# SURFACE VEHICLE INFORMATION REPORT

J2836™/3 FEB2024

Issued 2013-01
Revised 2024-02

Superseding J2836/3 JAN2017

Use Cases for Plug-In Vehicle Communication as a Distributed Energy Resource



## RATIONALE

The baseline document was first published in January 2013, and a revision was published in January 2017. One purpose of this revision is to update the document based on subsequent activities in the area of distributed energy resources and vehicle-to-grid. A major revision to SAE J3072 was published in March 2021. This was driven by the release of IEEE 1547-2018 and IEEE 1547.1-2020 and rulemaking by the California Public Utility Commission regarding V2G-AC. SAE J3072 is currently being revised to align with the soon-to-be published UL 1741 Supplement C and the SunSpec Alliance IEEE 2030.5 V2G-AC Profile.

SAE revised SAE J2847/2-202309 to include considerations for V2G-DC and V2H-DC, revised SAE 2847/3-202311 to include considerations for V2G-AC and V2H-AC, and issued SAE J2847/5-202310 to include considerations for V2L-AC and V2V-AC.

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# 1. SCOPE

This SAE Information Report establishes use cases for a plug-in electric vehicle (PEV) communicating with a DER Managing Entity (DME) as a distributed energy resource (DER) which is supported by SAE J2847/3. This document also provides guidance for updates to SAE J2847/2 to allow an inverter in an EVSE to use the PEV battery when operating together as either a DER or as a power source for loads which are not connected in parallel with the utility grid. Beyond these two specific communication objectives, this document is also intended to serve as a broad guide to the topic of reverse power flow (discharging) and vehicle-to-grid (V2G) technology.

## 1.1 Purpose

Distributed energy resources are small, modular distributed generation (DG) or energy storage systems that provide electric power or energy where it is needed on the distribution grid. A PEV using a "utility-interactive inverter" can be hooked up in parallel with the primary grid power, and it is defined to be a DER. The use of a PEV as a DER will be called vehicle-to-grid (V2G). The term is often associated with the concept of an aggregator coordinating the power flow of many PEVs to provide frequency regulation for the bulk grid. However, V2G is not just about the bulk grid. The V2G and DER functionality can also be used by a facility energy management system (EMS) to offset other facility loads during periods of peak demand. These are only two of many possible V2G applications.

Even if a PEV is not capable of reverse power flow, it can still be used as a DER device to allow for active control of charging for grid purposes. The use of a variable load for grid purposes is sometimes called demand dispatch or demand management. This can be considered a single-sided use of a DER device and is no different than a generator that can only vary power output. This is sometimes designated as V1G. Both V1G and V2G are considered to be forms of Vehicle Grid Interaction (VGI).

A PEV could also serve as a power source for tools or other devices, where grid power is not available, or provide emergency backup power for a home following a loss of grid power. These are all off-grid applications. This is all about pure reverse power flow, and it can be engaged manually using controls and displays provided by the vehicle manufacturer (VM). For these applications, the vehicle is just like a portable standby generator.

In all the discussion of the benefits of reverse power flow and the use of a PEV as a DER, it is important to always remember that the primary purpose of the energy stored in the vehicle battery is transportation. While it may be acceptable for a stationary grid storage unit to discharge all afternoon and recharge at night, a PEV participating in a V2G application may need to be fully charged by the end of the workday. The use cases for a PEV serving as a DER will need to account for two objectives: serving the grid in a V2G application and having enough energy by the time of departure to meet its transportation needs.

Figure 1 provides an overview of the purpose of the document. A stationary, grid-connected energy storage system (ESS) is shown at the top of the diagram. It is a DER. There is a great deal of work going on to integrate ESS units into the grid. A PEV with an onboard inverter looks like the stationary ESS and can be a DER device. This system is shown in the middle of the diagram. The possible use of reverse-flow capable PEVs, as inverter-based ESS units, has generated significant interest. This potential use of PEVs has become known as vehicle-to-grid (V2G-AC). Alternatively, the inverter could be located externally in the electric vehicle supply equipment (EVSE), in which case the PEV battery is only used to supply or absorb DC power as required by the inverter. This system concept (V2G-DC) is shown at the bottom of the figure.

It is sometimes assumed that a premises network will use the IEEE 2030.5 (IEEE Standard for Smart Energy Profile Application Protocol), known as SEP2, for communication and the PEV will be able to use this protocol for communication directly through the EVSE to the energy services interface (ESI). The ESI can be thought of as the gateway between the premises network and the outside systems. This SEP2 assumption may not be true for many premises networks, in which case the EVSE will need to translate messages from the protocol used by the local network into SEP2 used by the PEV. SAE J2847/3 will define the communications between the EVSE and the PEV for those cases where the inverter is onboard the PEV. It is expected that the EVSE to PEV communications would be by powerline carrier (PLC) on the control pilot. If the premises network uses SEP2 and the EVSE is not needed to perform protocol translation for the PEV, it may be possible for the PEV to use a wireless link directly to the network.

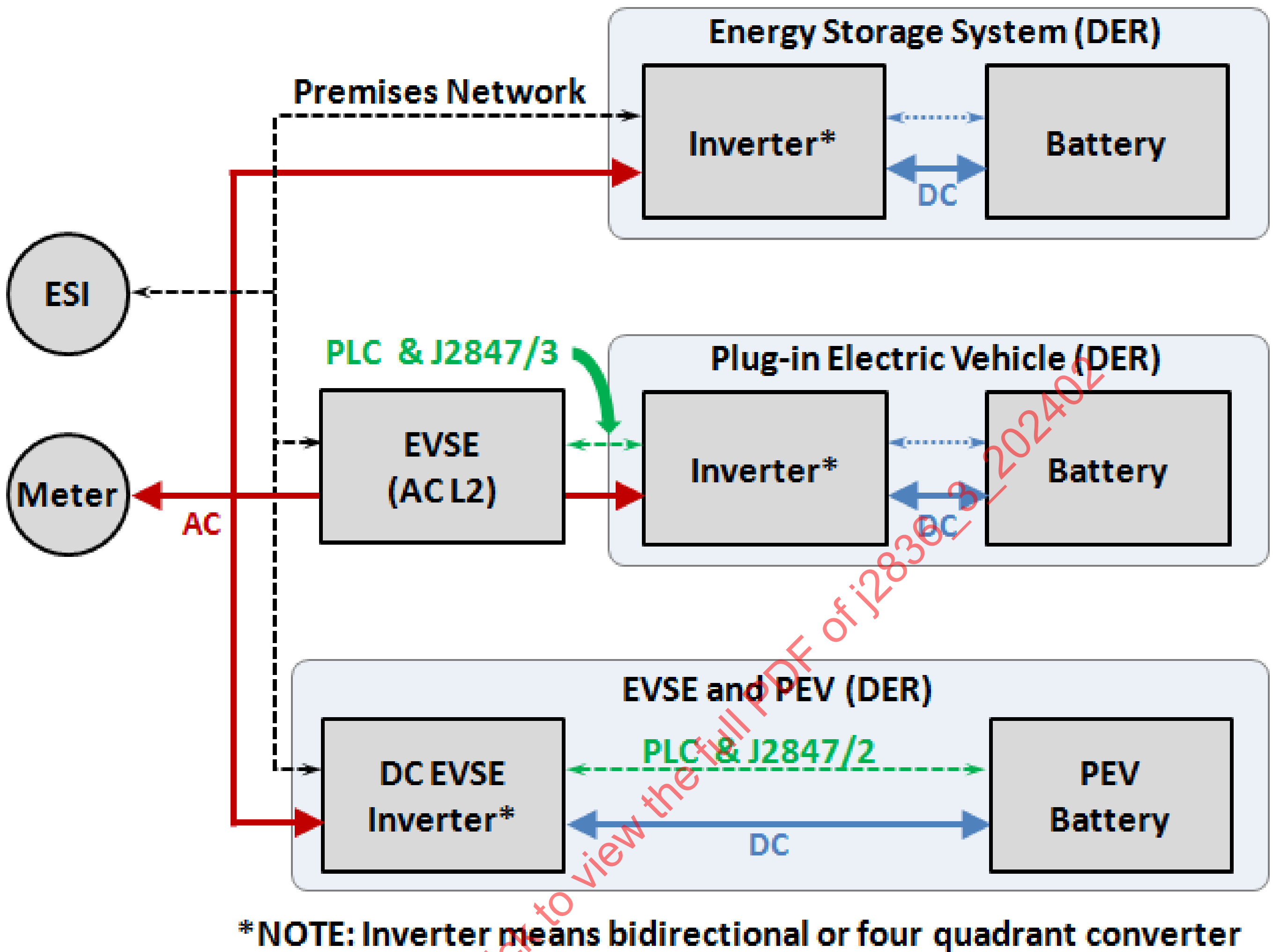



*Figure 1 - Purpose of document*



When the inverter is in the EVSE, it will need to directly interact using the network protocol. This could be SEP2, but in many sites could be a different protocol. The use cases in this document and SAE J2847/3 could help with the design of the EVSE communications, but there are other documents such as IEC 61850-7-420 ED2 that could be directly used by the EVSE manufacturer. An external inverter will need to interact with the battery management system (BMS) of the PEV. This will be like the communications used for fast charging as defined by SAE J2847/2, but the focus will be very different, and changes will be required for DER use (refer to SAE J2847/2). For fast charging, the PEV BMS manages the charging current using the data link. For DER use, the inverter will draw from the battery or push into the battery whatever current is needed to perform its DER function. In this case, the BMS defines limits for the inverter but does not manage the inverter power conversion.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2836/1 Use Cases for Communication Between Plug-in Vehicles and the Utility Grid

### 2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

#### 2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1715 Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology

SAE J1772 SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler

SAE J2836 Instructions for Using Plug-In Electric Vehicle (PEV) Communications, Interoperability and Security Documents

SAE J2836/2 Use Cases for Communication Between Plug-in Vehicles and Off-Board DC Charger

SAE J2836/4 Use Cases for Diagnostic Communication for Plug-in Electric Vehicles

SAE J2836/5 Use Cases for Customer Communication for Plug-in Electric Vehicles

SAE J2836/6 Use Cases for Wireless Charging Communication for Plug-in Electric Vehicles

SAE J2847/1 Communication for Smart Charging of Plug-in Electric Vehicles Using Smart Energy Profile 2.0

SAE J2847/2 Communication Between Plug-in Vehicles and Off-Board DC Chargers

SAE J2847/3 Communication for Plug-in Vehicles as a Distributed Energy Source

SAE J2847/5 Communication Between Plug-in Vehicles and Customers

SAE J2847/6 Communication for Wireless Power Transfer Between Light-Duty Plug-in Electric Vehicles and Wireless EV Charging Stations

SAE J2894/1 Power Quality Requirements for Plug-In Electric Vehicle Chargers

SAE J2894/2 Power Quality Test Procedures for Plug-In Electric Vehicle Chargers

SAE J2931/1 Digital Communications for Plug-in Electric Vehicles

SAE J2931/4 Broadband PLC Communication for Plug-in Electric Vehicles

SAE J2953/1 Plug-in Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)

SAE J2953/2 Test Procedures for the Plug-in Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)

SAE J2954 Wireless Power Transfer for Light-Duty Plug-in/Electric Vehicles and Alignment Methodology

SAE J2954/2 Wireless Power Transfer for Heavy-Duty Electric Vehicles

SAE J3068 Electric Vehicle Power Transfer System Using a Three-Phase Capable Coupler

SAE J3072 Interconnection Requirements for Onboard, Grid Support Inverter Systems

SAE J3105 Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices

SAE J3400 NACS Electric Vehicle Coupler

2.2.2 ANSI Accredited Publications

Copies of these documents are available online at https://webstore.ansi.org.

ANSI C84.1 American National Standard for Electric Power Systems and Equipment - Voltage Ratings (60 Hz)

2.2.3 EPRI Publications

Available from Electrical Power Research Institute, 3420 Hillview Avenue, Palo Alto, CA 94304-1338, Tel: 800-313-3774, www.epri.com.

3002008217 Common Functions for Smart Inverters: 4th Edition

2.2.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61850-7-420 Communication Networks and Systems for Power Utility Automation - Part 7-420, Basic Communication Structure - Distributed Energy Resources Logical Nodes

IEC TR 61850-90-7 Communication Networks and Systems for Power Utility Automation - Part 90-7: Object Models for Power Converters in Distributed Energy Resources (DER) Systems

2.2.5 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE 1547 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces; Ed 2018 and later

IEEE 1547.1 Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces; Ed 2020 and later

IEEE 1547.2 Application Guide for IEEE Standard 1547TM, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

IEEE 1547.3 Guide for Monitoring Information Exchange and Control of Distributed Resources with Electric Power Systems

IEEE 1547.4 Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

IEEE 1547.6 Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks

IEEE 1547.7 Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection

IEEE 1547.8 Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547

IEEE 1547.9 Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems

IEEE 2030.5 IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard

2.2.6 NFPA Publications

Available from National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 70® National Electrical Code® (NEC®)

2.2.7 NYSERDA Publications

Available from New York State Energy Research and Development Authority, 17 Columbia Circle, Albany, NY 12203-6399, Tel: 518-862-1090 or 1-866-NYSERDA (toll free), https://www.nyserda.ny.gov.

Report 11-08 Electric Transportation Energy Storage System Feasibility Study

2.2.8 SunSpec Alliance Publications

Available from SunSpec Alliance, 4040 Moorpark Avenue, Suite 110, San Jose, CA 95117 Tel: 408-217-9110, https://sunspec.org.

IEEE 2030.5 V2G-AC Profile

2.2.9 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062, www.ul.com.

UL 1008 Standard for Transfer Switch Equipment

UL 1741 Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources

UL 1741 SB Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources - Supplement B

UL 1741 SC Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources - Supplement C

UL 2202 Standard for Safety for Electric Vehicle (EV) Charging System Equipment

UL 2594 Standard for Safety for Electric Vehicle Supply Equipment

UL 9741 Outline of Investigation for Bidirectional Electric Vehicle (EV) Charging System Equipment

# 3. DEFINITIONS

This document builds on SAE J2836/1 and should be considered to be a supplement to that document for the purpose of reverse power flow and for the PEV serving as a distributed energy resource for the grid. Terms that are first introduced in this document, or that are particularly relevant to reverse power flow or the use of a vehicle as a distributed energy resource, or that are modified from the definitions provided in SAE J2836/1, are defined in this section. Please refer to SAE J2836/1 and SAE J1715 for the definition of other terms.

## 3.1 BIDIRECTIONAL CONVERTER

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.

## 3.2 DEMAND RESPONSE AND LOAD CONTROL (DRLC)

Demand response and load control (DRLC) is a common function set used to control shedding load on demand from the electric grid. It is a more active form of load management than price signals and can be used to target specific high load devices. A plug-in vehicle can serve as a variable or interruptible load while charging and participate in DRLC programs.

## 3.3 DISTRIBUTED ENERGY RESOURCES (DER)

Distribute energy resources (DER) are small, modular distributed generation (DG) and storage technologies that provide electric power or energy where it is needed on the distribution grid. DG, which includes gensets, solar panels, and small wind turbines, only serve as a source of energy. Storage is a unique form of DER because, unlike pure DG, the unit can provide either energy or variable demand. Plug-in vehicles can serve as DER storage systems.

## 3.4 ELECTRICAL CONNECTION POINT (ECP)

Each DER unit has an electrical connection point (ECP) which is the point of electrical connection between the DER source of energy (generation or storage) and the local electric power system (EPS).

## 3.5 ELECTRIC VEHICLE POWER EXPORT EQUIPMENT (EVPE)

This is defined by NEC 2023 as the equipment, including the outlet on the vehicle, that is used to provide electric power at voltages greater than or equal to 30 VAC or 60 VDC to loads external to the vehicle, using the vehicle as a source of supply.

## 3.6 ENERGY MANAGEMENT SYSTEM (EMS)

The term energy management system (EMS) is used in this document to describe a computer system that can communicate with a PEV or EVSE for the purpose of controlling the charging or discharging of the PEV battery. An EMS can exist at several tiers: customer premises, distribution level, or system level. These computer systems may go by other names, but the term EMS will be used generically in this document.

## 3.7 EXPORTABLE POWER PANEL (EPP)

An exportable power panel (EPP) is a vehicle-mounted set of NEMA receptacles that is used to provide power to external loads. The cords from the loads are plugged into the EPP receptacles.

## 3.8 FORWARD POWER FLOW (FPF) - CHARGING

Forward power flow (FPF) means the direction of energy for charging a vehicle. While the term “forward” suggests a positive sign convention, care must be used with any communications because the convention for DER devices is to use a positive sign to designate energy produced (discharged) by the DER.

## 3.9 FOUR-QUADRANT CONVERTER

This term refers to an electronic device that can produce or absorb both active and reactive power. When a PEV is discharging, the device serves as an inverter converting DC current to AC current. It can displace the AC current waveform relative to the AC voltage waveform to generate or absorb reactive power, depending on whether it leads or lags the supplied current relative to the grid voltage. The device converts AC power to DC current to charge the PEV battery. It can also shift the consumed current relative to the grid voltage waveform to produce or absorb reactive power.

## 3.10 INVERTER

AC power is generated from a DC source, such as a traction battery, using a device called an inverter. For operation as an off-grid, standalone power source, the inverter regulates the frequency and voltage, and the connected loads determine the current flow from the inverter. A grid-connected inverter (i.e., utility-interactive inverter) must act as a current source and synchronize to the frequency of the grid voltage waveform. A bidirectional converter or four-quadrant converter are often just referenced as being an inverter.

## 3.11 POINT OF COMMON COUPLING (PCC)

This is point where the local (premises) and utility EPS connect. This would normally be at the electric meter.

## 3.12 POWER FACTOR (TOTAL, DISPLACEMENT, AND DISTORTION)

Displacement power factor is defined as the ratio of active (or real) power in watts to apparent power in volt-amperes at the fundamental frequency (50 Hz/60 Hz). It is a measure of the phase shift that occurs between line voltage and line current when the AC line is loaded with a linear load having reactive characteristics, such as an AC motor. The line current is sinusoidal in shape but either leads or lags the line voltage in phase.

Apparent power is the vector sum of active power and reactive power (volt amperes reactive, VAR). Active and reactive power are two sides of a right triangle with apparent power as the hypotenuse. The angle between apparent power and active power vectors is the phase angle between the voltage and current waveforms. If the voltage and current are perfectly aligned, then only active power is transferred; this is a power factor of unity and is the most efficient for transfer of energy.

Distortion power factor is the ratio of fundamental current to total rms current. The line current distortion is normally the result of non-linear loading of the AC line. Total power factor is the product of displacement power factor and distortion power factor. If voltage distortion is negligible, total power factor is equal to the displacement power factor.

## 3.13 POWER FACTOR CORRECTION

Power factor correction means compensating for any reactive power associated with power conversion to achieve a power factor close to unity for the system. A power converter can be designed to control the phase angle between voltage and current during either charging or reverse power flow. This functionality can be used to correct for low power factor of a premises. It can also be used help support voltage on the distribution or transmission system.

## 3.14 REGULATION SERVICES (FREQUENCY REGULATION)

Regulation services are used to continuously fine-tune the balance of active power (watts) between power generation and demand. In many power markets, this function, called frequency regulation or automatic generation control (AGC), is priced separately from power generation and procured as an ancillary service.

## 3.15 REVERSE POWER FLOW (RPF) - DISCHARGING

Reverse power flow (RPF) means the direction of energy for discharging a vehicle. While the term “reverse” suggests a negative sign convention, care must be used with any communications because the convention for DER devices is to use a positive sign to designate energy produced by the DER.

### 3.16 UTILITY-INTERACTIVE INVERTER

An inverter intended for use in parallel with an EPS to supply common loads and sometimes deliver power to the utility. This is also called a grid-connected inverter.

### 3.17 VEHICLE-TO-GRID (V2G)

When vehicle power is fed into the bulk electric grid or a microgrid, we refer to it as “vehicle-to-grid” power, or V2G. A PEV in V2G operation is considered by utilities to be a DER. V2G is really about bidirectional flow and not just reverse flow. The term V2G includes the special case where only the rate of charging can be dynamically controlled; sometimes, this is referred to as V1G. V2G-AC designates the use of an onboard inverter feeding AC power back through the EVSE. V2G-DC designates the use of DC current from the PEV battery with an inverter located in the EVSE.

### 3.18 VEHICLE-TO-HOME USING AN ONBOARD INVERTER (V2H-EPP)

Vehicle-to-home describes the capability of a vehicle to act as a backup “generator” for selected critical loads in a home isolated from the power grid (for example, after the failure of the power grid). The vehicle onboard inverter regulates the voltage and frequency, and the power flow is routed to NEMA receptacles on the vehicle EPP. A power cord plugs into a NEMA receptacle on the vehicle panel and to the home’s electrical service through a transfer switch that isolates the critical loads to be powered by the vehicle from the grid. The loads served by the vehicle onboard inverter must be disconnected from the grid before any power can be provided to these loads. The inverter output must be disconnected from the vehicle’s AC receptacle to prevent voltage from being applied to the pins. The AC connection to the EVSE cannot be used for V2H using the onboard inverter because the AC EVSE must receive power from the premise to operate. However, if another power source is regulating the voltage and frequency for an islanded home and powering the AC EVSE, the vehicle can engage through the EVSE in V2G mode using its onboard inverter.

### 3.19 VEHICLE-TO-HOME USING AN EXTERNAL INVERTER (V2H-DC)

Vehicle-to-home using an external inverter and DC reverse flow from the vehicle though the charging connector is called V2H-DC in this document. An external EVSE inverter can be designed to use an internal battery to operate its control pilot and other electronics when grid power is not available. This inverter could regulate voltage and frequency when it is not connected to the bulk grid, and it could act as a current source if it is operating in V2G mode into a live grid or microgrid. An EVSE and premises that is V2H-DC capable can seamlessly switch between V2G and V2H-DC. Grid-tied inverters used with home solar (PV) systems have this mode switching capability today and can even automatically operate the transfer switch to isolate the home from the grid. The vehicle cannot discriminate between V2G and other modes. It is all just reverse DC flow, and the full responsibility for compliance with IEEE 1547 rests with the EVSE. It is also possible to design a portable battery powered inverter unit to provide V2L-DC and V2V-DC capability using the vehicle charging receptacle for DC reverse power flow.

### 3.20 VEHICLE-TO-LOAD (V2L) USING AN ONBOARD INVERTER (V2L-EPP)

Vehicle-to-load means the transfer of energy from the vehicle to a load. This can be used to support power to tools and other items not connected to a home or the grid. The vehicle onboard inverter regulates the voltage and frequency, and the power flow is routed to NEMA receptacles on the vehicle EPP.

### 3.21 VEHICLE-TO-VEHICLE (V2V) USING AN ONBOARD INVERTER

In the context of reverse flow, vehicle-to-vehicle means the transfer of energy from one vehicle to another. The term is generally used more broadly in the industry to refer to vehicle-to-vehicle communications, so it is best to avoid confusion and just consider this application to be a special case of V2L-EPP. The vehicle onboard inverter regulates the voltage and frequency, and the power flow is routed to NEMA receptacles on the vehicle EPP. An AC Level 1 cordset is plugged into a NEMA 120 VAC receptacle on the source vehicle exportable power panel and connected to the vehicle charging receptacle of the receiving vehicle.

3.22 VOLTAGE SUPPORT

Voltage support is performed at two levels: at bulk generation and transmission level by the system operator, and at the feeder level by the distribution utility. At the transmission system level, voltage support is an ancillary service related to the compensation of reactive power (VARs). Some generators are capable of producing or absorbing reactive power in addition to providing real power. There are also special devices that apply a variable capacitive load at transmission levels to compensate for the inductance of transmission lines and reactive loads. At the feeder level, voltage must be controlled from the substation to the end of the feeder. This is generally done with a tapped transformer that can adjust the head end voltage. Capacitors are installed along feeders to compensate for reactive power. Sometimes, these can be switched. A device called a distributed static compensator can be used to dynamically provide reactive power compensation. A stored energy system with a capability to control both real and reactive power flow (a four-quadrant power converter) can provide voltage support at system level (like a generator) or at a distribution level (like a distributed static compensator or tapped transformer and switched capacitor bank).

4. TECHNICAL REQUIREMENTS

This major section discusses issues and considerations related to pure reverse power flow (discharging) under manual control and the use of a PEV as a DER for use in various types of vehicle-to-grid applications. While this section is called “technical requirements,” it is part of an information report, not a standard or even a recommended practice, and cannot be used to define actual requirements. Some of the discussion may read like requirements, which in some cases is a reflection that requirements in some existing standards may apply, or in other cases just provides guidance for actual standards that may need to be written. The primary purpose of this section is to suggest functionality that may need to be considered for implementation in either an inverter located in either the PEV or EVSE. It also defines use cases to serve as a guide for communication requirements that would be documented in SAE J2847/3 for communication between an EMS and a PEV onboard inverter. These same use cases could also serve as a guide for communication requirements between an external inverter in the EVSE and an EMS. SAE J2847/3 could be used for the EVSE to EMS communication, but the SAE documents are primarily focused on communication with the PEV. For the external inverter, communication between the EVSE and the PEV BMS will be documented in an update of SAE J2847/2. This section reviews some of the considerations needed for reverse DC power flow to an external inverter.

Section 4.1 describes the relationship of this document to SAE J2836/1. One top-level use case (PEV4) and three detailed use cases (PR2, U6, and U7) are introduced.

Section 4.2 discusses the basic types of pure reverse power flow (V2G, V2H, V2L, and V2V). PEV onboard and EVSE external power conversion are reviewed. This section provides guidance for the detailed use case PR2, customer discharges the PEV.

Section 4.3 discusses general issues related to communications for reverse power flow. Data entry and manual control of reverse power flow are reviewed. The architecture for communication between an EMS and the inverter in the PEV and the EVSE is described. Considerations for communication between an external EVSE inverter and the PEV BMS are also reviewed.

Section 4.4 reviews work on inverter-based distributed energy resources being done by EPRI and IEC regarding the use of smart inverter functions in DER devices.

Section 4.5 discusses V2G applications behind the meter, for the distribution feeder, and for the entire EPS. The concept of operational bandwidth is described along with its relationship to the different V2G applications. The relationship of the SAE use cases to the different V2G applications is shown.

Section 4.6 provides considerations for use case U6 (basic DER) which is concerned with the control of active (charging or bidirectional) power by an EMS during a V2G application.

Section 4.7 discusses power factor and reactive power. It provides considerations for use case U7 (advanced DER). U7 provides functions for direct control of power factor or reactive power. It also provides autonomous functions.

Section 4.8 discusses considerations for the top-level use case PEV4 (PEV as a DER). PEV4 considers the broad process flow from enrollment as a DER device in a V2G application, active participation in a V2G application, to payment for the services rendered, and to contract termination. It deals with considerations for conflict resolution where multiple allocations are running concurrently.

Section 4.9 discusses issues associated with the approval by a utility of the interconnection of a DER that consists of the fixed site EVSE and a roaming PEV with an onboard inverter. This is unprecedented. The SAE J3072 standard was developed to address these issues.

## 4.1 Relationship of SAE J2836/3 to SAE J2836/1

This document builds on the use cases and general requirements described in SAE J2836/1 and must be read in that context. This is not a standalone document and should be considered to be a supplement to SAE J2836/1 for the purpose of reverse power flow (generation/discharging) and for the PEV serving as a DER for the grid. Because of the timing of updates to the various documents in the SAE J2836 and SAE J2847 series, there may be some temporary inconsistency between the documents. In the event of any inconsistency, the most recently released document should be used for guidance. For example, SAE J2836/1 provides a detailed use case E (general registration and enrollment process) for enrolling a PEV in any utility program. This use case should apply to reverse flow applications as well as to charging, for which it was originally written, but it may need to be updated in a future release of SAE J2836/1 to accommodate any new information needed for reverse power flow. It is more appropriate to update this use case than to create a new standalone detailed use case in SAE J2836/3 for basic enrollment.

SAE J2836/1 identifies four top-level use cases in the main document and then provides a detailed description of each in its Appendix A. “Customer attributes” (PEV0) applies to reverse power flow, and it even identifies a “specific function” for “discharge” (PR2). The remaining three top-level use cases, “utility provides services to PEV customer” (PEV1), “customer connects PEV to premises energy portal” (PEV2), and “customer enrolls in a PEV demand side management program” (PEV3), do not specifically mention the use of the PEV as a DER device. There are many elements of PEV0 through PEV2 that should apply to a PEV serving as a DER device, and these top-level use cases may need to be extended to include DER functionality. PEV3 is more specialized for demand management programs. A new top-level use case, “PEV as a distributed energy resource” (PEV4), is discussed in 4.8 and defined in Appendix A of this document.

SAE J2836/1 also identifies 17 detailed use cases. Figure 2, which is derived from SAE J2836/1, shows these detailed use cases. A comprehensive description for most of these use cases is provided in Appendix B of that document. Use cases were not provided in Appendix B for discharge (PR2), diagnostics (PR3), or vehicle manufacturer specific (PR4). They are described in the PEV0 use case, but they are not listed in the main body of the document. Use case “customer discharges the PEV” (PR2) is discussed in 4.2.11 and defined in Appendix B of this document.

The basic enrollment use case (E), the three PEV connection and energy transfer use cases (S1 to S3), and the four location use cases (L1 to L4) all apply to reverse power flow and DER applications. Some modifications to each of these might be required to specifically accommodate reverse flow, but they are all relevant. There are no EVSE connections or locations that are unique to reverse power flow to the utility grid, although the EVSE for both S2 and S3 must be designed to support reverse power flow. SAE J2836/1 defines five specific utility programs. At present, these are all associated only with charging. “Time of use program” (U1), “real time pricing program” (U3), and “critical peak pricing program” (U4) are all informational utility programs that allow the PEV to make informed decisions about when to charge to minimize the cost of charging. There is no active control of start or stop of PEV charging by the utility. The PEV owner benefits from reduced cost of charging. The utility benefits by incentivizing the PEV owner to shift charging to off-peak periods. These use cases have no direct role to play for execution of DER functionality, but it is possible that price signaling could be used with DER functionality to gate participation of the PEV.

The “discrete event program” (U2) allows the utility to stop charging during a demand response event. This is a rare event with significant advanced notice. The top-level use case PEV3 uses the discrete event program. U2 has no role to play for DER applications, although U2 and PEV3 describe ancillary service type programs and provide some guidance for how DER functionality can be used for other ancillary services.

The "optimized energy transfer program" (U5) allows direct management of the start and stop and the power level used during a PEV charging session. It authorizes a power level for charging but does not require the PEV to actually charge at that authorized value. In most cases, the PEV would charge at the highest authorized power (within the control pilot and charger constraints), but the use case doesn't require it. While SAE J2836/1 only defined U5 for charging, the IEEE 2030.5 Smart Energy Profile 2.0 (SEP2) implemented U5 as a function called "flow reservation" and extended it to allow the power and energy request to be for either charging or discharging. The use of flow reservation is described in SAE J2847/3.

Use case "basic distributed energy resource" (U6) is discussed in 4.6 and defined in Appendix C of this document. It provides for the capability to control both forward (charging) and reverse (discharging) active power flow to a commanded value. The controlling entity provides new settings to the smart inverter as needed to support the V2G application.

Use case "advanced distributed energy resource" (U7) is discussed in 4.7 and defined in Appendix D of this document. Unlike U6, which describes only a single function, U7 serves to describe a group of smart inverter functions (beyond U6), each of which could be optionally implemented in addition to U6 by the inverter system. For a four-quadrant converter, U7 includes functions that a DER controlling entity could use to directly set either the power factor or the value of reactive power. U7 also defines an autonomous volt-VAR function which would be activated by and use curves provided by a DER controlling entity. This document only discusses those smart inverter functions which were relevant to V2G and required by IEEE 1547-2018. There are many more functions defined by EPRI and IEC which could be implemented by an inverter system and supported by future versions of SEP2.

There are two fundamentally different approaches for a PEV and the EVSE to which the PEV is connected to collectively serve as a DER. In one case, the inverter is located onboard the PEV; in the other case, the inverter is located external to the PEV in the EVSE, or even beyond if a DC microgrid is used. While the term vehicle-to-grid (V2G) is generally associated with both configurations, and that convention will be followed in this document, V2G would be more properly used only with the case of the PEV onboard inverter. A more descriptive term for the EVSE inverter case would be to call it "EVSE-to-grid." There are some very unique technical and regulatory considerations associated with a roaming PEV onboard inverter that do not apply to a stationary EVSE inverter.

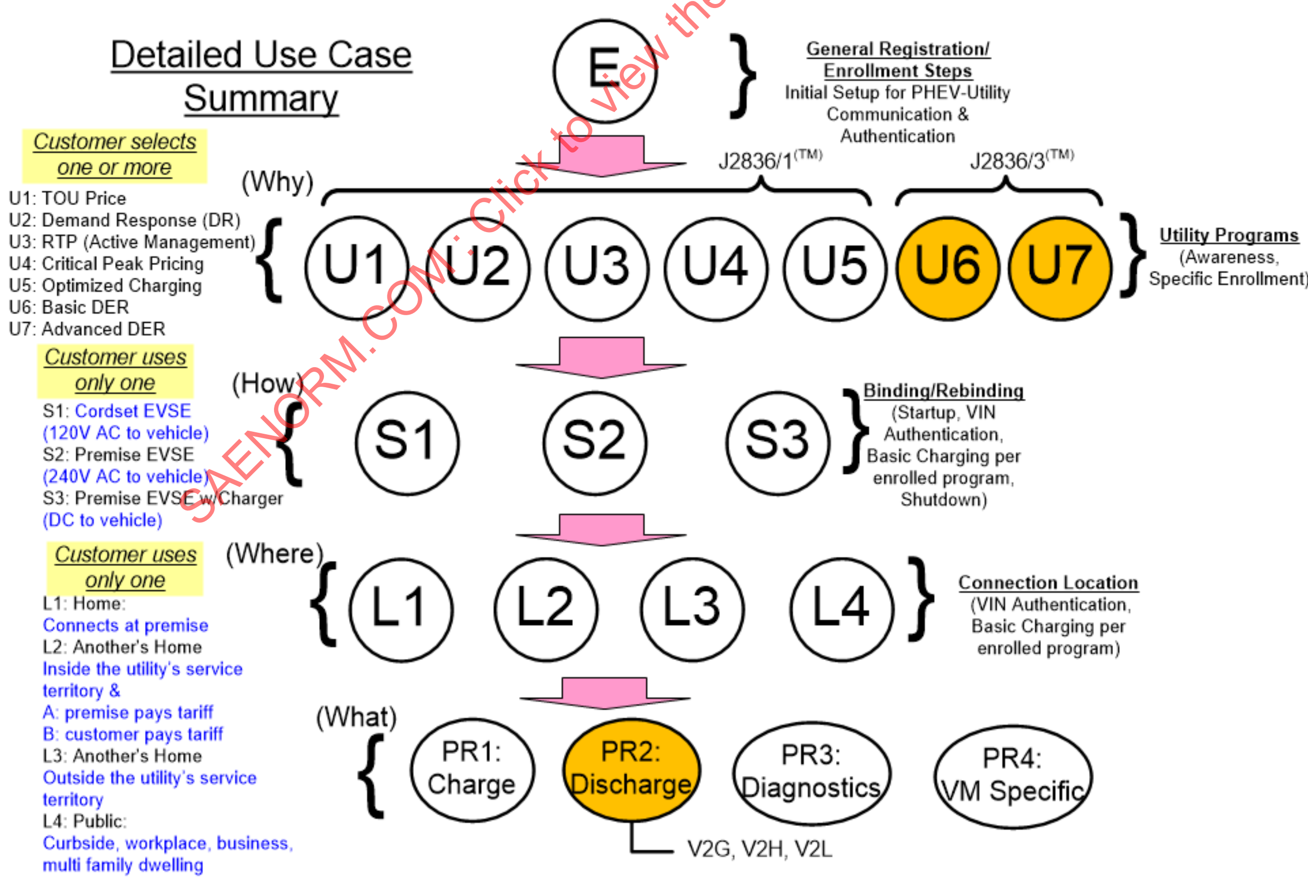



*Figure 2 - Summary of detailed use cases*

4.2 Types of Reverse Power Flow

AC power is generated from a DC source, such as a traction battery, using a device called an inverter. For operation as an off-grid, standalone power source, the inverter regulates the frequency and voltage, and the connected loads determine the current flow from the inverter. A grid-connected inverter must act as a current source and synchronize to the frequency of the grid voltage waveform. The grid voltage and frequency are far too stiff for a single inverter to shift them. 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 be capable of being reversed and convert from DC to AC in the other direction to serve as an inverter. A grid-tied power converter can be designed to either lead or lag its sourced current relative to the grid voltage during either charging or inverter operation. This is called a four-quadrant converter. For simplicity, the bidirectional and four-quadrant converters are often just referred to as an "inverter" when discussing reverse power flow. That convention will be followed here.

