A Perspective on Reverse Flow

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Types of Reverse Flow

SAE J2836-3 defines four types of reverse flow: Vehicle to Grid (V2G), Vehicle to Home (V2H), Vehicle to Load (V2L), and Vehicle to Vehicle (V2V). V2H, V2L, and V2V are used exclusively for reverse flow from a vehicle to a home, a load, or another vehicle and no connection to the power grid is allowed for any of these modes. V2G is really about bidirectional flow and not just reverse flow. Also, it is the only mode that allows a vehicle to return power to a home, business, or charge station which is actively connected to the grid.

Power Conversion Basics

AC power is generated from a DC source, such as a traction battery, using a device called an ***inverter.*** The inverter can be either a source of voltage or of current. If the inverter is not connected to a power grid, it must set the frequency and act as a voltage source for the isolated system. The current flow and power consumption are determined by the loads. This capability is used for V2H, V2L, and V2V modes.

If the inverter is connected to the grid, the grid is very stiff and it sets the frequency and the system voltage. A ***grid-tied inverter*** must be synchronized with the grid frequency and it must be a current source. If there is a power failure the inverter must either automatically turn off or cause the house to disconnect from the grid. This is for the safety of workers that may be repairing downed lines. The now isolated vehicle must switch inverter mode and set the frequency and voltage for the islanded home. Grid-tied inverters for PV solar systems have this dual mode capability. These inverters must conform to the Underwriters Laboratories Inc., "UL Standard for Safety for Inverters, Converters, Controllers and Interconnection Systems Equipment for Use with Distributed Energy Resources," ***UL 1741***. The system must also comply with the "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," ***IEEE 1547***.

A ***bidirectional converter*** is the term used for a device that can convert from AC to DC in one direction to serve as a battery charger and then be capable of being reversed and convert from DC to AC in the other direction to serve as an inverter. The device needs to be able to act as either a voltage source or a current source when providing AC power.

The power conversion electronics can be located in the vehicle or in an external unit. PEVs all provide an on-board charger to support AC L1 and AC L2 charging. An external charger (AC to DC converter) is used for DC charging. Some vehicles may include a dedicated inverter to supply external loads.

Essential Reverse Flow Capability for V2L and V2V

Every PEV should provide at least one vehicle mounted 120 VAC, 20 Amp, GFCI protected NEMA 5-20 receptacle that can be used to plug in tools, vacuums, or other appliances (V2L) and can be used with the AC L1 cordset for charging another vehicle (V2V). This capability is sometimes provided on a conventional vehicle. The power conversion could be performed by a dedicated inverter or by using a bidirectional converter in place of the on-board charger. The inverter should be capable of sourcing at least 16 Amps at 120 VAC. This will provide all vehicles with the basic capability to "jump" another vehicle (V2V) using the standard AC L1 cordset. This is the most practical and low cost way of providing V2L and V2V capability. The inverter should be energized using a dedicated power switch in the vehicle. No special communications are required.

Enhanced Exportable Power for V2L and V2H

A PEV may elect to provide more than one NEMA 5-20 receptacle. It may also be desired to generate and provide access to 240 VAC power. NEMA 14-30 or NEMA 14L-30 receptacles are often provided on portable generators for this purpose. This AC power could be generated using a dedicated 240 VAC inverter or by using a bidirectional converter in place of the on-board charger. The 240 VAC service could be hooked up to a home power port to provide a limited emergency backup capability (V2H). No special communications are required. ***NEMA receptacles cannot be used for V2G applications because these will require bidirectional flow.***

Exportable Power for V2L using the SAE J1772™ Connection

Reverse power could be flowed back from the vehicle SAE J1772™ receptacle that is normally used for charging. A vehicle bidirectional converter could be used to generate 240 VAC power or DC power could be provided to an external inverter or bidirectional converter. If the J1772™ connectors are to be used for V2L or V2V, special external equipment will be required. It is not expected that vehicles will be used to source power at levels higher than 20 kW and the J1772™ C1 connector will be adequate for all reverse flow requirements.

Specialized equipment will be needed if a standard exportable power panel is not provided on the vehicle. Two load centers are described. The PEV and load center can be thought of as a portable genset.

V2L AC L2 External Load Center

If the J1772™ connector is to be used for AC exportable power, this special equipment will be needed. The load center will have a hardwired cable with an attached J1772™ plug. The minimum load center will incorporate the appropriate NEMA receptacles. GFCI protection may be required if this is not built in to the vehicle. This could just be a dumb panel with all other controls and displays provided by the vehicle. Alternatively the load center could incorporate some controls and displays as is done on portable generators. The vehicle and the external load center comprise the "portable" generator.

