVs as a resource in wholesale ancillary service markets, but due to the small size of regulation markets, additional opportunities, such as enabling greater penetration of renewable energy and participation in capacity markets, will need to be established for long term integration.

A Fully Integrated System and the Forward Capacity Market. While participating in demand side management programs at the utility level and serving as regulation resources in wholesale ancillary service markets are good first steps in understanding EVs' roles as grid resources, ultimately, a comprehensive approach to GIV could lead to much more substantial benefits. When EVs are fully integrated and acting as flexible storage resources, they can contribute to a more reliable, resilient, and sustainable grid in which generation and demand are essentially decoupled. This will allow greater integration of renewable resources, enable more efficient use of existing resources, and potentially enable EVs and renewable resources to jointly participate in the ISO-NE Forward Capacity Market.

RECOMMENDATIONS

While the idea of a fully integrated system in which EVs play a critical role in providing much needed storage to the grid, contribute to load flattening, participate in wholesale markets, and enable the integration of renewables may seem to be a distant reality, there are steps we can take now to begin in that direction.

EV Rates. To ensure the additional load created by EV adoption is not detrimental to the grid and existing distribution infrastructure, efforts must be made to establish the additional demand as a manageable load. EV owners must be made aware of time of use rates, and regulators and utilities should consider specific EV rates that are simple to understand and beneficial enough to incent participation when designing rate structures and developing demand response riders. Specifically, the Vermont Public Service Board (PSB) will need to convene and lead this effort. The extensive implementation of smart grid infrastructure is a unique asset in Vermont and its applications should be considered.

Coordination of Participants and Stakeholders. For a full GIV system to be realized, the Federal Energy Regulatory Commission (FERC) and ISO New England, state regulators, utilities, auto manufacturers, management system software developers, and EV owners will all need to be part of the conversation. A GIV framework and model, as well as a roadmap to realize it, need to be developed for Vermont, and all stakeholders need to be actively involved in this process. Consideration of best business models, private sector infrastructure, actors, roles, and regulatory issues must all be addressed through stakeholder engagement.

Standardization. To ensure safety and compatibility throughout a GIV system, standards must be developed and adopted for communication, physical interfaces, technology, control equipment, power conversion, and facilities. The Society of Automotive Engineers (SAE) has largely led this effort, but many organizations will contribute, including the Underwriters Laboratories, Inc., National Fire Protection Association, Institute of Electrical and Electronics Engineers, International Code Council, National Electrical Contractors Association, National Electrical Manufacturers Association, and Alliance for Telecommunications Industry Solutions.[1] Auto manufacturers, software developers, and utilities must coordinate efforts to ensure compliance with developed standards—communication throughout the standards process with regulators will be essential.

Cost-Benefit Analyses. As GIV benefits and services evolve, cost-benefit analyses must play an important role in decision making. Values of GIV benefits as well as the costs are largely unknown, and must be determined and considered as technologies are developed, systems evolve, and pilot projects expand. Demonstration projects will aid in uncovering and determining the value of costs and benefits.

Demonstration. With such high levels of complexity, varying stakeholder roles, and regional differences in utility and grid operations, standardization of GIV systems is a challenge. Market structures and energy dispatch vary from one ISO or RTO to the next, and the roles of utilities vary both within and between ISOs and RTOs. All of these factors will impact vehicle-to-grid interactions and the role EVs play within the electrical power system. Addressing the unexpected and unforeseen complications has proven to be a significant task. It is not possible to identify all of these complexities without going through the process of creating a GIV project. A demonstration project in ISO-NE, specifically in Vermont, will begin to help uncover the intricacies of a system in this region.

EVs as Part of the Conversation. We are in a period of rapidly evolving energy systems—increasing amounts of distributed generation, integration of renewables, demand side resources, advanced metering infrastructure—and as changes and restructuring occurs, it is important to ensure that EVs are part of the discussion. Regulators, RTOs and ISOs, and utilities must all be aware of the potential role EVs can play in contributing to grid reliability and resilience.

1. Introduction

At 50 million MMBtu annually, the transportation sector consumes the largest share (34%) of energy in Vermont[2] as well as contributes the most significant quantity of greenhouse gas (GHG) emissions in the state (46%).[3] The vast majority of transportation energy comes from petroleum products used to fuel internal combustion engines. Because widespread use of plug-in electric vehicles (EVs) can greatly reduce fossil fuel consumption, transportation energy costs, and mobile source air pollution in Vermont, the State's Comprehensive Energy Plan has established a goal of powering 25% of vehicles with renewable energy sources by 2030.[4] A shift from fossil fuels to the electric grid as the primary supplier of energy for transportation has the potential to pose new challenges for utility providers with regards to peak power management, but this shift also presents new opportunities which, if properly managed, could result in net benefits to the grid overall.

EVs are well suited for demand side management because vehicles are in use for mobility less than five percent of the time[5,6] and EVs, on average, need to be charging for approximately 10-20% of the day, indicating that this represents a flexible load amenable to shifting.[7] A second potential benefit of EVs is that they have been demonstrated to be capable of integration with the electric grid. Grid Integrated Vehicle (GIV) or Vehicle to Grid (V2G) technology enables EVs to provide valuable services to the grid, enhancing reliability and resilience, either through modulating the level of charging (uni-directional control) or through bi-directional flow of power between the vehicle battery energy storage system and the electric grid.[8] A sustainable electric grid with high levels of renewable resources will require significant storage assets for balancing and stabilization; GIV technology will enable fully integrated EVs to play this critical role and potentially serve as a resource in wholesale capacity markets.

This paper will begin by providing background on electric vehicles, electric vehicle charging, EV fleet projections and potential impacts, and the concept of vehicle-to-grid integration. To explore various ways in which EVs can serve as resources to the electric grid, integration will be approached in an incremental manner, with opportunities presenting the fewest barriers explored first. From this perspective, the benefits or grid resources that will be examined include:

- Demand side management programs with EV charging providing a manageable load;
- Aggregated EVs serving as resources in the wholesale level ancillary service market through integration with the regional grid operator; and
- A fully integrated system in which aggregated EVs provide storage resources coupled with renewable energy sources providing distributed generation guarantees in capacity markets.

Technological and regulatory requirements necessary for the services and benefits to be realized will be presented along with potential values where possible. While answers cannot be provided for all questions regarding what a complete GIV system will look like in Vermont, final recommendations attempt to identify the questions that need to be addressed, who must be involved, and steps necessary to move towards a system in which EVs add significant value to Vermont's electric grid.

1.1 ELECTRIC VEHICLES AND ELECTRIC VEHICLE SUPPLY EQUIPMENT

Electric Vehicles

Electric vehicles (EVs) as referenced in this report describe a class of automobiles that uses electric motors powered by electrical energy stored in a battery for propulsion. These vehicles are available in a variety of models with varying ranges and capabilities, and are plugged in to a source of electrical power to recharge. EVs can be either all electric (AEV) powered solely by energy stored in the vehicle's battery system, also referred to as battery electric vehicles, or plug-in hybrid electric vehicles (PHEV) capable of operating solely on electric energy for a certain distance after which an auxiliary internal combustion engine is engaged to offer additional range. For the purposes of this report, the defining feature of an EV is that it must plug into an electrical energy source to charge its battery system.

Electric Vehicle Supply Equipment

Recharging EVs is accomplished through connections to electric vehicle charging equipment, also referred to as Electric Vehicle Supply Equipment (EVSE). This is a protective system which communicates with the vehicle and monitors electrical activity to ensure safe charging. There are two primary types of EVSE: alternating current (AC) EVSE and direct current (DC) fast charging EVSE.

AC EVSE allows for the transfer of AC power from the electric grid, through the EVSE, and into the vehicle through the industry standard J1772 port connector.[i] With AC EVSE, charger electronics within the vehicle rectify the AC power supplied by the EVSE into controlled direct current (DC) for storage in the battery. Fast charging DC EVSE inverts AC to DC power off-board the vehicle and delivers high voltage direct current (typically over 400 V) straight to an electric vehicle's battery system.

There are three levels commonly used to describe the charging power of EVSE: Level 1, Level 2, and DC Fast Charging, as described below.

Level 1. The simplest form of charging, Level 1 EVSE uses a 120V connection to a standard residential/commercial outlet capable of supplying 15-20 amps of current, for a power draw usually around 1.4 kW when charging.

Level 2. Level 2 charging requires a 208/240V AC power connection and significantly reduces charging time. Home users commonly use 240V power for electric clothes dryer appliances and many commercial customers have 3 phase electric service with 208V power. Either voltage works well for Level 2 charging. The J1772 standard connector used by most EVs can theoretically provide up to 80 amps of current (19.2 kW), although most vehicles presently available only use up to 30 amps for 3.3 to 6.6 kW charging.