The purpose of a PEV and the energy stored in its battery is transportation. All other uses of the vehicle and the energy stored in its battery are secondary to that primary purpose. Consuming the energy, or even delaying the start or extending the time for charging the battery, increases the risk to the customer that the vehicle will not be able to perform its intended purpose if an unexpected need for travel arises. In the discussion of the benefits of reverse power flow and the use of a PEV as a DER, it is important to always remember that the primary purpose of the energy stored in the vehicle battery is transportation.

Pure reverse power flow is very useful for powering tools or other devices at a remote site where grid power is not available; this capability is called vehicle-to-load (V2L). A PEV can also use pure reverse power flow to provide a "jump start" to another PEV; this capability is called vehicle-to-vehicle (V2V). Vehicle-to-home (V2H) describes the capability of a PEV to act as a backup "generator" for selected critical loads in a home isolated from the power grid (for example, after the failure of the power grid). The PEV is connected to the home's electrical service through a transfer switch that isolates the critical loads to be powered by the PEV from the grid. Because these are all off-grid applications, the onboard or external inverter must regulate both the voltage and the frequency, and it is the connected loads that determine how much energy flows from the vehicle battery. This is all about pure reverse power flow, and it can be engaged manually using controls and displays provided by the VM.

Vehicle-to-grid (V2G) is the only mode that allows a PEV to return power to a home, business, or charge station which is connected to a live grid. When an inverter is connected to the bulk grid, it must be synchronized with the grid frequency, and it must act as a current source. If there is a power failure, the inverter must automatically turn off. This is for the safety of workers that may be repairing downed lines. A small, modular storage device connected to the grid is defined as a distributed energy resource (DER). The real value of a PEV to the grid is its ability to serve as a DER device and provide precisely controlled bidirectional power flow, not just reverse flow. The term V2G is often associated with the concept of an aggregator precisely coordinating the bidirectional power flow of many PEVs as DER devices to provide frequency regulation for the bulk grid. But this is only one of many possible V2G applications.

The most basic V2G operation is for a homeowner to start a vehicle's onboard inverter and set a steady power output manually. The homeowner might want to use the PEV to offset a home air conditioner load during an afternoon peak and then recharge the PEV battery at an off-peak time. 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 under a net metering program. While it may be possible to manually control reverse flow for this purpose, it is much more effective to use a home EMS. Communication between the EMS and the PEV is required to allow the EMS to control the PEV reverse flow to manage the total demand at the meter. When the PEV is providing reverse power flow based on instructions from a home EMS, it is serving as a DER device. It is not appropriate to refer to this as capability as V2H, as is sometimes done, because V2H (as defined by this document) requires the PEV to be isolated from the grid. V2H is for emergency backup or for homes that are not connected to the grid.

Article 625.48, "Interactive Equipment," of the 2023 National Electrical Code (NEC) provides that "electric vehicle supply equipment that incorporates a power export function and that is part of an interactive system that serves as an optional standby system, an electric power production source, or a bi-directional power feed shall be listed and marked as suitable for that purpose. When used as an optional standby system, the requirements of Parts I and II of Article 702 shall apply; when used as an electric power production source, the requirements of Parts I and II of Article 705 shall apply."

The inverter characteristics for each type of reverse power flow are summarized in Table 1. There are three basic types of reverse power flow: V2G, V2H, and V2L (where V2V is a special case of V2L).

***Table 1 - Inverter characteristics***

| Basic Type of Reverse Power Flow | Inverter Characteristics | | | |
|---|---|---|---|---|
| | **Grid State** | **Regulated Output** | **Frequency** | **NEC®** |
| V2G | Grid-tied | Current | Synch | 705 |
| V2H | Off-grid | Voltage | Regulate | 702 |
| V2L(V) | Off-grid | Voltage | Regulate | N/A |

An EVSE utility-interactive (grid-tied) inverter (V2G-DC) must conform to UL 1741 SB. An onboard utility-interactive inverter system is certified to SAE J3072, and the interconnecting AC EVSE is certified to UL 1741 SC. UL 1741 SC and SAE J3072 are intended to supplement and be used in conjunction with IEEE 1547-2018 and IEEE 1547.1-2020 or later versions.

When an onboard inverter is used for V2G, the AC power flows directly through the charging coupler to the EVSE and to the live grid. An SAE J1772 single phase charging coupler can be used for V2G-AC or V2G-DC, and this connection is often shown in figures in this document. Other single phase charging connectors, such as SAE J3400, can also be used. And the SAE J3068 connector can be used for three phase V2G operation. A utility-interactive inverter in the EVSE can draw DC reverse power through the charging coupler, or it could possibly use SAE J2954 wireless transfer equipment. For off-grid applications using a vehicle onboard inverter, AC power could be routed to a vehicle-mounted EPP which would provide standard NEMA receptacles like those found on a portable generator.

The charging coupler could not normally be used for off-grid applications because the EVSE control pilot circuit would not have power and the vehicle could not engage in power transfer. This is true for both an onboard inverter and DC reverse flow to an external inverter. However, if the EVSE is modified to use an internal “cold start” battery to operate its control pilot and other electronics when grid power is not available, V2H can be achieved. Because an external EVSE inverter is part of the premises infrastructure and may even control the transfer switch, this use of a modified EVSE to engage in DC reverse flow is lower risk. The external inverter could automatically change from current mode V2G to voltage mode V2H after the island is created. It is recommended that an onboard inverter always operate as a utility-interactive (V2G) inverter when using the charging coupler, and therefore, the inverter could not engage in V2H mode even with a modified EVSE.

SAE defines each type of reverse power flow by combining a designation for a basic type with the designation for the port on the PEV used for the transfer (e.g., V2L-EPP, V2G-AC). These are summarized in Table 2 for several different applications of reverse power flow. Two new basic types are introduced which are variations of V2G used with AC (V2M) or DC (V2D) microgrids. These will be defined later. The PEV power transfer ports are the DC coupler, AC coupler, EPP, and wireless power transfer (WPT). The paragraph number where each SAE type is discussed is listed below the type designation.

*Table 2 - SAE types of reverse power flow*

| Reverse Power Flow Application | Basic Type | PEV Power Transfer Port | | | |
|---|---|---|---|---|---|
| | | DC | AC | EPP | WPT |
| Power plug-in loads which are not connected to a facility power system | V2L | V2L-DC<br>4.2.5<br>J2847/2 | V2L-AC<br>4.2.6<br>J2847/5 | V2L-EPP<br>4.2.1 | |
| Charge another electric vehicle; special V2L | V2V | V2V-DC<br>4.2.5<br>J2847/2 | V2V-AC<br>4.2.6<br>J2847/5 | V2V-EPP<br>4.2.1 | |
| PEV is only source of backup power for islanded home (NEC 702) | V2H | V2H-DC<br>4.2.5<br>J2847/2 | V2H-AC<br>4.2.6<br>J2847/3 | V2H-EPP<br>4.2.1 | V2H-WPT<br>4.2.4<br>J2847/6 |
| Connected in parallel with utility grid (NEC 705) or to islanded AC microgrid with strong VF source | V2G | V2G-DC<br>4.2.3<br>J2847/2 | V2G-AC<br>4.2.2<br>J3072 | | V2G-WPT<br>4.2.4<br>J2847/6 |
| Connected to a “weak” islanded AC microgrid; special case of V2G | V2M<br>(V2G) | V2M-DC<br>4.2.7 | V2M-AC<br>4.2.7 | | |
| Connected to a DC microgrid which could be in islanded facility; special case of V2G | V2D<br>(V2G) | V2D-DC<br>4.2.8 | | | |



4.2.1 Use of EPP (V2L-EPP, V2V-EPP, V2H-EPP)

A vehicle can provide an onboard generator to regulate voltage and frequency for loads connected to NEMA outlets mounted on the vehicle. This is called an exportable power panel (EPP). NEC 2023 Article 625.60 (“AC Receptacle Outlets Used for EVPE”) applies to the EPP. For operation as an off-grid, standalone power source, the inverter regulates both the frequency and the amplitude of the output AC voltage waveform, and the AC current flowing from the inverter is determined by the connected loads. The inverter must be rated to a power level which can support the connected loads, or the inverter voltage may droop, or the inverter may even shut down due to a reaching a current limit.

Vehicle-to-load (V2L) describes the basic capability of a PEV to use an onboard inverter to power external loads that are plugged into the receptacles on a vehicle-mounted EPP. V2L-EPP is the basic off-grid capability, and V2H-EPP and V2V-EPP are special V2L applications. The EPP provides standard NEMA receptacles, such as NEMA 5-15R for 120 VAC 15 A service, NEMA 5-20R for 120 VAC 20 A service, and NEMA 14L-30 for 240 VAC 30 A service. Panels such as this are found on portable generators. The appropriate protective devices for the receptacles must also be provided in the PEV. The onboard inverter regulates both the voltage and frequency for the off-grid applications.

Safety interlocks should be provided to prevent the inverter from applying AC voltage to the pins of the vehicle charging connector when it is regulating voltage and frequency for the NEMA receptacles. For example, switches could be provided in the PEV to route power to the EPP and isolate the mains (L1 and L2) of the SAE J1772 receptacle. Figure 3 shows a configuration for interconnecting with the EPP. An EVSE would not normally be connected to the PEV during V2L-EPP operation, but it is possible that the PEV could be connected to an EVSE and the switches (S1 and S2) prevent injecting voltage into the grid.

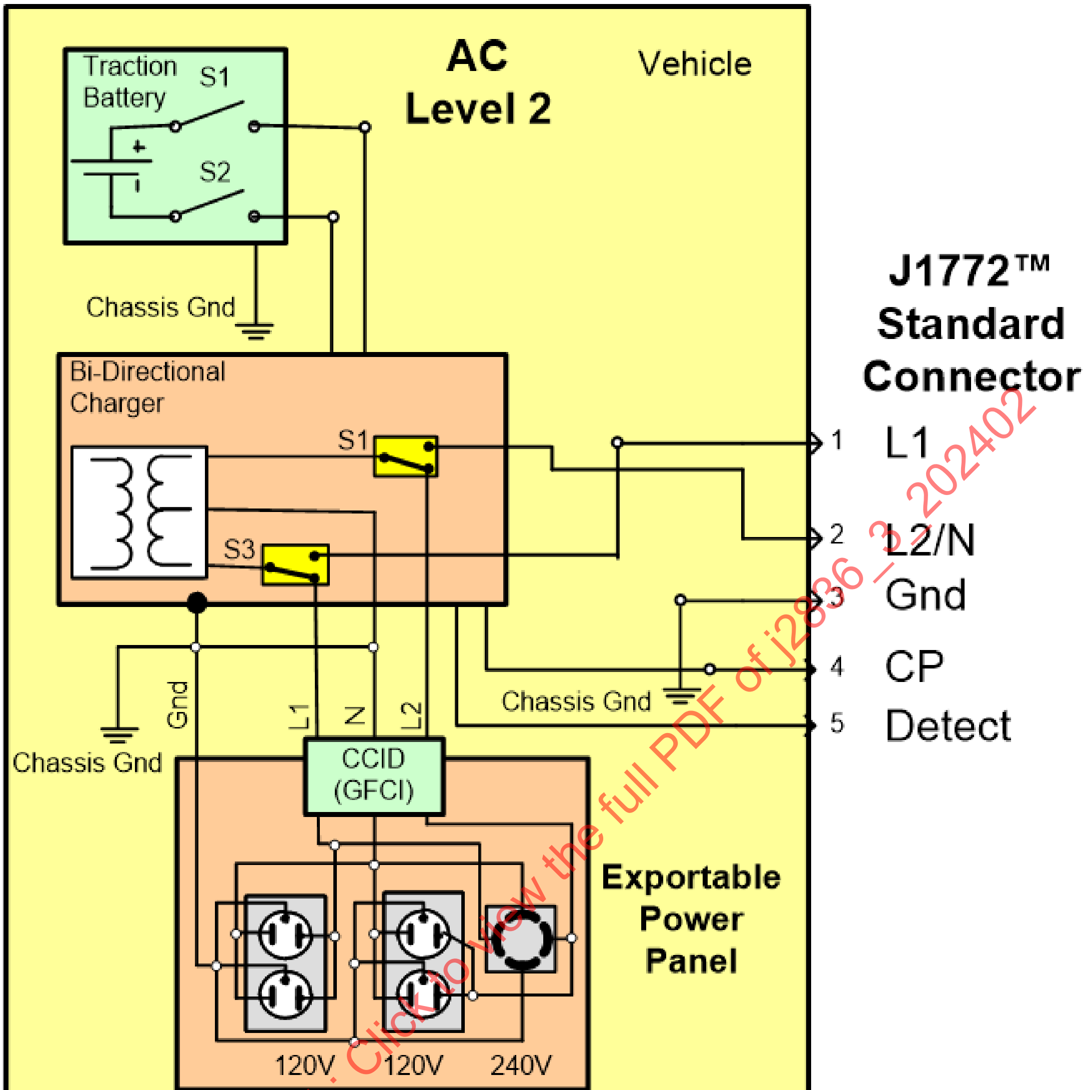



*Figure 3 - Exportable power panel for V2L-EPP*



V2V-EPP power flow is similar to a vehicle getting a "jump start." A battery electric vehicle (BEV) will not move without usable 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 even AC Level 1 charging. The simplest way to do this is to plug the PEV AC Level 1 cordset into a NEMA 120 V outlet on the source PEV's EPP. This V2V-EPP is really V2L with a PEV as the external load. V2V-EPP should be controlled using onboard controls and displays.

V2H-EPP describes the capability of a PEV to serve as a backup "generator" for selected critical loads in a home following the failure of the power grid. An onboard inverter regulates the frequency and the voltage. Power is routed from the inverter to a vehicle-mounted EPP which provides standard NEMA receptacles similar to those found on a portable generator. A cable connects the PEV to the home backup power port. V2H-EPP should be controlled using onboard controls and displays.

An example of a V2H-EPP installation is shown in Figure 4. This figure also shows the PEV connected through an EVSE for V2G-AC, which will be discussed in the next section. The PEV would not normally be hooked up to the EVSE and to the backup power port at the same time. This is not a safety concern because the inverter must be disconnected from the charging coupler whenever the inverter is engaged in V2H-EPP operation. The EVSE and the home's backup power port could be located such that it is not even possible to connect both at the same time.

This is the same type of installation used with any backup generator. Article 702 of the NEC, "Optional Standby Systems," applies to integration of the PEV with the home. After a power failure, the homeowner positions the PEV near the home's backup power port and connects it to a vehicle 240 VAC NEMA outlet with a special cable. The transfer switch isolates the critical load panel from the grid and connects it to the backup power port. If the critical loads were not disconnected from the grid during V2H-EPP operation, it could cause safety issues for repair personnel. The PEV inverter is then started and begins producing power for the home during the emergency.

The onboard inverter should never be allowed to operate as a "utility interactive inverter" when using the NEMA outlets. It should only operate as a standby system and regulate voltage and frequency. Also, voltage should not be applied to the pins of the vehicle charging coupler when it is being applied to the EPP. An automatic transfer switch should not be used because this could allow grid power to be applied back through the vehicle outlet when power is restored. NEC Article 702.4 requires the PEV inverter to have adequate capacity and rating to supply all of the equipment intended to be operated at one time.

If a home has a renewable energy power system that is designed to switch over to become the voltage and frequency source for an islanded home following a grid failure, this could cause problems if the PEV is connected in parallel using V2H-EPP mode. In this case, both inverters would be independently setting the voltage and frequency for the home. This could create stability and load balancing problems. The PEV could be connected through the EVSE in V2G-AC mode if it was downstream of the transfer switch, but it is likely that the inverter would trip out in a weak microgrid. An external system may be able to perform load balancing by adjusting the voltage and frequency setpoints of the sources.

NOTE: For this version of the document, it will be assumed that the PEV will be the sole power source for any off-grid operation.

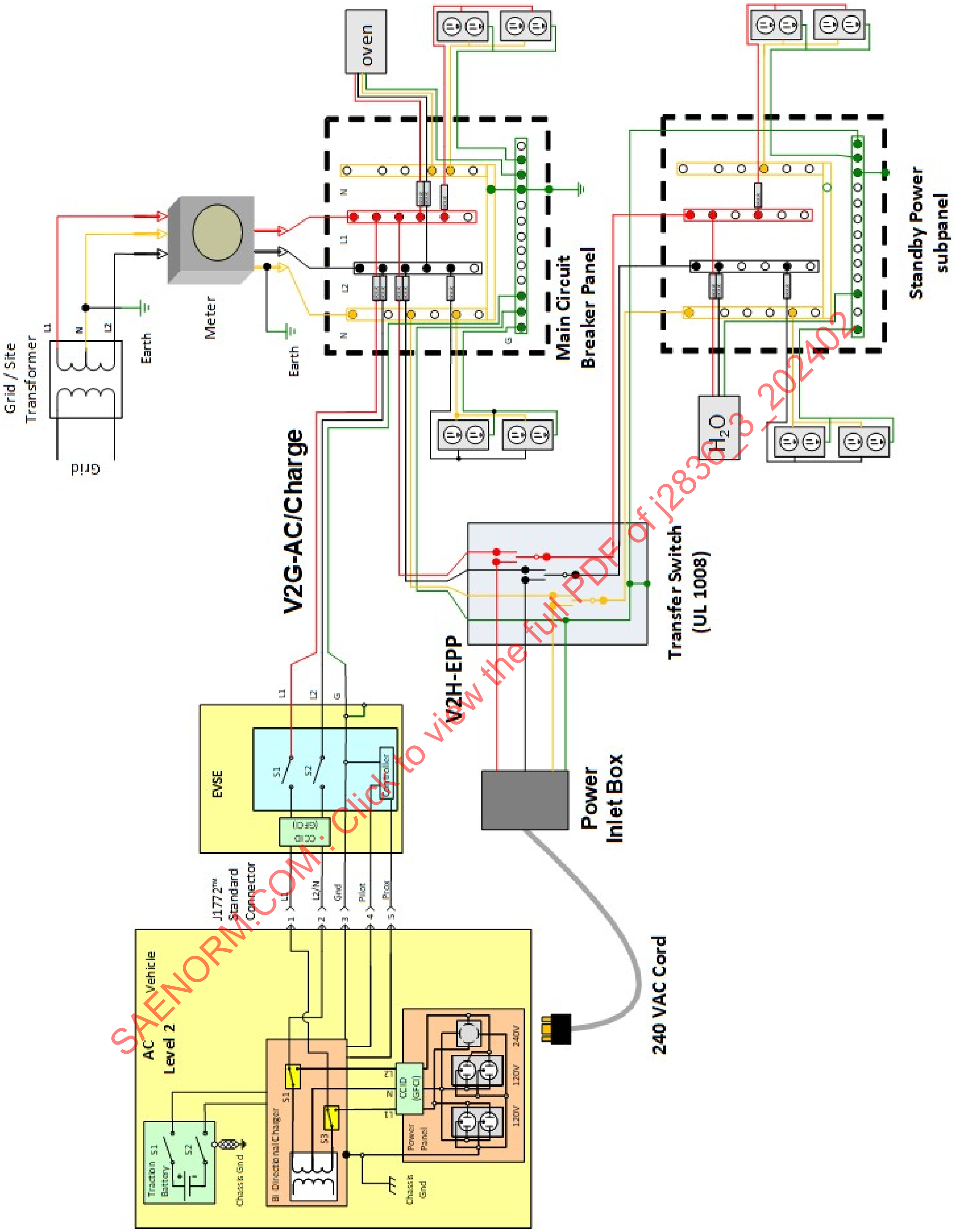





*Figure 4 - V2H-EPP and V2G-AC with onboard inverter*

### 4.2.2 Vehicle-to-Grid Using Onboard Inverter (V2G-AC)

An example of the integration of a PEV with an onboard inverter and an AC Level 2 EVSE for V2G-AC is shown in Figure 4. The L1 and L2 lines from the EVSE are connected to circuit breakers in the main circuit panel of the premises across 240 VAC or 208 VAC. If the home does not support backup power, there will not be a transfer switch leading to a separate panel for critical loads. The transformer serving the home will perform the balancing of the 120-V loads at the premises. No current will pass on the ground circuit from the panel to the EVSE to the PEV. The neutral and earth ground are connected at a single point in the main panel.

This figure also shows the use of a PEV as an optional standby source for V2H-EPP, which is discussed in another section. The PEV would not normally be hooked up to the EVSE and to the backup power port at the same time. This is not a safety concern because the outlets on the EPP must be disconnected from the inverter whenever the inverter is engaged in V2G-AC operation. The EVSE and the backup power port could be located such that it is not even possible.

A special EVSE is required to support V2G-AC. It must meet the requirements of SAE J3072. This is discussed in more detail later in the document. The SAE J1772 control pilot engagement logic will work equally to connect the PEV for either charging or reverse flow. The current limit set by the control pilot will be identical for both forward and reverse flow. The inverter must not source more current than allowed by the control pilot. The normal default should always be for the PEV to engage in charging. The operator must always enable the reverse power flow. This would normally be accomplished using vehicle controls and displays.



The onboard inverter could be a bidirectional or four-quadrant converter. A utility-interactive inverter operates as a current source and synchronizes its output to the grid frequency. This type of inverter must meet the requirements of IEEE 1547, which requires the inverter to stop discharging if the grid voltage or grid frequency falls out of a specified range for a specified duration. This can be as short as 160 ms for certain abnormal voltage or frequency transients. Once the inverter trips, it is not allowed to reengage for 5 minutes after the grid frequency and voltage return within limits. Reverse flow must not be allowed when using an AC Level 1 cordset connected to a standard outlet in the premises. A utility-interactive inverter designed to operate into a grid voltage of 240 VAC will automatically prevent reverse flow into a 120 VAC nominal voltage.

For manually controlled, pure reverse power flow, no communication between PEV and EVSE or beyond is required, except as defined by SAE J3072. Steady reverse flow can be completely managed by the vehicle operator using only those PEV controls and displays provided by the VM. The vehicle operator can set the output power up to the limit established by the control pilot.

The more advanced V2G-AC applications will require the PEV to operate as a DER device. These will require communication with an EMS in the home, at a utility, or with a third-party aggregator. The EMS needs to be able to communicate with the PEV inverter to coordinate forward and reverse power flow. A primary purpose of this document is to define the communication requirements between the PEV and the EMS to enable operation of the PEV as a DER in V2G applications.

### 4.2.3 Vehicle-to-Grid Using DC Reverse Power Flow (V2G-DC)

V2G-DC is fully defined by SAE J2847/2 (2023-09 or later). The PEV battery can be used as a source of energy for an external inverter in the EVSE. The external inverter draws DC current from the PEV. Bidirectional power conversion electronics could allow the EVSE to operate as a DC charger and also be capable of acting as a utility-interactive inverter. A four-quadrant power converter could also be provided.

The same SAE J1772 engagement logic will be used for DC charging and discharging. Just as for DC charging, communication is required between the EVSE and the PEV. Powerline carrier on the control pilot will be used for digital communication, on the 5% PWM value. Requirements are defined in SAE J2931/1 and SAE J2931/4. The communication messages for controlling reverse power flow are defined by SAE J2847/2. SAE J2847/2 will require some additional messages or expanded definitions (to allow negative currents, for example) to allow DC reverse flow. If the vehicle's BMS and communication capability are not capable of supporting reverse power flow, reverse flow will not be possible even though the external electronics are capable of generating AC power.

Any EVSE with an inverter will by design support DC reverse power flow. It will include all of the SAE J2847/2 communication capability needed to draw DC reverse power from a PEV that supports DC reverse power flow. It is possible that some PEVs may not support reverse flow from the vehicle battery to the EVSE. The communications may not support it, or the vehicle itself may not support it. In this case, the PEV and EVSE will only be able to perform DC charging.

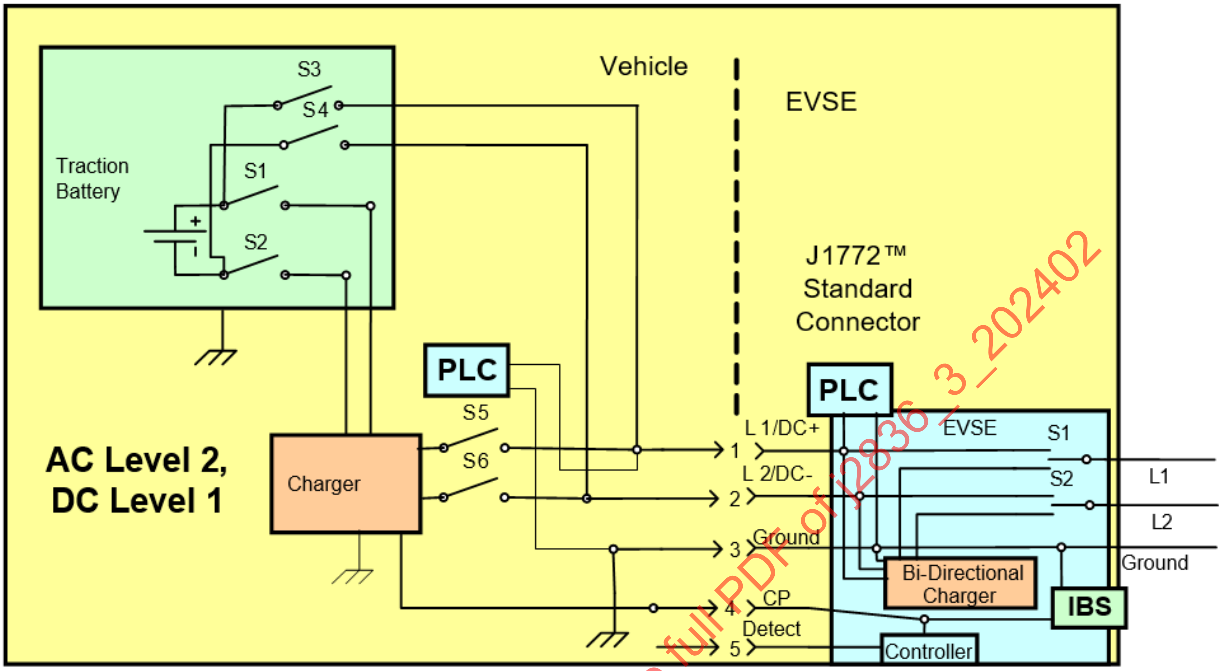



*Figure 5 - System architecture for DC Level 1 V2G-DC*

For DC charging, the SAE J1772 standard connector can be used, and this is called DC Level 1 charging. The connector pins are limited to 80 ADC. Figure 5 shows the standard SAE J1772 connector with external conversion using the DC Level 1 interconnection to the EVSE. With a 500-VDC battery and 80 A of DC current, this would transfer power at 40 kW. The actual power transfer would be limited by the premises branch circuit rating. A DC Level 1 charger on a 240-VAC 40-A branch circuit will have an effective power limit of 7.7 kW. The same will be true for reverse flow. An external inverter on a 40-A circuit will need to limit current to 32 A (80%) and deliver no more than 7.7 kW to the premises continuously. The EVSE power electronics could potentially be limited to a lower value. And the PEV battery may also constrain the maximum DC current. The maximum transfer will be based on the lower of the ratings established for the battery, the electronics, the branch circuit, the connector rating, and other constraints.

Figure 6 shows the combo SAE J1772 connector with external conversion. The combo connector uses the same core as the standard connector and adds terminals 6 and 7 to accommodate DC Level 2. The combo connector is limited to 200 A which would transfer power at 100 kW for a 500-VDC battery. Again, the rating of the EVSE, the circuits supplying the EVSE, and the current limits set by the BMS will govern the actual maximum transfer capability.

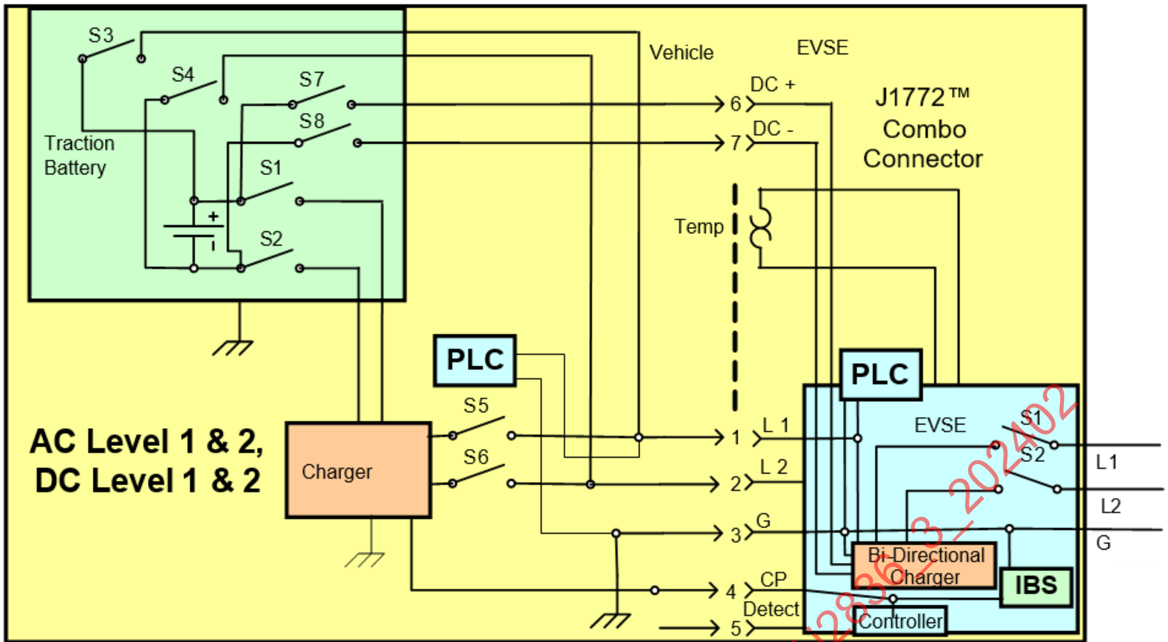



*Figure 6 - System architecture for DC Level 2 V2G-DC*



While reverse flow and VAR capability can be provided for all DC levels, it is not as likely that DC Level 2 or DC Level 3 charge stations could be effectively used to participate in utility use cases using only the connected PEV as a source of stored energy. These are expensive specialized systems, and their purpose is to quickly charge a PEV. PEVs don't generally connect to these charge stations for very long. However, it is possible that a site with several charge stations could draw on reverse flow and VAR capability to help smooth grid power fluctuations as PEVs come and go from the location. It is more likely that a lower-cost DC Level 1 EVSE, that can afford to be occupied for extended periods, would be used for V2G applications.

#### 4.2.4 Vehicle-to-Grid (Home) Using Wireless Power Transfer (V2G-WPT, V2H-WPT)

SAE J2954 establishes an industry-wide specification that defines acceptable criteria for interoperability, electromagnetic field and compatibility, minimum performance, safety, testing, and alignment for the wireless power transfer for electric and plug-in electric vehicles. SAE J2836/6 establishes use cases for communication between PEVs and the EVSE for wireless power transfer as specified in SAE J2954. SAE J2847/6 establishes requirements and specifications for communications messages between wirelessly charged electric vehicles and the wireless charger.

The published versions of these documents (as of the publication date of this document) only address unidirectional charging, from grid to vehicle, but bidirectional energy transfer may be evaluated for a future standard.

V2G-WPT is the term used to designate potential future capability for an off-board bidirectional or four-quadrant converter to use bidirectional wireless power transfer with the electric vehicle to engage as a DER. The ability to perform V2H-WPT without any facility power is more complex than for V2H-DC, so the V2H-WPT mode will not be considered for now.

4.2.5 DC Reverse Power Flow for Off-Grid Applications (V2H-DC, V2L-DC, V2V-DC)

V2H-DC and V2L-DC are fully discussed in SAE J2847/2. V2H-EPP using a vehicle onboard inverter was described earlier, where power flows from the vehicle to the home transfer switch using the vehicle EPP and not by the charging connection to the EVSE. An external inverter (EVSE) could be designed to use an internal “cold start” battery to operate its control pilot and other electronics when grid power is not available. This type of inverter could regulate voltage and frequency when it is not connected to the bulk grid. This type of V2H operation will be called V2H-DC because it uses external conversion with a special cold start external inverter. The inverter could act as a current source when it is operating in V2G mode into a live grid or microgrid. Some grid-tied inverters used with home solar (PV) systems have this mode switching capability today and can even automatically operate the premises transfer switch to isolate the home from the grid. This is shown in Figure 7.

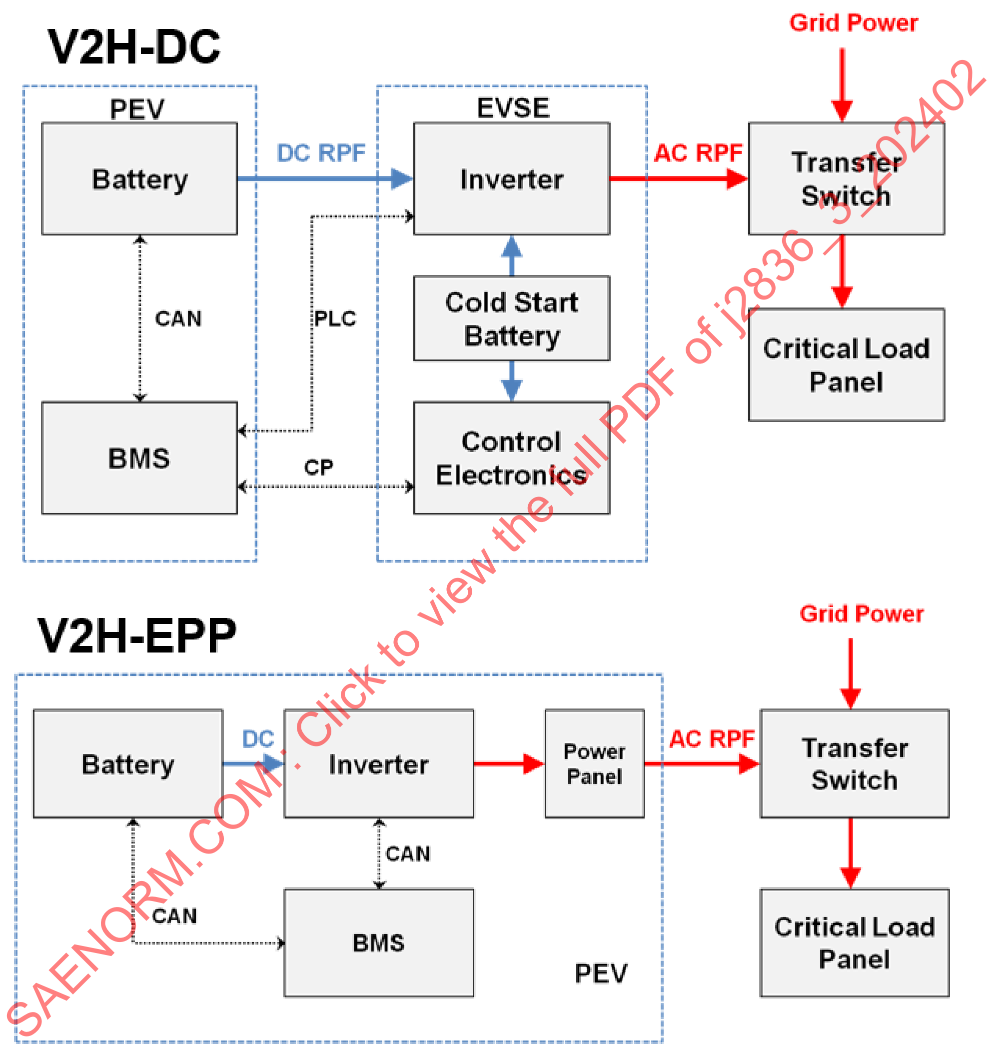




***Figure 7 - V2H-EPP and V2H-DC reverse power flow***

V2G-AC and V2G-DC behave the same way beyond the EVSE. The V2G term will be used for both in other sections of this document. The external inverter does not need a battery backup for the control pilot if it is only going to be used with a live grid or in an islanded microgrid with another device serving as the frequency and voltage regulator. Because the grid safety is associated with the inverter, there may be some differences in the communication approach with the vehicle and the EVSE and inverter behavior when using onboard V2G-AC versus external V2G-DC.

For DC reverse flow, the vehicle cannot discriminate between V2G-DC and V2H-DC. It is all just reverse DC flow from the vehicle, and the full responsibility for compliance with IEEE 1547 rests with the external inverter.

For a vehicle equipped with an onboard inverter in a home that only has an AC Level 2 EVSE and that has the required transfer switch, the emergency backup power for the home can be provided using the V2H-EPP capability. If the home does not have the required transfer switch, the V2L-EPP capability could be used to provide power to specific home appliances using extension cords.

If the homeowner wants to have a DC Level 1 charging capability to allow faster charge times, it may be worth buying a DC Level 1 bidirectional or four-quadrant converter with the ability to operate off-grid. There are many possible variations of the design that could include automatic transfer switches. This equipment would allow for faster charging and automatic islanding and backup power for the home. This would also allow higher power V2G-DC operation than might be available using an onboard inverter through an AC Level 2 EVSE (V2G-AC).