V2L DC L1 External Load Center

DC power could be sourced directly using the vehicle J1772™ connector and the power conversion performed in the load center. This would be much more expensive than an AC load center, but may be the only option if the vehicle does not include a bidirectional converter or a dedicated exportable power inverter. This load center must communicate with the vehicle to coordinate battery usage. A PHEV may be allowed to operate the engine to maintain battery charge. ***Special communications (equivalent to SAE J2847-2 for DC Charging) will be needed to coordinate between the external inverter and the vehicle.***

While these load centers may be useful for specialized application, most owners would prefer to have direct access to NEMA receptacles mounted on the vehicle.

Essential Vehicle to Vehicle Capability

A battery electric vehicle (BEV) will not move without useable energy in its battery. There may be occasions where a BEV needs some additional energy at a location where a power outlet is not available for AC L1 charging. This is never required for a plug-in hybrid electric vehicle (PHEV) because it can always travel using its gasoline engine. In an emergency it may be desired for a PHEV or BEV to transfer some energy to a stranded BEV. The simplest way to do this is to plug the vehicle AC L1 cordset into a NEMA 5-20 outlet on the source vehicle.

Service Vehicles are not Reverse Flow Vehicles

Service vehicles will be needed to provide power to stranded BEVs. It is possible, although not likely, that these vehicles will be plug-in electric vehicles – they can easily be conventional vehicles. These vehicles are really mobile commercial charge stations. The service vehicle can directly generate the AC power using an engine mounted or dedicated generator. It only takes a 32 Hp genset to produce 20 kW at 85% efficiency. It could also carry an energy storage system and a 50 kW fast charger. There are many ways to do this. It's not relevant where the mobile charger gets the energy. It is just a mobile charge station. The service vehicle could incorporate both an AC L2 EVSE and a DC charger. A DC charger would be the most useful for a road call, but some vehicles may not be capable of DC charging.

High Power V2V using a Jumper Cable Unit

Specialized equipment will be needed to transfer power from one PEV to another using the J1772™ connectors. It is not envisioned that many vehicles be capable of transfer at higher than 20 kW.

V2V AC L2 Power Transfer Unit

This unit has two hardwired cables with J1772™ C1 plugs. One is connected to the vehicle providing power and it is designated as such. The other is connected to the vehicle to be charged and is designated as such. The unit provides all of the functionality of an AC L2 EVSE. The source vehicle provides 240 VAC power at 60 Hz. This will be an expensive unit. It is not clear who would buy such a unit. A service vehicle could carry one, but it would be just as easy to build the EVSE into the service vehicle. Special communications may be required with the source vehicle to establish output power, if it is adjustable, and set the control pilot.

V2V DC L1 Power Transfer Unit

This unit has two hardwired cables with J1772™ C1 plugs. One is connected to the vehicle providing power and it is designated as such. The other is connected to the vehicle to be charged and is designated as such. The unit includes a DC to DC converter. It acts as a DC L1 charger. This will be a very expensive unit. It is not clear who would buy such a unit. A service vehicle could carry one, but it would be just as easy to build the charger into the service vehicle. ***This unit will need to communicate with the battery management system of the source vehicle and also serves as a DC charger and implement J2847-2 messages with the receiving vehicle.***

Every PEV should provide a NEMA 5-20 receptacle to be used for exportable power and be capable of sourcing 16 Amps. This can be used for emergency assistance to a stranded BEV using the AC L1 cordset. Service vehicles will be needed that can provide DC fast charging for road calls. It is not likely that anyone would purchase the specialized equipment needed for high power V2V transfer.

Vehicle to Home (V2H)

Vehicle to Home describes the capability of a vehicle to act as a backup "generator" for selected critical loads in a home following the failure of the power grid. The home must be disconnected from the grid before any power can be provided to the home. The connection to the home electrical service must be through a transfer switch. Transfer switches used in this optional stand-by system must be in accordance with Article 702 of the National Electrical Code, ANSI/NFPA 70, and with the "Underwriters Laboratory Standard for Transfer Switch Equipment," ***UL 1008***.

The utility service enters the home and routes to a distribution panel for the non-critical loads. Then power flows through the transfer switch to a panel for the critical loads. The vehicle must be capable of supporting the expected power of these critical loads. Sometimes these panels and switches are physically combined. In some cases all of the loads can be supported and a single panel after the transfer switch is all that is required.

When emergency power is needed, the vehicle could be connected to a home backup power port using a dedicated vehicle mounted NEMA connector. A manual transfer switch could be used. This is the same setup used with a generator. Digital communications are not required for this type of operation.