DC Fast Charging. Sometimes referred to as Level 3, DC EVSE delivers high power directly into an EV's battery system, enabling rapid charging. There are three main connectors for fast charging equipment by

[i] Tesla Motors does not use the J1772 port connector, but does offer an adapter.

various manufacturers:

1. CHAdeMO used by Nissan, Mitsubishi and Kia;
2. SAE Combo used by American and European makes, such as Chevrolet, BMW and Mercedes-Benz; and
3. Tesla's Supercharger used exclusively on Tesla Model S and later vehicles. Tesla has also announced an adapter allowing their owners to use CHAdeMO equipment.

1.2 ELECTRIC VEHICLE FLEET PENETRATION PROJECTIONS AND LOAD MANAGEMENT

Electric vehicles are rapidly gaining popularity in Vermont; since July 2012, EVs have seen a quarterly growth rate of nearly 40%. As of January 1, 2014, 596 EVs were registered in Vermont, spread across 130 communities.[9]

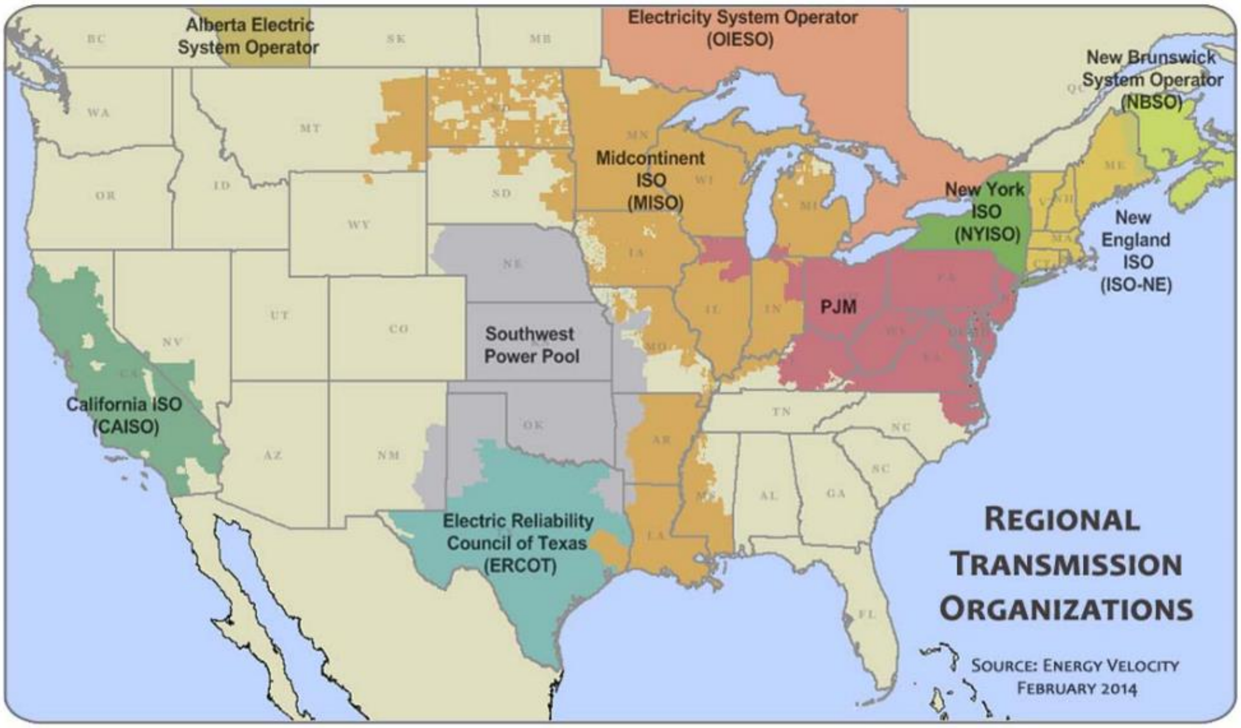
In a report for the Vermont Agency of Transportation, DuBois & King, Inc. and the Vermont Energy Investment Corporation projected and estimated the size of the future EV fleet in Vermont.[10] Using national sales projections in conjunction with projections from the U.S. Energy Information Administration, the Center for Automotive Research, and the Vermont Agency of Natural Resources' Air Pollution Control Program, a range of 5,649 – 23,000 EVs were projected to be registered in the state by 2023. For a longer term estimate, the state's Comprehensive Energy Plan (CEP), which calls for 90% renewable energy by 2050, would require approximately 143,000 EVs by 2030 and 515,000 by 2050.[11]

To consider the additional electric load resulting from widespread adoption of EVs, a study at the University of Vermont modeled the electric demand for various penetration levels of plug-in hybrid electric vehicles (PHEV) with a twenty mile all-electric range. This study found that with 50,000 PHEVs, the electric demand for the vehicles would represent approximately 5.14% of the total MWh demanded in 2005; 200,000 PHEVs would require a 20.55% increase in MWh of energy.[12]

However, because excess capacity is built into the grid, researchers at the University of Vermont have concluded that, if charging occurs during off-peak hours, the Vermont grid is capable of supporting more than 100,000 EVs without needing to expand generation and transmission capacity.[13] This is consistent with a number of other studies conducted in various parts of the country indicating that there is sufficient idle production and transmission capacity to power a significant percentage of light-duty vehicles with grid supplied electricity without constructing new generating facilities or upgrading local grids.[14, 15, 16, 17, 18, 19, 20] The key element, however, in all of these studies is that charging must be actively managed to occur primarily at off-peak times.

To ensure sufficient capacity to meet demand of customers and access to transmission resources, the Federal Energy Regulatory Commission (FERC) established the voluntary formation of grid operators, or Independent System Operators (ISO) and Regional Transmission Organizations (RTO). Figure 1 below shows the existing RTO/ISOs and their coverage areas.

Figure 1: Regional Transmission Organizations / Independent System Operators

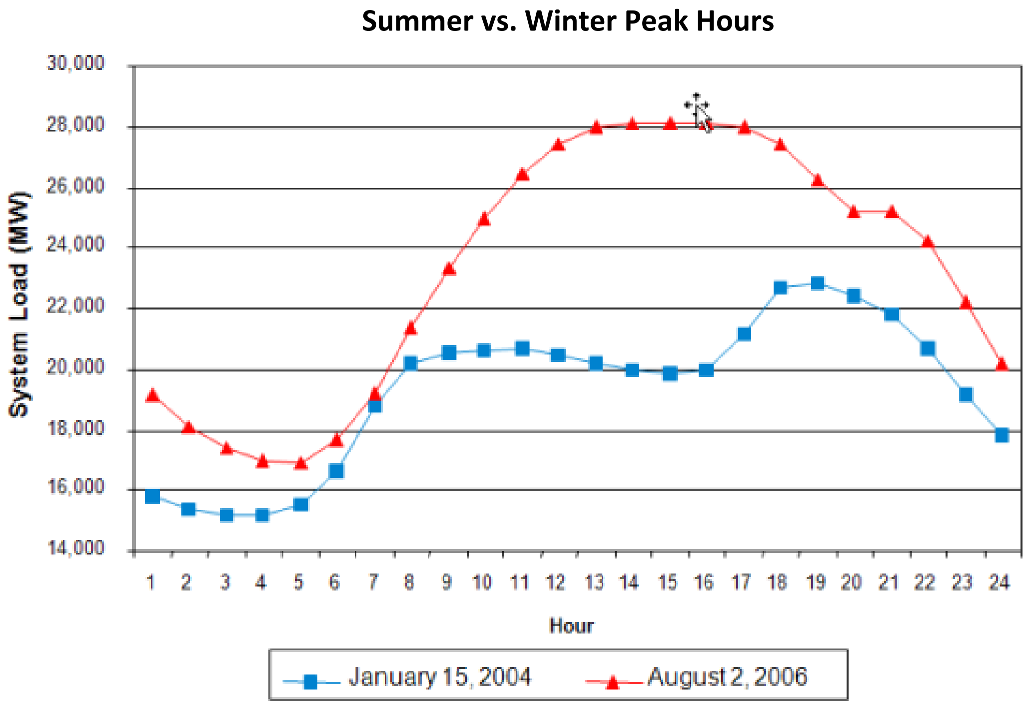


Source: FERC, http://www.ferc.gov/industries/electric/indus-act/rto.asp

To meet the needs of customers during periods of peak demand, grid operators must maintain capacity in excess of that which is needed to meet normal levels of demand. This responsibility requires ISO New England (ISO-NE), the focus of this paper, to maintain an additional 2,500 MW of power capacity needed for fewer than 100 hours per year.[21] The result is that the electricity transmission and generation infrastructure is used well below the limits of its capability much of the time.