It is also possible to design a portable battery powered converter unit to provide V2L-DC capability using the vehicle charging receptacle for DC reverse power flow. This could allow higher power transfers than could be provided using an onboard inverter. A custom V2L-DC unit may be an alternative to using a large portable genset if the vehicle onboard inverter can't provide sufficient V2L-EPP power for use at remote sites. It's not likely that anyone would carry around such a large converter just for emergency V2V-DC use. It is easier to call a specially equipped service vehicle or use an onboard V2V-EPP capability with an AC Level 1 cordset.

#### 4.2.6 Vehicle-to-Home (Load or Vehicle) Using Modified EVSE (V2H-AC, V2L-AC, V2V-AC)

During V2G-AC operation, the onboard utility-interactive inverter may be required to stop discharging as a current source in as short an interval as 160 ms following a collapse of grid voltage or frequency. The loss of grid power would also impact the EVSE control pilot circuits, and this would cause the PEV to disconnect its power circuits from the charging receptacle. When utility power is restored, the EVSE control pilot would become active and the PEV could be able to resume V2G-AC operation. The onboard inverter system is certified to meet these grid safety requirements. V2H-AC is discussed in J2847/3, and V2L-AC and V2V-AC are discussed in J2847/5.

If the home was intentionally disconnected (islanded) from the utility grid following a power failure or for other reasons, a regular AC EVSE would not be able to engage the PEV for charging or discharging unless a backup power source, such as a PV array, was supplying the islanded home. In this situation, the PEV might be able to engage in V2G-AC operation to supplement the primary power source.

However, a special AC Level 2 EVSE could be designed with a small rechargeable battery or other source to power the control pilot electronics when grid power is not available. If the VM provided a means to switch the onboard inverter from grid-tied operation to acting as a voltage and frequency regulator, the PEV could become a power source for the islanded home. This is known as V2H-AC. The vehicle operator would need to be very careful to ensure that the home is disconnected from the utility grid, because this would create a safety hazard to put power back into a failed distribution circuit. The vehicle operator must also ensure that no other power source is independently engaged and regulating frequency and voltage. The VM is relying solely on the operator for ensuring the safety of this V2H-AC operation because it is not possible for the vehicle to directly measure whether the home has been islanded or the grid has failed. This is true for V2H-EPP, but this mode requires a special connection to be made between the vehicle EPP and the home emergency backup port.

It may be possible to design the V2H-AC EVSE and the PEV to automatically switch from V2G-AC to V2H-AC operation following disconnection of the home from the utility grid. This would require high integrity communication to ensure that a PEV only automatically engaged in V2H-AC operation if the home is disconnected from the utility grid and the PEV is the primary source for voltage and frequency regulation for the islanded home. While automatic mode change may provide a more convenient response to a grid power failure, the lack of actual operator engagement in the mode change has higher risk to unintentionally feeding power back into a failed grid.

A special portable AC EVSE box with NEMA outlets could be created to allow V2L-AC operation. It is not clear why such a box would be created if vehicles with onboard inverters are directly equipped for V2L-EPP. The V2L-AC box would not have the safety implications discussed for V2H-AC because it would be clear that the loads were isolated from the grid.

NOTE: V2H-AC using an onboard inverter with a modified AC L2 EVSE will not be considered further in this version of the document. The preferred approach would be to use either V2H-EPP or V2H-DC for this purpose. It is less risk for the VM to only allow the onboard inverter to operate in V2G-AC mode when connected to the AC EVSE.

### 4.2.7 Vehicle to Microgrid (V2M-AC, V2M-DC)

This document looks at V2G applications at several levels in the EPS: at the level of the bulk grid, at the level of the distribution feeder, and behind the meter. But in each domain, the inverter, whether onboard the PEV (V2G-AC) or in the EVSE (V2G-DC), is considered to be connected to the bulk grid. V2M-AC and V2M-DC designate modes where a smart inverter operating in a V2G mode may need to be coordinated by a microgrid EMS to balance power delivery.

There is much discussion today about microgrids. When a microgrid is connected to the bulk grid, there is no impact on the ability of a PEV using V2G-AC to engage in reverse flow and maintain full compliance with IEEE 1547. The inverter operates as a current source synchronized with the bulk grid frequency. The inverter must trip in as short a time as 16 ms if the bulk grid frequency or voltage falls outside defined limits. But if the PEV is in a microgrid which is disconnected (or islanded) from the bulk grid, an IEEE 1547 compliant inverter may prove to be too sensitive for this application. The PEV does not have enough power to shift the bulk grid frequency, but if the PEV is one of several distributed resources in an islanded microgrid, it may have enough power to shift the microgrid frequency and force itself to trip off. This is acceptable if the PEV is not “certified” to operate in an islanded microgrid. But this may not be the desired outcome if the microgrid is depending on one or more PEVs to provide power in the islanded microgrid.

NOTE: Inverter operation in an islanded microgrid, other than as a current source and in strict conformance to IEEE 1547, will not be considered in this version of the document.

### 4.2.8 DC Microgrids (V2D-DC)

Figure 8 shows the use of a DC microgrid for power distribution within a facility. This architecture could be used for any level of DC charging. However, for the purpose of this discussion, assume that this is a “park and charge” location and that DC Level 1 charger stations will be used on a 380-VDC circuit in place of AC Level 2 charge stations on 240-VAC circuits. The DC microgrid facilitates the interconnection of solar PV systems, small wind turbines, and facility battery banks. This eliminates potential problems of integrating many grid-tied inverters into a facility AC power distribution system because the DC microgrid uses a single utility-interactive inverter to connect all the DC power flows with the grid. The microgrid can also support DC loads and electronically controlled motors (just as is done with the PEV traction motor).

A considerable number of off-board DC chargers are expected to be AC-to-DC converters. However, if the facility has a DC energy source (stationary storage or PV), consideration should be given to a DC-to-DC converter that is generally more efficient than an AC-to-DC converter; plus, it only requires one conversion, instead of DC to AC to DC. All the communications defined by SAE J2847/2 between the charger and the PEV can remain unchanged. The source of power to the charger is not of concern the PEV. There is no such thing as a four-quadrant DC-DC converter. Only bidirectional DC power flow is possible, and this prevents the PEV from directly engaging in providing VAR to the grid. Only the facility inverter can do this using DC power from the PEVs. The basic DER functionality could be used to control forward and reverse power flows by the facility inverter or even beyond.

A 380-VDC bus, shown in Figure 8, is a reasonable level for DC-DC conversion for vehicle batteries from 200 to 600 V. This bus voltage is being promoted by the Emerge Alliance, although a 600-VDC bus might be more appropriate for a fast charge facility to minimize current flow. These are facility decisions, but they do impact the design of the DC-DC converters.

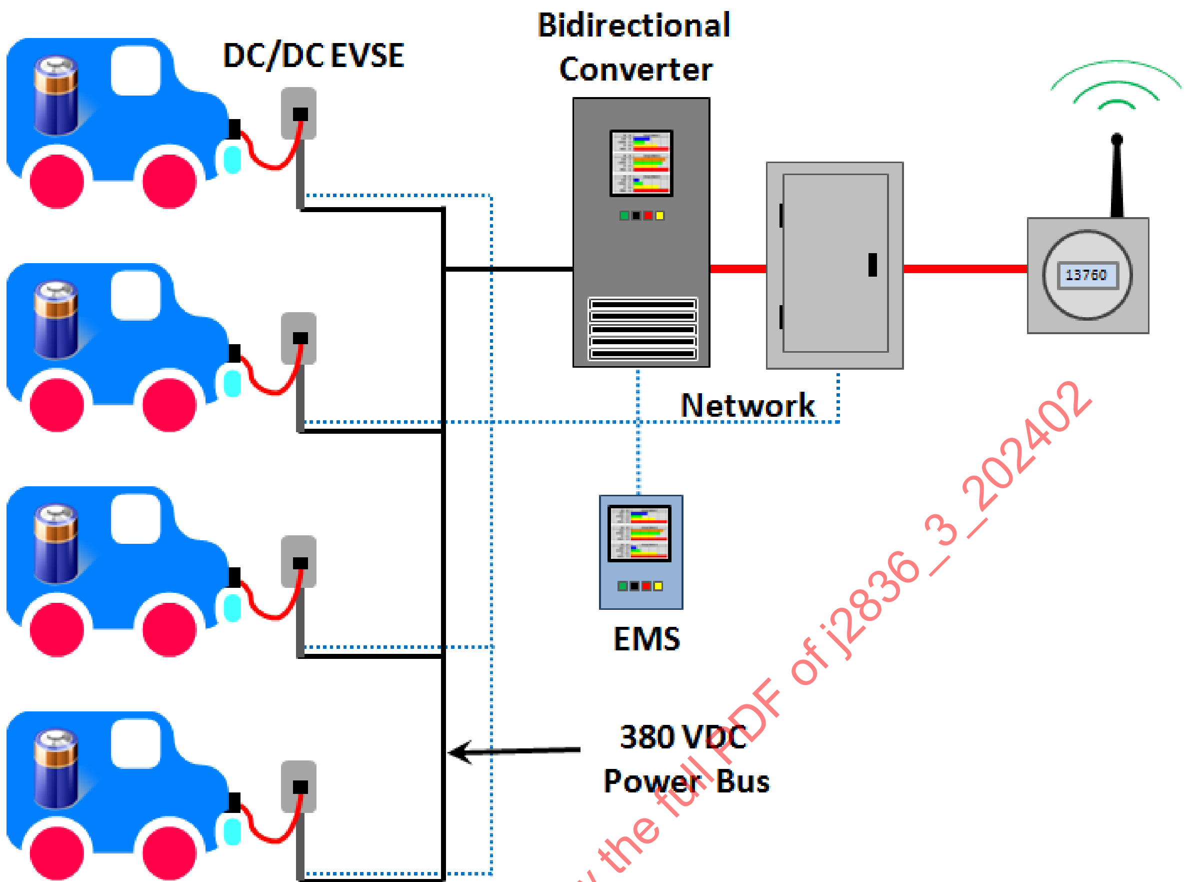



*Figure 8 - DC microgrid (V2D-DC)*



4.2.9 Use Case PR2 - Customer Discharges the PEV

Several scenarios for the use case PR2, customer discharges the PEV, are defined in Appendix B. The V2G scenarios provide for either manually setting the discharge power or enabling the PEV to participate in a DER program. For the other modes, the inverter is manually activated as a voltage and frequency source. Communication is not required with any EMS for basic discharging. Communication is required with an EMS for the PEV to participate as a DER. Manual operation is performed using vehicle controls and displays.

The scenarios are listed in Table 3. The naming convention begins with the type of reverse power, followed by whether the power flow is controlled manually (MAN) or as a DER device, and then by whether the transfer of power from the PEV is by EPP, SAE J1772 AC, SAE J1772 DC, or wireless (WPT). Discharging under scenario PR2-V2G-DER-AC is of V2G-AC type, controlled as a DER device, using SAE J1772 AC transfer from the vehicle. DC transfer is always from the PEV to an external inverter in the EVSE and uses the conductive coupler.

*Table 3 - Scenarios for use case PR2*

| Use Case PR2 Scenario Name | Use Case PR2 Scenarios Characteristics | | | |
|---|---|---|---|---|
| | Type | Control | Inverter | Outlet |
| V2G-DER-AC | V2G-AC | DER | Onboard | SAE J1772 |
| V2G-DER-DC | V2G-DC | DER | External | SAE J1772 |
| V2G-DER-WPT | V2G-WPT | DER | External | Wireless |
| V2G-MAN-AC | V2G-AC | Manual | Onboard | SAE J1772 |
| V2G-MAN-DC | V2G-DC | Manual | External | SAE J1772 |
| V2G-MAN-WPT | V2G-WPT | Manual | External | Wireless |
| V2H-MAN-EPP | V2H-EPP | Manual | Onboard | NEMA |
| V2H-MAN-DC | V2H-DC | Manual | External | SAE J1772 |
| V2L-MAN-EPP | V2L-EPP | Manual | Onboard | NEMA |
| V2L-MAN-DC | V2L-DC | Manual | External | SAE J1772 |

## 4.3 Communications for Reverse Power Flow

The inverter is the focus of all communication for reverse power flow. The inverter can be in the PEV with AC power routing through the EVSE to the electric power infrastructure (V2G-AC). Alternatively, the inverter can be in the EVSE and DC power flows from the PEV through the coupler to the inverter in the EVSE (V2G-DC). In both cases, the PEV and EVSE work as a pair to provide reverse power flow to the grid.

The vehicle operator must be able to interact with controls and displays on the PEV, the EVSE, or other equipment to enable and manage reverse power flow. There are two distinct ways to communicate with the inverter to manage reverse power flow. One way is for the vehicle operator to use the human machine interface (HMI) on the PEV or EVSE to manually initiate and terminate pure reverse power flow, and no communication with any external EMS or another controller is involved. The second way is for the vehicle operator to enable the PEV to participate as a DER device, and an EMS will initiate, manage, and terminate reverse flow as needed. This is illustrated in Figure 9.

For both situations, controls and displays must be provided for the operator to enter the required information and enable actions. The vehicle and EVSE manufacturers will provide proprietary controls and displays for this purpose. Some information and commands must be directly entered using PEV controls and displays, and alternate data entry locations may not be permitted. For other information, the preferred data entry location may be at the inverter, which could be onboard the PEV or in the EVSE. Alternate data entry locations, such as a premises EMS or a mobile device, may be authorized for certain information.



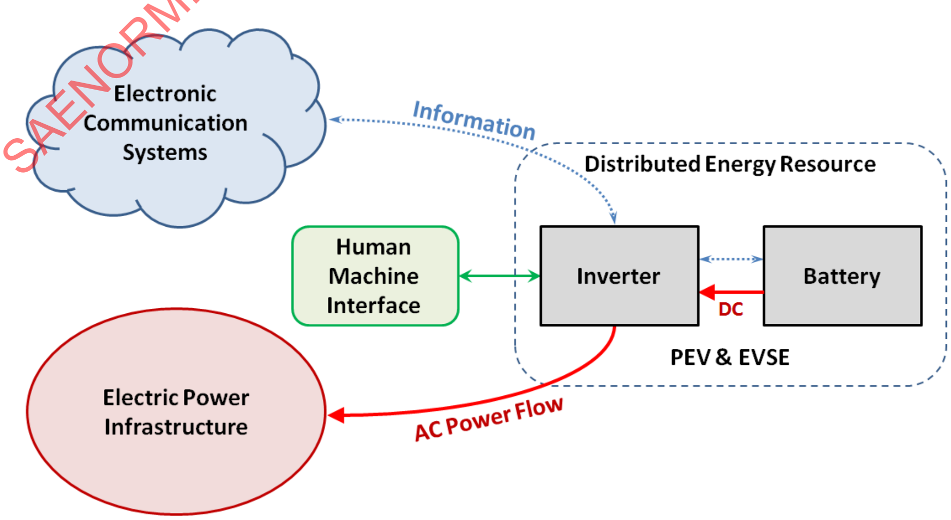



*Figure 9 - Interfaces with inverter of a DER device*

#### 4.3.1 Data Entry, Customer Communications, and Sources of Information

It may be possible to enter data at multiple locations. For example, the data entry for the "time charge is needed" (TCIN) could be done using controls and displays of the PEV, the EVSE, or even a remote device. However, the data entry is not the actual "information" until it is accepted by the designated "source" of that information, which is not necessarily the data entry location. Think of a data entry as potential value for the information, and it does not become the actual information until the designated source for that information accepts, validates, and prioritizes the information.

TCIN is a key parameter that defines the state of the PEV. The PEV must be the source for that information. Even when TCIN is entered into the PEV controls and displays, it must still be validated by logic in the vehicle before it is accepted. If there is an error in data entry (for example, a time earlier than the current time), the PEV HMI software should indicate an error and ask the operator to correct the information. The data entry should only be stored in the PEV as TCIN after it has been validated. Then, any other entity that needed to know TCIN could request it from the PEV.

If TCIN were entered into the EVSE, the EVSE might do some validation, such as earlier time than present time, and then it would need to provide it to the PEV for the PEV to consider. The EVSE should only hold the data entry for a potential value for TCIN. After the vehicle processes the data entry and updates its TCIN, then the EVSE will be able to request TCIN from the source, which is the PEV.

Data entry, while it may come from multiple places, should always go to the source where it is transformed into validated information. The source entity should determine the protocol for selection - such as last entered rules, or lowest power rules, or PEV rules. If the source cannot communicate - for example, the PEV can't communicate with an EVSE, but TCIN was entered into the EVSE - the EVSE might use its data entry for TCIN in lieu of the PEV TCIN value because it cannot access the "source." But these rules would be embedded in the operational software of the EVSE.

These are not communication protocol decisions. These are decisions that are made by the embedded functional software in the application. The communication protocol must allow for the data entry for certain information to be moved from the HMI device to the "source" device for the information.

The use cases in this document will assume that data entry is made and validated and moved to the designated "source" device. It will assume, for example, that TCIN is entered on some control panel and that TCIN will be available from the PEV as the sole designated source when needed.

#### 4.3.2 Manual Control of Reverse Power Flow

The most basic V2G capability is to have the vehicle operator connect the PEV to the grid through an AC Level 2 EVSE and manually engage the PEV onboard inverter using controls and displays provided by the VM (V2G-AC). The EVSE must be certified to SAE J3072 (as discussed in 4.9). The EVSE provides site DER settings for the onboard inverter and authorizes the PEV to discharge. The SAE J1772 control pilot establishes the maximum forward and reverse AC current that can be supported by the premises branch circuit. The upper discharge limit is the lower of the rating of the onboard converter, the maximum discharge rate setting provided by the EVSE, and the control pilot. The AC EVSE cannot be used by itself to engage the PEV in discharging. But if the PEV is set up to discharge (rather than charge) when it detects the EVSE is ready, the EVSE can control the start and stop of discharge. The EVSE can also reduce the discharge level below that of the rating onboard inverter by using the control pilot. The VM could provide the capability for the PEV to start charging immediately, to start after a programmed delay, or at a programmed time. The PEV could also allow discharging to be stopped immediately, after a programmed delay, at a programmed time, or when the battery state of charge reaches a specified minimum level. It is also possible to set a lower power (current) limit for the session. These manual control modes are at the discretion of the VM.

For DC discharging, digital communication is required between the PEV and the external power convertor (EVSE) to manage the actual DC reverse flow (V2G-DC). The communication required for the PEV to coordinate with the external converter (EVSE) for both forward and reverse DC power flow is defined by SAE J2847/2. The same vehicle controls and displays used for onboard conversion could be provided to initiate and control external conversion. While the digital link between the EVSE and the PEV could allow an intelligent EVSE to initiate reverse flow rather than charging, it is preferred that the selection of manual reverse versus forward flow be performed using a specific vehicle authorization. It may be possible for a vehicle operator to enter this authorization into the PEV using EVSE controls. This maintains the same relationship as that used with an AC Level 2 EVSE. An intelligent AC or DC EVSE can control start and stop but should not provide the authorization to enter reverse flow. The default without specific authorization for reverse flow using vehicle controls should be to start charging.

A homeowner might use this manual control capability for PEV reverse flow to offset other home loads at peak times and then recharge the PEV at off-peak times. While it is possible to just discharge into the grid by manually programming the PEV or the EVSE, it is preferred to use a home EMS for this type of operation. Many utilities offer net metering programs and allow, for example, a home photovoltaic system to push power into their grid. However, other utilities may only allow the residential load to be offset and do not allow reverse flow to the grid. The meter may not even be capable of reverse flow. In this type of region, a homeowner would have to calculate the home load and then set the power output of the PEV to be less than that. This could be dynamic. A home EMS would be able to keep track of this and adjust the PEV output to maintain a net zero for the home.

Manual control is the only way to engage the onboard inverter to supply power to the EPP for V2H-EPP, V2L-EPP, and V2V-EPP. The VM may even provide a capability to manually engage reverse flow through telematics. There could be different degrees of sophistication for modes of operation depending on the VM. The vehicle could provide programmed start and stop times or time delays for V2H-EPP operation. For these modes, the inverter operates as a voltage source and the power delivered is determined by the loads. It cannot be set to a specific power delivery as it can for V2G-AC operation. If the load is too large for the inverter, it will reach a current limit and either trip or allow the voltage to sag.

A Plug-in Hybrid Electric Vehicle (PHEV) may offer the capability to operate the engine to maintain the charge of PEV battery during reverse flow. This should always be engaged manually at the PEV to allow the operator to ensure that there is adequate ventilation, and it is safe to operate the engine. While engaging the engine for emergency backup in off-grid V2H-EPP situations may be useful, it would not be environmentally friendly to use the engine for rate arbitrage in V2G-AC operation, and it may not even be cost effective.

### 4.3.3 Examples of Manual Control Data Entry

The operator must be able to use controls and displays on the PEV, the EVSE, or on a remote device to start, stop, and set the power for reverse flow. These settings are shown in Figure 10. For V2G operation, the power level must be defined. This can be done as an explicit value or as a percent of the maximum available reverse power. The display could show both values as the setting is entered. Data entry for power is not required for V2H or V2L because the inverter regulates voltage and frequency, and power is determined by the load. It may be desired to allow for some minor adjustment of these setpoints.



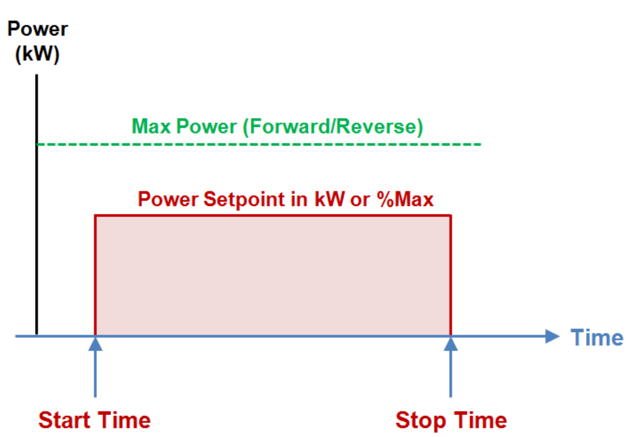



*Figure 10 - Key parameters for manual control*

The manual controls for starting reverse flow must include a start now capability. Controls may also provide for starting after a time delay or starting at a specified local time. The controls should not allow entry of a negative delay or a starting time earlier than the current time. These are illustrated in Figure 11.

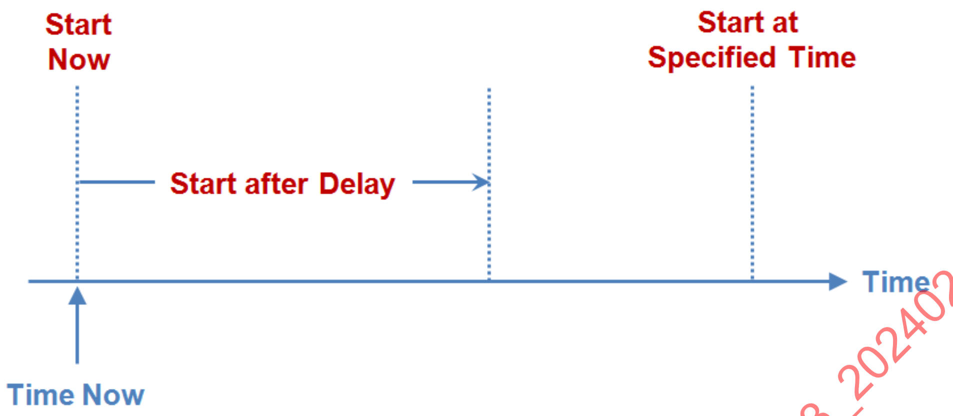



*Figure 11 - Options for manually controlling startup*

The manual controls for stopping reverse flow must include a stop now capability. This immediate stop capability must be prominently displayed whenever reverse flow is being provided. Controls may also provide for stopping after a specified duration of reverse power flow or stopping at a specified local time. The controls should not allow for entry of a negative duration or an earlier specified stop time than the actual start or expected start time. These are illustrated in Figure 12. Manual controls should also be provided for defining a minimum state of charge. This is an additional condition, and reverse flow would stop at the earlier of the designated stop time or the battery reaching the minimum state of charge (SOC).

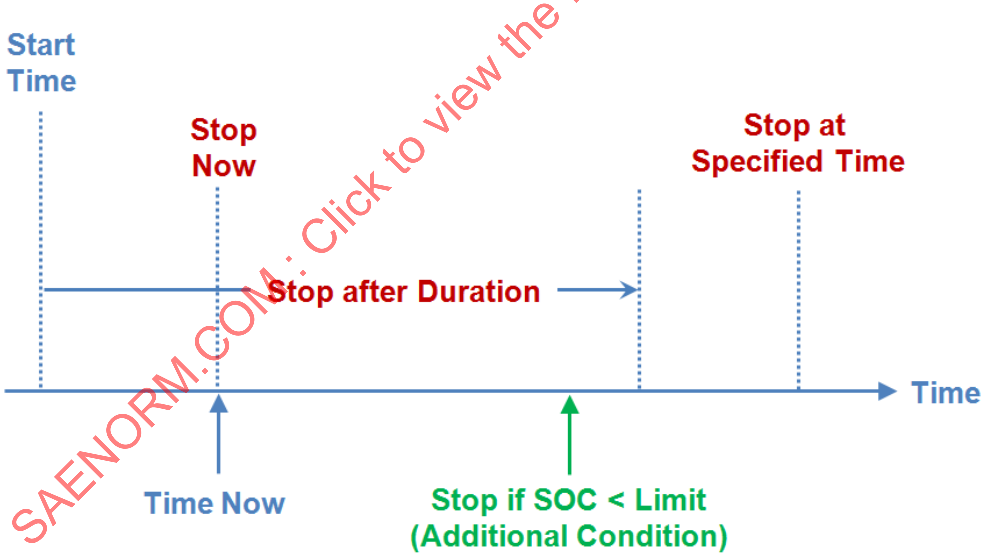



*Figure 12 - Options for manually controlling termination*

4.3.4 EMS Control of Power Flow

Figure 13 shows 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 balancing authority, 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 could 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 and an EVSE.

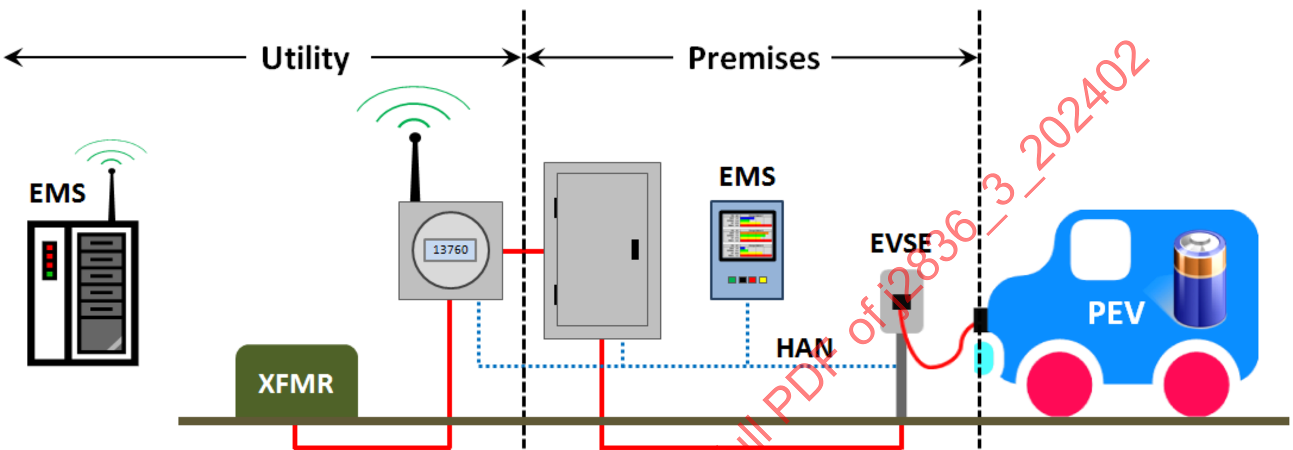



*Figure 13 - Relationship of the utility, premises, and PEV*

V2G operations can be performed in different domains: the bulk grid (or balancing area), the distribution system, and behind the meter. All of these V2G applications depend on communication between some EMS and an EVSE and PEV pair. There is the potential to have an EMS in each of the electric power domains. They might not always be called an EMS, but it's a good generic name.

The figure shows a home area network (HAN) connecting the meter, premises EMS, and EVSE. This could be any media from ZigBee to Wi-Fi to cable to PLC. The EVSE is directly connected to the network, and the PEV connects to the EVSE using PLC. The EMS could use a wireless link to connect directly to the premises network. In a private residence, the network could be based on internet and SEP2 (as could the PEV). Other protocols (such as BACnet) could be used in commercial or industrial facilities. In this case, network protocol translation could be performed by the EVSE. The figure shows the utility EMS communication coming through the meter (as it could with the advanced metering infrastructure, AMI), but it could come into the HAN through another gateway. This also shows the utility using a radio frequency link to the premises, but it could be by internet on optical fiber or cable.

V2G applications will require communication between some EMS and the EVSE-PEV pair. Also, the applications will require control algorithms to be executed by the EMS and the EVSE-PEV pair. V2G applications will require communication to a network to engage with an external premises or higher tier EMS. The PEV could use PLC to communicate with an EVSE that is connected to a premises network for the purpose of engaging in higher level V2G applications. There may be other communication options, such as Wi-Fi, that could be used by the PEV to directly connect to a premises or another network.

4.3.5 Electronic Communication With the Inverter

The entity containing the inverter's DER logic and power electronics should be the focus for communications for an EMS because it is the inverter that actually controls the reverse power flow and other DER functions. Messages may be relayed through other entities between the EMS and the inverter, but it is the inverter that must act on the message. This discussion assumes that the EMS communicates with the EVSE using IEEE 2030.5 (SEP2). It is the inverter that implements the DER functionality in its electronics and embedded software. The term "inverter" is broadly used in this discussion. It could be that a computer implements the higher level inverter functionality and sends simple messages on a local bus to command active power (P) and reactive power (Q) settings for the power conversion device. Or a communication device may just decode SEP2 messages and reformat them into CAN or Modbus messages for an intelligent inverter device. Or the inverter device in either the EVSE or PEV may be able to directly accept SEP2 messages, and the PEV communication function could just route these messages to the smart inverter.

Figure 14 shows communication with an inverter in the EVSE. When the inverter is in the EVSE, the EVSE and PEV will engage in DC forward and reverse power flow. This example shows the controlling EMS engaging with an EVSE computer using the DER function of SEP2, as shown by green arrow. The EVSE computer creates P/Q setpoint values to be used by the power electronics based on the DER command messages. This example assumes that the EVSE uses Modbus to communicate between its computer and the inverter power electronics. The BMS in the PEV provides information to the EVSE controller, such as maximum forward and reverse DC current limits that the battery can support, as shown by the red arrow. The messages associated with control of DC flow between the EVSE and the PEV are governed by SAE J2847/2 and use PLC signaling on the control pilot per SAE J2931/4. The example shows the PEV using CAN for internal communication and converting between CAN and SAE J2847/2 message for engaging with the EVSE.

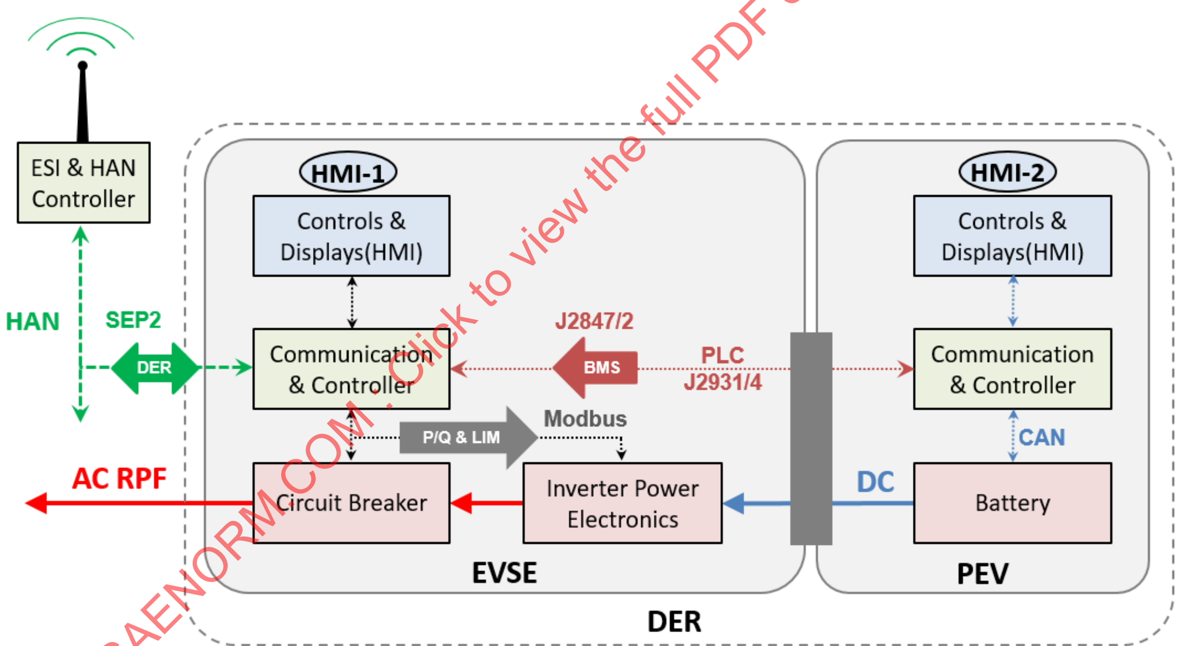





*Figure 14 - Communication with EVSE inverter*

Figure 15 provides an example of communication by an offsite EMS with an onboard inverter. This example assumes that the EVSE has two connections to the HAN. One path is used by the EVSE as a network device for its own purposes, such as allowing an EMS to set the value of the SAE J1772 control pilot signal. The EVSE also provides a capability to directly pass the SEP2 XML encoded internet messages from the EMS to the PEV using a MAC/PHY bridge. The EVSE activates this bridge only if it is secure to do this for the connected PEV. The actual internet content in SEP2 just flows through the EVSE from the HAN to the PEV communication controller. The green arrows designate the SEP2 DER information. The PEV controller processes the SEP2 DER functions and provides P/Q setpoints to the power electronics using CAN messages.

Just as electronic communications should focus on the inverter, the HMI entries should also be at the entity containing the inverter. This involves less communication. If the inverter is in the EVSE, it makes more sense to engage the inverter at the EVSE. Each of the figures shows HMI-1 and HMI-2 for the preferred and alternate data entry location.

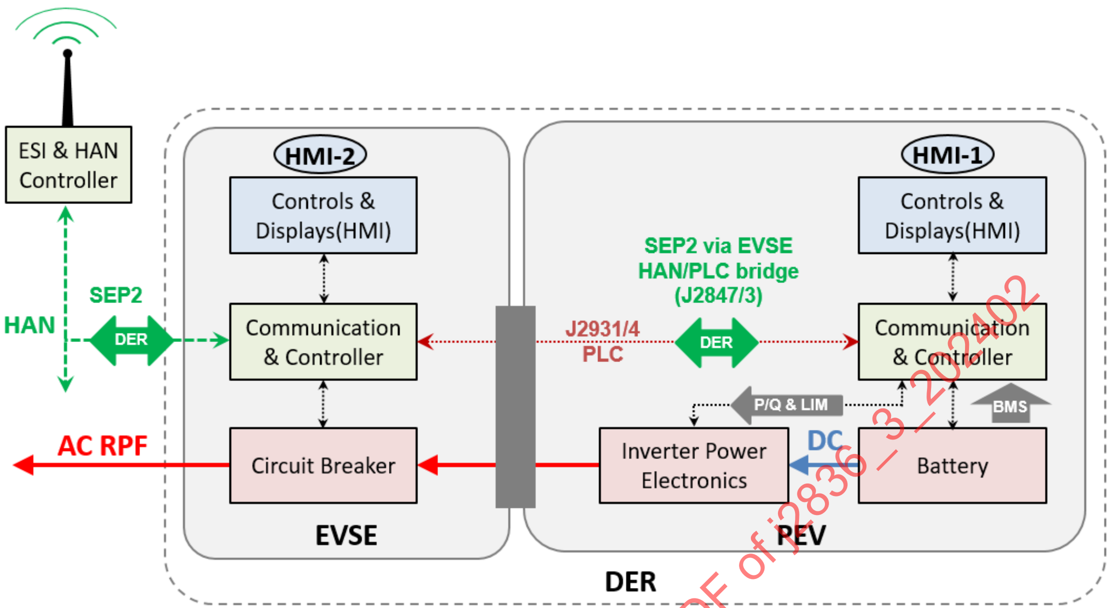



***Figure 15 - Communication with PEV inverter***

4.3.6 Communication Between EVSE and PEV for V2G-DC

Figure 16 expands on Figure 14 to highlight considerations for management of DC power flow of the PEV battery when an EVSE inverter is engaged in performing as a DER for V2G-DC applications. This example assumes that the DER controlling entity and the EVSE communicate using SEP2. The green SEP2 box represents the conversion of the information for use within the EVSE computer. IEC TR 61850-90-7 defines smart inverter functions, and the EVSE is expected to implement compliant functions. This IEC document will be discussed later. The IEC 61850 software in the EVSE would provide P/Q setpoints to the conversion electronics. Unlike for DC fast charging where the PEV controls the charging current of the EVSE, the inverter pulls or pushes whatever DC current it needs to execute the IEC 61850 DER function, subject to DC current limits provided by the PEV BMS. The PEV provides these limits to the EVSE by sending PLC messages on SAE J1772 control pilot. These are encoded using the SAE J2847/2 protocol. The EVSE inverter needs to provide certain DER information and capabilities back to the DER controller, and it needs certain information from the PEV to create the IEC 61850 data. This information will also be defined in SAE J2847/2.