If the J1772™ connection to the EVSE is used as the power port, the transfer switch wiring will need to be different than that used with a generator. The EVSE must be connected to the grid power to be able to perform charging, but it must be disconnected after a grid power failure. This type of capability is required for V2G operation which will be discussed later. An automatic transfer switch is needed if the vehicle is expected to immediately provide backup power. Digital communications may be required to activate the transfer switch, configure the EVSE for reverse flow, and interact with a home energy management system.

V2H also describes the capability of a vehicle to be used as a temporary "generator" for a home that has no connection to the grid. It may be possible for a PHEV to provide extended external power by using its engine to become a genset.

Vehicle to Grid (V2G) for Home Use

While the term V2G is generally associated with the concept of aggregating many vehicles to create a large virtual electricity storage system for the grid, it is possible that a home owner might want to use the PEV battery to supply power to the home during peak periods and then recharge the PEV battery at off peak times. The net power flow into the home may still be positive – although it is possible that a utility could allow and compensate a homeowner for reverse flow from the home. A home energy management system could be used to manage the vehicle discharging and charging. It is not appropriate to refer to this as capability as V2H, as is sometimes done, because V2H requires the vehicle to be isolated from the grid. V2H is for emergency backup or for homes that are not connected to the grid. V2G is the only mode that allows a vehicle to return power to a home, business, or charge station that is actively connected to the grid. This private use of reverse flow is a V2G activity and the same type of V2G communication that might be used between a utility and the PEV could be used between a home EMS and the PEV.

An Overview of Grid Scale Electricity Storage

To appreciate V2G as an aggregation of vehicles to create a virtual storage system, it is important to understand the use of electricity storage in the grid. This section provides an overview of the different types of storage systems used or planned for use in the grid.

Bulk Storage

Over 2.5 percent (22,000 MW) of the power generation capacity of the U.S. grid is actually provided today by a form of electricity storage known as Pumped Hydroelectric Storage (PHS). There are 40 PHS plants in operation in the United States. A water reservoir is built on a hilltop and used for a normal hydroelectric power plant when the grid needs more power. The reservoir must be refilled by pumping water back up the hill and this provides an extra off-peak load for wind turbines or nuclear plants. This is not as efficient as just using the primary generation source to serve the load because of the round trip efficiency losses but it does allow the power to be applied when needed. No other form of energy storage can compete with PHS for bulk storage. For example, the PHS facility at Raccoon Mountain, Tennessee, can generate 1600 MW for 22 hours. Power is established by the vertical drop and the number of water turbines (for discharge) or pumps for storing energy. Duration is determined by the volume of the reservoirs.

Compressed Air Energy Storage (CAES) is another form of bulk storage. Excess power from the grid is used to compress air in a sealed underground cavern and the energy is stored thermodynamically in the compressed air. When power is needed, the compressed air is then fed into a gas turbine power plant. Normally two thirds of the power of a gas turbine is used by the compressor stage of the unit. In this case all of the turbine power is delivered to the electric generator. Today there is only a single 110 MW CAES plant in the United States in Alabama. It can produce power for 26 hours. The first and only other CAES is in Germany and rated at 290 MW. A 150 MW plant is being constructed in New York and a 300 MW plant in California supported by Federal Stimulus grants. Other large CAES installations have been discussed in Ohio and Iowa but have not been started yet.

Both PHS and CAES are proven, mature technologies and are ideal for bulk storage. These bulk storage facilities are very large and are located remote from load centers. They are properly considered to be generation assets for the grid.

Substation Level Storage

Today, Sodium Sulfur (NaS) is the most widely deployed battery technology for grid applications. The battery modules are only produced by NGK Insulators in Japan. There are over 300 MW installed globally, with most applications in Japan. The largest installation in Japan is 34 MW at the Rokkasho wind farm. The NaS battery is capable of delivering rated power for 6 hours. General Electric is completing a factory in Schenectady, New York, to produce an advanced Sodium Metal Halide battery which will be very competitive with NGK's battery.

Another form of storage is to convert power into kinetic energy by spinning up a flywheel. Modern flywheels are very high speed rotors that are magnetically suspended in a vacuum. Beacon Power is building three 20 MW facilities dedicated to frequency regulation. Flywheels are very efficient at power cycling, but are not useful for energy applications. At rated power the flywheel can deliver power for only 15 minutes. Flywheels are a proven technology and well suited to providing frequency regulation for many years without wear out.

Other technologies are moving from demonstrations to larger applications with support of Federal Stimulus grants. Flow batteries, such as Zinc-Bromine, are very good for energy applications. Primus Power is building a 25 MW facility with three hours of storage at rated power. Lithium Ion batteries, which are a core technology in electric vehicles, are also being deployed in grid applications at substation scale. A123 Systems is working with Southern California Edison to field an 8 MW facility with four hours of storage at Tehachapi, California, for wind firming. AES and A123 Systems are installing a 20 MW unit in Johnson City, New York.