While the additional load introduced by the adoption of EVs could be potentially problematic and have negative impacts on the grid if it occurs in an uncontrolled manner, it also presents great opportunities if managed strategically. If measures are taken to confine charging primarily to times in which demand on the grid is low, EVs could help to fill valleys in system demand. Figure 2 below illustrates the daily fluctuation in load for sample summer and winter days. Increasing load at the points of lowest demand has the impact of flattening this daily variation, thereby mitigating the efficiency losses and thermal cycling stress that accrue from ramping large generators up and down and enabling greater utilization of electric power infrastructure with high capital costs and low marginal costs of use.[22, 23, 24] The increase in operational efficiency and utility profitability of the load flattening that can occur from off-peak EV charging, or demand side management, could ultimately be passed down to customers in the form of reduced electricity rates.[25]

Figure 2: Example Daily Load Variation, ISO-NE



Source: ISO NEWSWIRE, http://isonewswire.com/updates/2011/12/5/iso-ne-forecasts-adequate-power-to-meet-demand-this-winter.html

1.3 GRID INTEGRATED VEHICLES (GIV) AND GRID SERVICES

In addition to providing new demand for electricity and contributing to the more efficient use of utility resources, EVs also have the ability to contribute to grid reliability as a resource in various wholesale markets. Because the power grid currently has very limited storage resources, energy must be utilized at the exact moment it is produced. In regions with competitive wholesale markets, the grid operator is responsible for managing this and maintaining perfect balance between generation and demand. ISO-NE maintains this system balance through three main markets: energy, capacity, and ancillary service markets. Energy markets are the primary place power is bought and sold; capacity markets invest in future capacity resources; and ancillary service markets ensure reliability in electricity production and transmission.[26]

Storage, however, provides the opportunity to decouple demand or load from generation.[27] When capacity exceeds demand, storage resources can remove the excess from the grid. Conversely, when demand exceeds capacity, storage resources are then available to provide additional capacity to the grid. EVs have the capability to serve as this storage. While not in use for transportation (approximately 95% of a day), EVs are available for a secondary function. When equipped with appropriate connections to the grid, EVs are able to dispatch energy back to the grid in addition to pulling energy from the grid while charging. This has been termed vehicle-to-grid (V2G) power.[28]

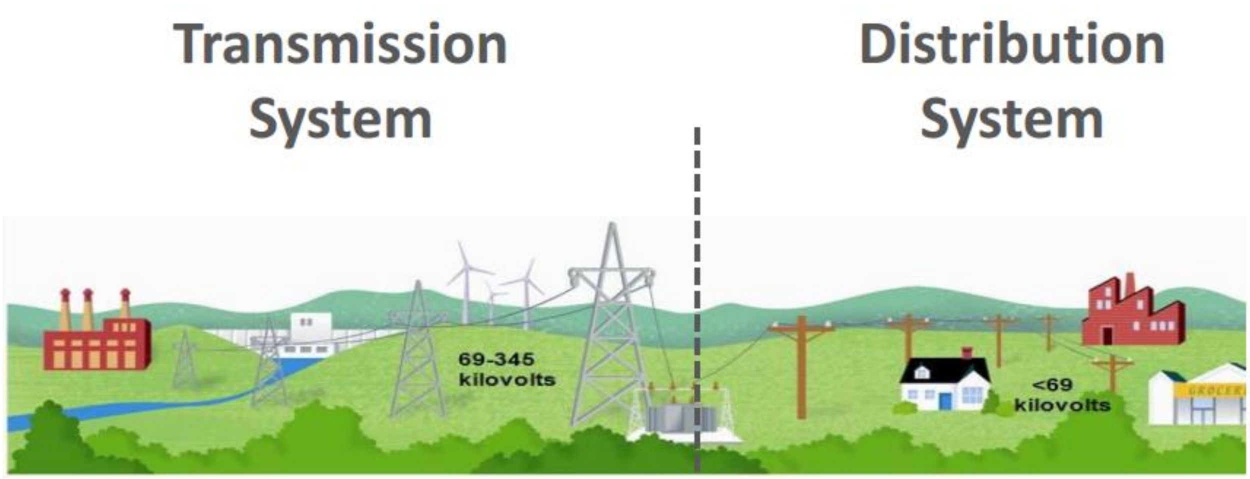
While storage can theoretically serve as a resource in any of these markets, the structure of the ancillary service markets best match the strengths of EVs. Operating reserves, one type of ancillary service, provide a margin of supply such that sudden disruptions or outages can be managed without service interruption. Regulation, the other ancillary service market run by ISO-NE, maintains the optimal balance on the grid by adjusting to minute-to-minute variations in demand.[29] Traditionally, both ancillary service markets are served by operators of natural gas plants because of their capability to modulate output rapidly and precisely. However, due to lower capital costs, their ability to vary output quickly, and their lower maintenance costs, EVs are considered to be potentially better ancillary service resources than generators.[30] Additionally, ramping gas turbines in such a manner has been shown to increase NO_X emissions[31], suggesting that reduced health impacts represent additional advantages of using battery storage to serve this need.

This application of EVs as resources in the ancillary service markets, specifically as a regulation resource, has been the focus of most GIV research to date. This paper will explore how such a system could be structured in ISO-NE, as well as consider how EVs could participate in ISO-NE's capacity markets and contribute to greater renewable energy integration.

2. Grid Services and Resources

As introduced above, there is the potential for EVs to provide a variety of resources to the electric grid. Because these markets vary significantly from region to region, state to state, and even from one utility to another, we will focus on ISO-NE, and where appropriate, specifically on Vermont. For context, Figure 3 and Figure 4 illustrate the electric power system and market structure in Vermont. Specifically, Figure 4 identifies the five basic roles that each regional power system must manage[32] and how those roles and responsibilities are filled within Vermont.

Figure 3: Electric Power System Illustration



Source: ISO New England Inc., http://www2.leg.state.vt.us/CommitteeDocs/Senate%20Natural%20Resources/ISO%20New%20England/3-24-2014~Eric%20Wilkinson~ISO%20New%20England%20Overview%20(power%20point).pdf

Figure 4: Vermont Electric Market Structure

Generation	Transmission	Distribution	Demand-Side Management	System Optimization and Balance
Utility + Utility calls on Independent Power Producers	Vermont Electric Power Company, Inc. (VELCO)	Utility maintains distribution	Utilities and independent service providers	ISO New England

KEY: Regulated Monopoly | Market Driven | Hybrid

Adapted from: Harvey, Hal and Sonia Aggarwal. "America's Power Plan. Overview: Rethinking Policy to Deliver a Clean Energy Fugure." Energy Innovation, p.11. http://americaspowerplan.com/site/wp-content/uploads/2013/10/APP-OVERVIEW.pdf

In an effort to make expanded adoption of EVs a desirable asset, rather than a burden on the grid, benefits with the fewest barriers will be presented first. As more complex benefits and services are explored, the technological and regulatory steps necessary for the benefits to be realized will be presented. Potential values of benefits will be discussed where possible.

2.1 DEMAND SIDE MANAGEMENT

In Vermont, the *average* peak demand per residential customer is approximately 0.9 kW,[33] however peak demand can exceed 4 kW for residential customers when multiple large appliances are in use at once. If Level 2 EVSE is available at homes, the power of EV charging is determined by the vehicle charger, typically either 3.3 or 6.6 kW. This indicates that it is possible for home charging to increase peak load significantly. However, because electric infrastructure is designed to meet this peak demand, utility resources are not used at full capacity for much of the time.[34] These two factors indicate that a critical first step in the integration of EVs into the electric grid must involve efforts to ensure that charging occurs at off-peak times in such a way that is beneficial to the grid, or at very least, not detrimental to grid reliability.[35]

Demand-Side Management, defined as the “selection, planning, and implementation of measures intended to have an influence on the demand or customer-side of the electric meter, either caused directly or stimulated indirectly by the utility”[36] provides the means to do this.

With EVs, this form of load management can be accomplished through either direct or indirect control of charging.[37,38] In a direct control scenario, an EV owner grants an external party (e.g. the utility) the ability to directly control the flow of electricity into their vehicle; in an indirect scenario, charging behavior of EV owners is more passively manipulated through use of price signals. Additionally, with the proper connections, controls, and incentives, EV owners can even charge their vehicles when demand is low and dispatch energy back to the grid at times when demand is high.