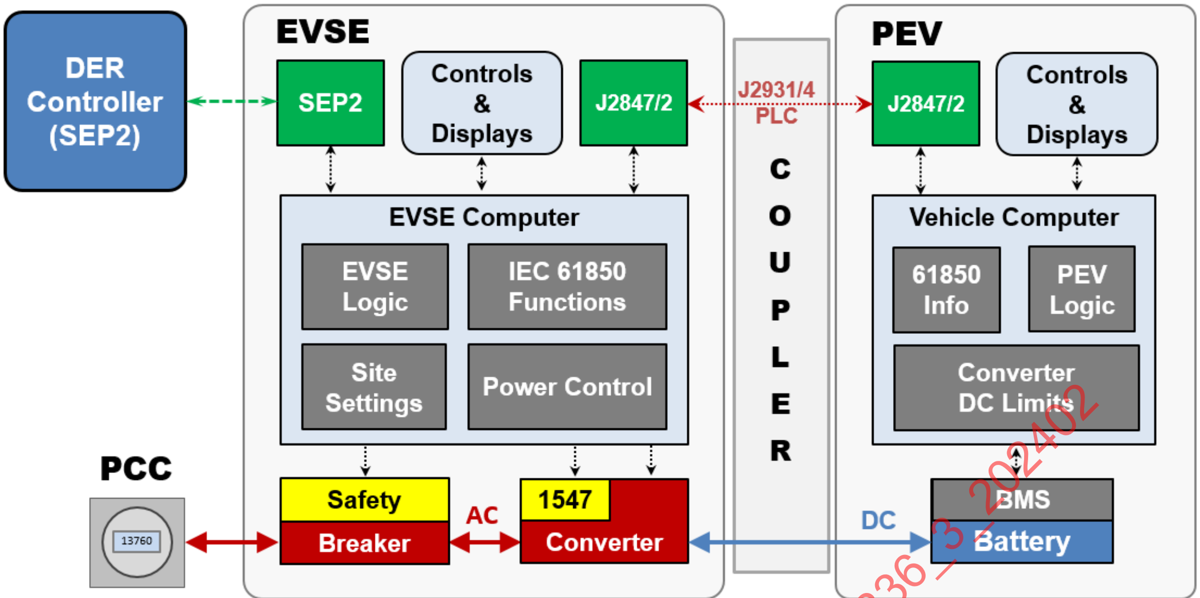



*Figure 16 - External inverter details*



DC power flow needs to be controlled differently by an external inverter than by an external fast charger. For fast charging, the BMS establishes the current profile and effectively controls the entire charging operation by coordinating with the external charger over the PLC link using SAE J2847/2 messages. The fast charger provides current flow as requested by the vehicle. For DER use, the external inverter must control the DC forward or reverse flow from the battery to deliver or absorb power as requested by the controlling EMS. The BMS needs to establish the current limits for forward and reverse DC flow, and the inverter control electronics must manage the current flowing in or out of the inverter to stay within the established limits. The BMS must always protect the vehicle battery by either reducing the authorized limits or even disconnecting the battery, but the current flowing in and out of the battery must be as directly controlled by the inverter. This requires a new DER mode to be implemented in SAE J2847/2.

The DER device must provide a maximum forward power and a maximum reverse power rating to the controlling EMS. The EMS will command power to or from the DER as a percent of these maximum ratings. This will allow the EMS to adjust DER units of different sizes by commanding similar percent. It can also control the exact power output of an individual DER by computing the percent of rating needed to achieve the target power level. The rated maximum should be continuously available over the session. The rating is the lower of the limits established by the battery system, the inverter rating, and any limitations of the branch circuit. Even though a battery may be able to absorb 15 kW, if the EVSE is on a 40-A branch circuit, the maximum forward power for the system will be limited to 7.7 kW, and this is the rating that will be reported to the EMS as the maximum forward power. The flat rated forward or reverse power may not be available across the full range of state of charge of the battery. This limitation is communicated to the EMS from the DER by providing the available duration at the flat rated power for both discharging and charging. The available duration value will change throughout the session change as the SOC changes during DER use. This will be discussed more in 4.6.1. The new DER mode in SAE J2847/2 will provide for any additional information needed by the EVSE from the PEV.

Figure 17 shows a typical charging profile of power versus SOC during fast charging. In this example, the vehicle draws 45 kW up to 20% SOC, and this falls to 15 kW at 80% SOC when fast charging stops. The PEV manages the current provided by the external charger. If the vehicle had a 30-kWh battery and could go 90 miles at 45 mph, it would consume battery energy at a continuous rate of 15 kW. The battery may be called on to deliver 75 kW during acceleration or absorb 45 kW at the start of fast charging, but these are not sustained. For this vehicle, a flat rating for continuous discharge could be 15 kW. The dashed red line at 15 kW represents a VM defined value for the maximum DC forward power that can be used for a DER session. The inverter should be able to command 15 kW of forward power for SOC ranging from 0 to 80%. The fact that the battery could absorb 45 kW at 20% SOC is not useful for using the PEV as a DER device. This is only an example. It is the responsibility of the VM to define the value to be used for maximum DC forward power, and it is not expected that the value would change during a session. The value is intended to be a discharge rate that is achievable for a continuous discharge from 100% SOC to some minimum SOC level. The same approach would be used with other settings.

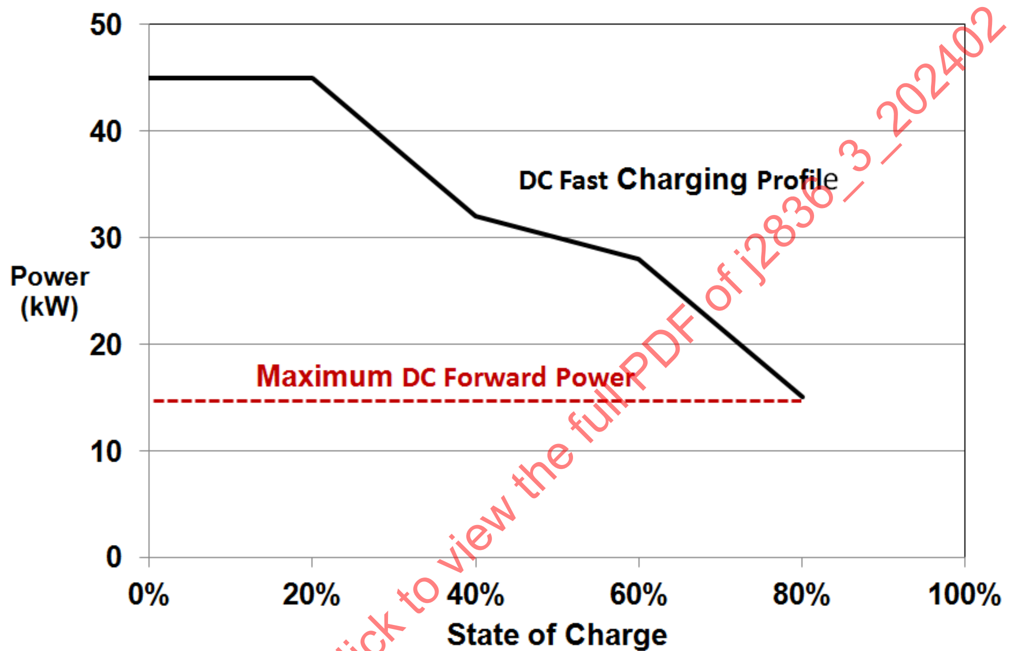



*Figure 17 - Typical fast charging profile*

In the functional diagram, the inverter directly measures frequency, voltage, and current at the ECP of the inverter. It also measures the DC voltage and current. It controls the power electronics to either generate AC current from DC flow from the battery or the reverse. This is not unlike controlling a traction motor. The DER functions can be complex. The volt-VAR autonomous function, when switched on by the EMS, works by measuring the AC line voltage and producing VARs based on a stored curve of VAR versus volts. Another autonomous function measures frequency and either produces forward or reverse active power based on a curve of power versus frequency.

While it is possible to do, it may not be prudent to design a system where the vehicle is expected to include the full DER functional capability and act as the DER device for the EMS and then seek to control the inverter power electronics at a low level by sending current and phase angle commands using the DC control protocol link. This is much more complex than keeping the control functions with the inverter. There are business issues, liability considerations, and other factors that favor keeping the DER functionality with the inverter power electronics.

For an external inverter, this document assumes that the EMS communication will be received by the EVSE. The PEV will not act on DER messages because it is not serving as a DER device. The EVSE inverter and the PEV BMS will coordinate on the DC forward and reverse power flow using communications defined by SAE J2847/2.

4.3.7 Information Exchange Considerations

Organizations may use different terminology and units of measure to describe the same things. This applies to the terminology, sign conventions, units of measure, and typical scale factors. For example, a scientist may prefer to express energy in joules. A power company engineer might refer to electrical energy in kilowatt-hours. A mechanical engineer could express it in foot-pounds or British thermal units. Without knowing the unit of measure, a value of 2.5 for energy is meaningless. Even if the base unit of measure is agreed to be watts, sometimes the scale of the system determines the context of the value. For an electronic device, a rating of 2.5 could mean watts; for a home appliance, it would most likely mean kilowatts; and for a large generator, it would most likely mean megawatts or even gigawatts. When the context is known, the scale is often obvious.

When information is exchanged between two entities, it is important to agree on all of the attributes of the element of information that is to be exchanged. The name that is used to describe it by one entity is much less important than all of the attributes. Two different applications can use different names for an item as long as there is a mutual understanding of all of the attributes when that information is exchanged.

It is critical that anyone using information from a source understand the meaning of that information. For a measured value, the user may need to know exactly what is being measured, the accuracy, the resolution, the units of measure, any power of ten multiplier, when it was measured, how often it is measured, and other characteristics. There are different ways to know. If the communication content is to be minimized between entities, all of the participants can agree on the characteristics of information to be provided by each source. A binary label can be defined to identify the item of information, and a binary value can be provided. A communication protocol could allow 12 bits for a label, which would allow 4096 different items to be defined for all of the participants and say 32 bits for the data. The predefined scale factors and label codes allow the receiving entity to identify the item of information and to convert the binary data for internal use. When communication is more robust, it is possible to send the value and all of the attributes with the information.

In describing use cases in this document, terminology may be used such as "maximum reverse power flow" and expressed in kilowatts. The same information for a DER device might be referred to as "Wmax" in the IEC 61850 object model and expressed in watts. SEP2 may identify it as "setMaxW." It is not important that same terms be used everywhere as long as the attributes of the actual information are mutually understood.

Figure 18 shows an example where System 1 may be a PEV and System 2 may be a utility EMS. The vehicle proprietary software may use a name "MaxRevPwr" for maximum reverse power and use a single precision variable with the power in kilowatts. The utility EMS software may use an internal name of "Wmax" for that information and use it in watts. To exchange information, the communication software in System 1 converts the internal variable into a message with some label "XYZ" and in some format such as Int32. It is using deciwatts to preserve one decimal place in the binary translation to an integer.

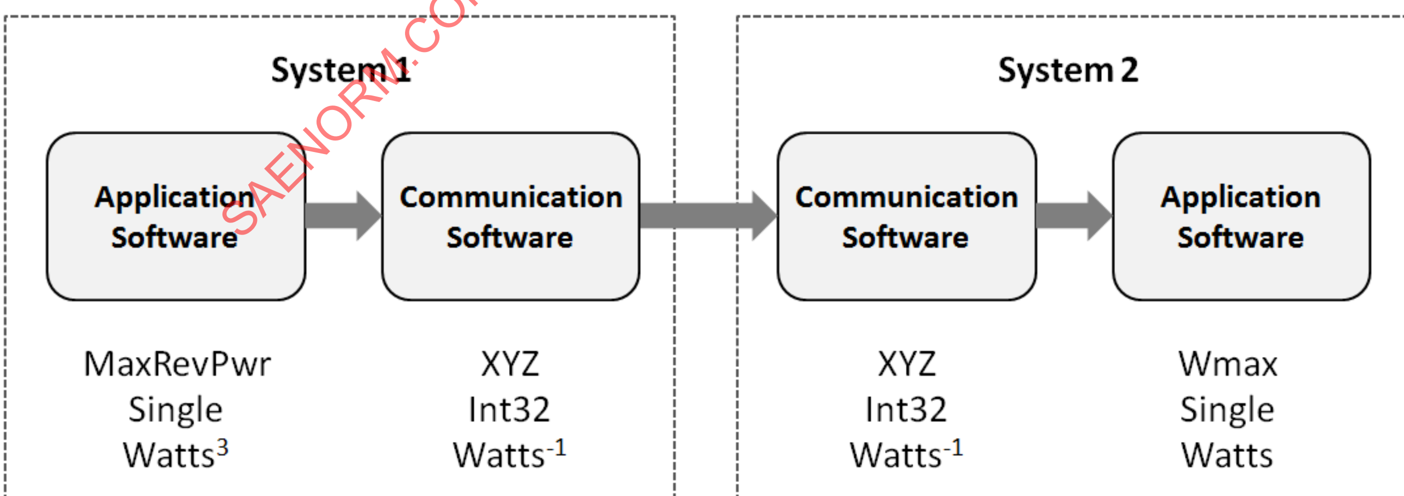



*Figure 18 - Example of information exchange*

The use cases in this document may not use terminology or units of measure that are exactly the same as those of SEP2 or the IEC 61850-90-7 technical report. The terminology used in this report is only for the purpose of understanding the basic information that needs to be exchanged to perform the function, and it is not intended to define the exact communication protocols to be used for the exchange. It was decided to use more descriptive terms in this document and not try to use the terminology from a specific protocol or object model. The SAE J2847/3 document will extend the use cases from this document into communication messages.

## 4.4 Inverter-Based Distributed Energy Resources

Distributed energy resources are small, modular distributed generation (DG) and storage technologies that provide electric power or energy where it is needed on the distribution grid. DG, which could be a diesel generator, gas microturbine, solar panel array, or small wind turbine, can only serve as a source of energy. However, energy storage systems are a unique form of DER because, unlike pure DG, the unit can also serve as a variable load. PEVs can be considered to be DER storage systems. Even a PEV that is not capable of reverse power flow can be used as a DER device to allow for active control of forward power flow for grid purposes. The use of a variable load for grid purposes is sometimes called demand dispatch or demand management. This can be considered to be a single-sided use of a DER device and is no different than a generator that can only vary power output.

Most conventional DG devices use electric machines to produce electricity. The power output can be controlled, and some are capable of producing or absorbing reactive power (VAR). The rotational speed of the machines is synchronized with the grid frequency. These systems generally have significant rotational and thermal cycle inertia, and power level changes do not happen quickly. If these devices must be controlled by a distribution utility, this is customarily done by issuing commands. This can even be done using the telephone and asking an operator to adjust the power.

Some forms of DG, such as solar PV systems, have no spinning machines. These devices are fundamentally DC devices, and an inverter is required to convert to AC power. An inverter can be controlled in the same manner as a classic DG device by using direct commands for forward or reverse power as well as power factor (VAR). But inverters can incorporate the computational capability to provide advanced functional capabilities that automatically change power and VAR based on measured grid conditions. Energy storage systems can offer four-quadrant power conversion capabilities along with the advanced functional capabilities. There is a great deal of interest in deploying inverters with this enhanced functionality in solar PV systems and stationary grid storage systems.

It is not clear yet if there is sufficient economic benefit for PEVs to go beyond simple command-response inverters to include the autonomous functionality. This is primarily being driven by concerns about power quality on distribution feeders caused by increased levels of solar and small wind turbines along the feeder.

### 4.4.1 Integration of DER With the Feeder

Electric power systems (EPS) were designed based on a model of power flowing one way from large power plants through transmission lines to distribution substations. Generally, power leaves the substations on radial distribution feeder circuits to feed the customer loads. The voltage for a distribution feeder is set at the substation using a voltage regulator or a tapped transformer. The voltage drops along the length of the feeder as customer loads are served. The utility sets the head end voltage high enough (but below an upper limit) to ensure that the voltage for the last customer is above a minimum required value. Because customer loads are not purely resistive, banks of capacitors may be placed along the feeder to correct power factor along the feeder. Some capacitors are fixed, and some may be capable of being switched on and off as power factor changes as loads vary.

This control paradigm gets more challenging when DG is added along a feeder and the power is no longer coming exclusively from the substation. Even if the DG is only reducing the net load of a customer on the feeder, it can adversely impact the ability of the utility to manage the voltage and power quality along the length of the feeder. Fossil fuel DG provides a steady power output and is more predictable than renewable sources such as solar photovoltaic (PV) systems or small wind turbines. The daily and hourly power output for solar PV can be planned for based on weather forecasts, but the higher frequency power output variation caused by cloud passage is random. Wind puffs can cause similar upsets to power planning for wind turbines.

IEEE Standard 1547-2003 was the first of a series of standards developed by Standards Coordinating Committee 21 (SCC21) on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage concerning distributed resources interconnection. This standard was designed to ensure the safe interconnection of DER to the EPS. A DER must disconnect or stop providing power based on excursions of frequency or voltage beyond the specified limits. These limits from the 2003 standard are shown in Figure 19 for a 240-V reference and are based on the nominal voltages from ANSI C84.1. The clearing time for disconnecting power varies based on the level of the voltage excursion and can be as short as 160 ms. This example is based on nominal voltage of 240 VAC. These default values were modified by Amendment 1 in 2014. A major revision to IEEE 1547 was published in 2018 which introduced "smart inverter functions" and major modifications to abnormal voltage and frequency monitoring and response. For the example in this section, the IEEE 1547-2003 values will be used because they are still representative of the issues.

A utility will normally regulate voltage along a feeder to between 95 and 105% of the reference voltage. If line voltage sags below 88% or swells above 110%, this is considered abnormal. An inverter must ride through first and then stop producing power when abnormal voltage is detected. If the voltage drops below 88% but not below 50%, the inverter must stop (or clear) within 2 seconds. And if voltage drops below 50%, it must clear within 160 ms. For a rise in voltage above 110% but below 120%, the inverter must clear within 1 second. And for voltage above 120%, it must clear within 160 ms. The inverter must also monitor frequency and stop producing power if the frequency falls below 59.3 Hz or rises above 60.5 Hz. Once the inverter disengages following a fault condition, it is not allowed to immediately reengage when the fault condition ends. Other rules govern reconnect, which may include waiting for 5 minutes after conditions return to normal.

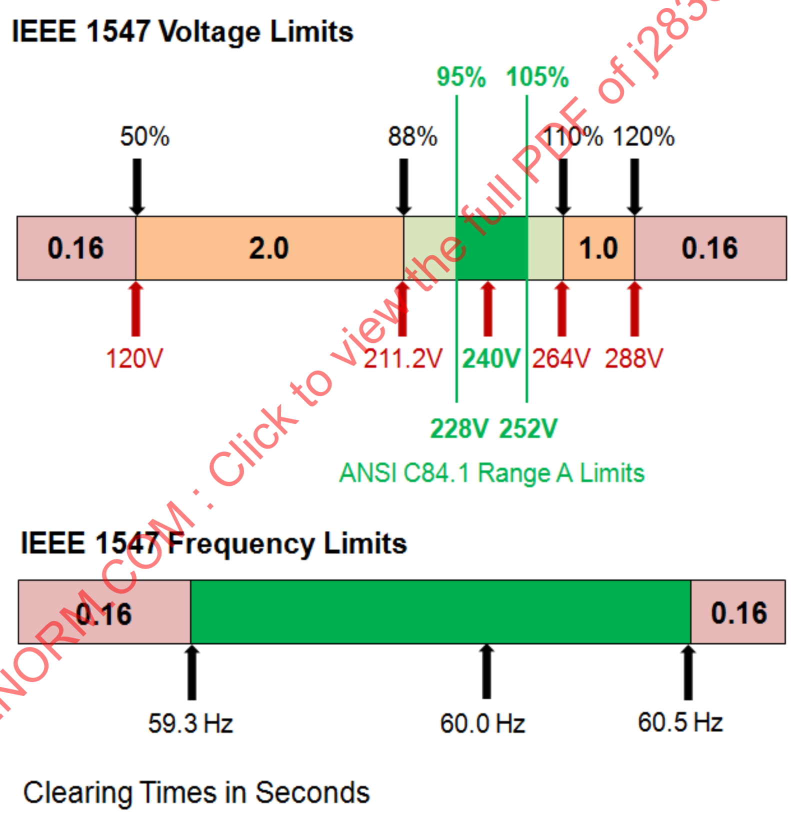



*Figure 19 - IEEE 1547-2003 limits*

Energy storage systems have been deployed as part of solar PV systems primarily to allow excess solar energy to be captured during the day for reuse at night. This was ideal when customers were not allowed to provide excess power to the grid. With net metering, there may be more value to the customer in supplying the excess solar power to the grid during peaks and operating from grid power in the evening. The storage system is still useful for maintaining steady output during cloudy conditions and for emergency backup of the home. These storage systems were not intended to be a grid resource, but there is increasing interest in using the storage systems to help stabilize the voltages on the feeders.

For a storage device, such as a PEV, the IEEE 1547-2003 limits apply to situations when the power is being discharged. IEEE 1547-2003 does not apply to loads. These limits apply to the inverter function but are not automatically flowed down to the charger function of a power converter. However, there may be special circumstances, such as where a storage device may be providing voltage support to the grid, for which bidirectional application of these limits would apply. IEEE 1547.9-2022 was published as a guide to energy storage applications, including electric vehicles.

4.4.2 Smart Inverter Functions

The Electric Power Research Institute (EPRI), working with the U.S. Department of Energy, Sandia National Laboratories, and the Solar Electric Power Association, initiated a collaborative effort in 2009 to define common inverter functions and communication protocols for the integration of smart DER with the grid (EPRI Program 174). The primary focus of the activity was on inverter-based solar PV systems and stationary battery energy storage systems. The initiative engaged many people representing inverter manufacturers, system integrators, utilities, universities, and research organizations. The resulting work products have provided valuable input to many standards organizations and activities, including the U.S. National Institute of Standards and Technology (NIST), the IEEE, and the International Electrotechnical Commission (IEC). EPRI documents the functions in *Common Functions for Smart Inverters*, which was updated periodically after EPRI reconvenes the working group to consider new functions or to modify existing functions. The most current version 4 of the report was published in 2016. The EPRI document is free to the public, and SAE recommends it as the best source for learning about smart inverter functions.

The NIST Smart Grid Interoperability Panel (SGIP) established a Priority Action Plan (PAP-07) for Energy Storage and DER Interconnection Guidelines. One of the objectives of PAP-07 was to develop and harmonize object models of energy storage into IEC 61850-7-420. IEC 61850 is a standard for the design of electrical substation automation and is a part of the International Electrotechnical Commission’s (IEC) Technical Committee 57 (TC57) reference architecture for EPS. IEC 61850-7-420 defines the information models for the exchange of information with DER. Working Group 17 of IEC TC57 is responsible for IEC 61850-7-420, which was first issued in 2009.

An interim step in the revision of IEC 61850-7-420 was for IEC TC57 WG 17 to create IEC 61850-90-7 as an informative technical report to provide guidance for the revision. The report describes the functions for inverter-based DER systems, including photovoltaic systems, battery storage systems, electric vehicle charging systems, and any other DER systems with a controllable inverter. It defines the IEC 61850 information models to be used in the exchange of information between these inverter-based DER systems and the utilities, energy service providers, or other entities which are tasked with managing the volt, VAR, and watt capabilities of these inverter-based systems.

The combined efforts under EPRI Program 174 (Integration of Distributed Renewables - Smart Inverter Communication Initiative), NIST SGIP PAP-07, IEEE SCC21 1547.9 WG, and IEC TC57 WG17 to develop the smart inverter functions is making great progress. The abstract data models defined in IEC 61850 are being mapped into a number of protocols.

The advanced inverter functions described by the EPRI and PAP-07 documents are summarized in this section. These functions were developed primarily for solar PV systems and associated storage systems. They can also be applied to standalone, stationary storage systems. The use of a PEV as a DER was not a significant consideration during the development of these functions. The primary purpose of a solar PV system is to produce power and energy - as much as possible for as long as possible. The primary purpose of a PEV is transportation, and producing any power and energy for the grid increases the risk that the PEV will be able to meet unexpected transportation needs. There are some functions defined in these documents that do not make sense for a PEV to implement. There are others that could be implemented but may not make economic sense based on the relatively small energy capacity of a PEV relative to a solar PV system. And there are other characteristics of PEVs that are not included in the DER model that must be accounted for in the communicational protocols for PEVs.

There are two fundamental approaches to the control of DER devices: direct control functions and autonomous functions. These approaches will be briefly discussed in the following subsections and in more detail later in the document.

### 4.4.3 Direct Control Functions

Both EPRI and IEC have defined five inverter functions for DER devices that are based on direct control. The IEC calls them immediate functions. These direct control functions assume a tightly coupled interaction between the inverter-based DER systems and a controlling entity (utility, energy service provider, or customer EMS). These controls require communication channels with high availability between the controlling entity and the inverter-based DER systems, since the controlling entity must maintain direct knowledge of the inverter-based DER system status and capabilities. It is expected that inverter-based DER systems will revert to "default" states if communications are unavailable for some pre-specified length of time. Some of the direct control functions are described below using the EPRI terminology.

Several direct control functions are described below. The IEC implementation for a DER storage device is not sufficient for use with a PEV because of the additional considerations associated with a PEV. This needs to be considered in any protocol used with the PEVs. A grid storage unit can operate to a minimum reserve SOC and does not have the additional constraint that the storage system must be recharged by a specific time. The controller cannot just operate a PEV to stay above the minimum SOC. It must plan the use of the PEV during a session to achieve grid requirements and charge the vehicle. This requires additional information exchange between the PEV and EMS and more sophisticated EMS algorithms than required for stationary storage, which is the basis of the EPRI and IEC work. The headings are based on the EPRI definitions of the five functions.

#### 4.4.3.1 Battery Storage Direct Charge/Discharge Management Function (IEC Function INV4)

This function requests the storage system to charge or discharge at a specific rate (as a percent of maximum charging or discharging rate). To account for diversity in the size of storage systems, the function requests a percentage quantity based on the capacity of the system. For active power out requests (reverse power flow - storage discharging), the positive percent is relative to the current value of the maximum discharging rate. For active power in requests (forward power flow - storage charging), the negative percent is relative to the current value of the maximum charging rate. The discharging capacity of the inverter and the charging capacity of the charger may differ. The controlling entity has access to these parameters and can use these to compute the value for the percent setpoint if a specific value in watts is desired. It is possible that this function could be expanded in the future to allow either type of setpoint to be provided. A timeout period is included for reverting to the default state of the inverter-based DER system to ensure that a missed or lost command does not impact normal operations beyond that timeout period. This is the most basic DER function for a PEV. This function did not fully support the use of an EVSE-PEV storage system, and SAE use case U6 extended this function to better support vehicle needs.

#### 4.4.3.2 Battery Storage: Coordinated Charge/Discharge Management Function

This function was added to version 3 of the EPRI report based on SAE U6. While it uses EPRI terminology for parameters rather than the SAE terminology used with U6, they are exactly the same function. The need for a vehicle to achieve a target SOC by a defined expected time of departure is important for vehicles. But it may be equally important for a stationary ESS to be ready to provide backup for an expected arrival of severe weather in the area. The command structure is exactly the same from the DER controller to the DER. The difference is only the additional signals that can be optionally used. IEC is expected to include the new U6 DER status parameters in the object model.

#### 4.4.3.3 Fixed Power Factor Function (IEC Function INV3)

Fixed power factor will be managed through issuing a power factor value. A timeout period is included for reverting to the default state of the inverter-based DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period. The INV3 function is included in U7, which is described in Appendix D.

#### 4.4.3.4 Fixed Reactive Power Function

This document also includes a fixed reactive power function within the U7 function group because it is supported by the Smart Energy Profile 2.0 (refer to IEEE 2030.5-2013). This function could be used when a specific amount of reactive power must be absorbed or supplied. This is particularly useful if reactive power is needed when a zero active power. This function is not specifically described by EPRI or IEC as a direct function, but it is discussed indirectly.

#### 4.4.3.5 Connect/Disconnect Function (IEC Function INV1)

The inverter is commanded to disconnect from the EPS using an actual switch and not by commanding the inverter power output to off. This function is not related to intentional islanding and refers to the management of a switch that separates at the DER, leaving customer premises loads connected to the grid. This DER function should not be used with a PEV with an onboard inverter because it is also serves as its charger and it should always remain connected to the EVSE. The EVSE can be used to disconnect the PEV using its internal breaker. This capability can be part of an EVSE management function that could also be used to set the control pilot. It is not clear that this needs to be part of the EVSE or PEV DER capability.

#### 4.4.3.6 Maximum Generation Limit Function (IEC Function INV2)

This function sets the maximum generation level as a percentage of the DER capacity. This function is useful for a solar PV system that has an unconstrained power output that varies with solar radiation. This function can be used to set the upper limit. The unconstrained generation (discharging) level for a PEV is zero, and it will only discharge above zero if it is commanded, and this is the purpose of the INV4 function. This function is not needed for a PEV for limiting discharging. This function is not currently set up to limit charging, although it could be extended to allow it. However, INV4 could also be extended to allow the setpoint to be either a target or a limit for charging. This approach is taken for U6. There are applications where a specific charging rate is required of a DER and others where it may only be necessary to keep the DER below a specific charging rate.

#### 4.4.3.7 Battery Storage Price-Based Charge/Discharge Function (IEC Function INV5)

This function provides a pricing signal (actual price or some relative pricing indication) from which the inverter-based DER system may decide whether to charge the storage or discharge the storage, and what rate to charge or discharge. This is not an essential DER function for a PEV. The pricing functions of SEP2 provide this capability for charging. It is not likely that a PEV would engage in energy arbitrage and discharge at high prices and charge at low prices. It is more likely that the home EMS would deal with the price decisions and engage the PEV using the direct INV4 management function. Price-based discharging is not expected to be beneficial for a PEV, and INV4 is expected to be used to control all discharging for PEVs.

### 4.4.4 Autonomous Functions

The autonomous functions are an exciting new concept for DER devices. They are based on the DER inverter directly measuring line voltage, frequency, or power flow at the Reference Point of Applicability (RPA) and then automatically responding by adjusting the amplitude and phase angle of the current flow to achieve the desired result. For each type of function (such as volt-VAR), there can be several different selectable modes which consist of an input-output curve (defined by a tabular array) and other parameters. The arrays and parameters for each mode are sent ahead of time, which could be once at enrollment or even at the start of a session. The controlling EMS selects the predefined mode, and the DER automatically engages and executes the function as defined by the mode.

Examples of a few of the autonomous modes being considered by EPRI Program 174 and IEC TC57 WG17 are briefly described below. The complete description of the various autonomous functions can be found in IEC 61850-90-7. Many of these functions are more useful with larger fixed DER devices, such as solar PV installations which provided the motivation for the new functions. The functions are not all appropriate for a small roaming storage device which may pop up on different feeders and only be available for limited durations. Some functions may be more appropriate when using a fixed EVSE inverter than when using a PEV onboard inverter. There may be some issues as to how a roaming PEV onboard inverter can be authorized by a distribution utility to participate in certain DER functions.

Some of the autonomous modes for use with a PEV will be part of utility use case U7, advanced distributed energy resource. Considerations for incorporating autonomous functions will be discussed in more detail later in this document.

#### 4.4.4.1 Volt-VAR Function

This function allows a DER inverter to manage its own VAR output in response to the local service voltage. Since distribution utilities could be requesting VAR support from many different inverter-based DER systems with different capabilities, different ranges, and different local conditions, it would be very demanding of the communications systems to issue explicit settings to each inverter-based DER system every time a VAR change is desired. This function allows volt-VAR behaviors to be configured into an inverter using arrays that establish a volt-VAR relationship or curve for use during normal power system. Each volt-VAR behavior is associated with a volt-VAR mode, and requests can be made to change modes by simply specifying the desired mode. This allows DER inverters to be addressed in groups, with each having tailored volt-VAR behaviors, and yet all able to be switched from one mode to another with minimal communication overhead.

#### 4.4.4.2 Volt-Watt Function

This function provides a mechanism to control output power based on the local voltage. Some utilities have described circumstances where high solar PV system output and low load causes feeder voltage to go too high at certain times. There have also been instances where a large number of customers served by the same distribution transformer have solar PV systems which cause the local service voltage to become too high. The result is that certain PV inverters do not turn on at all. Existing distribution controls are not able to prevent these occurrences. The volt-watt function allows the DER inverter to automatically reduce its own maximum power output as the voltage at the PCC exceeds a configurable, utility defined limit. For this function, a voltage-watt array is defined consisting of volt-watt pairs. There can be multiple voltage-watt modes configured into an inverter and selected by the utility depending on conditions.



#### 4.4.4.3 Frequency-Watt Function

The frequency-watt function is used to mitigate frequency deviations by countering them with reduced or increased power. When short-term (transient) frequency deviations occur, autonomous responses to such events are desirable because response must be fast to be of benefit. Long-term frequency deviations or oscillations can be corrected in the bulk grid using regulation services. However, in smaller systems or during islanded conditions, frequency deviations may be longer in duration and indicative of system generation shortfalls or excesses relative to load. Deviations from nominal frequency can cause grid instability, particularly if they cause significant amounts of generating equipment to trip offline.

#### 4.4.4.4 Watt-Power Factor Function

The watt-power factor function can be used to automatically adjust power factor as the feed-in power of the DER increases. For low power output, the inverter current could be set to lag the line voltage waveform, and for high power output, the current could be set to lead the voltage. This could range typically from 0.90 lagging (overexcited) to 0.85 leading (underexcited). This is the typical power factor adjustment range of a synchronous generator from which the terms “underexcited” and “overexcited” originate.

### 4.4.5 Abnormal Voltage and Frequency Ride Through

If an inverter is providing autonomous volt-VAR or frequency-watt services for the grid, it does not make sense for the inverter to clear based on the IEEE 1547 default values for abnormal voltage or frequency events to allow sufficient time for these functions to work. But if the abnormal event continues to persist, the DER must clear. This can be achieved by using four configurable clearing functions for abnormal low or high voltage or frequency.

One of these functions is called the low voltage ride through (LVRT) function. The LVRT function consists of a set of voltage-duration data points that define a “must disconnect” specification curve and another set of data points that define a “must remain connected” specification curve. This function will be discussed in more detail in 4.7.6.

## 4.5 Use Cases and V2G Applications

Use cases can be constructed at many levels. The most talked about, if not the defining, application for V2G is the concept of aggregating a large number of PEVs to perform frequency regulation for the bulk grid. Figure 20 shows the scope of a use case for an aggregator providing frequency regulation services to a balancing authority by controlling the charging and discharging of a fleet of PEVs. The blue dashed oval defines the scope of this use case. The figure also shows a small red dashed oval around a single PEV and EVSE which is labeled U6. This represents the scope of the SAE use case for enabling a single PEV to charge or discharge in response to external commands received by the PEV from an authorized EMS.

These are both use cases: one constructed from the perspective of an aggregator and the other from the perspective of an individual PEV. This document will refer to these higher tier use cases as “V2G applications.” Certain minimum information must be exchanged between an individual PEV and the aggregator to allow that vehicle to participate in the V2G application. This is the focus of use case U6. There are many things that the aggregator must do, such as back-office communication between the aggregator and the balancing authority, which may be critical elements of the aggregator’s use case (i.e., V2G application) but have no direct relevance to an individual PEV.