Most demonstrations of battery storage for the grid have been systems of at least two megawatt in size, connecting to the grid at distribution voltages of 4 kV to 34 kV. The system operators will generally not deal with power sources of less than one or two megawatts.

Community Energy Storage

In 2009 a new concept started to emerge at American Electric Power (AEP) - a concept based on aggregating many small 25 kW storage units to create a large virtual storage system. They called this concept Community Energy Storage.

A CES unit has a power of 25 kW with up to three hours of storage at rated power. It connects to the 240 volt secondary of the pad mounted transformer serving a group of homes. These units can act autonomously to control real and reactive power along a distribution feeder and they can also be aggregated as a fleet to form a large virtual storage system to serve the larger needs of the grid – for the feeder, the substation, or the control area. During power failures the units can disconnect from the grid and be islanded to provide power to the residences served by the transformer and improve power quality. With support from Federal Stimulus grants, AEP will be demonstrating a distributed two MW storage system in Ohio using 80 CES units and DTE Energy will be demonstrating a 500 kW system in Michigan that uses 20 CES units.

It is becoming more challenging to regulate voltage and reactive power along a distribution feeder. In the ideal situation the utility uses a switched tapped transformer to set the voltage at the start of the feeder at a distribution substation. The voltage is set higher at the substation and it drops off towards the end. Capacitor banks are placed along the feeder to correct power factor. Things get more complicated if power is injected along the feeder by PV arrays or other distributed generation. Some dynamic loads can cause voltage and reactive power problems along the feeder. It is very difficult to control this from only the substation. Dynamic reactive devices can be added – but a storage system with a four quadrant converter also provides this capability. By distributing storage systems along each phase of a feeder, this gives the capability to control the real and reactive power along the feeder. Longer term balancing can be done by central command. Short term voltage support can be done autonomously.

In electricity markets that have not been restructured, a vertically integrated electric utility could purchase, install, and operate CES - at least for the purpose of providing services to their own distribution grid. Its use for frequency regulation, voltage support, spinning reserve, and load following would not have to be bid as a market service and the cost of the CES units could be built into the rate base. It still needs to be justified to the state public utility regulators versus other alternative solutions. Recovery of investment would follow the same regulatory approvals as other capital equipment.

In a state that has restructured, such as New York, only an independent power producer can purchase, install, and operate energy storage. There are regulatory issues that must be resolved for electricity storage systems to be operated by a distribution utility. Today storage systems are considered to be generation assets and current regulations prohibit a distribution utility from generating energy. This is reserved for independent power producers. An Independent System Operator or Regional Transmission Organization (ISO/RTO) purchases ancillary services from the independent power producers. Also the system operator does not want to deal with small sources – they will generally only deal with bids of at least one or two megawatts, depending on the system operator. An independent power producer could aggregate many CES systems to reach a two megawatt capacity, but there are problems with this approach. Unlike a centralized storage system connecting to the transmission grid, the CES units are all over the distribution grid and this could create problems for the distribution utility if they are not part of the process and possibly providing operational control. These regulatory issues are being discussed.

The V2G Concept – an Extension of Community Energy Storage

V2G can be looked at as an extension of the Community Energy Storage concept. An individual CES unit has a power rating of 25 kW and it takes a fleet of at least 80 CES units to provide 2 MW of power. A Chevy Volt has an onboard charger capable of 3.3 kW and it takes a fleet of more than 600 vehicles to provide 2 MW of power. It's just a matter of the scale of the aggregation. The charging and discharging of both fleets must be centrally managed. The grid system operator sends Automatic Generation Control (AGC) commands to a fleet aggregator and the fleet aggregator in turn commands each vehicle. The fleet operator needs to consider many more factors than the grid operator – this is true for CES units as well as PEVs. The CES units are located at different places, the state of charge may all be different, and many other factors may need to be considered in allocating commands to each unit. For PEVs there is the additional complication of making certain that the vehicle is charged by the time of disconnect. This is not something that a grid system operator will want to perform directly.

There is an additional complication for PEV fleets. A CES unit will directly connect to the distribution transformer and will not be located within a private facility, behind a meter. The aggregator for the ISO/RTO will most likely be the distribution utility that owns the CES units. The business and operational issues for the PEV aggregator are more complex. The vehicles are all privately owned and they may be parked in a privately owned facility that has its own interest in managing their total facility power demand. These unique business issues will be discussed in more detail later.