Whatever the mechanism, the goal behind these approaches is the same. Redistributing energy usage such that it is more evenly spread throughout the day enables utilities to use existing infrastructure more efficiently and meet increased usage without needing system upgrades.

Indirect: Time of Use Rates

Time of use rates are perhaps the most basic form of demand side management and represent a simple and effective method through which EV charging can be controlled. Rate design can be structured to encourage off-peak charging, smoothing the electric load over the course of a day. Given the amount of electricity needed for EV charging and the ease with which owners can shift the timing of their charging, the growth of EV ownership is a perfect opportunity to encourage time of use rates.[39] Some utilities have even implemented special time of use rates specific to EVs.[40]

While EV owners are likely to plug in their EVs whenever they return home, it is possible to set a timer or automate controls to delay the start of charging. Research on the behavior of EV drivers has shown that owners will in fact determine and set charging start times in response to time of use rates.[41,42] In fact, at-home-charging start times have been shown to correspond to time of use rate plans and off-peak times, indicating the effectiveness of such programs.[43]

Direct: Controlled Charging

One potential risk of time of use rates is a spike in demand at the start time of the off-peak prices.[44] Policies that encourage EV owners to set an end time to their charging, rather than a start time, can mitigate this issue. Due to the vehicles' various states of charge and the time needed to obtain the desired level of charge, this will serve to randomize the time at which various vehicles start charging.[45]

However, another way to avoid this is through direct demand side management programs, or controlled charging. Through participation in a demand response program, EV owners give utilities direct control of their charging; this allows the utilities to stop charging when the grid is reaching peak demand, engage charging when a valley emerges in grid demand, or even modulate the current to the vehicle for more fine-tune load-leveling.[46] While modulating the charging of an EV may be a novel concept, utilities have extensive experience providing dramatically reduced rates or incentives for participants, where the utility has the ability to interrupt specific load (e.g. water heaters) as necessary.[47]

Still in use today, many utilities offer direct load control options to their customers. A 2010 FERC survey reported that approximately 5.7 million residential utility customers in the United States participated in some form of direct load control program.[48] In a typical program, the utility offers a special off-peak rate to customers who are willing to install a second electric meter in their home, which is then connected only to one or more appliances, often including a water heater. Direct load control programs yield financial benefits for both ratepayers and utilities, while adding greater stability and efficiency to the grid. The industry is quite familiar with this and adopting a similar program for EVs would appear to be straightforward.

Vehicle to Home and Vehicle to Building

One potential advantage of time of use rates will be the ability of EV owners to feed energy to a home (V2H) or building (V2B) when demand is high. In these cases, EVs will actively shift load by charging when demand is low and discharging and supplementing building energy use when demand is high. The peak shaving aspect of V2B and V2H is especially advantageous for building owners subject to peak demand charges.[49] Establishing the infrastructure necessary to allow EVs to discharge energy safely to a home or building will also lay the groundwork enabling EVs to serve as backup power sources in times of emergency and power outages.[50]

Vermont

Utilities in the State of Vermont fall under the regulatory jurisdiction of the Vermont Public Service Board (PSB). For decades, PSB has mandated that utilities make time of use rates available for customers. They are voluntary programs and uptake is very limited, as many customers may not be aware of their existence nor understand how to benefit. However, if customers do wish to enroll in the time of use rates offered by their utility, details of the plans are available online.[51] A common perception held by those in the state who are interested in alternative rate structures like time of use is that they are overly complicated and that the benefits are minimal. For example, there may be variation by day of the week, multiple times of day, and seasonal adjustments for peak and off-peak rates requiring a level of attention for the customer that, given the minimal savings, does not seem worth the effort.

Technology Requirements

For the implementation of time of use rates, or indirect demand side management, little to no additional technology is required for the vehicles. Many EVs are currently equipped with the ability to delay the start of charging with an onboard timer or have the ability to remotely-control the start or end of charging.[52] Ford Motor Co. has even developed a mobile application with the ability to track the time of use rates of utilities and indicate when off-peak times start.[53]

However, metering is a key element for effective application of time of use rates.[54] One way in which this can be done is through Advanced Metering Infrastructure (AMI), often referred to as smart grid technology. The term smart grid is used to indicate the two-way flow of information between users, distributors, and producers of electricity. AMI can be used for sub-metering of EV charging times, enabling the appropriate rates to be applied. Vermont is in a unique position in that a statewide Smart Grid initiative has brought AMI to more than 90% of ratepayers in the state, including those served by Vermont Electric Cooperative (VEC), Green Mountain Power (GMP), Burlington Electric Department (BED), Washington Electric Cooperative (WEC), and Stowe Electric Department (SED).

For demand side management programs in which utilities are granted direct control of EV charging, the technological needs become more advanced. There is the potential for this to be accomplished through AMI, however, more advanced communication will likely be needed. Because the primary use of an EV is for transportation, owners will need some level of confidence that their vehicle will be charged when they need it for travel; they will need to be able to coordinate that information with the utility. A variety of technologies and communication systems are emerging, enabling EV charging controls, many of which use cellular connections for controlling charging.[55]

Major automakers appear to be leading this effort. OnStar has developed technology and a set of smart grid application programming interfaces (APIs) capable of managing demand response programs by connecting with the utilities' AMI technology. This technology is also able to communicate vehicle charging data to utilities, making it useful for metering for time of use rate programs.[56] In a project with TimberRock Energy Solutions, Inc., OnStar is demonstrating the ability of their software to start, stop, and modulate the amount of charge going to a fleet of Chevrolet Volts.[57] Additionally, Cadillac recently released the ELR with the OnStar smart grid capability built in.[58]

To expand the concept of controlled charging to a system where EVs provide energy to homes (V2H) or buildings (V2B) requires additional technology. Because energy will need to be discharged from the battery, a separate inverter is necessary to convert the DC power in the battery to AC electricity for the home or building.[59] Additionally, safety controls are necessary to prevent the backflow of energy to the grid.

While this technology is not currently available in the U.S., Nissan is offering devices capable of V2H and V2B in Japan. The Leaf-To-Home system enables EVs to discharge power to the home, supporting peak shaving, emergency power supply, and reducing the cost of electricity.[60, 61] Nissan is also field testing a V2B technology that will connect up to six Leafs to an office building, enabling their batteries to supplement the building's electricity consumption when it is most expensive. The system is designed such that regardless of the amount of power drawn from the vehicles, it ensures that the vehicles are fully charged by the end of the day for owners to drive home.[62]

Regulation and Policy Needs

With respect to demand side management programs, the technology needed is largely ready, although not widely used. To move these programs and systems forward, coordination between the utilities and Public Service Board (PSB), the auto manufacturers and software developers, and the Society of Automotive Engineers (SAE) in developing standards is critical.

While time of use rates are available in Vermont, few ratepayers are aware of this, and fewer take advantage of them (e.g. approximately 2% of Green Mountain Power ratepayers opt for time of use rates), and the value of participation is unclear. The PSB and utilities have the ability to incentivize efficient use of electricity and load shifting by promoting time of use rates to EV owners as well as taking EV charging into account when designing rate structures and demand response riders. Additionally, further investigation into the value of demand side management programs for utilities is necessary to ensure rates are designed appropriately and EV owners are compensated fairly.[63]

In developing technologies connecting the utility technology (AMI) with the telematics systems of EVs, auto manufacturers, software developers, and utilities must coordinate efforts to develop standards using open networks such as OpenADR. SAE has actively been creating recommended practices and standards for communications methods.[64,65]

To enable V2B and V2H technology to be implemented safely, codes and standards are needed for equipment and facilities. The PSB will need to work with other State agencies to ensure the safety of these systems.[66]

Finally, V2B and V2H technology involve the backflow of power out of the EV battery. EV warranties do not currently allow this. There is the risk that implementing such a system would result in voiding the battery warranty. Testing is required to assess the impact of this backflow on the battery, and warranties revised accordingly. Because V2B and V2H require additional technological and regulatory barriers to be addressed, it is expected and suggested that time of use rates and controlled charging programs will be approached first.

Potential Value

Managing EV load will be very beneficial to utilities. In addition to providing new demand and additional revenue, EVs also present demand that is flexible and potentially controllable. Utilities can benefit by taking advantage of this to smooth load by filling valleys, allowing more efficient use of existing infrastructure and deferring upgrades to the distribution system. Recognizing and quantifying this benefit to utilities is critical to ensure the value is passed on to ratepayers in general, but specifically to EV owners in the form of reduced rates.

While there are currently no EV specific rates available in Vermont, time of use rates and a rate tariff for controlled water heating service provide examples of the savings potential from variable rates.