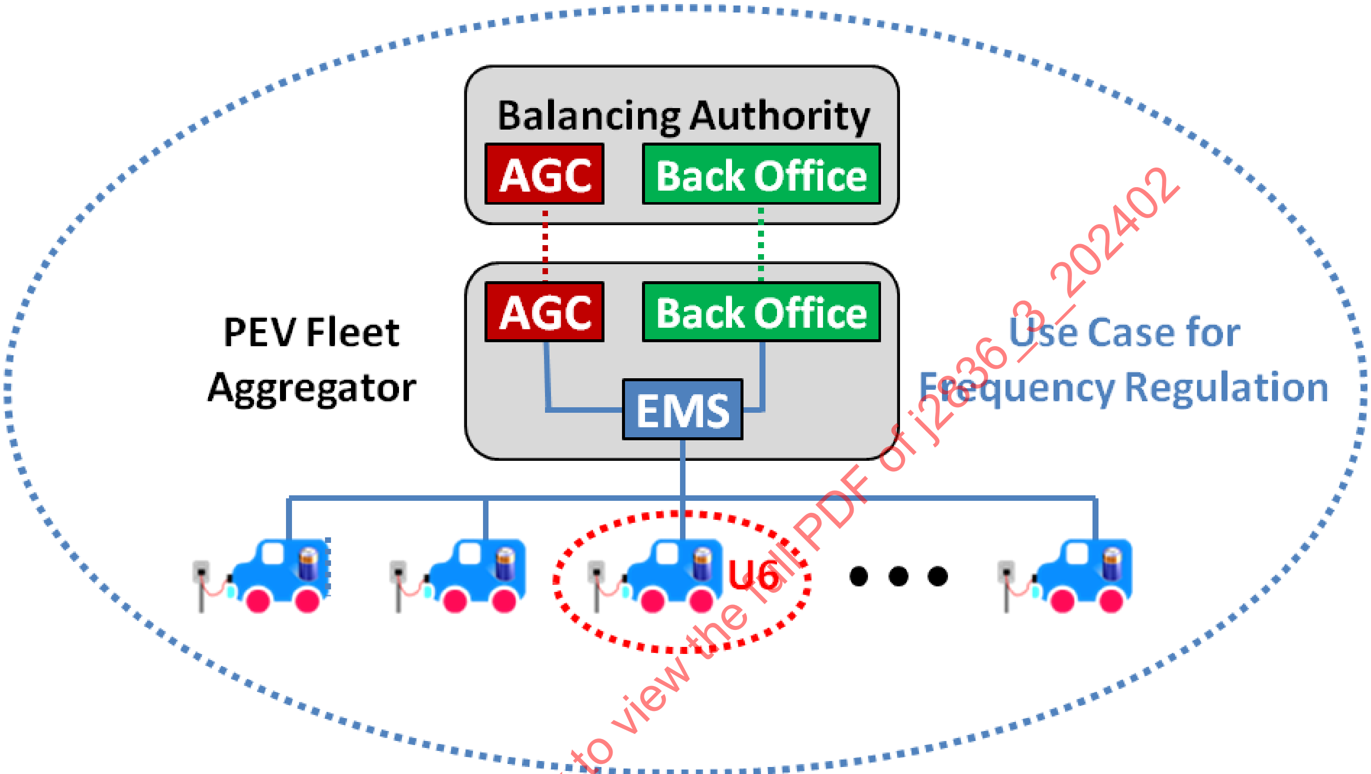



*Figure 20 - Use cases and V2G applications*



Each V2G application will be associated with a specific domain of the EPS: the bulk grid (or balancing area), the distribution system, or behind the meter. Each V2G application will also have a characteristic interval between requests for changes to the charging or discharging power level of individual PEVs participating in the application. This is referred to as the “operational bandwidth” in this document. V2G applications will require a minimum power transfer capability (PTC) for the participating vehicles. Some V2G applications can be accomplished with PEVs that only have chargers, others will require discharging, and others will require the capability to provide or absorb reactive power (VAR). The SAE use cases are built around a required PTC of the PEV and EVSE and the information required to engage it. In summary, each V2G application will serve a specific domain, will have require a specific operational bandwidth, and the PEV must be capable of engaging in a specific SAE use case.

4.5.1 V2G Application Domains

In this document, the EPS is segmented into three domains: bulk power or balancing area, the distribution system, and the behind-the-meter customer. This breakdown is useful for thinking about V2G applications. The domain is defined by the primary purpose that the controlling entity (EMS) is serving. It is possible that a PEV may be engaged simultaneously with an EMS from more than one domain.

For the bulk grid, the specific location of each PEV is not important, other than the PEV is in the balancing area. And many PEVs must be aggregated to have a meaningful impact on the area. The aggregator's EMS must engage with each PEV that is participating in the service and gather information on the time each vehicle plans to depart and the current vehicle state information. It must process the information from all of the vehicles and decide how to allocate the charging and discharging power requests to all of the participating vehicles. This is not a trivial problem to manage the fleet to meet aggregated power demanded by the system operator and at the same time satisfy individual constraints of each vehicle. These algorithms will most likely be highly proprietary and will be very sophisticated.

While the balancing authority seeks to maintain the energy balance across the entire balancing area, there could be local power quality or congestion problems that a distribution utility must resolve. The distribution utility will use tapped transformers to set the voltage at the substation end of a distribution feeder. A distribution management system (DMS) or a substation control and data acquisition (SCADA) system adjusts the transformer taps to set the head end below the upper voltage limit and the tail end above the lower voltage limit. If there are no photovoltaic arrays, small wind turbines, or generators (DER) along the feeder, the voltage would decrease from the substation to the end. When DER is added to the feeder, this complicates the process of managing voltage along the feeder. Electric motor loads on the feeder are inductive loads, and capacitors are often placed along the feeder to compensate. Some are fixed, and others can be switched by the DMS to compensate for variation in the reactive loads. This is called voltage support and is part of maintaining power quality. There are also phase-to-phase imbalances to consider. Some DER and some loads may be able to be adjusted by the DMS to alleviate congestion and avoid overloads on distribution equipment. DMS and SCADA can be thought of as an EMS. For the distribution feeder, the PEVs must be on the feeder to be useful, and for some applications, the specific location and phase to which the PEV is attached are important.

Power and energy management by a home EMS can benefit the premises. A utility may establish energy prices that are higher during peak periods to incentivize customers to consume energy at off-peak periods. A residential customer could use an EMS to manage the number of loads active during peak periods. Commercial businesses often have two meters: one to measure energy use and another to measure the peak average power used during any 15-minute interval during a given month. There is real value in avoiding a spurious 15-minute peak that could be easily shifted by an EMS. The behind-the-meter applications are more focused, although there can sometimes be synergy between what a PEV can do behind the meter, on a feeder, and in the control area. For example, a PEV that cuts back on charging during a peak to manage behind-the-meter prices is helping reduce feeder congestion and reduce energy demand in the balancing area. Sometimes, these could be in conflict. For example, a PEV in a parking garage that increases its rate of charging in response to a frequency regulation command from an aggregator could potentially cause a peak monthly demand problem for the facility and cause congestion on a feeder.



### 4.5.2 Use Cases and Power Transfer Capability

SAE J2847/1 defines messages for five "utility" use cases; they are labeled U1 to U5 for "utility," not for "use" case. This document defines two new utility use cases: U6 and U7, described in Appendices C and D, respectively. The use of the word "utility" doesn't restrict these use cases for use by classic electric power industry utilities. It really refers to any system beyond the PEV that wants to influence or manage the charging or discharging of a PEV connected to the power grid. There are many possible applications and scenarios for how a PEV that is capable of reverse flow could be used to support the grid. The seven utility use cases are listed in Table 4. This table shows the PTC of the inverter supported by each use case. The inverter could either be onboard the PEV or external in the EVSE.

U1 to U5 are only based on charging the vehicle using an onboard or external charger. Even if the PEV or EVSE has a four-quadrant converter, these use cases only deal with charging. U5 is the only one of the charging use cases that allows the limit to be changed. For many V2G applications, the charger must be capable of operating to a commanded upper limit. If the charger is operating to a commanded power limit, it cannot exceed the limit, but it may fall below the limit as needed for charging. In the absence of a competing application or vehicle BMS constraint, the PEV charger would normally be expected to follow the limit.

U6 allows for bidirectional active power flow. Reverse power flow must always be to a setpoint. Unlike a solar PV system, which is designed to provide power and can be limited, the optimal power output of a vehicle is zero, so a limit is meaningless. Some V2G applications will require the charger to consume or source a specific power, and it is expected to do this unless notification is provided to the EMS that it cannot. U6 provides for firm commands for both forward and reverse power flow. The vehicle must protect its battery and not compromise operator or facility safety, and this must always take precedence over power consumption or delivery, but the key difference between a limiting operation and a commanded operation is the need for notification of non-performance. When a firm forward target power level is not required by the application, U6 could allow the EMS to command charging to a limit and not to a setpoint.

U7 allows for four-quadrant power conversions. The minimum capability for U7 is the ability for the converter to control power factor under command. This is accomplished by sifting the phase angle of the current sourced by the inverter relative to the voltage waveform of the grid. Advanced inverters are being developed for solar PV systems and grid storage systems that are capable of automatically changing power levels or power factor in response to changes in a measured parameter such as voltage or frequency. Some V2G applications may require the automatic functions and others may only require capability to change power factor by command. It is not clear how many PEVs or EVSEs will implement the advanced functions.

***Table 4 - Utility use cases***

| Use Case | | PEV-EVSE Power Transfer Capability | | | | | |
|---|---|---|---|---|---|---|---|
| | | Charger Limit | | Commanded Power Setpoint | | | Automatic |
| Code | Name | Fixed | Variable | Forward | Reverse | Power Factor | Functions |
| U1 | Time-of-Use | X | | | | | |
| U2 | Direct Load Control | X | | | | | |
| U3 | Real-Time Pricing | X | | | | | |
| U4 | Critical Peak Pricing | X | | | | | |
| U5 | Optimized Energy Transfer | | X | | | | |
| U6 | Basic DER | | X | X | X | | |
| U7 | Advanced DER | | X | X | X | X | X |

4.5.3 Operational Bandwidth

Operational bandwidth (OBW) is defined by the ability to communicate and act on specific messages, the maximum rate of the message traffic, and the response time for actually achieving a target power flow. This is illustrated in Figure 21.

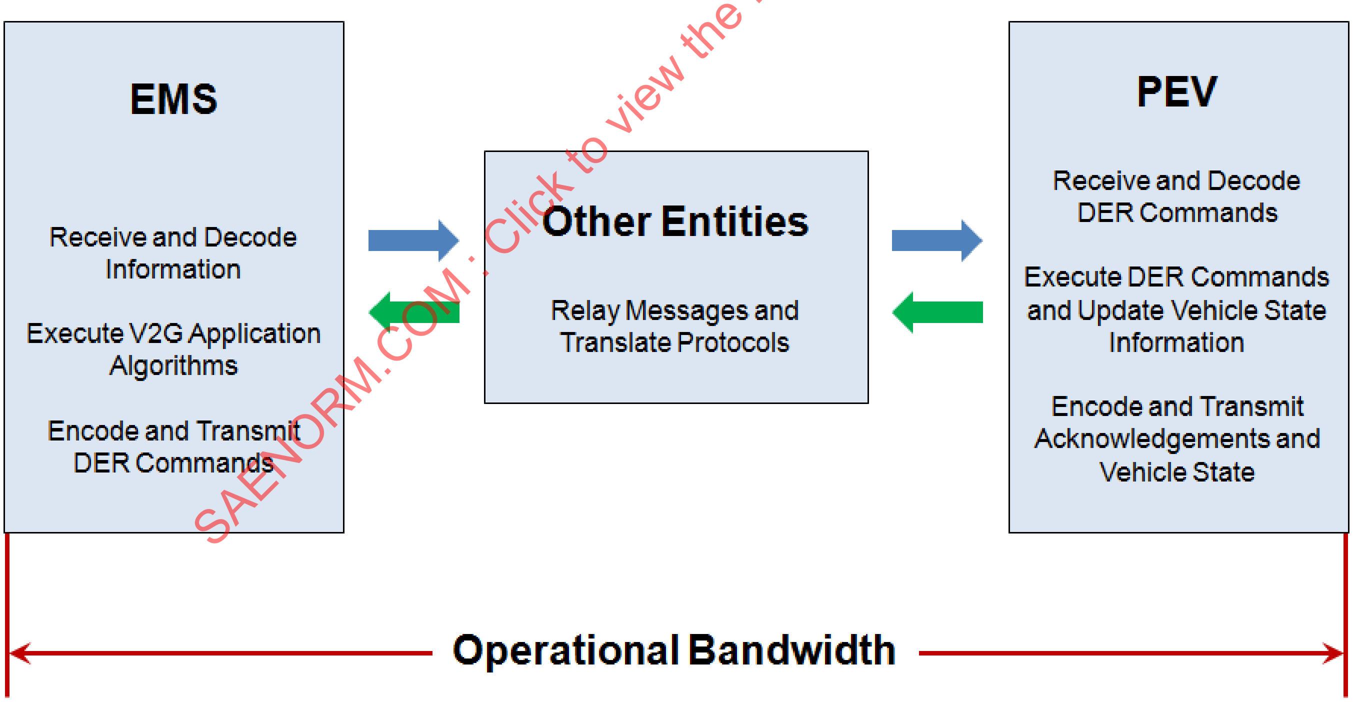



***Figure 21 - Elements that define OBW***

Four tiers of OBW are defined: hours, minutes, seconds, and cycles. OBW applies to the end-to-end system. The PEV, EVSE, EMS, and any other upstream systems must all have the appropriate software and communication capability to accomplish the change in power transfer at appropriate level. The slowest performing element of the system defines the operational capability of the system. Table 5 provides a summary of each operational bandwidth.

*Table 5 - Examples of OBW*

| Characteristic | Operational Bandwidth (OBW) | | | |
|---|---|---|---|---|
| | **Hours** | **Minutes** | **Seconds** | **Cycles** |
| Fastest response | 15 minutes | 1 minute | 1 second | 1 cycle (16 ms) |
| Application example | Time of use | Load following | Frequency regulation | Voltage support |
| Communication | Advanced metering infrastructure | Real-time dispatch | Automatic generation control | Autonomous functions |
| Typical update rate | 15 minutes | 5 minutes | 3 seconds | Cycles |

Hours defines an OBW for messages and system responses needing no more frequent update than every 15 minutes. Many of the most basic interactions between the PEV and the grid can be performed in advance, or at the start, of a single charging session. For example, a delayed start time for charging can be established for a session. The utility AMI communication operates at a low bandwidth of approximate 15-minute updates. The AMI system could be used by a distribution utility to increase or decrease a power limit during a charging session to help manage the total load on a specific residential transformer. This provides additional control capability beyond relying on time of use rate schedules.

Minutes defines an OBW for commands at intervals as short as every minute with an expectation of “immediate” response. Some V2G applications will require the messages to be received and acted on at intervals of 1 to 5 minutes. Commercial buildings often have two meters: one to measure energy (kWh), and another to measure the peak 15-minute average power demand (kW) that occurs at any time during a month. It may be essential for a commercial parking garage to be able to tightly manage startup times and adjust charging rates to level the rolling 15-minute average peaks for the facility. This could require communication between a facility EMS and all of the charging PEVs every minute or two to adjust power flow. Real time energy market systems update generation and variable load schedules on a 5-minute interval or less. If a PEV is to participate in demand dispatch or load following (with reverse flow), the commands to change power flow could be at intervals of 5 minutes or less. The PEV would be expected to “immediately” make the power change when the message is received.

Seconds defines an OBW for commands as short as every second with an expectation of “immediate” response. Generators, variable loads, and energy storage systems that participate in the ancillary services market for frequency regulation receive AGC signals every several seconds. The AGC rate varies by system operator but is in the order of 3 to 6 seconds. The participating system is expected to immediately start to respond to the AGC command when received. For demonstrations of V2G conducted by PJM Interconnect, the AGC commands were sent every 3 seconds to a computer at the University of Delaware, which then sent commands to each of three PEVs. The university computer acts as the aggregator and apportions a share of the total command to each of the PEVs based on PEV SOC, TCIN, and other requirements. This is for both forward and reverse flow.

Cycles defines an OBW for system response to grid power needs in as short an interval as one cycle. One cycle of 60 Hz power has a period of 16.7 ms. The cycles capability does not require a command and response at this rate. An ESS that is capable of producing reactive power can provide voltage support for the grid. One method to provide this capability is to establish a schedule for reactive power versus grid voltage. The power conversion electronics measures the grid voltage and adjusts the phase angle of its current flow with the grid voltage to provide the appropriate reactive power. This autonomous operation can be done in cycles. Devices such as a distributed static compensator operate this way today. The power schedules to be used for this mode can be sent to the power electronics any time before a session starts. The voltage support mode can be initiated, and even stored schedules can be switched as frequently as every several seconds by command from an EMS. The OBW is still cycles because the system is operating in real time. Reactive power does not always need to be provided autonomously. There may be other modes where it could follow a command and response protocol using a seconds or minutes OBW.

These four levels are indicative of the types of end-to-end performance that is required to perform certain V2G applications by the EMS. The EMS may not require the same level of performance from all of the devices on the network to meet its objectives. For example, a frequency response aggregator will receive AGC commands every few seconds from the system operator, but it may not need to engage with every PEV in its aggregation during every interval. It may only need to command power level changes for a small subset of the vehicles to make the needed adjustment for the system. The vehicle response time to received messages will not generally be the limiting factor.

### 4.5.4 Examples of V2G Applications

Table 6 lists several examples of V2G applications along with several defining and enabling characteristics for each. This is not intended to be an exhaustive list of possibilities for V2G interaction, and other terminology may be used by others for these sample applications. The primary objective for this document is highlight potential applications for bidirectional and four-quadrant power flow and the use of the PEV as a DER. Some of the applications will be discussed in more detail later sections.

***Table 6 - Examples of V2G applications***

| Domain | V2G Application | Operational Bandwidth | Use Cases |
|---|---|---|---|
| System | Encourage off-peak charging | Hours | U1/3/4 |
| System | Demand response events | Hours | U2 |
| System | Real time energy (load following) | Minutes | U6 |
| System | Frequency regulation | Seconds | U6 |
| System | Voltage support service | Seconds | U7 |
| Distribution | Transformer load management | Hours | U5/U6 |
| Distribution | Feeder load management | Minutes | U6 |
| Distribution | Renewable energy integration | Seconds | U6/U7 |
| Distribution | Feeder voltage support | Cycles | U7 |
| Customer | Energy cost management | Hours | U5/U6 |
| Customer | Demand charge management | Minutes | U6 |
| Customer | Facility power quality | Cycles | U6/U7 |



The first column shows the domain of the EMS that controls the PEV for the specific V2G application. The PEV can serve the bulk system, the distribution utility, or the customer facility.

The second column provides the name of the V2G application.

The third column shows the typical OBW required for performing the end-to-end application. It is shown as hours, minutes, seconds, and cycles. This is the typical bandwidth required to implement an application. For frequency regulation, the AGC signal is sent out every 3 to 6 seconds, depending on the system operator. It may be that an aggregator can engage in this service for a system operator but use a lower update rate for each of the vehicles in the aggregation. It may be that some of the applications that could use autonomous schedules and operate in cycles may be able to be explicitly commanded in seconds.

The fourth column lists the SAE use case(s) that supports the V2G application. SAE J2836/1 defines U1 through U5 and relate only to the vehicle as a charging load. This document defines requirements for use cases U6 and U7, in Appendices C and D, respectively. U6 is used for V2G applications that require bidirectional active power flow. However, U6 can also be used for V2G demand dispatch applications that only require dynamic control of charging power. U7 provides the capability for an EMS to actively control reactive power. U7 also provides for autonomous DER functions.

Many of the V2G applications listed in the table can be performed without reverse flow and communication requirements for U1 through U5 are fully defined in SAE J2847/1. However, U5 and U6 overlap. U5 provides for the direct management of the rate of charging, and nothing in the SAE J2836/1 use case description constrains the power available updates to low OBW (hours). In theory, U5 could be used for frequency regulation by accepting commands from an aggregator every few seconds to adjust charging rate. However, the implementation of U5 in the Smart Energy Profile may limit its use to applications where all of the changes to the rate of charging must be scheduled at the start of a session. However, U6 is specifically required to be capable of making adjustments to the rate of charging or discharging every several seconds. In these examples, U6 is used for demand dispatch applications for which commands to change the rate of charging are expected regularly during the charging session, and U5 is for applications where all of the changes to the rate of charging can be prescheduled at the start of a session.

#### 4.5.5 Balancing Area (Bulk Power) Applications

##### 4.5.5.1 Encouraging Off-Peak Charging and Demand Response Events

A primary concern that utilities have with PEVs is the potential adverse impact that they could have on the bulk power grid if they charged during peak load periods. The power grid has significant excess generation capacity at night, and utilities want to encourage off-peak charging. Most of the early consideration was to provide incentives for PEV owners to charge at night. Use cases were developed and documented in SAE J2836/1 to provide the capability for a utility to communicate with the EVSE and PEV for this purpose. Four utility use cases are described in SAE J2836/1 and associated messages are described in SAE J2847/1 to provide these capabilities: time of use (U1), direct load control (U2), real time pricing (U3), and critical peak pricing (U4) provide these capabilities. While the utility does not actually command the start of charging, the intention of the use case is to establish a favorable time for the start of charging or the interruption of charging for a scheduled demand response event. The use of price schedules to guide start times for charging could result in a large jump in demand if large numbers of vehicles start at the exact same time. This can be mitigated if a randomization time window is also used by the PEV as part of this function.

##### 4.5.5.2 Real Time Energy (Load Following and Demand Dispatch)

As discussed earlier, the grid system operator updates generation (or load) schedules every 5 minutes to keep the system in balance. This is sometimes called load following for generators or demand dispatch for variable loads. This is usually considered to be part of the real time energy market for the bulk grid, but in some areas, it may be considered to be an ancillary service. These assets are dispatched as step changes for each 5-minute interval. This is not frequency regulation (which will be discussed later). Unlike a generator (which can only adjust output up or down for load following) or a pure load (which may be capable of increasing or decreasing consumption for demand dispatch), a storage device can swing from production to consumption and seamlessly engage in both load following and demand dispatch.

An individual PEV may not have enough power and energy capacity to directly participate in this market, but many PEVs could be controlled by an aggregator to play in this market. While the availability of PEVs with full bidirectional capability enhances the capacity of the aggregator, it is possible to modulate the demand of vehicles that are only charging to engage in demand dispatch. The aggregator needs to establish a base level of charging for all of the PEVs. Each PEV can be at a different base level. The aggregator increases or decreases the collective rate of charging as commitment to the grid system operator change between 5-minute real time intervals.

##### 4.5.5.3 Frequency Regulation

The most talked-about application for V2G is the concept of an aggregator signing up thousands of PEVs to perform frequency regulation for the bulk grid. The aggregator bids this ancillary service to the ISO/RTO as a block of capacity. This was typically a minimum capacity bid of 1 MW or 2 MW, but the minimum bid level is now being reduced by many system operators. The aggregator receives AGC signals from the system operator every few seconds and in turn adjusts the rate of charging or discharging for each PEV in this large fleet to perform the service. The PEV owners are compensated for participating in the program.

Frequency regulation can also be performed using demand dispatch for a fleet of vehicles that are only charging. This is sometimes referred to as "V1G," although other terms have been used. It is less risky for a PEV than full V2G frequency regulation because it does not cause any additional cycling of the battery and the vehicle is always moving toward achieving the desired state of charge at departure. It is possible for an aggregator to have a mixed fleet of vehicles with some that can only participate in demand dispatch and others that can offer full bidirectional power capability.

##### 4.5.5.4 Voltage Support Service

In order to maintain transmission voltages within acceptable limits, facilities under the control of the system operator are controlled to produce (or absorb) reactive power. The amount of voltage support service (VSS) that must be supplied is determined based on the reactive power support necessary to maintain transmission voltages within limits that are generally accepted in the region. VSS is normally provided by large generators and special VAR compensation devices at the transmission level. It could be possible for an aggregator to provide VSS by directly managing the power factor of a large, aggregated fleet of PEVs.

#### 4.5.6 Distribution System Applications

##### 4.5.6.1 Transformer Load Management

Most of the early utility concern was about managing the aggregate impact of charging PEVs across a control area: the impact on the bulk power system. Today, there is increasing interest in managing power flow at the level of a single residential transformer and the distribution feeder. During the early years, the PEVs will not have any substantive impact on the grid, even at peak times, but they can create local problems.

If four families on a single residential transformer all have electric vehicles and start charging at exactly midnight, this could create an overload problem for the transformer. The utility could install a larger transformer to resolve the problem. However, another solution would be to stagger the start times. Instead of starting to charge all four PEVs at midnight, it could make more sense to start one at 8:00 p.m. and start another every 2 hours. The utility could still offer a preferred rate for the 8:00 p.m. start.

Another desired capability is the ability to control the rate of charging. In a time of use program, the PEV would start charging at the power rating of its charger. This will result in the shortest charging time. A PEV with a 6-kW charger that needs 5 kWh of energy could complete charging in 1 hour. But if a utility knew that the PEV wasn't leaving until 6:00 a.m., it could authorize a charging rate of 2 kW, and the PEV would complete charging by 3:00 a.m. if it started at midnight. This is another option in addition to staggering start time.

The optimized energy transfer (U5) use case in SAE J2836/1 was designed to provide this capability. A distribution utility EMS can establish a maximum power level for charging, and it can be changed during a charging session. It also allows direct control of the start of charging. Update rates of 15 minutes or more should not be a problem for this type of operation, and U5 is designed to provide this capability.

If PEVs with reverse flow capability are present, U6 can be used to provide reverse flow to offset charging loads of other PEVs served by the transformer. Instead of starting a PEV early to avoid a peak at the start of a time of use window, one vehicle could offset the power requirements of another vehicle to help spread out the charging loads.

##### 4.5.6.2 Feeder Load Management

This is similar to participation in the real time energy market. The difference is the source of the command. A distribution utility command center may want to manage congestion at a substation or along a feeder by controlling the load or sourcing power on a specific feeder. Some of this could be done by only managing the aggregate charging load on a feeder, but this can be enhanced with bidirectional flow.

##### 4.5.6.3 Renewable Energy Integration

Renewable energy sources may experience short-term power fluctuations. Solar PV arrays are subject to power fluctuations as clouds move past. Wind turbine output can vary in the short term because of wind gusts or sags. This can create problems on the distribution feeder. The larger balancing area may not see any problem of load and generation mismatch because of an averaging effect across the area. But a feeder may experience more fluctuation which can cause voltage sags or swells and other power quality issues along the feeder. PEVs along the specific feeder can serve as a variable load to absorb excess power or provide energy to compensate for a short drop. PEVs near the tail end could be sourcing power, and those at the head end could be absorbing power. The distribution of PEVs along the feeder can be a significant benefit. While this section discusses renewable sources, similar disturbances can come from load switching. Lower frequency disturbances can be thought of as power limiting or offset where the corrections can be done over several minutes. Short-term disturbances could occur over seconds and require faster response. Frequency does not shift locally (it is the same across the area), but voltage can vary dynamically along the length of the feeder.

##### 4.5.6.4 Feeder Voltage Support

In some cases, the voltage along the feeder can be supported by adjusting real loads or providing real power under the command of a distribution utility control system. This has already been discussed. In other cases, reactive power (VAR) must be provided. A four-quadrant converter can provide this capability. In some cases, the need for VARs is slow enough to allow it to be dispatched. Some disturbances require adjustment in cycles. This is too fast to command from a substation, but inverters can be designed to measure the grid voltage and respond with VARs according to a preprogrammed volt/VAR schedule. Different schedules can be used for different feeder situations.

#### 4.5.7 Customer Applications

##### 4.5.7.1 Energy Cost Management

One purpose of a premises EMS is to manage the total energy use during the day to minimize energy costs. The EMS measures the total power demand of the premises and adjusts the charging power of the PEV and other controllable loads to optimize energy costs. A high OBW is generally not required for managing energy usage unless there is a high energy cost penalty for short peaks, in which case the EMS should operate more like a peak limiter.

A home EMS could call on a PEV to provide reverse flow to offset another residential load in order to maintain the entire premises load below a target limit. 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. It is not appropriate to refer to this as capability as vehicle-to-home (V2H), as is sometimes done, because V2H requires the PEV 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 PEV to return power to a home, business, or charge station that is actively connected to the grid.

##### 4.5.7.2 Demand Charge Management

Most commercial facilities, and some residential units, have both energy and demand charges. The demand program varies widely by utility. It can be based on either 15-minute or 30-minute average peak power. It can be based on the single highest peak at any time during the month. In some cases, there may be differentiation for peaks that occur during high demand periods versus low demand. In any case, there is a price to be paid for widely varying loads. The price per kW can be expensive. For some utilities, it can be $15 to $20 per peak kW. If a facility never exceeded 50 kW during the entire month, but for one 15-minute interval the power peaked at 100 kW, the extra demand cost would be $750 for a $15-per-kW rate. At an energy price of $0.10 per kWh, the extra energy used during that peak only costs $5.00.

A large parking facility could face significant demand charges if PEVs all arrived in the morning and immediately started to charge. The facility EMS can actively manage both the starting time and power limits for the charging sessions of each vehicle to shift. Power adjustments need to be made at intervals between 1 and 3 minutes to control the aggregate average over the rolling 15-minute window. The power balancing can be enhanced by using some of the vehicles to provide power to the facility.

##### 4.5.7.3 Facility Power Quality

Some facilities may have equipment that causes large power surges that do not last long enough to impact the 15-minute demand but could cause voltage surges or sags that adversely impact other equipment. A facility EMS may be able to detect these and command changes to vehicle charging or reverse flow in seconds and help mitigate these. Some may happen too fast for an EMS to command correction, but automatic schedules could be used, and VAR compensation may be needed to correct facility power factor.

### 4.6 Considerations for Utility Use Case U6 - Basic Distributed Energy Resource

This use case is based on EPRI's "battery storage: coordinated charge/discharge management" function. There are two major aspects of any use case. One is the definition of the information that must be communicated with the PEV or EVSE or both. The actual use case for communication is described in Appendix C, and SAE J2847/3 will define the implementation of the communication using SEP2. The other aspect of a use case is the definition of the functionality that must be embedded in the PEV or EVSE that will allow the inverter to perform the functions based on the communications. This section describes the functionality required to create the information that is required to be exchanged with an EMS and the expected behavior of the PEV and EVSE in response to messages from an EMS.

### 4.6.1 Maximum Forward Power and Maximum Reverse Power

A battery has a nameplate energy capacity, measured in watt-hours (Wh), but not all of this energy can be used by the vehicle. It may not be desirable or even possible to discharge every cell in the battery completely without causing damage. Similarly, it may not be desirable or possible to fully charge every cell either. The usable battery capacity is the amount of energy that can actually be used by the vehicle. The nameplate capacity is what is generally published for a vehicle. The usable capacity can vary from the nameplate capacity based on the equalization of the cells during charging, the age of the battery, the temperature, and many other factors. It is also possible that the VM may intentionally cut back on topping the battery off or depleting it to zero as part of managing the battery life. Only the VM can know the actual usable capacity of a battery, and maybe not even completely. Figure 22 shows battery and power flow characteristics.

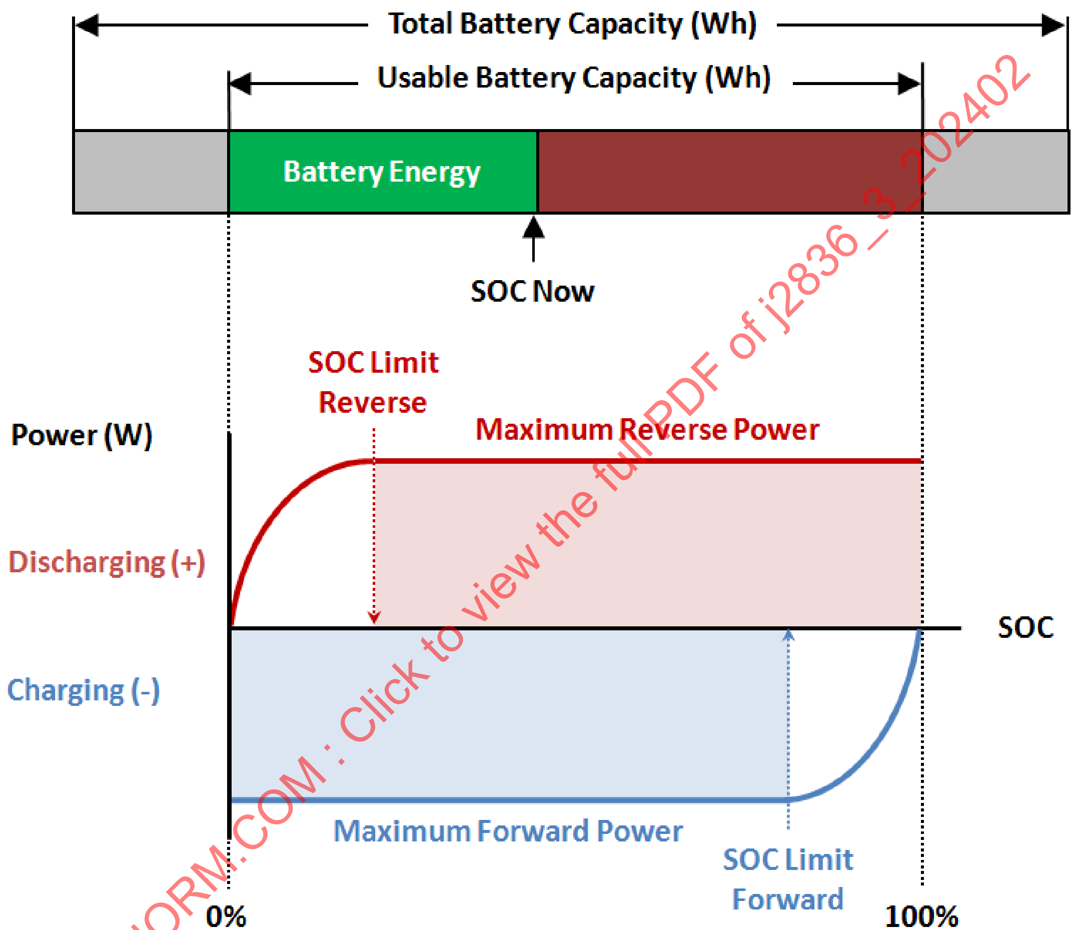





*Figure 22 - Power and battery characteristics*

State of charge (SOC) is the fraction of battery capacity that is available and ranges from 0 to 100%. An SOC of 0% means that there is no energy left, and an SOC of 100% means that the battery is full. The figure shows the SOC as being measured across the usable battery capacity, but it could be defined relative to either. For the driver's SOC display and for use in range calculations, it would be most useful to know the usable capacity and the SOC relative to the usable capacity. Who wants the gauge to read 90% when it is full and 15% when it is empty? For a BEV, zero SOC could be at the bottom of the usable range with no reserve. For a PHEV, it might be desired to show zero SOC at the bottom of the charge depleting range. The vehicle BMS might use the full range of SOC across the nameplate capacity. SOC is not that useful outside the vehicle BMS except for indicative display purposes.

A battery charger normally starts in a constant current (constant power) mode, and as the battery gets close to being fully charged, it changes to a constant voltage mode. In the constant voltage mode, the power drops off as the battery state of charge approaches 100%. Regulating voltage helps prevent overcharging cells that may operate at a higher voltage than others in the battery system.

During the constant current mode, a charger would normally provide current at the lower of the rated value of the complete charging system or the current limit established by the control pilot. The charging system limit is based on the charger power electronics as well as any DC current limits established by the BMS. The maximum AC charging current and the line voltage of the charger define the maximum forward (charging) power. The blue rectangle in the figure defines the zone for unrestricted forward power flow.

The SOC used to trigger the mode change (SOC limit forward) is not something that would be communicated outside of the charging system, but it can be used by the PEV to calculate a more useful parameter for external use by an EMS: the duration at maximum forward power. This will be described in a later section.

The behavior for reverse (discharging) power flow is similar to charging. In this case, the maximum discharge current would be the lower of that established by the control pilot or the rating of the inverter system. As with charging, the system power constraint will be based on the inverter electronics and the maximum DC current permitted by the BMS.

The lower limit for constant power discharge may be set for battery protection and life considerations or to protect a specific energy reserve value. If it is a specified reserve value, the PEV may share it, but just as with charging, the availability of discharge can be better defined for an EMS by the PEV providing the duration at maximum reverse power. The red rectangle in the figure defines the zone for unrestricted reverse power flow.

The maximum forward and reverse power limits should be based on the continuous power capability of the battery system across a wide range of battery SOC. A PEV battery system is capable of power surges during acceleration, regenerative braking, or portions of the fast-charging profile, but these should not be part of the DER rating. See 4.3.6 for more discussion.

#### 4.6.2 EPRI and IEC Direct Charge/Discharge Storage Function

U6 was based on the “battery storage: direct charge/discharge management function” defined in the EPRI *Common Functions* document and on “Function INV4: request active power (charge and discharge storage)” defined in IEC 61850-90-7. This section provides a brief overview of the EPRI and IEC function for direct management of the charging and discharging of a storage DER device. EPRI adopted the SAE U6 function and issued it in version 3 of its report as “battery storage: coordinated charge/discharge management function.”

This function is intended to provide a simple mechanism through which the charging and discharging of battery storage systems may be directly managed. This function assumes that the intelligence which determines charging or discharging resides outside the storage system and that the storage system (to the extent possible) follows the requests it is given. This function allows an EMS to periodically issue commands to a storage DER to request that it charge or discharge at a specific active power level.

The utility/ESP or the customer EMS takes the following actions for each command:

1. Request a pre-defined set of status information from the DER device, including the status values and the timestamp of the status. This step is optional because the EMS may have already attained sufficient information about the DER for its purposes based on previous enrollment activities. For some loosely coupled EMS-DER applications, the status request may only need to be performed at the start of a session. More complex EMS algorithms may require current status information in advance of each command.