V2G as with any storage system is really about bidirectional flow. However, some of the benefit can be achieved by only changing the rate of charging of each vehicle or the number of vehicles charging in a large fleet. This is sometimes referred to as V1G. It is a form of demand dispatch. All of the fleet aggregation is still needed, except reverse flow is not required. It takes twice as many vehicles in the fleet to achieve the same net power. SAE J2847-1 provides utility messages to enable V1G. The Optimized Energy Transfer use case provides this capability.

Grid Frequency Stability

The power grid is a massive machine that converts fossil fuels, nuclear energy, and renewable energy into electric power and then transmits the power to the loads. If the power generation and consumption are in perfect balance, the grid maintains a target frequency of 60 cycles per second. Most of the grid power comes from steam turbine or gas turbine generators that are designed to NOT regulate to a target rotational speed. If the total load on the grid increases all the generators slow down, or droop. This is good because as the grid frequency drops the load reduces automatically and the system stabilizes at a reduced frequency. This is called primary frequency regulation or governor response. Without this inherent stability created by the rotating machines and passive loads, the grid would be extremely difficult to control. Because the frequency doesn't "run away" there is time to add generation to return the frequency back to the target. The reverse happens if the load decreases.

Even though the grid is stable in the very short term because of governor response, the system operator must still match the power supply and demand to maintain the grid frequency within a specified band. This balancing act is a complex process based on forecasting loads and scheduling generation to meet these forecasts. Most of the generators are scheduled one day in advance to provide a specific power output for each hour of the day. These generation schedules are then adjusted one hour ahead to adjust for variances in the daily load forecasts. Real time changes to the generation schedules are also made on five minute intervals. Also, every hour of the day some generators are scheduled to be automatically controlled (AGC) by grid computer systems to increase or decrease their power output in seconds to help match power supply and demand and hold grid frequency - this is called frequency regulation. This is considered to be an Ancillary Service versus the more traditional use of a generator as a source of energy. The real time (load following) energy dispatch at the five minute intervals are also done with an objective of maintain the frequency regulation generators at a zero net energy delivery.

Most frequency regulation today is provided by generators. During a given hour a 30 MW gas turbine generator may be scheduled to deliver energy at a power level of 28 MW and it may also be independently contracted to provide up to 2 MW of frequency regulation. It does this by changing its generation level from 26 MW to 30 MW in response to AGC commands.

The discussion so far has been about increasing or decreasing generation to match supply and demand for power. The markets and systems are set up to do this. The legacy systems are not set up to dynamically control loads. Load control has generally been through rolling blackouts, curtailments, or other scheduled reductions during emergencies. It is not typical for a utility to request a customer to increase their load. The Smart Grid will provide the potential to dynamically adjust certain loads. This active demand management will provide a new capability to match supply and demand. Increasing and decreasing loads is equivalent to increasing and decreasing generation. Actively managing the timing and power levels for charging many thousands of electric vehicles can be an outstanding source for demand management for the grid in the future. This can be done without reverse flow.

Electricity storage systems are unique because they operate best at a steady level of zero and charge or discharge around it to provide regulation. The primary disadvantage of storage system versus a generator is the limited energy capacity. Many AGC systems are not yet capable of issuing negative AGC commands, so some modifications are needed to accommodate stored energy systems. Energy storage systems can respond instantly to AGC commands. Generators take time to respond, even if operating at a high power level. The market prices do not currently reward the storage systems for their quick response and this allows generators to be more competitive than storage systems in bidding for regulation. FERC is currently evaluating the concept of providing a higher market value for fast response systems.

The University of Delaware and the MAGIC Consortium

One of the first proponents of the concept of vehicle to grid (V2G) was Dr Willett Kempton of the University of Delaware. He with several graduate students (Dr. Steven Letendre, now a professor at Green Mountain College, and Dr. Jasna Tomić, now with CALSTART, and others) did much of the early conceptual work. The University of Delaware joined with PJM Interconnect, AC Propulsion, Pepco Holdings, Comverge, and the Atlantic County Utilities Authority to create the Mid-Atlantic Grid Interactive Cars Consortium (MAGICC) to demonstrate the V2G concept.

AC Propulsion modified a Toyota Scion xB to create an electric vehicle, called the eBox, capable of reverse flow at a power of up to 19 kW. It has 35 kWh of stored energy. The eBox is able to accept Automatic Generation Control commands from PJM and source or absorb power for use during frequency regulation. Demonstrations were first conducted in October 2007. They are continuing at PJM with additional vehicles. Scott Baker, who was with the University of Delaware during these demonstrations, is now with PJM interconnect and is an excellent resource for the status of these projects.