Table 1 below presents three potential scenarios for the additional monthly cost of charging an EV, assuming an increased demand of 250 kWh per month.[67] Under the flat rate example, this additional electricity will cost $40.13 per month. If peak/off-peak time of use rates are used, this cost will drop to $25.53. However, this plan applies to a household's entire energy use, so all energy used during peak times will be more expensive, and all energy used at off-peak times, not just the EV charging, will be less expensive. Therefore, while the cost of EV charging is reduced, it is unclear how the remainder of the household's energy costs will be impacted. It is likely that this would be perceived as too complicated and not likely worth the risk for many EV owners. In the final scenario, a rate is considered that is currently applied to water heaters, specifically those that are put under the direct control of the utility to interrupt if need be. In this rate, customers receive a dramatically reduced rate, specifically applying only to the water heater. This is directly comparable to how an EV rate could work, where the utility is given the ability to interrupt charging if demand rises too high. In this scenario, the energy cost for EV charging is slightly more than the time of use rate, due to an additional daily base rate for additional metering, but because the balance of the home's energy remains under the standard, flat rate, there is less variability and fewer unknowns for customers.

In order to incentivize EV owners to take advantage of the variable rate and ensure that charging will occur primarily at off peak times, the variable rate needs to present enough opportunity above the standard rate that it appears worthwhile. In these example rates, the water heater rate plan, allowing for interrupted service if needed, presents a significant enough difference over the flat rate that EV owners would likely participate and adjust their charging to off-peak times. The basic peak, off-peak time of use rate, applied to a household's entire energy consumption however, would not likely incentivize EV owners to participate and manage their charging. The higher peak rate applied to all energy use, not separating out EV charging, appears too risky and not worthwhile.

Table 1: Hypothetical EV Electric Use under Various Rate Structures

Example	Rate Type	Rate Structure	Average Monthly Additional Electric Cost due to EV Charging
Green Mountain Power Residential Service Plan[68]	**Standard, flat rate**	**$0.436 per day +** **14.959 cents/kWh +** **$0.01091 / kWh** **Energy Efficiency Charge**	= (0.14959 * 250[i]) + (0.01091 * 250) **= $40.13 / month**
Green Mountain Power Residential Time-of-Day Service Plan[69]	**Peak/off-peak time of use rate**	**$0.544 per day +** **17.599 cents/kWh peak** **7.823 cents/kWh off-peak +** **$0.01091 / kWh** **Energy Efficiency Charge**	= [(0.544-0.436)[ii] * 30] + (0.07823[iii] * 250[i]) + (0.01091 * 250) **= $25.53 / month**[iv]
Green Mountain Power Controlled Water Heating Service[70]	**Interruptible load rate**	**$0.267 per day +** **6.502 cents/kWh +** **$0.01091 / kWh** **Energy Efficiency Charge**	= (0.267 * 30)[v] + (0.06502 * 250[i]) + (0.01091 * 250) **= $26.99 / month**

i. Assumes 250 kWh / month electric use for EV charging[71]
ii. Increased base rate above standard residential rate is added
iii. When available, off-peak rate is used for all charging
iv. There is the potential that the increased rates during peak times could in fact cause overall electric costs to increase. For the purposes of this example, it is assumed that the increased peak rates and decreased off-peak rates will balance for customers' residential electric use.
v. Additional base load for interruptible load rate structure in addition to standard, residential base payment

2.2 WHOLESALE ANCILLARY SERVICE REGULATION MARKET RESOURCES

As EV adoption increases and interaction with the utilities evolves, the next logical step is for EVs to be aggregated to serve as resources in the wholesale markets. As discussed above, the RTO/ISO ancillary service markets provide the most near-term potential for this. Both operating reserves and regulation markets are potentially good fits for EVs. However, because most research to date has been on EVs serving as resources in the regulation market, this will likely be the opportunity with fewer near-term barriers, and therefore, the focus of this section.

Regulation is a service that maintains the Area Control Error (ACE)—the balance between load, generation, imports, and exports—within a specified tolerance of zero on average over a ten minute period. Minute-by-minute fluctuations in demand cause the ACE to dip below and rise above zero, requiring injection or withdrawal of power to maintain balance within the acceptable range.[72] The RTO/ISO sends out dispatch instructions to regulation resources to increase or decrease power to the grid. Resources are expected to accurately respond to these signals instantaneously by either increasing or decreasing generation.[73]

V1G and V2G

The charging and discharging of a battery is able to be adjusted quickly and accurately making EVs attractive resources in regulation markets through bi-directional charging of their battery system. Through bi-directional charging (V2G), EVs are able to quickly inject and withdraw small amounts of power to and from the grid.

However, this same function can also be accomplished through uni-directional charging by modulating the charge of EVs (V1G, also referred to as V2G half). Curtailing load (reducing charging) provides the same services as ramping up generation: it provides balance when electricity demand exceeds supply. Conversely, increasing load (increasing charging) has the same impact as ramping down generation: it provides balance when supply exceeds demand.[74] However, with uni-directional regulation, the availability for the resource to participate will be limited by the size of the battery and state of charge. In other words, with V2G regulation, the state of charge of the battery remains relatively constant with only slight charges and discharges; with V1G, the battery will eventually be fully charged and unable to provide further regulation.

ISO-NE

In ISO-NE, economic dispatch occurs every five minutes, whereas some RTOs/ISOs dispatch hourly, indicating that generation and demand are kept in balance on a frequent, regular basis. This results in relatively small regulation needs and a small regulation market.[75] The implication of this, as will be discussed below, is that the price for regulation services in ISO-NE is relatively low when compared to other RTOs/ISOs.

To participate in a regulation market currently, resources must bid into the market on an hourly basis. All resources are stacked in the order of their bid price, and resources are selected starting with the least expensive resource up to the point where the needed resource quantity is met. All resources are then compensated at the price of the final bid accepted, the Regulation Clearing Price (RCP).[76]

Traditionally, regulation services have tended to be provided by natural gas generators and storage hydro resources. In 2007, FERC issued Order 890 regarding non-generating resources providing regulation services. ISO-NE established an Alternative Technology Regulation (ATR) Pilot Program in response. The goal of the Pilot Program was to allow alternative technologies (e.g. batteries, flywheels, demand response) to provide regulation services, enabling ISO-NE and the owners of the ATR resources to evaluate the economic feasibility and implications of their participation in the regulation market.[77] ATR resources participated in the regulation market on a self-scheduled basis (they were not required to bid into the market) and were compensated at the RCP.[78]

In 2011, FERC issued Order 755 which found that compensation methods were "unjust, unreasonable, and unduly discriminatory" towards non-generating resources in regulation markets.[79] RTOs/ISOs were required to establish a two-part payment method for regulation services that enabled resources to be compensated both for capacity (being available to provide regulation services) and mileage (actual performance providing service).[80] However, prior to Order 755, ISO-NE was already implementing a regulation payment system including capacity and mileage payments similar to what FERC was requiring. While some modifications were necessary to make ISO-NE's payment structure compliant with the FERC order, much of the basic structure remained largely unchanged.[81]

These changes have been made, and in May 2014 the ATR Pilot Program will be ending. At that point, ATR resources will participate in the full regulation market now compliant with FERC Order 755.[82] With ISO-NE's experience gained in the ATR Pilot Project and with a payment structure in place awarding both capacity and mileage, this market presents opportunity for EVs to serve as regulation resources.

Additionally, some RTOs/ISOs require that regulation resources be able to provide bi-directional interaction with the grid, and some require resources to provide equal amounts of regulation up and regulation down service.[83] In ISO-NE, this is not the case. When bidding into the regulation market, resources provide a high and low limit representing the range in which they can provide regulation. When resources are dispatched, ISO-NE actually sends specific instructions. Rather than a broad dispatch signal to inject or withdraw, ISO-NE indicates specifically to what power levels resources should adjust. Therefore, this range could be entirely negative allowing both regulation up and regulation down to be provided through uni-directional, modulated charging.[84]

Technology Requirements

While the market structure is in place for EVs to participate in the ISO-NE Regulation Market, the technological needs are substantial.

Aggregation

ISO-NE requires a minimum resource size of 1 MW for participation in the regulation market.[85] Therefore, one critical technological component of EVs providing regulation services is aggregation. For example, at an average power rating for the Chevrolet Volt of 3.3 kW, it would take over 300 vehicles to provide the minimum resource size. The number of vehicles needed to aggregate a 1 MW resource varies by numerous factors, but the most important is the power level. The power level is determined by either the charger (onboard or off-board) or the EVSE connection, whichever is weaker. Table 2 below illustrates this variation by multiple vehicle types and connection levels. Because many factors (such as vehicle availability and state of charge) impact the number of vehicles needed, this is intended to show the magnitude and variation of aggregation needs, rather than to present specific numbers. Approaches to vehicle aggregation are discussed below as well as the technological needs for each.