2. Issue command to the DER device to request a change to the active power (charge/discharge) setpoint for the storage system. Each command has four elements: an active power setpoint value, a time window, a ramp time, and a reversion timeout. These parameters are shown in Figure 23.

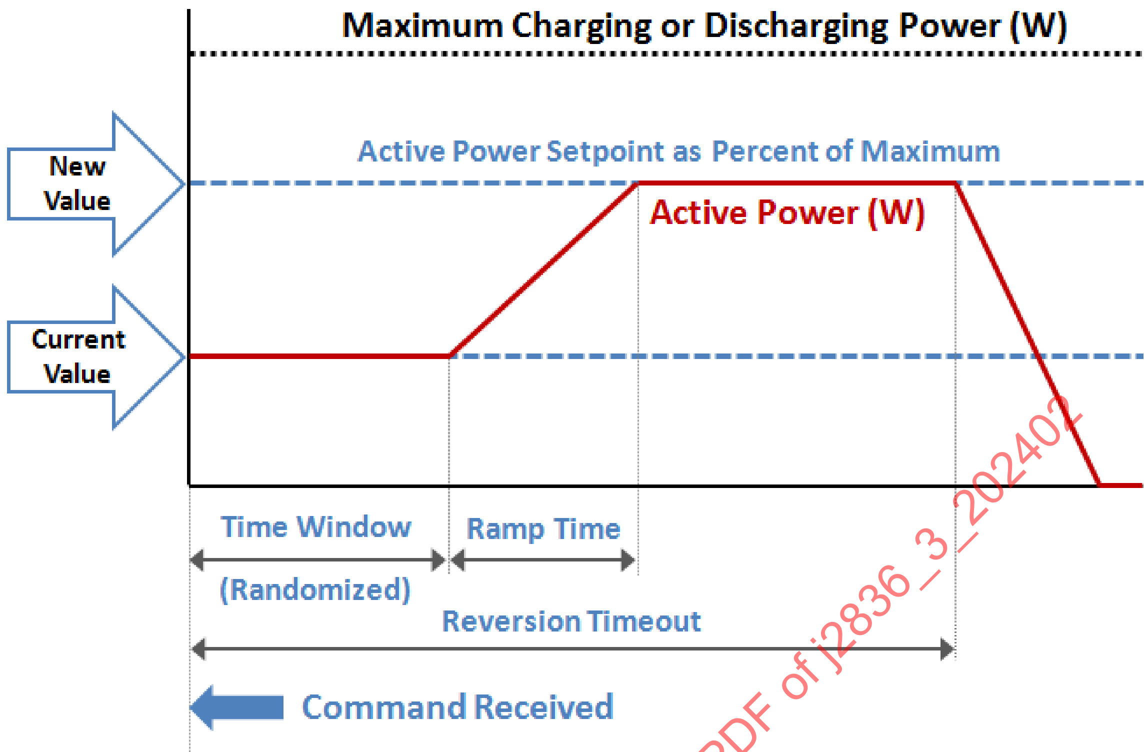



*Figure 23 - Basic elements of the power setting command*



The active power setpoint value is provided as a percentage of the maximum reverse (discharging) power or maximum forward (charging) power of the storage unit. This setting is provided as a percentage between positive 100% (discharging) and negative 100% (charging). It is recognized that the maximum charging rate and the maximum discharging rate may differ, such that a setting of 50% charging might result in a different power magnitude than a setting of 50% discharging. It is understood that this is a “request” and that the actual ability of the end device to either charge or discharge will be affected by many factors.

Time window is a time over which the DER randomly delays prior to starting to put a new charge or discharge rate setting into effect. For example, if the time window is set to 30 seconds, then the DER would delay a random time between 0 and 30 seconds prior to beginning to make the new setting effective. If the time window is set to zero, the setpoint change starts immediately. Time window is optional.

Ramp time is the time for the DER to move from the current setpoint to the new setpoint. For example, if a DER is operating at an active power (discharging) setpoint of 50% and a command is received to increase the setpoint to 80% with a “ramp time” of 20 seconds, the setpoint will ramp from 50 to 80% over 20 seconds at a rate of 1.5% per second. Ramp time is optional; if it is not included, a previously established default ramp rate can be used. The rate of change of the actual active power output could lag the change in the setpoint based on the inverter system dynamics.

Reversion timeout is a time after which a DER will return to its default charge or discharge setting (typically an idle state). This ensures that a missed or lost command does not impact normal operations beyond the timeout period.

This parameter is optional; if not included, a default timeout period for this function will be used.

3. Receive response to the command from the DER: successful (plus actual active power setpoint) or rejected (plus reason: equipment not available, message error, overridden, security error). This could be combined with the status request for applications with high update rates.

An example of the command sequencing is shown in Figure 24. This shows an application where the EMS issues commands to the DER at a regular update interval. The EMS requests status from the DER (shown by the green arrow) and uses this as part of developing the setpoint command for the DER device (which is shown by the blue arrow). The gray bar indicates the reversion timeout included with the command which must be longer than the command interval. Each command may optionally include a randomization time window (shown as a blue bar) and a ramp time (shown as a red bar). The actual random time delay is the product or a uniform random number and the value of the time window. The actual start of the ramp is indicated by the small red arrow coming out of the randomization bar. The example shows that the setpoint begins to ramp at this time and completes ramping based on the specified ramp time. The response to the command is shown by the upward red arrow (from the DER to the EMS). If this is to reflect a successfully achieved setpoint and possibly actual active power value, it should not be requested or issued until after specified time window and ramp time.

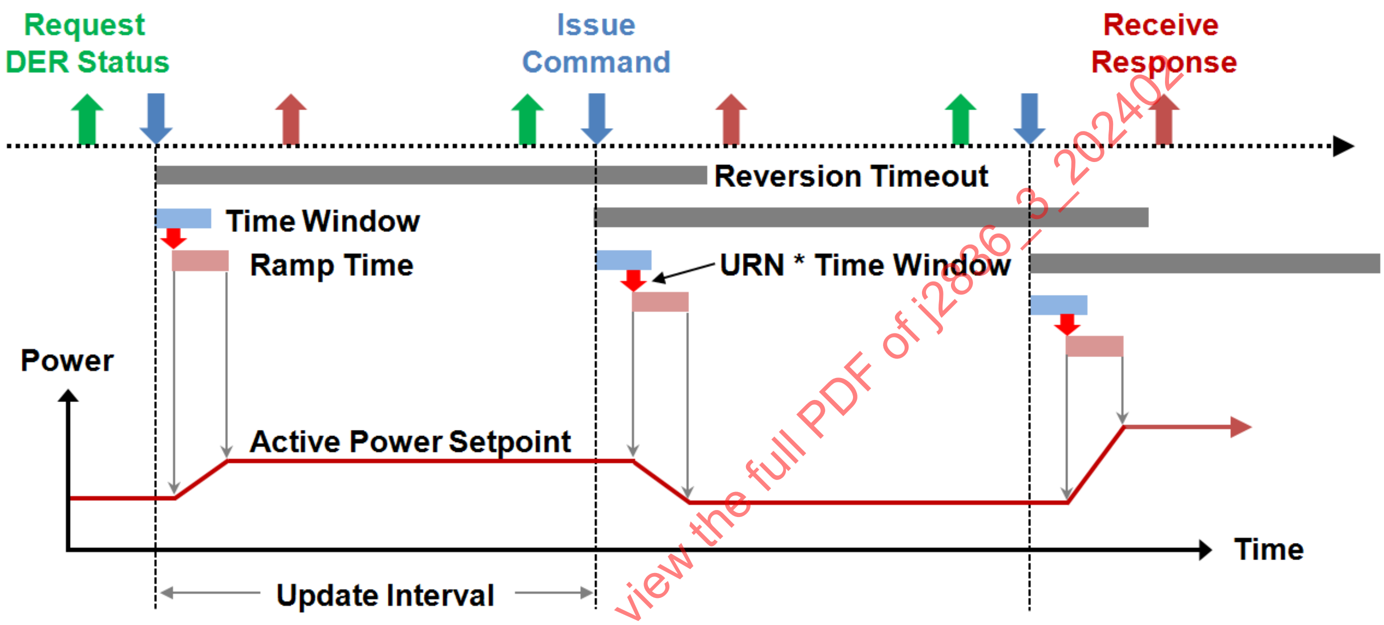



*Figure 24 - Example of command sequencing*

While the INV4 function can be executed by issuing commands one at a time in sequence with the expectation that the DER executes them immediately, the IEC model also allows for functions to be scheduled. Scheduling can be thought of as a separate function. The scheduling function could allow the command to be received by the DER but scheduled to execute at a specified time and not immediately as received. The scheduling function could also allow for a sequence of commands to be provided as a schedule.

For the purpose of U6, it will be assumed that the full command will include an optional UTC time with the default response of starting immediately. If the time is provided, the randomization time window will begin at the designated start time. If a UTC start time is not provided with the command or it is a time earlier than the current time, the randomization interval would begin immediately. It is recognized that in an actual implementation in a specific communication protocol this may be done by a separate scheduling function. But the ability to schedule a power change at a specific time is an important capability.



### 4.6.3 Target Setpoint Versus Limit Setpoint

Forward power flow to a target value (while it is still called charging) is not the same as charging within a specified limit.

For many applications, the utility is only concerned that a PEV maintains its charging rate below a specified limit. They don't care if the vehicle operates at the limit, below the limit, or is not even charging at all. Their concern is only that the PEV keep its power consumption below the limit. This functionality may also be called demand dispatch or demand management. The SAE J2836/1 optimized energy transfer (U5) use case defines this type of capability. Other applications will require the PEV to consume or source a specific target power level, and it is expected to do this unless notification is provided to the EMS that it cannot. The vehicle must protect its battery and not compromise operator or facility safety, and this must always take precedence over power consumption or delivery, but the key difference between a limit value and a target value is the need for notification of non-performance if the charging level is below the specified value.

Reverse power flow must always be to a specific target, and the INV4 function provides this capability. Unlike a solar PV system, which is designed to provide power and can be limited, the natural power output of a PEV is zero. Any power output will reduce the battery SOC and increase the risk that the battery will not have sufficient energy if the vehicle must be used unexpectedly.

The IEC provides Function INV2 for limiting the output of a generator. This function is not set up to limit the charging of a storage DER, but it could perform this function if it allowed for the limit value to be either positive (for production) or negative (for consumption). Alternatively, the INV4 function could allow for the setpoint command value to be either a target or a limit. For discharging, the value must always be a target. For charging, it could be either depending on the objective of the EMS application. A PEV will almost always follow the charging limit as long as it is operating in the constant current mode of its charging cycle. And it may not follow a target when the battery is in the zone where the charger must be in a constant voltage mode. The behavior of the charging system will be the same for a target value or a limit value much of the time, the primary difference being whether it is considered to be a reportable error condition if the charger is not operating at the setpoint.

When using optimized energy transfer (U5), the power level authorization (i.e., power available) from the EMS is only an upper limit. The vehicle could and generally would charge at the limit, but it could fall below the limit, and notification is not required that the charger is drawing less than the authorized power level. The INV4 function could be used to implement U5 if it is used with charging setpoint values and designates the setpoint as a limit.

### 4.6.4 Understanding PEV Charging Requirements

Some V2G applications will require an EMS to accept responsibility for cooperatively managing the charging session of each PEV. This will clearly be the case if an EMS at a parking facility is used to limit the facility peak monthly demand and at the same time minimize any PEV customer disappointment caused by incomplete charging. An EMS in this application would need to delay the start of charging for some vehicles, reduce the rate of charging for others, or even draw power from some vehicles that are participating as DER devices to maintain the facility demand below a limit. It may not be possible under some circumstances for an EMS to allocate power to each PEV during the day such that facility target limits are not exceeded and every vehicle is fully charged. This requires developing metrics for quantifying the cost of customer disappointment versus the cost of exceeding a facility limit. The EMS power allocation algorithms to do this effectively can be very complex. Central to any EMS algorithm is the ability to understand the charging requirements of each PEV and how it changes during the session.

Four parameters completely describe the charging requirements of a PEV: TCIN, maximum forward power, energy request, and minimum charging duration. These parameters are shown in Figure 25. The time now could be at the start of a session or during transfer. The figure shows the charging profile of power versus time that is required to complete the required transfer. The area under the power curve (shown in green) is the total required energy transfer.

One of the most essential parameters is the time that the PEV must complete charging. This is called the time charge is needed (TCIN). The PEV is the source of this information. TCIN can be directly entered using vehicle controls and displays. There may also be alternate methods to enter this time using the EVSE or even a mobile device. TCIN would normally not change during a session, but it is possible that a driver could update this using a mobile device. It’s impossible for an EMS to do any intelligent power allocation if it is not known when the PEV plans to be disconnected.

As described earlier, the maximum forward power is the lower of the rating of the PEV charging system or that defined by the EVSE control pilot. The term “power request” is used for this same parameter in the SAE J2836/1 optimized energy transfer (U5) use case. The term “maximum forward power” will be used in this document rather than “power request” to maintain consistency with the term “maximum reverse power.”

Energy request is the total energy needed at the input to the EVSE from the EPS. The VM will decide how to compute the energy request. Typically, this calculation must account for the actual usable capacity (UCAP) of the battery in the specific vehicle at that time (assuming that SOC is measured against UCAP). It also accounts for the efficiency of the power conversion and any parasitic loads that are time dependent and not proportional to power.

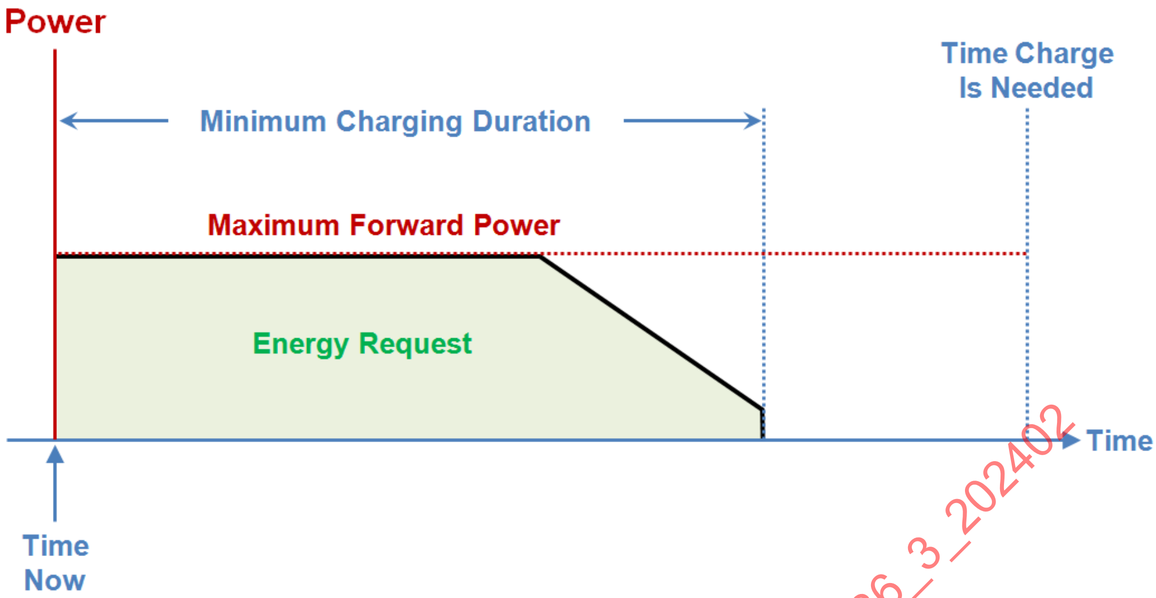



*Figure 25 - Parameters that define PEV charging requirements*

If it is assumed that the objective is to fully charge the battery, Equation 1 is an example of how energy request could be calculated:

$$\text{Energy Request} = \text{UCAP} * \frac{1.0 - \text{SOC}}{\text{Efficiency}} + \text{Parasitic Loads} * (\text{TCIN} - \text{Time Now}) \quad \text{(Eq. 1)}$$

The availability of energy request from the PEV mitigates the need for an EMS to carry out this type of calculation and retrieve information about the useable battery capacity, SOC, charger efficiency, and parasitic loads from the PEV.

One of the most important parameters is the minimum charging duration. This determines the latest time that an EMS can delay the start of charging for a PEV. Minimum charging duration is not simply equal to the energy request divided by maximum forward power. That is because the charger will change modes from constant current to constant voltage for the last part of the charging cycle. This is needed to avoid overcharging cells and to protect battery life. The BMS of the PEV is best equipped to define the profile or any buffer and calculate the minimum charging duration.

It is essential that during any V2G activity the PEV continuously update the energy request and the minimum charging duration. The battery SOC will change during charging or discharging, and the remaining energy required to complete charging and the time needed to do it will change. This is illustrated by the scenario shown in Figure 26, where a PEV is engaged in a V2G activity that requires a forward flow followed by reverse flow. The upper chart shows how the energy request varies during the session. It decreases during forward power flow, as expected. During reverse power flow, it increases and even rises above the energy request value at the time of connection.

On the right side of the lower chart, a charging profile is shown based on the energy request at time now. This defines the latest start time for the required energy transfer. This backloaded charging profile is extended on the upper plot as the dotted line labeled “Energy Transfer Capability at Maximum Forward Power.” When the energy request intercepts this curve, the PEV must revert to charging. At time now, the energy request plot could continue along the red arrow if discharging continues or follow the green arrow if charging is started at the maximum rate. If the V2G EMS were to use this PEV for more forward power flow, as shown by the green arrow, it may be able to stay engaged in V2G longer. This is critical information for the EMS because it indicates when the PEV must disengage from V2G and engage in unrestricted charging. The EMS may take this into consideration in how it schedules power flows.

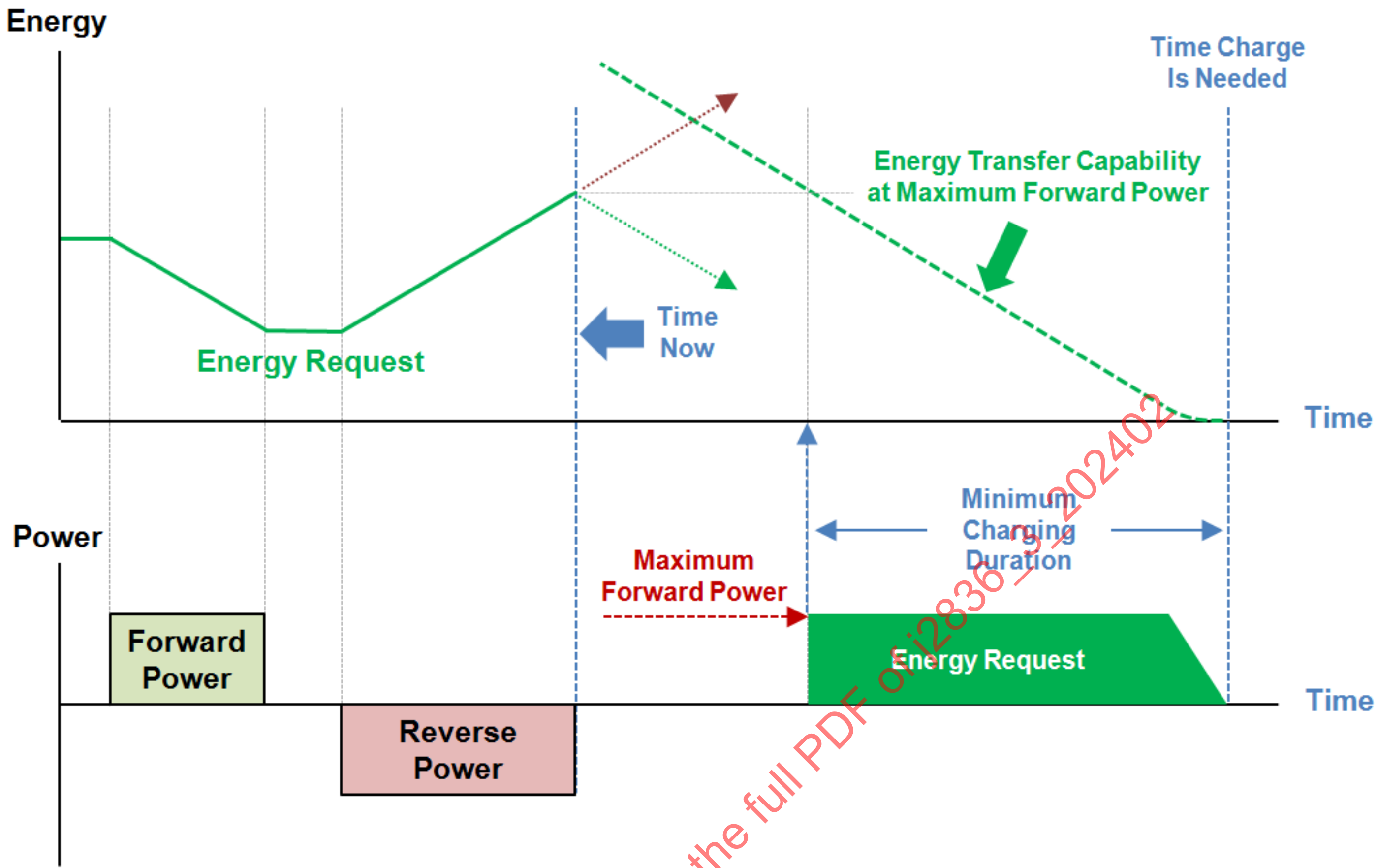



*Figure 26 - Relationship of charging parameters*



### 4.6.5 Duration at Maximum Forward Power Flow

An EMS may need to know how long the PEV can provide forward power at the maximum forward power. This is called the duration at maximum forward power. The top chart in Figure 27 shows a normal situation where there is some slack time in the charging (forward power flow) process. This will always be less than the minimum charging duration because it only considers the constant current portion of the charging profile.

The duration is based on knowing the SOC value (SOC limit forward) where the charger changes modes from constant current at the maximum forward power to constant voltage mode. If the SOC is below that limit, the duration could be calculated as:

$$\text{Duration Maximum Forward Power} = \frac{\text{UCAP} * \frac{(\text{SOC Limit Forward} - \text{SOC})}{\text{Efficiency}}}{\text{Maximum Forward Power} - \text{Parasitic Loads}} \qquad \text{(Eq. 2)}$$

This is only an example of how it could be calculated, and each VM will determine how to calculate the value.

The lower chart shows what could happen if more energy was requested than could be delivered, the driver moved in the time charging needed to be completed, or something interrupted charging. In this case, the time is established by the TCIN and not the battery physics.

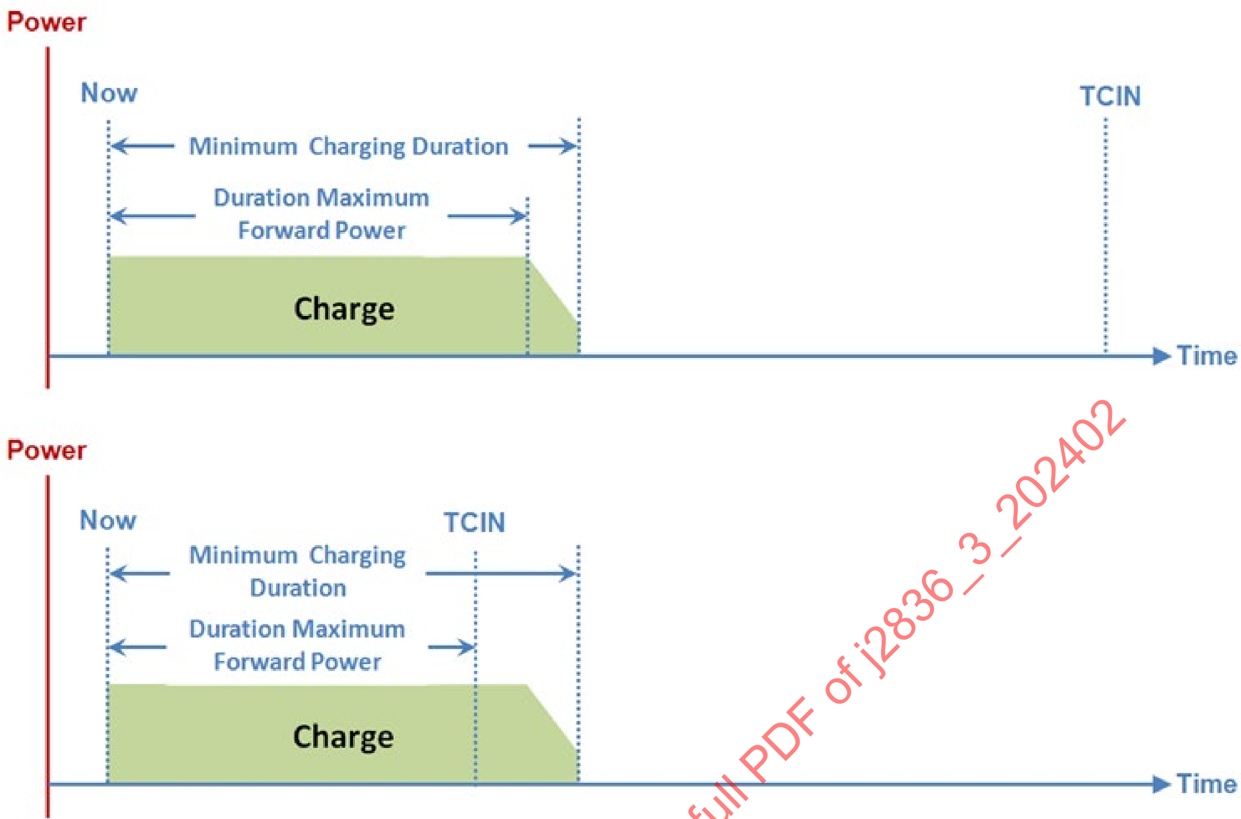



*Figure 27 - Forward power flow measures*

4.6.6 Duration at Maximum Reverse Power Flow

The PEV also needs to compute the duration at maximum reverse power and update it as battery SOC changes. This is shown in Figure 28. The unrestricted reverse flow limit can be simply calculated by using the greater of the minimum SOC limit for flat maximum reverse power or an operator-specified minimum reserve limit. This is not a trivial calculation, but the available battery energy can be converted to delivered power using the conversion efficiency and parasitic loads. Both of these actually work against the production of power and assist in the consumption of power. If the battery can be fully discharged to the specified limit and there is time to then fully recharge by disconnect, then the limit is set by the battery SOC. The top chart shows this situation. The lower chart shows a situation where the recharging the discharge and original charging requirements set the duration for maximum reverse power. At any time, the EMS needs to know how much power is available and for how long for both charging and discharging. While it is not exact, the EMS can trade power for time.

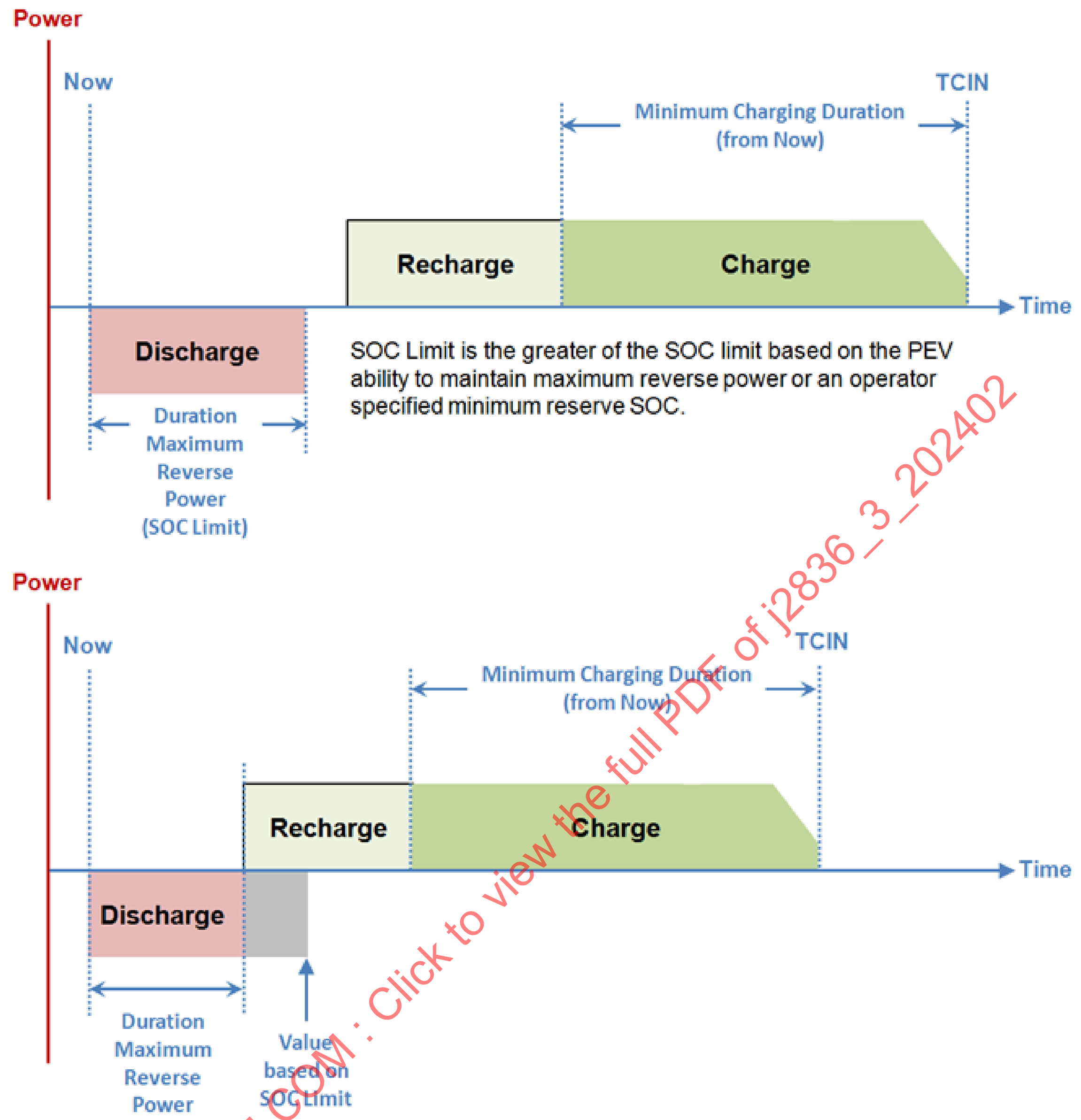



*Figure 28 - Reverse power flow measures*



It is more complex to determine the duration at maximum reverse power because of the need to allow for charging. This involves calculating the lowest value that the SOC could reach and still complete charging in the remaining time.

$$SOC\chi = SOC - \frac{\text{TCIN} - \text{Time Now} - \text{Minimum Charging Duration}}{\text{UCAP} * \left(\frac{\text{Efficiency}}{\text{Maximum Reverse Power}} + \frac{1}{\text{Efficiency} * \text{Maximum Forward Power}}\right)} \qquad \text{(Eq. 3)}$$

If there is slack time as shown in the upper chart (where SOCx is less than the SOC Limit Reverse), then:

$$\text{Duration Maximum Reverse Power} = \frac{\text{UCAP} * (\text{SOC} - \text{SOC Limit Reverse}) * \text{Efficiency}}{\text{Maximum Reverse Power} + \text{Parasitic Loads}} \qquad \text{(Eq. 4)}$$

If there is no slack time as shown in the lower chart, then:

$$\text{Duration Maximum Reverse Power} = \frac{\text{UCAP} * (\text{SOC} - \text{SOC}\chi) * \text{Efficiency}}{\text{Maximum Reverse Power} + \text{Parasitic Loads}} \qquad \text{(Eq. 5)}$$

These are messy equations, and each VM will define their own method. But the value makes it easy for the EMS to know how long the maximum reverse power can be used. While it is only approximate, the EMS can trade power for time.

#### 4.6.7 Time of Reference

The vehicle needs to continually update the value of the energy request and the durations at maximum forward power and reverse power. These measurements must also have an associated time of reference to allow the EMS to correct for any time delay in communication and use. For example, if the vehicle is sourcing reverse power at 3 kW, and maximum reverse power is 5 kW, and the time at maximum reverse is 0.5 hour, and the time of reference is 2:00:00, for the EMS at 2:02:00 using this information, the corrected time at maximum must be adjusted for the 2 minutes at 3 kW that would have been consumed. The energy content available at the time of reference was 5 kW for 0.5 hour to 2.5 kWh. During the 2 minutes at 3 kW, 0.1 kWh has been consumed, leaving 2.4 kWh. The corrected time at 5 kW is 0.48 hour. The EMS logic may not require this accuracy for planning, but the reference time allows for correction. This may be useful for longer update intervals.

#### 4.6.8 Recommended Information Available to EMS from PEV

Information that should be made available to the EMS from the PEV is listed in Table 7.

***Table 7 - Recommended PEV information for U6***

| Information | Units | Dynamic | Notes |
|---|---|---|---|
| Time charge is needed | UTC | | |
| Energy request | Watt-hours | Yes | |
| Minimum charging duration | Seconds | Yes | |
| Maximum forward power | Watts | | Power request (U5) |
| Maximum reverse power | Watts | | |
| Duration maximum forward power | Seconds | Yes | |
| Duration maximum reverse power | Seconds | Yes | |
| Active power | Watts | Yes | Actual value |
| Active power setpoint | Percent | Yes | Accepted value |
| Time of reference | UTC | Yes | |



Some of this information may not change over the session and may only be needed by the EMS at the start. Others (which are listed as dynamic in the table) will definitely change throughout the session and will be needed to be retrieved by the EMS at more regular intervals, possibly before each command. Not all V2G applications will require the EMS to acquire all of the available PEV information.

#### 4.6.9 Recommended Active Power Command and Command Response

The EMS must command the PEV to provide forward or reverse power flow. It achieves this by providing a new setpoint for active power. The setpoint is a signed percent value between -100 and +100%. A positive percent indicates discharging (reverse power flow), and the inverter sets the power to the specified percent of the maximum reverse power. A negative percent indicates charging (forward power flow), and the charger consumes power at the specified percent of the maximum forward power. This is exactly how it is defined in Function INV4.

The command must also have a start time parameter. One way is to start to change the setpoint immediately after the command is received, and another way is to specify an exact start time (UTC). For each of these basic methods, it should also be allowed to provide a randomized time window, as defined in Function INV4. If an EMS sends a specific UTC time that is earlier than the time now, it should be converted into immediate. The randomization must be consistent with the update interval. It doesn't make sense to have a 20-second randomization for a command that is updated every 5 seconds. If the time window is set to zero, the change begins immediately.

IEC Function INV4 allows a ramp time to be specified for linearly changing the setpoint value from the current value to the new value once the change is authorized to start. If a value of zero is specified, the setpoint will be immediately changed, although the dynamics of the inverter and its software will determine the ramp rate of the actual power. If the parameter is not provided, a default value could be used, which may be zero for a step change.

IEC Function INV4 does not include a specific stop time, but it does include a reversion timeout that serves this purpose if a new command is not received before the end of the timeout period. The receipt of the next command normally acts as the termination of the prior command. If the next command is not received by a reversion timeout, the PEV is expected to revert to zero output or resume charging, as appropriate. It is expected that new commands would be provided at an update rate that is consistent with the OBW of the V2G application. For frequency regulation, these commands may be required every 3 seconds. For management of a facility peak 15-minute monthly demand, the updates may be needed every 1 minute or 2 minutes. For managing loads on a transformer, these commands could be 15 minutes or longer. When a new command is received, it replaces the current setpoint. If the timeout is not specified, the PEV should use a default value that is consistent with the application.

The parameters associated with each active power setpoint command are listed in Table 8.

***Table 8 - Active power setpoint command parameters***

| Command Parameter | Units | Opt | Default | Notes |
|---|---|---|---|---|
| Setpoint value | Percent | | | Percent of maximum, negative is charging |
| Setpoint type | Boolean | Yes | 0 | Target = 0, Limit = 1 |
| Start time | UTC | Yes | Now | If UTC < time now, use start now |
| Time window | Seconds | Yes | 0 | |
| Ramp time | Seconds | Yes | 0 | |
| Reversion timeout | Seconds | Yes | 1000 | Application can have a default |

The PEV must acknowledge the command as successful or not successful. If the command is accepted and the power level change is then successfully implemented, the available response will include a measurement of the actual new active power level after it has been reached. If the command cannot be successfully executed, the available response shall indicate the reason.



### 4.6.10 Levels of EMS Engagement with a PEV

Three levels of engagement between an EMS and a PEV are described: minimal engagement, informed engagement, and cooperative engagement. The information available from the PEV to the EMS will support all levels, but an EMS may not want to acquire or use the information. The level of engagement will depend on the V2G application, the capability of the EMS, and the communication channel between the EMS and PEV.