Many V2G references are available at the University of Delaware V2G website (http://www.udel.edu/V2G/) and the MAGICC website (http://www.magicconsortium.org/). The report by Willett Kempton et al, "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System," November 2008, is worth reading.

V2G and Battery Life

The battery is the most expensive subsystem in the vehicle, but it wears out from use – just like the vehicle brakes. The objective is to have it last for the useful life of the vehicle. It is not the kind of part that you can pull from a junk yard for a ten year old vehicle. The cost of a replacement battery could easily exceed the value of the vehicle at that point.

Battery life is driven by many things, but one key driver is the number and depth of cycles. It is cycles and not miles that wear the battery. Vehicle manufacturers can establish models for typical relationships between miles and cycles. This gets much more complex if batteries are cycled for other than transportation use. This is a consideration for battery warranty. The vehicle manufacturer could always measure cycles and switch to a cycle based warranty. But the vehicle owner could be faced with an expensive battery replacement and may not have factored this into the business model for offering up their vehicle for V2G operation.

A hybrid vehicle, or a PEV in charge sustaining operation, operates the battery in micro-cycles. Every acceleration and regenerative braking deceleration is a micro-cycle. The vehicle is designed to take hundreds of thousands of these cycles – these can be variations of less than 10% capacity. It could be at very high power, up to the rating of the traction motor, but a small amount of energy is used. The deep cycle from full to minimum charge would normally be a daily event for a PEV.

If fleet V2G use was more like the HEV cycle with five percent energy cycles at high power, this may not be very damaging. If the V2G use is deep cycles every hour, this could be more damaging.

One of the major business issues will be with battery life and manufacturer's warranty. This will also impact the resale value of a PEV. The person that would typically buy a ten year old vehicle is most likely not ready to spend thousands of dollars on a new battery pack.

V2G and On-Board Power Conversion

It is certainly technically possible to place a bidirectional power converter on a vehicle. It is a tradeoff of cost and volume versus customer value. The Nissan Leaf uses only a 3.3 kW on-board charger for a 25 kWh battery and takes seven to eight hours to recharge. This could have been reduced significantly by installing a 7.7 kW charger supplied by an EVSE on a common 40 Amp branch circuit (240 VAC). This must have been a cost and volume tradeoff with a view that an eight hour charge time is reasonable.

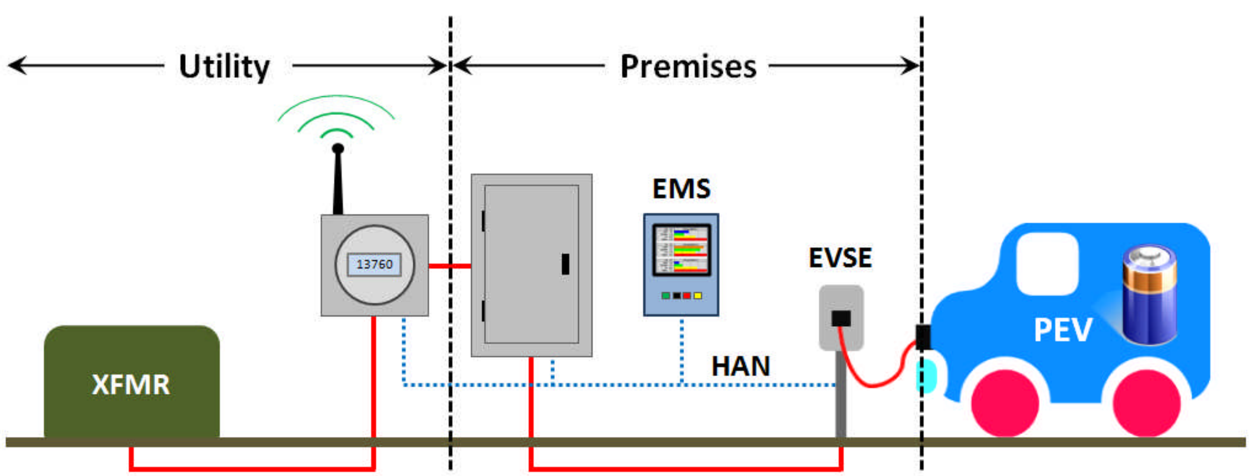
It may be more cost effective for a manufacturer to install a dedicated 2.0 kW inverter for powering external loads from a NEMA receptacle for V2L and V2H, than by replacing the on-board charger with a bidirectional converter and working the J1772™ interface for bidirectional power flow. This comes down to how many PEV customers want to use their vehicle to provide ancillary services for the grid. This will be driven by the return to the customer. The vehicle manufacturer could provide it as a customer option.