Table 2: Vehicles Needed for Minimum Resource Size

Vehicles	Connection Level	Power Level (kW)	Number of EVs Needed
Average EVs currently on the road	**Level 1**	**1.4**	**715**
Average EVs currently on the road	**Level 2**	**3.6**	**278**
Higher power EVs becoming available	**Level 2**	**6.6**	**152**
EVs retrofitted with more powerful charger	**Level 2**	**15**	**67**
Electric school buses (or other large vehicles) retrofitted with high power charger	**DC Fast Charging**	**60**	**17**

Aggregation of Vehicles vs. Aggregation of EVSE

One distinction to be made regarding aggregation is what specifically is being aggregated. Aggregation can be of EVs or EVSE. If EVs are aggregated, the vehicles will communicate with the aggregator and the location of charging does not matter. If EVSE is aggregated, the aggregator dispatches the equipment, and the specific vehicle connected is less relevant. This distinction is important because it largely determines where the intelligence (controls and communication technology) needs to be located.[86]

In either case, technology is needed to combine the multiple resources (either EVs or EVSE) into what appears to be a single 1 MW resource to the ISO. This technology will be the point of contact with the ISO, receiving the dispatch signals as well as the point at which the ISO monitors the accuracy of regulation performance. Additionally, the aggregation technology will be responsible for dispatching vehicles in response to the signals from the ISO. Once a signal is received from the ISO, the software will need to process the vehicles available, their state of charge, the schedule of each vehicle (i.e. the level of charge needed at what time), and be able to control the charging (or discharging) of each vehicle.

Fleet Aggregation vs. Geographically Dispersed Aggregation

In addition to questions of what is being aggregated (EVs or EVSE), aggregation also needs to address where vehicles (or EVSE) are located. In one case, vehicles can all be in one location, sharing one meter, as in a centrally located fleet setting. Alternatively, there is the potential to aggregate geographically dispersed vehicles, such as individually owned EVs at owners' residences.

Aggregation of fleets involves fewer technological barriers. Because vehicles are parked together, metering requirements are not necessary for each vehicle, but rather for the fleet as a whole.[87] Alternatively, when vehicles are geographically dispersed, aggregation technology would be required to determine how to combine vehicles behind multiple meters into one measureable resource to the ISO.

Because the focus of most pilots thus far has been in fleet settings where vehicles are behind one meter, the technology for aggregating geographically dispersed vehicles requires further development.

Communication and Metering

When aggregating multiple EVs or EVSE into one resource, communication and metering technology is also integral. ISO-NE has a set of communication requirements for all regulation resources enabling the communication of dispatch instructions and monitoring of regulation performance. These requirements will need to be met and tied into aggregation technology to form a system such that ISO-NE is able to send dispatch instructions. The aggregation software then dispatches vehicles or EVSE as appropriate, and then ISO-NE is able to monitor and measure the resource's performance. ISO-NE has acknowledged the development work necessary to enhance their market systems and real-time dispatch to effectively integrate storage resources.[88]

Additionally, if vehicles are owned by individuals, on-board metering of performance will be necessary for compensation to each owner[89]

Bi-directional Energy Flow

As previously discussed, current EVs are equipped with a charger that functions in one direction: inverting AC power from the grid to DC power to be stored in the battery. To provide bi-directional regulation services, an additional inverter is necessary to invert DC power from the battery back to AC power. Retrofitted vehicles used in pilot projects (discussed later) show this is possible onboard,[90] while the Nissan devices available in Japan show the potential for this off-board.[91, 92] Additionally, DC Fast Charging EVSE is capable of this bi-directional inversion. As discussed with the V2H and V2B examples though, concerns exist to the impact of the additional battery cycling and the implications for the battery warranty. However, nearly a year ago, Dr. Willett Kempton of the University of Delaware indicated that multiple car companies have expressed interest in developing vehicles equipped with bi-directional capabilities.[93] Because ISO-NE's regulation market does not require bi-directional power exchange of its regulation resources, this technological issue does not present an immediate barrier in Vermont.

Regulation and Policy Needs

Many of the regulation and policy needs for EVs to provide regulation services are similar to those needed for demand side management and utility-level vehicle integration. Stakeholders, including utilities and PSB, auto manufacturers and software developers, the SAE—and and in the case of wholesale market participation, ISO-NE and FERC—need to coordinate and agree upon the development of standards for communications, technology, and equipment.

Additionally, integration with the ISO-NE wholesale markets and the need for high levels of vehicle aggregation present additional challenges. The technological needs vary depending on the structure of aggregation, and regulators and stakeholders will need to address the questions determining the structure. Specifically, how will these resources be aggregated?

Aggregation Models

FLEET

One potential model for aggregation is to define the resource as a fleet of vehicles (and EVSE) with one owner. While this approach simplifies many technological points, it also limits participation. Complexity is significantly reduced in that all vehicles are managed by one person or entity (i.e. fleet manager) and vehicle schedules are largely known and often fixed.[94] This model, however, does not allow for the participation of individually owned EVs.

UTILITY AGGREGATION

A second approach to vehicle aggregation is for geographically dispersed vehicles (or EVSE) to be aggregated by a utility.[95, 96] In this approach, the utility would act as the market participant with ISO-NE and enroll customers to participate. An appealing aspect of this approach is that many necessary communication and technology components are already in place between the utilities and ISO-NE (e.g. utilities participate in ISO-NE wholesale markets) as well as between the utilities and customers (e.g. AMI).

INDEPENDENT THIRD PARTY AGGREGATION

A third approach to aggregation is for an independent third party to act as the ISO-NE market participant and coordinator of EV dispatch. Various entities such as auto manufacturers making use of onboard telematics, cellular providers with communications expertise, or existing demand service providers may be interested in playing this role.[97]

To enable a GIV system to move forward in which EVs are serving as resources in wholesale markets, regulators, ISO-NE, utilities, and other stakeholders will need to make decisions about how these systems should be structured to clarify ownership and participation. A clearly defined program in which customers understand what they are signing up for and how they benefit from participating will be necessary. Research and pilot testing will also be critical in determining interest and level of participation. Because the number of vehicles necessary to meet the 1 MW market requirement is a critical determinant of the benefits realized, level of participation or time available to serve in the regulation market will be an important component to understand.

Interconnection and Settlement

While determining an aggregation model will provide some clarity, details regarding interconnection and settlement will also need to be established. EVs serving as regulation resources present a unique challenge in that they are simultaneously a retail customer and a wholesale resource or market participant.[98] Again, ISO-NE (and FERC) and the utilities (and PSB) will need to work through the details of how this system can be structured and managed.

Potential Value

Because there are significantly fewer barriers to realizing the benefits of EVs serving as a regulation resource through V1G rather than V2G, this presents the best entrance into the regional grid wholesale markets. To assess the value of this, many factors must be considered.

First, the Regulation Clearing Price (RCP) will impact the level of benefits realized from participation as a regulation resource. As mentioned above, the regulation needs in ISO-NE are relatively small (currently averaging 60-65 MW[99]) due the frequent nature of energy dispatch. This results in a lower RCP than in many RTOs/ISOs. However, the RCP varies considerably,[100] and it is currently unknown the potential impact the new FERC compliant market structure will have on the RCP.[101]

Next, the number of vehicles needed to meet the 1 MW minimum resource size is an important determinant of the value of the service in that it determines the number of vehicles splitting the benefits. One significant factor impacting the number of vehicles needed is the power level of the EV or the EVSE. As shown above in Table 2, this is the primary factor dictating the number of vehicles needed. High-power connections are critical in realizing adequate benefits to justify the costs of participation in the market, as this will largely dictate the number of vehicles needed. Additionally, the level of participation of each vehicle is important. If vehicles are not participating in the market 24 hours per day, either more vehicles are needed to maintain a constant bid, or the resource cannot be bid into the market 24 hours per day. Also, because uni-directional, modulated charging is suggested, the state-of-charge of vehicles impacts the amount of time vehicles are available to participate. With modulated charging, vehicles do not discharge energy, and therefore, will not be available to provide regulation services once full.