For minimal engagement, the EMS may not care about the state of each PEV, its need to charge by a specific time, or even its ability to participate as a DER. It might broadcast a percent of maximum reverse flow command to all of the PEVs in its aggregation without actually bothering to gather the specific limits of each PEV. It might just assume an average value for the aggregation. The aggregator may have previously gathered information about the DER during enrollment, and it uses that information for estimating the available capacity. It may not even care if any individual PEV can actually provide the requested power. The expectation would be that the PEV would participate if it can and drop out when it can’t or must revert to charging.

An EMS using informed engagement would acquire certain vehicle state information to be used for planning power allocation, but it would not assume any responsibility for ensuring that the PEV completes charging during the session. It would expect that the PEV would drop out if it needed to revert to charging. It may plan its usage of each PEV to optimize its ability to perform the aggregated function. At this level, the EMS would expect confirmation that the requested power setting was accepted or rejected and notification if the PEV dropped out to charge.

Cooperative engagement requires the EMS to accept responsibility for ensuring that the PEV can complete charging by the designated time that charging is needed. The EMS might end the DER session before charging is complete, but the PEV should be capable of charging at its requested power level to achieve its target SOC by the expected time of departure. The full functionality of U6 should allow for cooperative engagement. A home EMS would be more likely to engage cooperatively than an aggregator serving hundreds of vehicles.

The expectation is that the PEV would gather, prepare, and present all of the information needed by an EMS to support the cooperative engagement. U6 will define this information. An EMS may not choose to retrieve or use the available information. This all depends on the V2G application and the embedded algorithms in the EMS for managing the PEVs.

The typical information requirements for the different level of EMS engagement are shown in Table 9.

***Table 9 - Levels of engagement***

| Levels of EMS Engagement | Minimal | Informed | Cooperative |
|---|---|---|---|
| Behavior of EMS and PEV for the level of engagement. PEV provides information to support any level of EMS engagement. | EMS broadcasts power commands without planning. PEV breaks off to perform charging. | EMS plans power commands based on available power. PEV breaks off to perform charging. | EMS manages power for the V2G application and also to meet PEV charging objectives. |
| **Information Requirements** | | | |
| Maximum forward power<br>Maximum reverse power | Optional | Required | Required |
| Duration max forward power<br>Duration max reverse power | | Required | Required |
| Time charge is needed<br>Energy request<br>Minimum charging duration | | | Required |

4.6.11 A V2G Example - Facility Demand Charge Management

This section provides an example of how a facility EMS could use some of the use case information in a simple algorithm to allocate power to minimize monthly demand charges. Commercial businesses pay a demand charge that is based on the highest average power reached during the month over either a rolling 15-minute or 30-minute averaging interval, depending on the utility. This can be a significant charge and a monthly rate of $15 to $25 per peak kW is not uncommon. A facility with ten AC Level 2 charge stations could achieve a peak facility demand of 66 kW if ten vehicles charge simultaneously at 6.6 kW each for a single 15-minute period at any time during a month. If this could be limited to 40 kW by effective power allocation, that would cut the peak demand by 26 kW and save the facility $650 on the monthly demand charge at a $25-per-kW rate.

The example algorithm does not enforce a hard limit, but it uses some simple intelligence to allocated power to each of the connected vehicles. The vehicles are all allowed to fully charge. A key allocation parameter is the utilization factor (UF), which is defined as the minimum charging duration divided by the difference between the time charge is needed and the time now. This denominator must not be allowed to be less than minimum interval.

$$\text{Utilization Factor} = \frac{\text{Minimum Charging Duration}}{\text{Limited(Time Charge Is Needed} - \text{Time Now)}} \quad \text{(Eq. 6)}$$

This algorithm is executed every 1 minute and is based on UF. The EMS gathers information from each connected PEV, executes the allocation algorithm, and then provides an active power setpoint value as a percent of maximum for each PEV. The reversion timeout period should be slightly longer than 1 minute. If ramp times or random time windows are used, they should only be a few seconds.

1. For vehicles, the least risk is to allow each vehicle to start charging immediately at its maximum forward power. All of the connected vehicles that have not completed charging are assigned a preliminary allocation of 100%. If the sum of all of the allocated power is less than a target facility limit, no further action is required.

2. If this preliminary allocation takes the facility over the target, vehicles with a UF less than 0.6 that have not already started to charge are allocated 0% of their maximum in order of increasing UF until the facility power is below the target limit, if possible. This establishes a late start for some of the vehicles.

3. If the tentative power allocation still exceeds the facility target, all vehicles with a UF less than 0.9 are assigned a power setpoint percent equal to 1.1 times their UF. For example, a vehicle with a UF of 0.7 would be assigned a setpoint value of 77%. Those with a UF of 0.9 or greater retain their preliminary allocation of 100%.

This algorithm was used as part of a project sponsored by the New York State Energy Research and Development Authority (NYSERDA) called the "Electric Transportation Energy Storage System Feasibility Study," which is documented in NYSERDA Report 11-08, May 2011. For a Monte Carlo simulation of a shopping mall scenario using 18 AC Level 2 charge stations, the peak monthly demand is reduced from an unmanaged monthly peak value of 77 to 58 kW for a facility target limit of 55 kW. The annual demand charges are reduced by $5700 for a monthly demand charge rate of $25 per peak kW. There is some art to selecting the target because the monthly demand peak follows the target value down to a point and then reverses as the target is further reduced. That is because this algorithm requires the energy request to be completed by the time charge is needed for each PEV, and at some point, early limiting to stay under an overly tight limit results in most vehicles receiving a setpoint of 100% later in their session.

There are many possible algorithms. This one is very simple. Approaches using artificial intelligence techniques that could predict arrivals and charging requirements could perform better. However, the purpose of this discussion is not to promote this specific algorithm, but it is to show how the information available to an EMS in use case U6 can be used for the intelligent allocation of power to vehicles. Also, this type of demand charge management is not something that allows the charging power profile to all be prescheduled at the start of a session. Other vehicles will be coming and going at a facility, and conditions impacting intelligent power allocation for any vehicle can change by the minute. For an EMS to manage a 15-minute peak facility demand, it needs to be executing the algorithm at least every minute or two and adjusting the power setpoint for individual vehicles as needed. Other V2G applications, such as frequency regulation, may require vehicle active power setpoint value updates as frequently as every several seconds.

## 4.7 Considerations for Use Case U7 - Advanced Distributed Energy Resource

Unlike use case U6 (basic DER), which is based only on IEC 61850 Function INV4, use case U7 (advanced DER) uses several IEC 61850 inverter functions. U7 builds on U6, which is only concerned with bidirectional power conversion, and adds the communications and functionality required to take advantage of four-quadrant power conversions. The IEC 61850 Function INV3, which allows the power factor of a DER device to be set to a fixed value by EMS command, is one of the U7 functions. Several functions are included to allow for the autonomous operation of the inverter to modes and schedules selected by the EMS. The actual use case for communication is described in Appendix D, and SAE J2847/3 will define the implementation of the communication. This section describes the functionality required to create the information that is required to be exchanged with an EMS and the expected behavior of the PEV and EVSE in response to messages from an EMS. While U7 could include many of the functions defined by IEC 61850-7-420 Ed2 (2021) or later, it shall include those functions required to meet the requirements of IEEE 1547-2018 or later versions. IEC 61850 defines many functions, but many of these functions may not be required to be implemented in a specific utility service area or even allowed to be optionally implemented.

### 4.7.1 Reactive Power, Apparent Power, and Power Factor

In a simple circuit consisting of an AC voltage source and a linear load, both the current and voltage are sinusoidal waveforms. For a pure resistive load, the current and the voltage remain exactly in phase, and their product at any point in time is always positive, indicating that the direction of energy flow does not reverse. For this pure resistive load, the product of current and voltage is called active (or real) power and is measured in watts (W). All the active power entering the linear, resistive load is consumed.

Inductors, which are sometimes called reactors, store energy in the form of a magnetic field. When a voltage is initially placed across the inductor coil, a magnetic field builds up, and it takes a period of time for the current to reach full value. This causes the current to lag the voltage in phase, and consequently, inductors are said to absorb or consume reactive power. A pure inductive load causes the current to lag the voltage by 90 degrees. Capacitors store energy in the form of an electric field. When a current flows into a capacitor to charge it, the voltage lags the current, or, equivalently, the current leads the voltage. These devices are said to generate reactive power. These relationships are illustrated in Figure 29. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. For pure inductance and capacitance, there is no net energy flow over one cycle, and the energy temporarily stored in the magnetic field of an inductor or the electric field of a capacitor is exchanged with the generator during every cycle. This flow of energy in the circuit is called the reactive power and is measured in volt-amperes reactive (VAR).

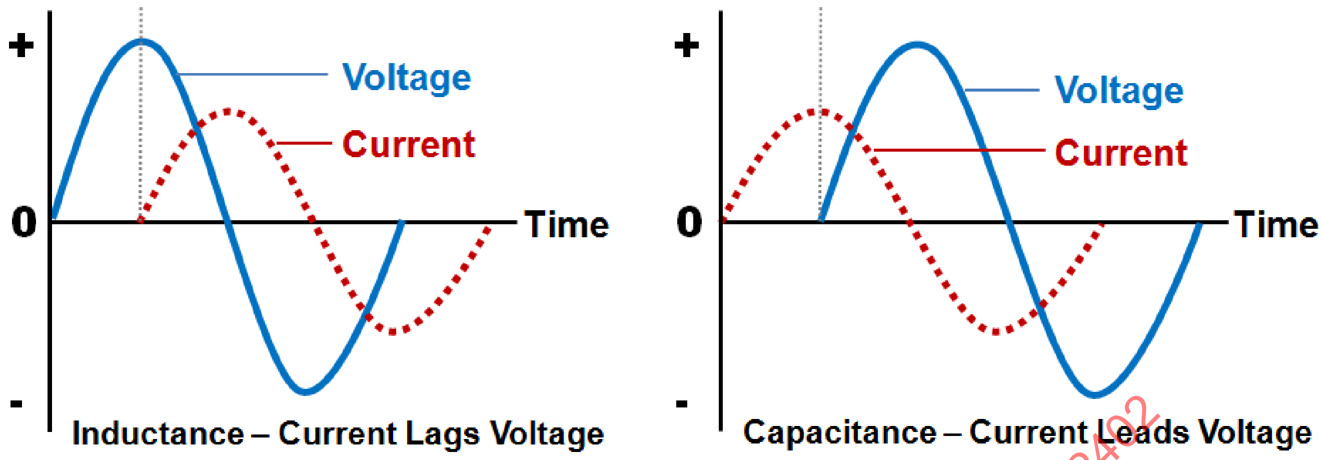



*Figure 29 - Effect of inductance and capacitance*

Practical loads have resistance, inductance, and capacitance. If all of the loads are linear devices, the simple circuit will have a pure sinusoidal voltage and current waveform displaced by a phase angle. A vector diagram can be created using root-mean-square (rms) values of the voltage and current waveform and the displacement phase angle between the two waveforms. This is shown in Figure 30. This "complex power" vector has a magnitude which is the product of the rms current and rms voltage, and it is called the apparent power, which is measured in volt-amperes (VA). The vector is rotated counterclockwise from the real ("x") axis by the phase angle between the voltage and current waveforms. The product of the apparent power and the cosine of the phase angle is the active power (W). The product of the apparent power and the sine of the phase angle is the reactive power (VAR). Although different terms are used for units of measure for active, reactive, and apparent power, they are all equivalent: the magnitude of 1.0 W equals 1.0 VA, which equals 1.0 VAR.

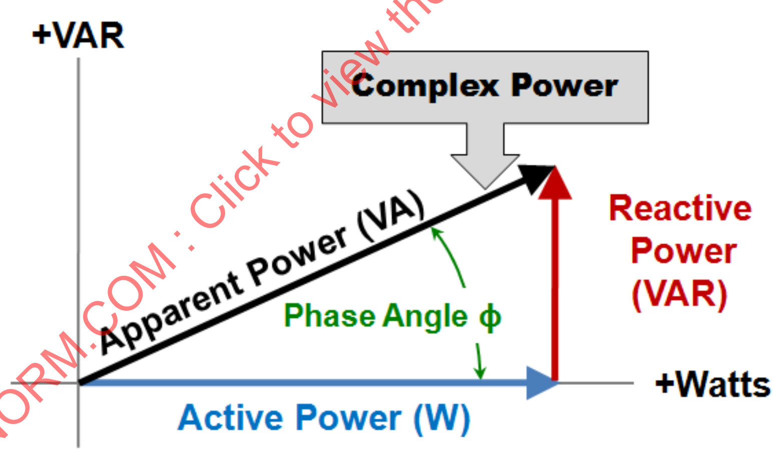



*Figure 30 - Components of complex power vector*

Power factor is formally defined as the ratio of the active power to apparent power. This is always true, even for highly distorted waveforms. By measuring rms voltage and rms current, the apparent power can be computed as their product. It is also possible to measure the active power. Power factor is a ratio of unsigned values, and it is not possible for apparent power to be less than active power. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle between the current and voltage sinusoid waveforms. Some care must be taken when using the cosine when the current leads or lags voltage by more than 90 degrees for which the cosine would be negative. Sign conventions for power factor, which by formal definition is an unsigned quantity with a value that can only range from zero to one, will be discussed in more detail later in this section.

Displacement power factor is defined as the ratio of active power to apparent power at the fundamental frequency (50 Hz or 60 Hz). For waveforms that are not highly distorted, this is approximately equal to the cosine of the phase angle ($\phi_1$) between the current and voltage at the fundamental frequency. Nonlinear devices, such as rectifiers, and other factors can lead to distortion of the waveforms. This is captured by the distortion power factor which can be computed as the ratio of the rms current at the fundamental frequency ($I_{1,\mathrm{rms}}$) to the total rms current ($I_{\mathrm{rms}}$). Total power factor is the product of displacement power factor and distortion power factor.

$$\mathrm{PowerFactor} = \left(\frac{I_{1,rms}}{I_{rms}}\right) cos\,i\,ne\Phi_1 \qquad \text{(Eq. 7)}$$

Power factor is a practical measure of the efficiency of a power distribution system. In an EPS, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. Utilities typically charge additional costs to customers who have a total power factor below some limit, which is typically 0.9 to 0.95. Sometimes, an electronic device is listed with a cosine ϕ number to represent power factor. A number of 0.98 would look very good, but if the device's distortion power factor is 0.9, the total power factor is now only 0.81: not very good.

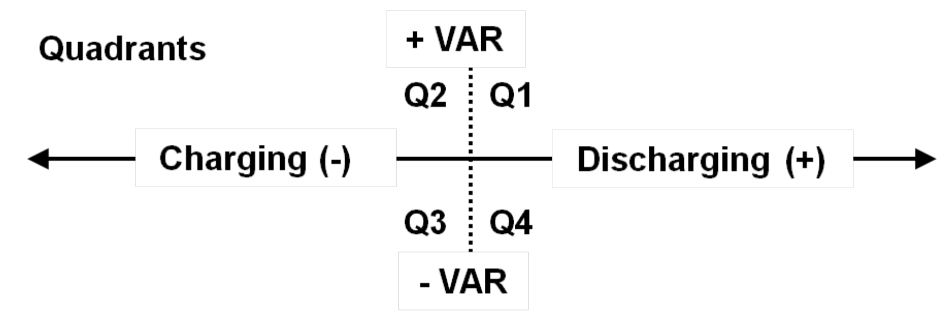
For the purpose of U7, power factor control is primarily about using an inverter to control the displacement power factor. This is done by directly controlling the phase angle of the supplied or consumed AC current relative to the grid voltage waveform. Modern power converters include power factor correction electronics to minimize harmonic distortion of the current. In subsequent discussion, the term "power factor" will be used to mean displacement power factor.

The IEC and the IEEE have different sign conventions for the inherently unsigned power factor. The IEEE and the Edison Electric Institute (EEI) convention is the same, and EEI is sometimes used to define this sign convention. The sign is used to convey additional information about what is actually an unsigned ratio of two positive magnitudes between zero and one. Some of this depends on the frame of reference.

There are two frames of reference for measuring power. Most of the discussion in this section has been about power flowing into loads from an AC generator. The consumer reference frame is generally used for equipment that consumes power where positive power flows into a load. The SAE terminology of forward (+) and reverse (-) power flow relative to a PEV uses a consumer reference frame. Power flow can also be looked at from the perspective of a generator where positive power flows from the generator to the load. Utilities typically use this producer frame of reference, and a DER device follows this convention. Discharging storage produces power and is positive power flow in this frame of reference. The producer frame of reference is used for U6 and U7.

Table 10 provides the IEEE (EEI) and IEC sign convention for power factor. The quadrants are shown in the diagram above the table. In a producer's frame of reference, active power is positive in Q1 and Q4 when it flows from a generator to a load, and it is negative in Q2 and Q3 when it flows from the load to the generator. Reactive power is positive for Q1 and Q2 and negative for Q3 and Q4 based on the axis convention. The top two rows of the table describe these characteristics. The IEEE sign convention denotes whether the current is leading voltage by using a positive power factor for Q2 and Q4 or lagging by using a negative power factor for Q1 and Q3. This is based on using the smaller included angle with the phase angle being limited to -90 to +90 degrees, which is equivalent to switching from a producer to a consumer frame of reference in Q2 and Q3. In the IEEE convention, the signed power factor is sufficient to determine where the inverter needs to set the current phase angle relative to the grid voltage.

***Table 10 - Power factor sign conventions***




| Attribute | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| Active power | Positive | Negative | Negative | Positive |
| Reactive power | Positive | Positive | Negative | Negative |
| IEEE sign | Negative | Positive | Negative | Positive |
| IEEE angle (-90 ≤ ϕ ≤ +90) | Lags (I) | Leads (C) | Lags (I) | Leads (C) |
| IEC sign | Positive | Negative | Negative | Positive |
| IEC angle (-180 ≤ ϕ ≤ +180) | Lags (C) | Lags (C) | Leads (I) | Leads (I) |
| IEC excitation | Overexcited | Overexcited | Underexcited | Underexcited |

The IEC uses a power factor sign convention that is aligned with the direction of active power flow from a producer, and it is positive in Q1 and Q4. It is redundant with the signed value of active power and does not provide any guidance as to whether the phase angle of current to voltage is leading or lagging as does the IEEE sign convention. However, because the IEC also measures the lead or lag angle using the full range of -180 to +180 degrees, it allows the power factor sign to be automatically assigned by using cosine ϕ. With the extended phase angle, current lags voltage for Q1 and Q2 and leads in Q3 and Q4. The IEC sign convention requires a “generator” excitation to be specified along with the signed power factor. The term comes from how synchronous generators are operated to supply or absorb reactive power.

Most generators connected to the grid are synchronous generators, meaning that they operate at the same electrical frequency. To supply reactive power, the generator exciter (which is a DC power supply) increases the field current of the rotor. This increases the magnetic field of the rotor raising the generator voltage, which causes reactive power to be supplied to the grid. Therefore, when a generator is supplying reactive power (+VAR), its mode of operation is referred to as overexcited, and it has a lagging power factor (Q1). When a generator consumes reactive power (-VAR), it is underexcited, and it has a leading power factor (Q4). For a generator, a lagging power factor is associated with the supply of reactive power to the grid. For a load, a lagging power factor is associated with absorbing reactive power (Q3). This creates some confusion as to whether positive reactive power is inductive or capacitive; it depends on the frame of reference.

It is possible that either the IEEE or IEC sign convention could be used by a V2G application for controlling power factor. Any command to an inverter to operate at a specific power factor must designate the power factor sign convention being used, provide a signed value for the power factor setpoint, and if the IEC convention is being used, also define whether it must be overexcited or underexcited. The key is that the inverter must set the phase relationship of the controlled current waveform at the correct angle with the grid voltage waveform.

Figure 31 shows the first quadrant for a four-quadrant inverter in a storage DER. This quadrant is for the supply of both active and reactive power to the grid. The inverter has a maximum apparent power limit for discharging which is determined by the inverter electronics, the energy storage system, and the branch circuit. For this quadrant, the minimum power factor is defined by the selection of the maximum reverse power limit relative to the maximum apparent power limit. The red shaded triangle is the operating region for power factor control in this quadrant.

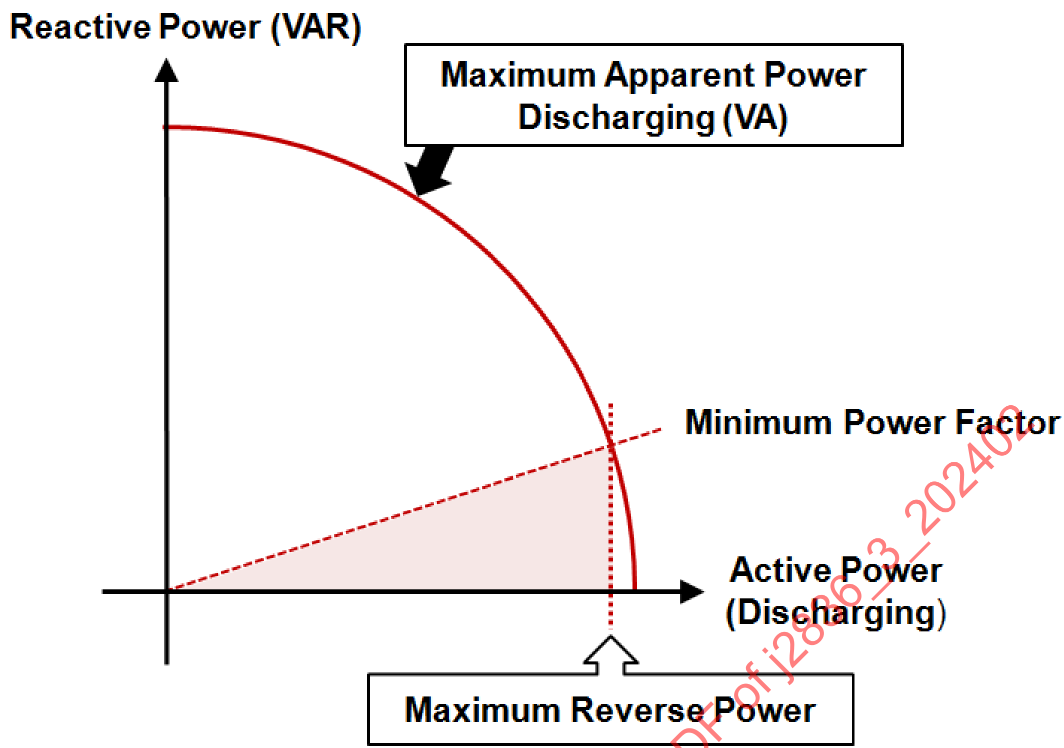



*Figure 31 - Minimum power factor*



When power factor is being controlled along with active power, it would be unusual to expect a minimum power factor below 0.85 leading or lagging. Synchronous generators do not have symmetric reactive power limits and may not be capable of absorbing more than 0.95 on some machines at rated output of active power. For an inverter, the lead and lag angles for power factors in the range of 0.85 should be capable of being symmetric. There could be a difference between charging and discharging if the maximum apparent power is not the same for both charging and discharging. While it is possible that there could be a different value for the minimum power factor for each quadrant (e.g., minPFQ1 to minPFQ4), for the purposes of a PEV, it is expected that the highest value from all four quadrants could be used to define a single minimum. In this case, the smallest angle should be selected to define a minimum power factor rating that can be used for all four quadrants. For a DER that operates at a continuous high output, such as a solar PV system or a charging PEV, this power factor mode provides an effective way to control reactive power through the power factor setpoint. However, the absolute reactive power is significantly limited by the constraint that full active power capability must be simultaneously available.

If the maximum inverter current is set by the inverter to exactly lag the voltage waveform by 90 degrees, the active power will be zero, and all of the maximum apparent power is supplied as reactive power. This is shown by the shaded gray rectangle along the reactive power axis in Figure 32. This would be a pure voltage support mode of operation for a DER. If an available reactive power limit is set at the intercept of the minimum power factor, this would allow reactive power to be controlled as a percent of the available reactive power across the full range of active power. This is shown by the blue shaded rectangle. Direct reactive power control could be an alternative function to controlling power factor, although power factor control is more traditionally used.

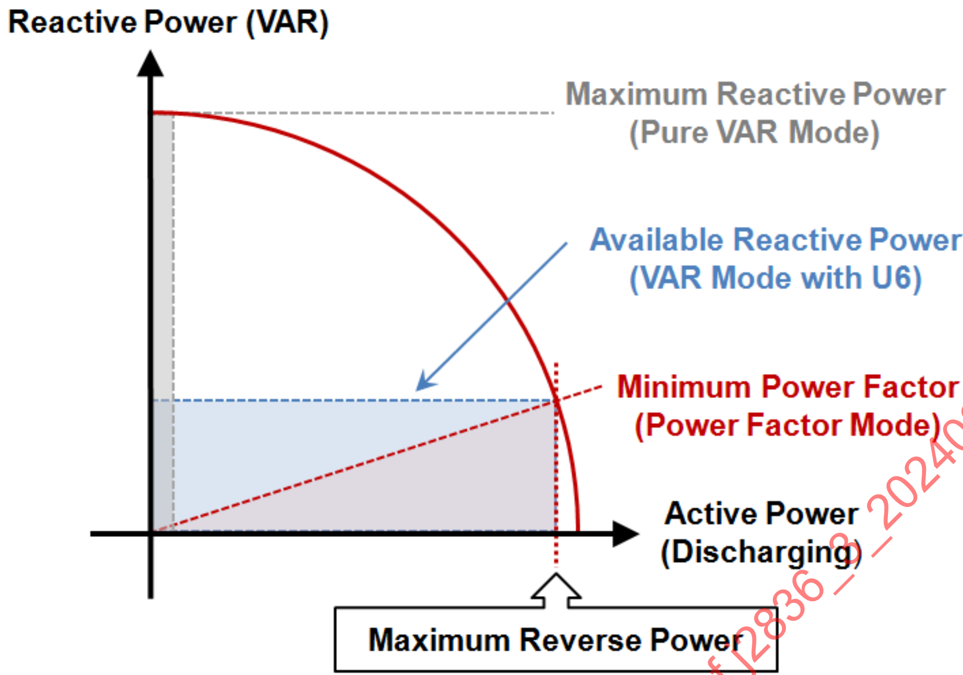



*Figure 32 - VAR and power factor zones*



Reactive power is like dealing with a weight on a spring. Once the weight is bobbing up and down, it does not take very much energy to sustain the oscillation. In the grid, the reactive energy goes between the magnetic fields of inductive elements and the electric fields of capacitive elements. Losses occur because of the circulating currents to move the energy between one storage medium and another during every half cycle. A storage system can use its inverter to directly move energy in and out of the grid every half cycle to produce or absorb reactive power. There will always be some power consumed from the battery or the grid to operate the inverter, but this will be small. Because the battery is charged and discharged during every half cycle, this does not result in deep cycling of the battery. There are many very small cycles, but the energy content is very small.

4.7.2 Reference Voltage and Reference Voltage Offset

The inverter can only directly measure parameters at its ECP to the local EPS. For many of the autonomous functions, the independent variable, such as voltage, needs to be based on conditions at the PCC. This is the point where the local and utility EPS connect. This would normally be at the electric meter. But there are applications, such as a single kW-level DER, where the Point of Connection (PoC) can be used for the functions instead of the PCC. The point where the functions and requirements of IEEE 1547 is met is defined as Reference Point of Applicability (RPA). There could be a voltage offset from the voltage that can be measured at the inverter and the PCC. This is called the reference voltage offset. The measured voltage at the ECP can be corrected to the reference voltage by adding the value of the reference voltage offset. This offset will be installation dependent. The distribution utility may even prefer that the offset be defined through the transformer to the connection to the feeder. For customer and system level V2G applications, this voltage offset correction may not be necessary. It is primarily needed for distribution V2G applications.

Figure 33 shows a local EPS with both an AC and DC EVSE. The ECP will be at the inverter output, and this is the point where the inverter can measure frequency, voltage, and other parameters. The voltage drop from the PCC to the ECP is shown as “VRefOfs” on the diagram. This drop is due to resistance in the wiring and other devices. The value of this constant may be a factor based on utility guidelines or an actual measured value. The inverter stores this setting.

While this is described by both EPRI and IEC in this manner, the actual offset is directly impacted by the current flowing between the PCC and ECP and cannot be a calibration constant. SAE informed both EPRI and IEC of this problem.

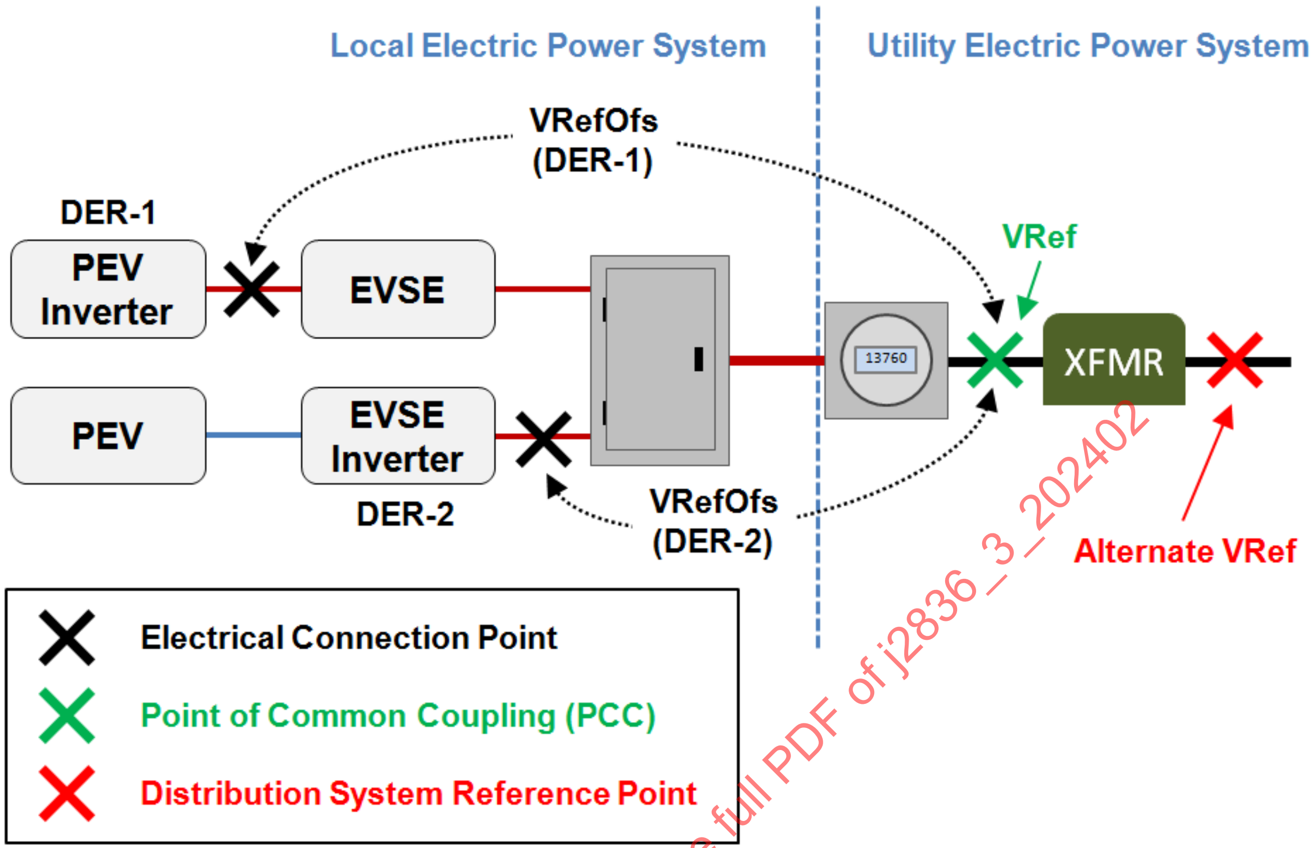



*Figure 33 - Voltage reference offset*



4.7.3 Recommendations for U7 Fixed Power Factor Function

This U7 function is based on the “fixed power factor function,” defined in the EPRI *Common Functions* document, and on “Function INV3: adjust power factor,” defined in IEC 61850-90-7. This section provides a brief overview of the EPRI and IEC function for direct management of the power factor during the charging or discharging of a storage DER device.

This function is intended to provide a simple mechanism through which the power factor of a DER may be set to a fixed value. The command structure is similar to that of INV4 in 4.6.2. The command would have a setpoint value for power factor, a randomization time window, a ramp time, and a reversion timeout. The setpoint value is a signed power factor. The command also designates whether the IEEE or IEC sign convention is being used. With the IEEE convention, the quadrant is easily determined because the inverter knows whether it is charging or discharging. With the IEC convention, the power factor sign only indicates the direction of the active power, and an additional item of information is required to determine the quadrant. The inverter must know the excitation or equivalently whether the current is leading or lagging the voltage.

This function is intended to be capable of being used with the INV4 (U6) function for controlling active power. The minimum power factor setting for this function must be capable of being achieved at the maximum forward power and maximum reverse power limits and all values between. The EMS should not request a lower absolute value of a power factor than the inverter is capable of supporting.

Information that should be made available to the EMS from the PEV is listed in Table 11. The parameters associated with each power factor management command are listed in Table 12. The command approach is as described in 4.6.9 for active power management. Some of the information from U6 is needed to understand the PEV status for charging if the EMS is engaged in also managing the charging session.

*Table 11 - Recommended PEV information for fixed power factor*

| Information | Units | Dynamic | Notes |
|---|---|---|---|
| Minimum power factor | None | | -1.0 to 1.0 |
| Time charge is needed | UTC | | |
| Energy request | Watt-hours | Yes | |
| Minimum charging duration | Seconds | Yes | |
| Maximum forward power | Watts | | Power request (U5) |
| Time of reference | UTC | Yes | |

*Table 12 - Fixed power factor setpoint command parameters*

| Command Parameter | Units | Opt | Default | Notes |
|---|---|---|---|---|
| PF setpoint value | | | | Power factor -1.0 to 1.0 |
| PF sign convention | Boolean | | 0 | IEEE = 0, IEC = 1 |
| PF excitation | Boolean | | | Underexcited = 0, Overexcited = 1 |
| Start time | UTC | Yes | Now | If UTC < time now, use start now |
| Time window | Seconds | Yes | 0 | |
| Ramp time | Seconds | Yes | 0 | |
| Reversion timeout | Seconds | Yes | 1000 | Application can have a default |



4.7.4 Recommendations for U7 Fixed VAR Function

This function is intended to provide a simple mechanism through which the reactive power of a DER may be set to a fixed value. The command structure is similar to that of INV4 in 4.6.2. The command will have a setpoint value for reactive power, a randomization time window, a ramp time, and a reversion timeout. The setpoint value is a signed percent of a defined maximum value. The type of maximum value to be used with the setpoint must also be defined in the command.

If this function is to be used with the INV4 (U6) function for controlling active power, the available reactive power should be calculated as the reactive power at the minimum power factor at the maximum charging or discharging power. This value of reactive power can be provided with active power ranging from maximum charge rate to maximum discharge rate. This is equivalent to operating in the blue zone in Figure 32. For pure voltage support with the PEV at zero active power, except for covering switching losses, the reactive power can be directly commanded as a percent of the maximum reactive power, which is based on the maximum volt amperes.

Information that should be made available to the EMS from the PEV is listed in Table 13.

*Table 13 - Recommended PEV information for fixed VAR function*

| Information | Units | Dynamic | Notes |
|---|---|---|---|
| Maximum reactive power | VAR | | |
| Available reactive power | VAR | | |
| Time charge is needed | UTC | | |
| Energy request | Watt-hours | Yes | |
| Minimum charging duration | Seconds | Yes | |
| Maximum forward power | Watts | | Power request (U5) |
| Time of reference | UTC | Yes | |

The parameters associated with each fixed VAR command are listed in Table 14. The command approach is as described in 4.6.9 for active power management. Some of the information from U6 is needed to understand the PEV status for charging if the EMS is engaged in also managing the charging session.

***Table 14 - Fixed VAR command parameters***

| Command Parameter | Units | Opt | Default | Notes |
|---|---|---|---|---|
| VAR setpoint value | Percent | | | Signed percent of selected limit |
| VAR limit type | Boolean | | 0 | 0 = %AvailableVAR, 1 = %MaxVAR |
| Start time | UTC | Yes | Now | If UTC < time now, use start now |
| Time window | Seconds | Yes | 0 | |
| Ramp time | Seconds | Yes | 0 | |
| Reversion timeout | Seconds | Yes | 1000 | Application can have a default |

4.7.5 Autonomous Curve Functions

IEC 61850-90-7 defines a number of autonomous functions. Many of these are based on the inverter measuring something (X) and then producing an output (Y) based a stored function (Y=f(X)). The independent variable (X) can be line voltage, frequency, active power, and other parameters. The function output (Y) could be a direct output of the inverter, such as active power, or it could be an indirect output, such as power factor, that needs some additional processing. In order to smooth potential step changes in inverter output, the IEC document allows for an optional first order lag function and an optional rate limit. These can be combined using a rate limited first order lag filter as shown in Figure 34. For each type of X-Y system (such as volt-VAR), there may be different stored curves with different filter gains and limits. A utility would select which stored curve set is to be used for a specific DER session.