It's all about "show me the money" for both the battery and inverter. The MAGICC demos clearly show that it is technically possible to put a bidirectional converter in a PEV and remotely control it to provide frequency regulation. There is nothing magic about charging and discharging a battery through a grid-tied bidirectional converter. This is fundamental to any grid-tied storage system. The magic needs to be in the grid systems integration and the business model.

Roaming, V2G, and the Premises Infrastructure

The critical role of the premises and its infrastructure is often overlooked in the discussions of roaming and vehicle to grid (V2G). The focus is most often about how the utility will communicate with the PEV to manage power flows (either in or out of the vehicle) and deal with the financial aspects of the transaction. Yet, the premises infrastructure is the gateway for connecting any roaming PEV to the utility. The Electric Vehicle Supply Equipment (EVSE) is the master control valve for electric power flow either to or from the PEV. No power can flow in or out of the PEV except as allowed by the EVSE. This makes the premises infrastructure the most critical element in any communication with the PEV.

The diagram below is a very simplified view of the world of electric power and electric vehicles. Utility in this chart means all of the relevant players in the electric power industry. It includes the distribution utility, the system operator, energy service companies, independent ancillary service aggregators, and others. The "utility world" ends at the meter. Any premises infrastructure provided by a utility beyond the meter or control over any equipment within the premises must be by mutual agreement of the premises owner with the utility.



The definition of premises is also broadly defined. It means everything from the meter to the PEV. It can be a residential property. It can be a commercial property with public access to charge stations. It can be a factory with employee access to charge stations. It might even be a group of charge stations along a street. There will always be a meter, a distribution panel, and an EVSE.

Roaming and the Ancillary Services Aggregator

One of the concepts being discussed is where an aggregator signs up thousands of PEVs to participate in demand dispatch (V1G) or full bidirectional service (V2G). The aggregator bids an ancillary service, such as frequency regulation, in a one or two megawatt block to the ISO/RTO. The aggregator then manages the rate of charging or reverses flow for each vehicle in this large fleet to perform the service. The vehicle owners are compensated for participating in the program.

This vision of roaming PEVs under the control of an aggregator is compelling. The aggregator establishes a service contract with each PEV owner and then pushes and pulls power from all over the grid to satisfy its commitment to the ISO/RTO. All of the PEVs are securely and privately communicating with the aggregator to coordinate the power flow and deal with the business transaction.

Who's accountable?

The problem with this vision of roaming is that the power does not directly flow between the PEV and the aggregator. While a PEV may roam, the point of connection of any PEV to the grid is always fixed. The PEV connects through an EVSE and the EVSE is always part of the infrastructure of some premises. The local distribution utility holds the premises owner accountable for the power demand and power quality at the interface. The premise owner is a key stakeholder.

The Utility will always hold the premises owner accountable for compliance with IEEE 1547 and power quality for any reverse flow. This is true today for distributed generation. It is not likely that a local utility would have a direct business relationship with a roaming PEV that would hold the charging facility premises owner harmless for a safety breach caused by the PEV. A PEV will never be allowed to put power back into any premises wiring and out to the grid without full coordination with the premises infrastructure.

A business will generally have demand and energy charges and may also be enrolled in demand response or other utility programs as a facility. The utility infrastructure is designed to support the facility. It would not be good for an independent aggregator to cause a demand spike during the month. If PEVs in a large parking garage are signed up with different aggregators, how is the total facility peak power demand managed? The facility needs to be accountable for managing its own loads and working with the utility.

Who's in control?

The flow of information and control authority is always a topic of interest – particularly with regard to roaming. As you move from the system of system perspective of the Smart Grid to the vehicle at the end of the power cord, the perspective changes. The large system thinkers see the PEV as a small element on a huge open network that must be secured. The vehicle manufacturer seeks first to protect the vehicle and the people and immediate infrastructure around the vehicle.

Safety considerations require that a PEV will never draw more power than the premises infrastructure can support. For AC charging this limit is set by the EVSE through an analog signal known as the Control Pilot. This is defined by SAE J1772™. The vehicle is designed to never draw more current than authorized by the EVSE Control Pilot. Even if the vehicle on-board charger is capable of drawing a higher power than this limit and the PEV receives a message authorizing a higher level, it will not override the Control Pilot. An intelligent EVSE can dynamically control the limit – it does not have to be fixed at the level supported by branch circuit. The EVSE is the ultimate control valve.   For DC charging the EVSE is the charger and it directly controls the amount of power it draws from the grid, but never more than the vehicle will accept.

The SAE has not yet defined the communications and protections required for reverse flow. However, safety and power quality considerations will most likely result in the EVSE becoming the ultimate master control for enabling reverse flow and for establishing the maximum level of current allowed to be sourced by the PEV.