Table 3 below presents potential benefits from EVs serving as regulation resources. Because RCPs can vary so substantially, a range of values is presented. The first two scenarios present illustrative configurations while the third example outlines the values actually realized in a demonstration project. These examples show the significant impact of the number of vehicles needed as well as the RCP in the final benefits. When individual vehicles with low power connections are aggregated, over 400 vehicles are needed, and with a low RCP, benefits can be as little as $5/month. However, if high power batteries with high power connections are used, as in the example of electric school buses, high RCPs could lead to monthly regulation service payments of approximately $672 per vehicle. However, values this high have not previously been suggested in any pilot projects or modeling efforts. In a demonstration project conducted by researchers at the University of Delaware, 15 vehicles retrofitted with high power chargers (18 kW) provided regulation services in PJM's ancillary service market and received approximately $150 per vehicle in one month.

Table 3: Potential Regulation Resource Values

Scenario	Level of Participation and Configuration	Regulation Clearing Price ($/MWh)	Monthly Benefit per Vehicle
Illustrative Examples			
Individual vehicles, connected through Level 2 EVSE, aggregated through third party	**1 MW resource, 3.6 kW connection, 50% participation rate[i] (360 hrs/month), 417 vehicles[ii]**	**$6.74 - $46.66[iii]**	**$5 - $40 / month**
Electric school buses, connected through Fast charging EVSE, aggregated through fleet management	**1 MW resource, 60 kW chargers, 50% participation rate[i] (360 hrs/month), 25 vehicles[ii]**	**$6.74 - $46.66[iii]**	**$97 - $672 / month**
Demonstration Findings			
University of Delaware PJM Regulation pilot project [102,103]	**100 kW resource, 18 kW chargers, 15 vehicles**	**$31.64[iv]**	**$150 / month**

i. A 50 percent participation rate was assumed to account for the fact that with uni-direction charging, the vehicle's state of charge is important, and vehicles will not be available to charge at all times.
ii. A multiplier of 1.5 was used to calculate the number of vehicles needed to account for the fact that not all vehicles will be able to participate at any given time due to state of charge, competing needs, and for any additional reasons.
iii. Range of regulation clearing prices was determined from 2012 – 2013 average values for ISO-NE's Regulation Market. [104,105]
iv. Average PJM Regulation Clearing Price for March, 2013. [106]

While in many cases, these benefits are significant enough to offset the cost differential between internal combustion engines and EVs, there are many costs associated with GIV that are not accounted for here. Logistical and administrative costs of establishing and maintaining a system of aggregated EVs, the costs of bidding into the ISO-NE markets, as well as the capital costs for technology and hardware are likely quite significant, and currently, largely unknown. Additionally, there are concerns about battery degradation resulting from additional cycling. However, using EVs as regulation resources through modulated charging should alleviate this concern, as additional wear is not put on the batteries.

Due to the complexity and costs of aggregation, regulation will likely hold the greatest potential for centrally dispatched fleets. With a single owner and fleet management already established, logistical and administrative costs will be reduced, and having all vehicles in one location will remove the need for geographic aggregation. Additionally, because the schedules of fleet vehicles are largely known and fixed, the challenge and cost of scheduling charging times is reduced.

While fleet aggregated vehicles serving as regulation resources by providing uni-directional modulated charging presents a potential entrance into the wholesale ancillary services markets, it is likely to be only a marginally profitable, long-term system. There is the potential that regulation requirements will increase as penetration levels of wind and solar resources increase; but many sources suggest that the markets for regulation services are small and likely to be saturated relatively quickly.[107] This is especially likely in ISO-NE due to the very small regulation needs.[108] Regulation therefore provides a good opportunity to establish EVs as a resource in the wholesale markets, but additional markets and opportunities, such as serving as operating reserve resources or enabling greater integration of renewable energy and participation in capacity markets, will need to be established for long term growth in value and demand for EVs as grid resources.

2.3 A FULLY INTEGRATED SYSTEM AND THE FORWARD CAPACITY MARKET

While participating in demand side management programs at the utility level and serving as regulation resources in wholesale ancillary service markets are good first steps in understanding EVs' roles as grid resources, ultimately, a comprehensive approach to GIV could lead to much more substantial benefits. When EVs are fully integrated and acting as flexible storage resources, they can contribute to a more reliable, resilient, and sustainable grid in which generation and demand are ultimately decoupled. This will allow greater integration of renewable resources, enable more efficient use of existing resources, and potentially enable EVs to participate in other wholesale markets such as the ISO-NE Forward Capacity Market.

The intermittent nature of renewable energy resources like wind or solar photovoltaic power present obstacles to full displacement of conventional energy generation sources like coal- or gas-fired turbine generators.[109] A proposed solution to the intermittency problem has been provision of energy storage such as pumped hydroelectricity, flywheels, thermal storage, or electrochemical batteries.[110] Regardless of the method, when renewable energy production surpasses demand at a given moment, excess electricity is stored and made available later when renewable energy generation is lower than demand, effectively decoupling demand and generation.[111]

Energy storage is not without complications. While from a technical perspective, additional storage does help maintain balance and stability on the grid, the high capital and operational costs relative to existing generation infrastructure make electrical storage economically challenging in the current market.[112] As battery technology evolves and EVs grow in market share, there is an opportunity to overcome these barriers. Currently, the primary use of an EV is as a mobility resource, and the batteries within the EV could serve a secondary role as electrical storage. It may be possible at a later date to consider the electrical storage as the primary use and the mobility resources of an EV as a secondary role. When aggregated at scale, a fleet or community of EVs while plugged in and not in use for mobility may serve as a balancing resource, compensating for the intermittency of renewable energy sources. In fact, when controlled charging is used to manage EV charging schedules, the estimated cost of integrating these vehicles is cut in half and the magnitude of savings is higher with a higher penetration of wind in the system.[113]

While there is not an obvious market in which EVs can sell their storage resources, rather than trying to modify markets, it can be instructional to consider existing markets, what they will pay for, and how EVs can provide that.[114] The ISO-NE Forward Capacity Market (FCM) provides one such illustration. In the ISO-NE FCM, guarantees are auctioned for the provision of grid resources to meet peak demand anticipated up to three years in advance. Future income is then assured, providing investment security so that these grid resources can be constructed in time to meet the need.[115] Demand side resources—energy efficiency, demand response, and distributed generation—are eligible to participate in the FCM along with generation.[116] In these cases, guarantees are bid into the FCM to reduce peak demand at a given point in future. Demand response projects require reduction of demand at times of critical peak; efficiency and distributed generation, which may lower the entire load curve, also result in decreased demand at peak.[117] Under this characterization, it is feasible that a third-party aggregator could coordinate the use of EVs as storage for distributed renewable resources and enter bids for the guarantee of EV storage in the form of distributed generation. Under such a scenario, a guarantee of future revenues could support the establishment of the aggregation system and the necessary technology, and any incremental revenue from the market can be passed on to subscribers as compensation.

In a period of a rapidly evolving energy systems—increasing amounts of distributed generation, integration of renewables, demand side resources, advanced metering infrastructure—as changes and restructuring occurs, it is important to ensure that EVs are part of the discussion. It is difficult to determine how market structures may change in this evolving system, but it is likely that storage will play a large role. As EV penetration rates increase, an aggregated system of EV battery storage could have significant value and benefit. Technology, standards, and regulation are all needed to enable and encourage the widespread adoption of electric vehicles, but a vision for a sustainable, renewably sourced electric grid in which EVs serve as valuable storage resources fully integrated into the grid's wholesale markets is possible. Demonstration and pilot projects around the country are beginning to show the first steps in this direction.

3. State of the Art: Grid-Integrated Vehicle Pilot Projects

Although still a new concept, with the first successful demonstration of GIV technology using a single vehicle in 2007,[118] multiple demonstration projects are beginning to show proof of concept, fleet scale pilot projects are being established, and the benefits of such a system are beginning to be evaluated.

3.1 UNIVERSITY OF DELAWARE

The pioneering GIV work took place at the University of Delaware with Dr. Willett Kempton and Dr. Steven Letendre, first introducing the concept in 1997 in their paper, *Electric vehicles as a new source of power for electric utilities*.[119] Since then, through various projects funded by Pepco Holdings, Inc., the California Air Resource Board, the LA Department of Water and Power, the Delaware Green Energy Fund, and Google.org, the researchers have continued to advance the state of the art, culminating with the public demonstration of a retrofitted EV interconnected to the PJM grid acting as a regulation resource in 2007.[120] In 2011, a group of University of Delaware researchers teamed up with NRG Energy, a large generator of electricity headquartered in New Jersey,[121] for a joint venture exploring the commercial potential of the V2G technology.[122]

Around this time, BMW and EV Grid provided 30 Mini E vehicles to the University's research. While typical EVs currently have chargers that run in one direction, inverting AC power from the grid to DC power to be stored in the battery at a power level of approximately 3 kW, these vehicles were retrofitted with AC Propulsion 18-kilowatt bi-directional chargers.[123, 124] With standards compliance and RTO and utility approvals, the project's resource officially became a participant in PJM's regulation market in February 2013.[125, 126]

Participating in the hour-ahead regulation market with a 100 kW resource of 15 vehicles aggregated together, the vehicles began providing regulation services, and for the month of March, receiving approximately $5 per day per car.[127] With the added vehicle electronics enabling V2G costs of about $400 per vehicle, the $1,800 per year regulation payment seems potentially cost effective.[128]

Plans to expand this pilot project include adding additional vehicles and adjusting the schedules such that the vehicles are not plugged in at all times.[129] BMW has produced 600 EVs with bi-directional chargers and has donated additional Mini Es to further the V2G development.[130] Honda has also joined the effort and has developed a 2014 Honda Accord Plug-In Hybrid equipped with a bi-directional charger as well as an additional communication device allowing for controlled charging and discharging in response to RTO/ISO regulation signals.[131]

3.2 DEPARTMENT OF DEFENSE

As one of the country's largest consumers of energy, the Department of Defense (DOD) is under various mandates to reduce dependence on foreign oil and greenhouse gas emissions. After years of research, the DOD is now investing $17 million to test if EVs can prove to be a cost-effective means of reaching this goal. Specifically, the economic benefits of providing ancillary services to the grid is being piloted and evaluated.[132, 133, 134, 135]

Seventy two V2G equipped non-tactical vehicles will be tested at four pilot locations (LA Air Force Base, California; Joint Base Andrews, Maryland; Fort Hood Army Base, Texas; and Joint Base McGuire-Dix-Lakehurst, New Jersey).[136, 137, 138] As of March 2014, installation is underway and ramping up.[139]

L.A. Air Force Base will focus specifically on serving as a resource in California ISO (CAISO) Regulation Up and Regulation Down markets. Being the first installation, many of the technological developments for the DOD V2G system are being implemented for the first time. Specifically, three technologies have been developed and are being tested to form the PEV Fleet Optimization Model. A software suite is providing aggregation and fleet management of charging and discharging; OpenADR is the technology being used for communication between CAISO and the base; and a near real-time optimization tool is being used to evaluate energy and ancillary service prices to ideally schedule services. These technologies will be used to coordinate the complex task of optimally scheduling vehicles taking into account vehicle needs for transportation, energy costs, and ancillary service market prices simultaneously.[140]

The L.A. Air Force Base has also encountered many challenges and difficulties through the various stages of installation. One interesting challenge is the need for regulatory and policy coordination enabling GIV systems. The base is struggling to work out the details of being a retail customer in Southern California Edison (SCE) territory while simultaneously serving as a resource in the CAISO wholesale market. Addressing this requires "participation and approval by several institutions, the AF and DoD, SCE and its regulator the California Public Utilities Commission, CAISO and its regulator the Federal Energy Regulatory Commission (FERC)."[141] This pilot project, while laying the ground work for future projects in CAISO, identifies the need for pilot projects in other regional grids to work through similar issues.

Ultimately, budget is one of the most critical considerations to the DOD pilot projects, and costs are being carefully evaluated before moving on through each step of the projects.[142] Interestingly, costs are considered largely unknown, and the pilot project locations were strategically selected to take place under different utility markets and structures to assess how costs will vary.[143, 144] Vehicle and EVSE procurements are anticipated to be completed in April 2014.[145]

3.3 FORT CARSON

In addition to the four pilot projects focused on EVs providing ancillary services, the Department of Defense is also participating in another ground breaking project involving electric vehicles and GIV technology. Fort Carson Army Post in Colorado Springs is the site of a demonstration focused on new energy technologies and microgrid development on military bases as part of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) project, led by the U.S. Army Corps of Engineers Omaha District.[146] The goals of the project include integration of renewables, reduction of fuel consumption, and increased security by developing a microgrid capable of being islanded, or completely disconnected from the local grid, if need be.[147]

One interesting aspect of the Fort Carson pilot project and the SPIDERS project overall, is the focus on microgrid development and the concept of islanding. Islanding occurs when the microgrid supports the load and continues to provide power when completely disconnected from the utility grid. Safety throughout the system, including for electric repair crews, is critical when connecting and disconnecting from the utility grid.[148] Lessons learned from grid islanding, especially with regard to safety, will be applicable to V2H and V2B systems.

In addition to microgrid support and providing backup power, a fleet of bi-directional EVs and EVSE are being used for regulation and peak shaving to earn money when not in use for transportation.[149] At 60 kW charge and discharge, the SPIDERS installation is the most powerful GIV demonstration to date[150] using five SAE J1772 bi-directional DC fast chargers and SAE compliant J1772 Conductive Charge Couplers for the first time.[151,152,153]

Aggregation, a critical component of the SPIDERS installation, provides a single point of contact to the grid and receives signals from the grid operator; however unique to Fort Carson, EVSE is aggregated rather than vehicles. This means that control intelligence and the inverter (charger) are located in the supply equipment. The aggregation software manages the schedules of the vehicles, ensures they are ready when needed, but sends dispatch instructions to the EVSE rather than to the vehicles. Software developed by MIT Lincoln Labs, determines optimal times for using renewables and EVs for peak shaving and sends instructions to the microgrid controller to be coordinated with the aggregator.[154]

The Fort Carson demonstration highlights two major developments in the state of GIV: the first application of SAE compliant J1772 DC EVSE and connectors, and the highest power charge and discharge demonstrated to date using DC EVSE.[155]

4. Recommendations and Future Research

While the idea of a fully integrated system in which EVs play a critical role in providing much needed storage to the grid, contribute to load flattening, participate in wholesale markets, and enable the integration of renewables may seem to be a distant reality, there are steps we can take now to begin in that direction. By focusing on benefits and services which present the fewest barriers first, we will have the ability to approach the advancement of GIV incrementally and strategically.

EV Rates. To ensure the additional load created by EV adoption is not detrimental to the grid and existing distribution infrastructure, efforts must be made to establish the additional demand as a manageable load. EV owners must be made aware of time of use rates, and regulators and utilities should consider specific EV rates that are simple to understand and beneficial enough to incent participation when designing rate structures and developing demand response riders. Specifically, the PSB will need to convene and lead this effort. The extensive implementation of smart grid infrastructure is a unique asset in Vermont and its applications should be considered.

Coordination of Participants and Stakeholders. For a full GIV system to be realized, FERC and ISO-NE, state regulators, utilities, auto manufacturers, management system software developers, and EV owners will all need to be part of the conversation. A GIV framework and model, as well as a roadmap to realize it, need to be developed for Vermont, and all stakeholders need to be actively involved in this process. Consideration of best business models, private sector infrastructure, actors, roles, and regulatory issues must all be addressed through stakeholder engagement.

Standardization. To ensure safety and compatibility throughout a GIV system, standards must be developed and adopted for communication, physical interfaces, technology, control equipment, power conversion, and facilities. The SAE has largely led this effort, but many organizations will contribute, including the Underwriters Laboratories, Inc., National Fire Protection Association, Institute of Electrical and Electronics Engineers, International Code Council, National Electrical Contractors Association, National Electrical Manufacturers Association, and Alliance for Telecommunications Industry Solutions.[156] Auto manufacturers, software developers, and utilities must coordinate efforts to ensure compliance with developed standards—communication throughout the standards process with regulators will be essential.

Cost-Benefit Analyses. As GIV benefits and services evolve, cost-benefit analyses must play an important role in decision making. Values of GIV benefits as well as the costs are largely unknown, and must be determined and considered as technologies are developed, systems evolve, and pilot projects expand. Demonstration projects will aid in uncovering and determining the value of costs and benefits.

Demonstration. With such high levels of complexity, varying stakeholder roles, and regional differences in utility and grid operations, standardization of GIV systems is a challenge. Market structures and energy dispatch vary from one ISO or RTO to the next, and the roles of utilities vary both within and between ISOs and RTOs. All of these factors will impact vehicle-to-grid interactions and the role EVs play within the electrical power system. As noted in the pilot project at the L.A. Air Force Base, addressing the unexpected and unforeseen complications has proven to be a significant task. It is not possible to identify all of these complexities without going through the process of creating a GIV project. A demonstration project in ISO-NE, specifically in Vermont, will begin to help uncover the intricacies of a system in this region.

EVs as part of the Conversation. We are in a period of a rapidly evolving energy systems—increasing amounts of distributed generation, integration of renewables, demand side resources, advanced metering infrastructure—and as changes and restructuring occurs, it is important to ensure that EVs are part of the discussion. Regulators, RTOs and ISOs, and utilities must all be aware of the potential role EVs can play in contributing to grid reliability and resilience.

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