From a system of system perspective it might seem appropriate for an aggregator to only communicate with a PEV and not with a premises EMS or EVSE. Some even foresee the aggregator using a wireless connection directly with the PEV. The reality is that a vehicle will always seek to protect itself and part of this protection is that it will never allow itself to override an EVSE. The ultimate control that the EVSE has is to disconnect the vehicle using its circuit breaker. Power will only flow in and out of a PEV if both the PEV and EVSE allow it.

Implications for communication with roaming vehicles

When a utility reaches inside a private residence and turns off a water heater, this is by agreement with the owner of the residence and for the benefit of the home owner. The contract isn't with the water heater for the benefit of the water heater.   If an aggregator reaches into a charging facility to manage the rate of charging of a PEV, it can't do this without a contract with the facility as well.

The facility needs to be engaged in any communication between any external aggregator and any PEV within the facility. The facility owner is ultimately accountable for the power flowing across its interface with the utility and it may need to be able to manage the aggregate load of the facility at any instant. If an aggregator directly communicates with a PEV to command an increase in the rate of charging, the facility may need to override this command. The facility can reduce power demand of a charging vehicle or disengage any reverse flow at the EVSE. This is ultimate control.

A facility owner could unilaterally decide to be the only source of control for the rate of charging for PEVs served by the facility. It can make it a condition of using the facility that PEVs charge using SAE J2847 optimized energy transfer. This does no harm to the battery and may be needed to intelligently manage total facility demand. Reverse flow is another issue. The facility can enforce this (at least in the down direction) by using the EVSE control pilot if the PEV does not follow facility digital commands.

It is much less complex if the first tier of load management is done by the facility EMS and the external aggregator deals only with the facilities. This is an established model. Facilities don't roam.

Reverse Flow Summary

All Plug-in Electric Vehicles (PEVs) should be equipped with an on-board inverter capable of providing at least 16 Amps at 120 Volts and at least one NEMA 5-20 receptacle for use in powering external loads (V2L). This capability can be used with an AC L1 cordset to allow one PEV to charge another (V2V). As an option vehicles should be able to produce 240 VAC power at up to 32 Amps and have a NEMA 14-30 or NEMA 14L-30 receptacle for use with heavier external loads or for emergency backup of critical loads within a home (V2H). This capability should be provided by vehicle manufacturers even if the vehicle is capable of full V2G operation using its J1772TM connection to an EVSE.

V1G capability will be available to any PEV capable of engaging in Optimized Energy Transfer using J2847-1 messages. Much of the value of using a fleet of PEVs by an aggregator for load following or frequency regulation can be achieved by just managing the charging sessions of the fleet. This does not harm batteries and never depletes the energy of the vehicle. If a primary motivation for the vehicle owner to have V2G is to participate in the ancillary services market, much of this benefit can be achieved without reverse flow.

V2G increases the capability of a PEV fleet for providing ancillary services. It can impact vehicle battery life. There may be infrastructure issues at home and at public charging facilities to allow the capability. The Optimized Energy Transfer case in J2847-1 can be extended to a full bidirectional capability and documented in J2847-3.

Aside from private V2G in the home or in a private microgrid with a local energy management system, the V2G concept is based on the aggregation of hundreds and maybe thousands of vehicles. This is a new systems integration concept. The ISO/RTO can engage with an aggregator in a traditional manner using established ancillary service markets for the transaction and using AGC commands to control the aggregate power. The aggregator has the major challenge.

The aggregator must deal with each distribution utility in the ISO/RTO control area and coordinate the power injection at each feeder location. Frequency regulation and load following power is usually connected at the substation level and not along a feeder. The new grid storage concept of Community Energy Storage (CES) will help establish this concept.

The aggregator must also manage the fleet to not disappoint the vehicle owners by ensuring that each vehicle in the desired energy state at disconnect. The aggregator will have to monitor the energy state of each vehicle, the expected time of departure, and the minimum time to recharge. This can be done, but it will be a complex optimization problem to manage the fleet to meet aggregate demands and also worry about each vehicle. This is less of a problem with CES units because there is much more flexibility on the time for recharging the units.

The aggregator must also manage the power flow for each premises. Vehicles don't connect through the ether to the grid. This is not a concern in a home. This will be an issue for multi-vehicle charging facilities that may have demand charges and other commitments with the utility. This can be very complex if vehicles in a facility are signed up with different aggregators. One option is to perform the aggregation in tiers with the facility aggregating the vehicles within it and the aggregator only deals with the facilities. This is a more traditional role for the aggregator.

The systems integration and business issues of fleet aggregation are the primary challenges to achieving the vision of creating and managing a large virtual storage system for the grid.