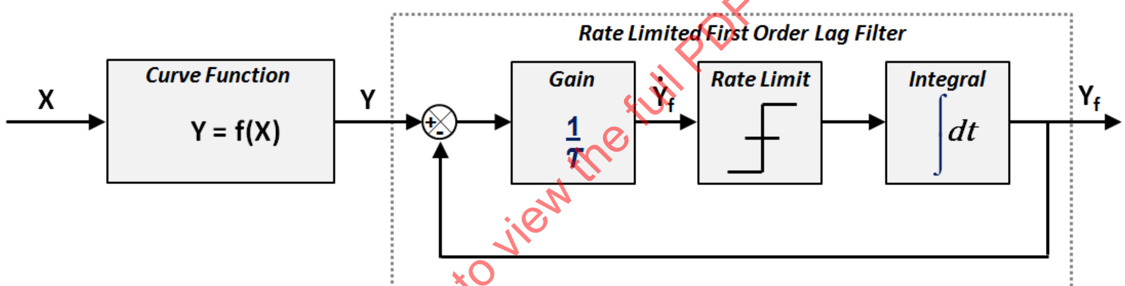



***Figure 34 - Structure of an autonomous function***

The functions are called curve functions because they are defined by a piece-wise linear array of (X, Y) data points. Linear interpolation is to be used to compute the value of Y for a value of X that is between the values of two data points in the array. Examples of two curves defined by four data points each are shown in Figure 35. For values of X outside the range of the array points, the value of Y for the end points is to be used. This is shown by the dotted lines in the sample functions. The top function shows a curve with deadband (zero output for a middle range of X). It is also possible that the values of X in the array reverse to create hysteresis. This is shown by the lower function.

The arrays must be received from a valid source, checked by the PEV for errors, and then stored in advance of a session. This could be long before they are needed to be used. The EMS controlling the PEV as a DER selects the function and curves to be used and either initiates it immediately or schedules it to run later.

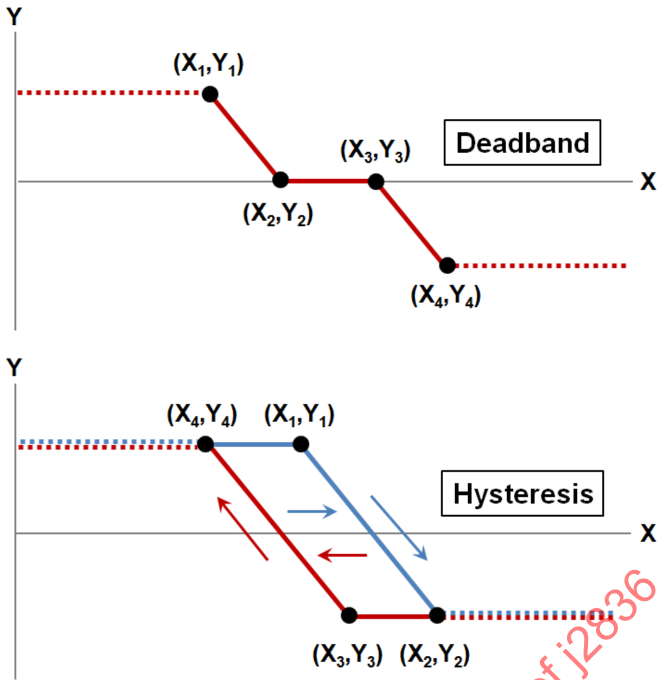



***Figure 35 - Array functions***



IEC 61850-90-7 defines a number of autonomous functions, and others may be added in the future. If an inverter is designed to receive and implement any of these functions based on a single array of (X, Y) points with a selectable X and Y, it should be easy to add new functions. The volt-VAR, frequency-watt, volt-watt, and watt-power factor functions are briefly described in 4.4.4 of this document. The IEC document provides much more background on how these and other autonomous functions can be used by a utility. The Smart Energy Profile 2.0 is expected to be used for communication with an onboard inverter, and it provides the communication structure for each of these autonomous functions. However, an external EVSE inverter could be connected to a network that is not based on SEP2, although other communication protocols are also including support for these functions.

4.7.6 Low and High Voltage Ride Through Functions

As discussed in 4.4.1, IEEE 1547-2003 requires that an inverter (while connected and producing active power) must stop producing power within a defined clearing interval if an abnormal voltage is detected. This standard worked well when there was a low penetration of DER devices on a distribution feeder. It was not a problem for the utility if a DER device tripped offline during a disturbance. But as the penetration of renewable sources, such as solar PV systems, increases, the utility might prefer that DER devices ride through the voltage disturbance without tripping and actively help to stabilize the voltage. The low voltage ride through (LVRT) and high voltage ride through (HVRT) functions are intended to provide this capability and have been added to the latest version of the standard, i.e., IEEE 1547-2018.

This section is primarily based on these functions as described in EPRI *Common Functions for Smart Inverters*. IEEE 1547-2018 defines these functions and expands on them. In jurisdictions that require conformance with IEEE 1547-2018, the IEEE guidance should be followed. This section is only for basic understanding of the concept.

The LVRT and HVRT concept is shown in Figure 36. Four piece-wise linear curves are defined. Two are located below the nominal voltage and represent the LVRT functions, and two are located above the nominal voltage and represent the HVRT functions. The y-axis shows the voltage as a percent of nominal (100%). The x-axis shows the duration of an event. The red curves define the "must disconnect" boundaries, and the DER must be disconnected before entering the red shaded regions. The green curves define the "must remain connected" boundaries, and the DER is expected to remain connected within the green shaded regions. The DER "may disconnect" outside the green curves. For a DER that uses an inverter, the inverter does not have to physically disconnect, but it must stop providing power. In IEEE 1547-2018, the "must remain connected" is further classified into two behaviors: Mandatory Operation and Momentary Cessation. In the standard, the Mandatory Operation boundary is not curve changeable, whereas the Momentary Cessation boundary can be changed. The figure only shows stair-step transitions, but sloping segments could also be provided to the DER by a utility using these arrays.

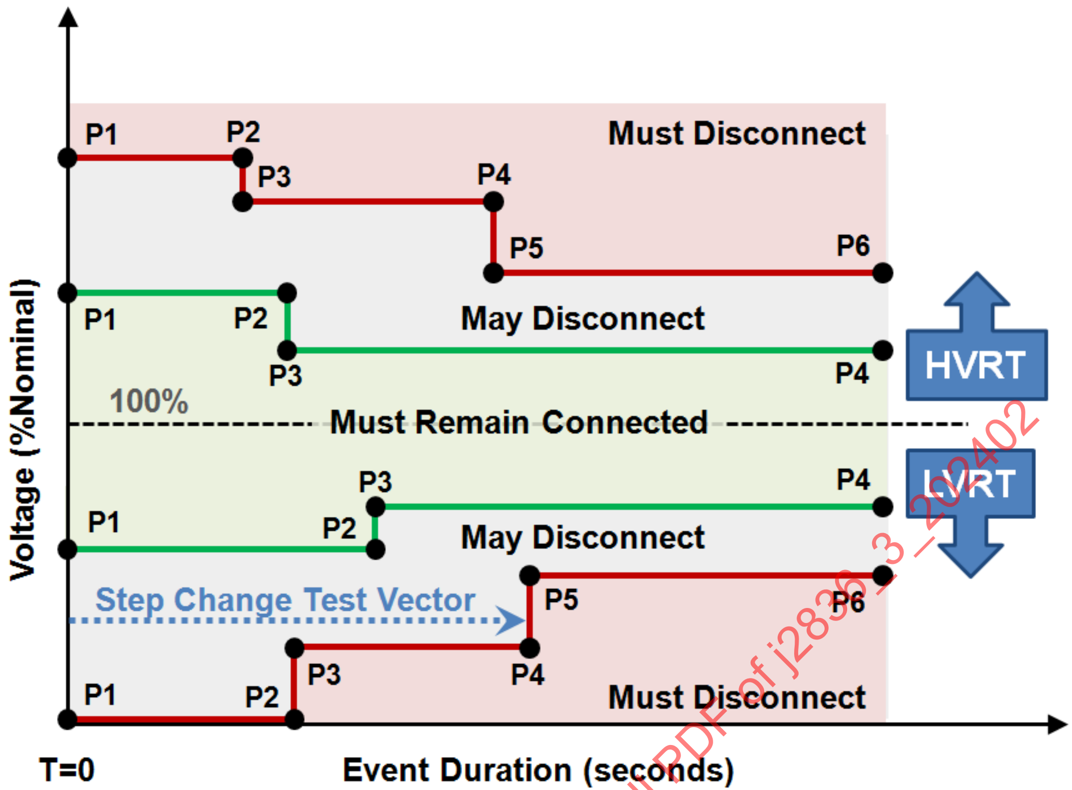



*Figure 36 - LVRT and HVRT concept*

The term LVRT implies that the “must disconnect” curve would be lower or longer than the IEEE 1547 limits when this function is being used; otherwise, it would not be a ride through of a low voltage event. However, nothing prevents the “must disconnect” curve being used to just implement the IEEE 1547 limits. This function provides flexibility in allowing the limits to be selected and not fixed in the inverter. It is not required to provide a “must remain connected” curve, in which case the “must disconnect” curve still separates the “must disconnect” and “may disconnect” regions. However, it would normally be expected that the inverter would remain connected in the “may disconnect” region if it could do so without harm to the inverter or PEV. When a “must remain connected” region is established, the expectation that the inverter remains connected is much higher, but it is still responsible for self-protection.

The LVRT and HVRT functions look like the other autonomous curve functions. However, these curves are only a specification of the voltage and duration limits for the inverter to implement and are not intended to be actual executable functions. These limits must be interpreted by using a perfect step change in voltage from 100% to a specified level and then reading the duration for crossing the boundary curve at that voltage level. This is illustrated by the dotted blue arrow. In this example, which is based on the LVRT “must disconnect” curve, for every step change in voltage to any value at or below the voltage value of point P5 and above the voltage value of point P4, the DER “must disconnect” before the event duration defined by the duration value of point P4 or P5. This is a specification limit which can be implemented many ways. Again, it is not appropriate to think of these curves as a gate for actual voltage waveforms. When the inverter receives a curve, it must analyze the curve and set up its hardware or software detection logic to implement the specified protection functions. This process will be described by example for an inverter that uses a set of event timers to execute the protection functions.

Figure 37 shows an LVRT “must disconnect” curve which uses a sloped line segment from P4 to P5. For the purposes of this example, which will use pure event timers to implement the function, the inverter will convert the sloped segment into a single intermediate level. This is shown by the inverter introducing two new data points, P45A and P45B, with voltage values set to the average of the voltage values of points P4 and P5. P45A is set to the duration value of P4, and P45B is set to the duration of P5. Individual event detectors and timers can now be set up for three events.

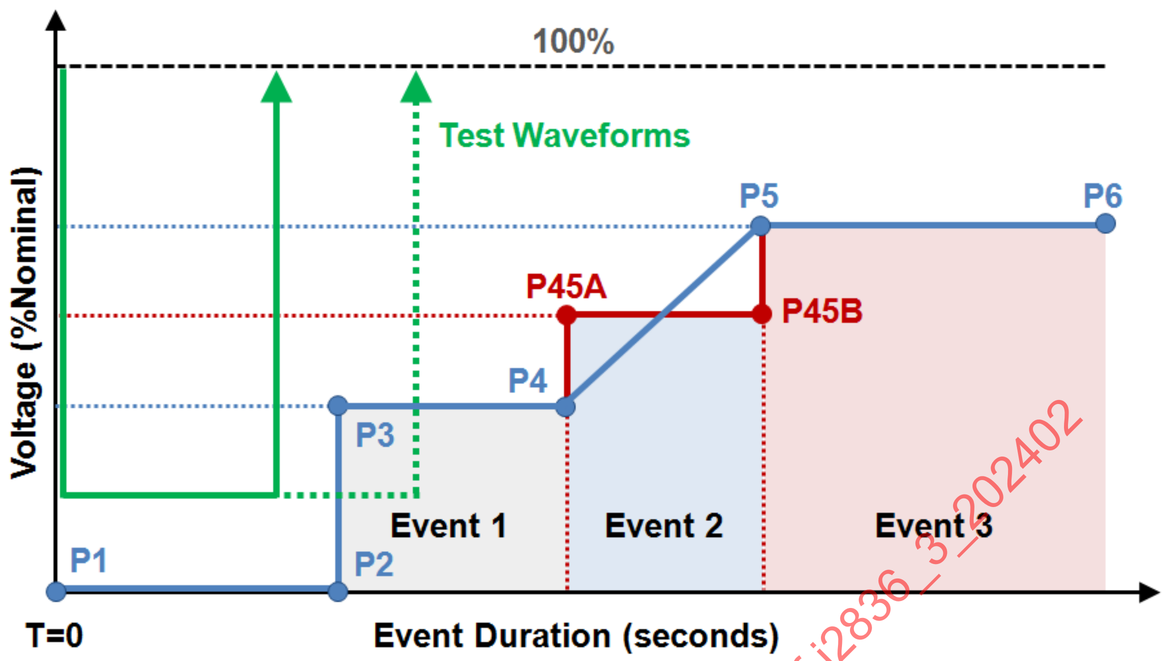



*Figure 37 - Example of LVRT implementation*



For Event 3, which is shown by the red shaded region, the event timer starts counting if the voltage drops below the value of point P5, and the event is ended and the timer is reset if the voltage rises above that value. The inverter must be off-line before the timer reaches the duration value of point P5. The inverter must account for any voltage measurement delays and any delays in ceasing to discharge following the timer trip when it sets up the timers, because the clearing times are based on the actual time to disconnect based on actual voltage transients. A similar timer can be set up for Event 2, which is now based on point P45A, and Event 1, which is based on point P3.

Figure 37 also shows two superimposed step changes in green: one with a solid line and one with a dotted line. These could be used to test the implementation of the function. Both step changes drop below the value of P3, which activates all three event timers. The sold line quickly returns to 100% before Event 1 would time out and all events are reset. The dotted line shows that Event 1 trips. The other events would reset, but it only requires one to trip the inverter. While this example is based on the step changes and this inverter design using timers will work perfectly for that condition, the timers will also work for arbitrary waveforms. Any individual timer activates when its threshold is crossed and resets when it crosses above it. So in a ramp down, the Event 3 timer would start before the Event 2 timer, which would start before the Event 1 timer. If Event 1 reset by a slight rise in voltage, Event 3 might still be active. If the voltage dropped back below the Event 1 threshold, it would restart the Event 1 counter and Event 3 may still be active. Again, the diagram is a specification based on pure step changes in voltage and not a voltage waveform gate.

It is possible to design an event detector that can use a sloped exit condition, such as the P4-P5 segment. In this case, the “event” would trigger when the voltage dropped below P5 and be reset if the voltage climbs above P5. However, in this case, the trip window would need a dynamic gate of trip voltage versus duration.

The IEC allows that these slopes can be converted to intermediate steps for inverters that only use event timers, as was shown in the example. The example showed using only a single intermediate level for vehicle inverters. However, more levels would provide a better approximation for a sloped segment. The single step conversion of sloped segments may not be a major concern to a utility for PEV inverters. Utilities that desire more steps to approximate a sloped segment than a single intermediate step could just send curves to vehicles with all of the steps defined.

This function defines only the mechanism through which the settings are communicated and does not define the settings that would actually be provided and used. Various countries, states, or other organizations, such as the IEEE, may issue specific L/HVRT requirements. The intention is that this function will be sufficiently flexible to support all such requirements. While the curves convey utility requirements to the inverter, the actual implementation by the inverter must also account for any inverter limitations and safety considerations.

Unlike solar PV systems, which are connected and providing energy for many hours, vehicles have very limited energy production capacity. Small DER devices, such as PEVs, may not be required to be capable of L/HVRT. And it is possible that even if they are capable, they may not be authorized by a utility to use the capability. It is possible that PEVs may be required to only use the IEEE 1547 limits.

#### 4.7.7 Loading and Executing Autonomous Functions

There are two distinct phases for autonomous functions: a loading phase and an executing phase. The general structure of each function can be designed into the inverter, but there can be several modes for each function which depend on a specific set of curves. It could be possible for an inverter to have several sets of curves for each function. These curves must be provided to the inverter from the utility during a loading phase. The utility can then instruct the inverter to execute a loaded function and curve set. The combination of a function and a set of curves are often called a mode. There can be several volt-VAR modes for the volt-VAR function.

The loading of curves and establishment of modes must occur before the mode can be activated. This could be done just prior to being activated by a utility as an integrated load and activate exchange. Alternatively, loading could be done as part of an initial enrollment process, and the utility would only need to activate a saved mode just prior to use.

The communication protocol and inverter functionality must allow for loading curves for specific modes and performing any necessary verification that the curves do not have defects. The provider of the curves should make certain that all of the data points are correct in advance of transmission to the inverter, but the inverter must check that there are not defects that could cause problems for the inverter. It will not be possible to verify that the curves always contain the intended functionality, but obvious defects, such as points with negative frequency for a frequency-watt curve, can be detected and the errors flagged to the provider. After the curves are verified, they would be saved by the inverter for that mode.

The processes of loading a mode schedule and of commanding a saved mode to activate are different scenarios in U7.



### 4.8 Considerations for Use Case PEV4 - PEV as a Distributed Energy Resource

Use case PEV4 (PEV as a distributed energy resource) describes the process steps needed to enroll in a V2G application (or program), perform the initial setup of the PEV or EVSE, engage in one or more sessions, be compensated for participation, and terminate the participation in the V2G program sometime in the future. This use case is defined in Appendix A. This section discusses some of the issues and considerations that guide the implementation of the use case.

#### 4.8.1 Show Me the Money!

The purpose of a PEV is transportation. A PEV needs to charge its battery to perform that purpose. It only needs to discharge its battery to accelerate and to cruise. Discharging its battery while the PEV is stationary increases the number of charge-discharge cycles over those required for only transportation. The use of reverse flow increases the amount of energy transfer needed to fill the battery and reduces the available time to do it. This increases the risk to the operator of not having sufficient energy in the battery if the PEV is needed for unexpected travel. The lowest risk for the PEV is to start charging as soon as it is plugged in and at the maximum rate that the PEV, the EVSE, and the grid can physically sustain. This may not be the most economically favorable approach for the PEV owner or in the best interest of other stakeholders, but it tops off the PEV battery in the shortest time.

A pure variable load is not formally considered to be a DER device because, unlike a solar PV system or an ESS, it never produces energy. Loads are always distributed, but they are not energy resources. Demand management generally refers to loads that can be scheduled to be interrupted during critical peaks. A PEV can suspend charging in response to such a prescheduled demand management event. Demand dispatch is a term that is being used to describe variable loads that can be dynamically controlled. Varying a load can be just as effective for a utility as varying the output of a generator. This document considers the use of pure variable rate charging, without any reverse flow, to also be a DER application.

Use cases U5 and U6 both provide the capability to directly manage active power flow during charging. While the use of reverse flow can double the range of active power control, many V2G applications can be very effectively performed by only varying the rate of charging of the PEV. Demand dispatch can be performed using only a charger which is less complex than a bidirectional or four-quadrant converter (inverter). Variable rate charging has no adverse impact on battery life because there is no increase in the depth or number of charging cycles. However, extending the duration of a charging session by delaying the start or reducing the rate of charging still increases the risk to the PEV of not having sufficient battery energy if an earlier-than-planned need to travel arises.

The use of reverse power flow (discharging) must have sufficient value to the PEV owner to offset any extra cost for the inverters (in the PEV or EVSE) and any potential reduction in vehicle battery life. Value isn't just about receiving cash payments or discounts, but value can still be evaluated using alternative business cases. For example, the use of a PEV for emergency backup of a home after a power failure (V2H) could be of value to a homeowner. The incremental cost of providing this V2H capability could be compared with the cost of a portable generator. Of course, the PEV may also provide other benefits that the portable generator cannot, such as the ability to participate in frequency regulation. This complicates the business case, but there will always be a value assessment that must be made by the PEV owner at the time of purchase of the PEV and EVSE and when considering participation in any application.

It is not the purpose of this document to perform value assessments of the various business cases for using a PEV with an EVSE as a DER for V2G applications. There are many technical, regulatory, and market issues to be worked to create viable and sustainable business cases for the use of a PEV as a DER device across the different V2G domains of balancing area, distribution feeder, and behind the meter. However, there must always be some perceived value to the PEV owner for participating in a V2G application, even for charging-only applications. This could be as simple as a receiving a lower cost for parking or charging by agreeing to allow a commercial parking facility to manage its demand charges by using its EMS to control the PEV rate of charging during the session.

4.8.2 The Business Deals

Every V2G application will be based on one or more business relationships, or "deals." Some entity will own the V2G application (or program) and will receive the direct benefit from using a PEV and EVSE as a DER. There are different tiers of deals for V2G applications. This document will be concerned only with the direct V2G deal between the EMS owner and the owner of either the PEV or the EVSE. An aggregator could bid frequency regulation services to a system operator and be compensated for that service. The aggregator uses its EMS to control a fleet of PEVs to perform the service. The aggregator compensates the PEV owners for their participation. The business deal of interest here is the one between the aggregator and each PEV or EVSE and not the one between the aggregator and the system operator.

The inverter is the core of a DER device. This is more complicated with V2G because it is always the combination of the PEV and the EVSE that form the DER, and the inverter could be in the PEV (V2G-AC) or the EVSE (V2G-DC). This discussion is about business deals and not the physical control of the inverter and vehicle battery.

Figure 38 shows two PEV4 scenarios and the various business deals that could be needed to engage in a V2G application.



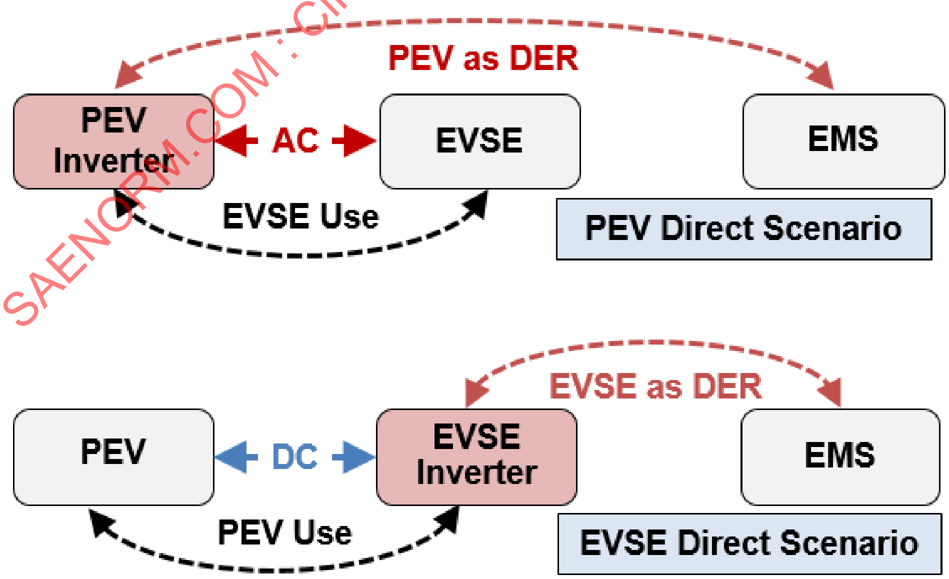



*Figure 38 - Business deals associated with V2G applications*

The scenario where the inverter is onboard the PEV is called the "PEV direct scenario." This is a V2G-AC type of reverse flow. The upper block diagram illustrates this business case. Two business arrangements are required to engage in the V2G program: one between the owner of the PEV and the owner of the V2G application (PEV as DER) and one between the owner of the PEV and the owner of the EVSE (EVSE use). The dotted red lines show the business relationship between the EMS owner and the owner of the entity containing the inverter (PEV in this case). The dotted black lines show the business relationship between the EVSE owner and PEV owner. In this scenario, the PEV owner compensates the EVSE owner for use.

For the purpose of these discussions, the dotted lines are not intended to show a communication link, only the business relationships between the EVSE owner, the PEV owner, and the V2G application EMS owner. For the purpose of this V2G-AC example, it can be assumed that the EMS is using the SEP2 DER function to directly engage the onboard inverter. The EVSE provides a MAC/PHY bridge to allow direct communication between the EMS and PEV. There may also be many intermediate communication systems and networks between the EMS and the EVSE. This diagram is only intended to show that the PEV agrees to allow its inverter to be used by the EMS to perform a V2G application in return for some value received by the PEV owner. The PEV can enroll in a V2G application and directly fulfill the contract.

These business agreements could be very formal agreements, or they may be very informal. For example, the use of the PEV and EVSE behind the meter by a home EMS would not require any business deals between the PEV and home EMS or between the PEV and EVSE. But there would need to be some setup information entered into both the home EMS and the PEV and possibly even the EVSE. At a public parking garage supporting PEV direct, the PEV would require a formal business arrangement with a frequency regulation aggregator and would have a simple payment plan of some sort with the garage (EVSE) owner for the use of the equipment, parking space, and energy.

The next scenario is designated as EVSE direct and is shown as the second block diagram. This is a V2G-DC type with the inverter located in the EVSE. The EVSE owner would directly sign up as a DER device with the V2G application owner (EVSE as DER). The EVSE owner also needs to compensate the PEV owner for use of the PEV (PEV use). Just as with the PEV direct scenario, these agreements could be very formal agreements, or they may be very informal. The owner of the EVSE receives value from the owner of the V2G program for participation. The owner of the PEV in turn receives some value from the owner of the EVSE, and this could be as simple as a preferred rate for parking and charging at a commercial parking garage.

If a commercial parking facility signs up to use all of its V2G-DC EVSEs to perform a DER application, this would be considered to be a building-to-grid (B2G) program. In this case, it would use a facility EMS to control the individual EVSE units. Each EVSE is "enrolled" with the facility EMS under this scenario. These internal EVSE as DER agreements between the many EVSE units and the building EMS would be informal; just what is needed to set up the communication. The facility itself is enrolled as a B2G provider using its EMS to communicate with the utility EMS. The B2G enrollment for the facility with the utility would be formal. Each PEV would have a PEV use with the parking facility for the DC power transfer. The facility may offer preferred parking rates or charging rates to PEV owners that allow the facility to vary the rate of charging or discharging of their PEVs during the day.

This discussion has been about business relationships between PEV, EVSE, and EMS owners and not about how the EMS communicates with the PEV and EVSE to perform the V2G application. As discussed in other sections of this document, the preferred DER control communication path should be between the EMS and the inverter regardless of whether it is located in the PEV or EVSE. For onboard inverters, the messages may need to travel from the premises network to the EVSE and across a PLC link to the PEV inverter. There may be many tiers of protocol translation between the EMS and the PEV inverter, but the control path is still direct.

### 4.8.3 Process Flow for the DER Direct Scenario

For a PEV with an onboard inverter, the use of a PEV as a DER can be described by a single process flow. There is a single integrated DER device. There is no business deal between the PEV inverter and the PEV battery. The communication between the PEV inverter and the PEV BMS is a private matter. This will be used to establish the process than can be used for the other scenarios.

The DER direct process is based on a V2G application operator using a PEV as a DER device. The major process steps are shown in Figure 39. The scenario is based on there being an entity with an EMS. It all begins with enrollment, which can be with a utility, with an ancillary services aggregator, with a building operator, or other entity. The enrolled PEV can then participate in actual V2G applications controlled by the service provider's EMS (as described in 4.5). The V2G operator will then compensate the PEV owner for participation in their V2G application. The service provider will have an EMS that is capable of engaging the PEV as a DER device. The blue shaded boxes are process steps that involve electronic interaction with the inverter. The other process steps do not require electronic communication with the inverter.

There are five major steps in the process: enrollment, initial setup, session, post-session, and termination. Each step will be briefly discussed.

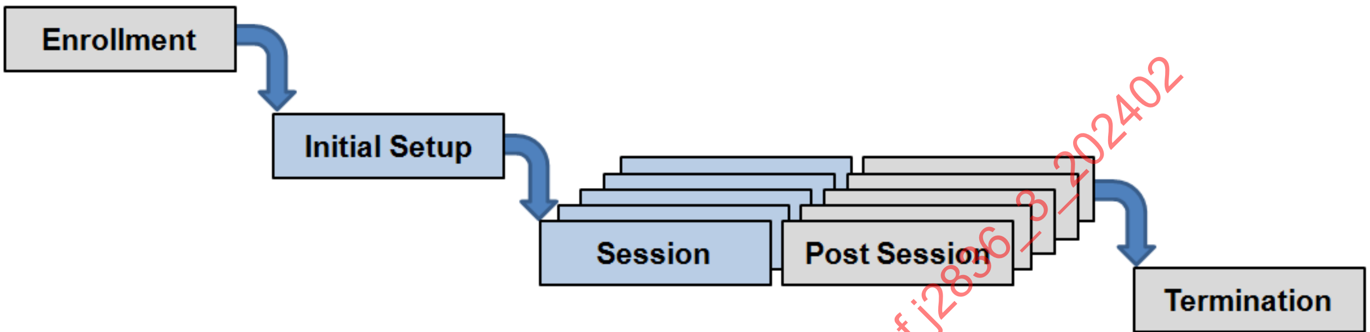



*Figure 39 - PEV4 DER process chart*



4.8.3.1 Enrollment Process Step

There are different V2G applications based on the domain and OBW. The enrollment process will vary based on the domain and the participants. Enrollment will be formal with a utility, energy services company (ESCO), EVSP, or ancillary service aggregator. It could be less formal at a parking garage. And at a private residence, it would be very informal. A generic enrollment use case (E) is described in SAE J2836/1.

A formal enrollment process will require an application by the PEV owner to participate, which can be in person, by phone, by internet, or even by mail. A contract will be made. This is just as with any other utility project for a residential owner. This may result in a password and a contract ID being provided to the PEV owner to be entered into the PEV to enable the PEV to participate in the application. At a parking garage, the driver may just be handed a ticket with the password that is required to activate the EVSE. This may be an automatic enrollment that allows the garage to manage the rate of charging during the session.

4.8.3.2 Initial Setup Process Step

Some of the V2G applications and some of the functions in use case U7 may benefit from a onetime setup to support many future V2G sessions. This may require manual data entry in the vehicle to perform the initialization. It also may require the PEV to be connected to the EVSE and the internet to download and configure settings. This may include loading curves to support autonomous functions as described in 4.7.7. It may be possible to perform this step at the start of a regular charging session that will use the specific new application, but it is not the same process as that used to set up every regular session. It is also possible that the initial setup could be performed as a background task during a session that is associated with a different V2G application.

4.8.3.3 Session Process Step

Figure 39 shows that for any given enrollment, there can be many sessions until participation the V2G application is terminated. The figure is not intended to denote parallel sessions. Some applications may only have a single session between enrollment and termination. Other applications may involve participation every time the PEV connects to an EVSE over many years.

The session step can be segmented into lower level process steps as shown in Figure 40. The active session is bounded by the plugging in of the PEV to the EVSE and the unplugging of the PEV from the EVSE, although some manual data entry can be performed in the PEV just before or just after plugging in the PEV.

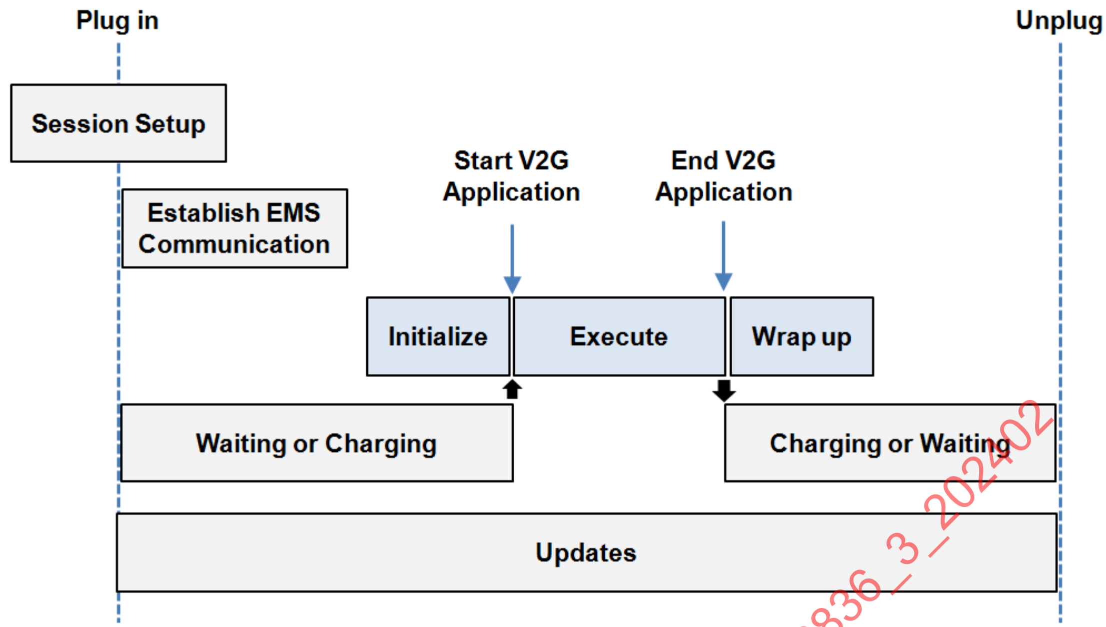



*Figure 40 - Elements of active session*



The session setup step is where the vehicle operator would enable the PEV to participate in a specific V2G application as a DER device. This could also be preauthorized and happen automatically whenever the PEV is plugged in at a specific EVSE location. Initial setup process step could also be performed for the intended V2G application during this step if it was not already performed during an earlier charging session. This is the process step where the vehicle operator also defines the time when the vehicle is expected to disconnect and it needs to be fully charged.

Immediately after being plugged in, the PEV must establish secure communication with the EMS controlling the V2G application and reach mutual agreement to engage in the application during the session. This is where the security of the connection is established and EMS and PEV are authorized to engage. Terms such as association, binding, protocol information exchange, certificate update, certificate installation, authentication, authorization, and identification apply to this process step.

This figure only shows one V2G application occurring within the connection period, but it is possible that several sequential sessions could be entered for a specific V2G application or for different applications. It is also possible that nonconflicting applications could run in parallel. A representative V2G application is shown by the blue shaded blocks. If the V2G application was not scheduled to begin immediately after plug in, the PEV could either wait or start charging, as determined by other operator settings. Use cases U5, U6, and U7 primarily deal with the processes and communication shown by the blue shaded boxes.

Before the V2G application starts, the EMS and PEV will perform an electronic initialization. This could occur immediately after plug-in and the establishment of communication, or it could occur just before the application starts sending the first command to the PEV. This is the time that information that may not need to be updated regularly during the V2G engagement is exchanged between the EMS and the PEV. Information that changes throughout the V2G engagement would be part of the execution phase.

During the execution phase, the EMS and PEV will exchange information and commands at a regular update rate, consistent with the OBW of the V2G application. This will continue until the V2G application releases the PEV, or the PEV needs to disengage to complete charging, or the operator disconnects the PEV from the EVSE.

Immediately after the V2G application ends, there may be some summary information that needs to be exchanged between the EMS and the PEV. This is done during the V2G wrap-up step. This step may not be needed if running summary information is provided to the EMS after each pass through the command loop. This avoids a potential problem if the vehicle is unplugged before the summary information is transferred. In this case, the PEV will need to complete the data processing and transmit it during a subsequent connection event.

The update block is not related to the V2G application being performed. While the PEV is engaged in charging or another DER activity, it is possible that curves and parameters could be updated for a future session as a background task during the current session. The initial setup process step described earlier could be performed this way. The update process could involve manual data entry and establishing communication with the EMS for a future new V2G application.

#### 4.8.3.4 Post-Session Process Step

After a PEV disconnects, there will need to be back-office post-processing by the V2G application owner to assess DER performance and determine compensation for services. Information needed by the EMS should be provided by the PEV prior to disconnect during the post-DER phase of the active session. If the disconnect happens before this transfer can be completed, the PEV needs to save the information and provide it to the EMS at the first opportunity when the PEV is connected again. For every connection event and V2G application engagement, there will need to be some post-session data processing.

#### 4.8.3.5 Termination Process Step

When a PEV owner no longer wishes to participate in a future session of a V2G application, the enrollment must be terminated. The formality of the enrollment will generally dictate the formality of the termination process. The contract terms will define the termination requirements for formal agreements. Some enrollments may only be for a single event and termination is automatic. Specific notification of application owner in person, by email, by internet, or by mail may be required. Manual update of vehicle settings may be required. An electronic exchange between the PEV and the application EMS may also be required. At the end of this step, the contract is considered complete, all final payments are completed, and the ability to engage in an electronic association between the PEV and application EMS is cleared.

### 4.8.4 Process Flow Differences for EVSE Direct Scenario

All of the steps shown for the PEV direct scenario apply to the EVSE direct. EVSE direct will require enrollment, initial setup, a session, a post-session, and termination. All of the elements within the session step also apply. As expected, there are some differences in the business deals and details of each step. One primary operational difference is the communication between the external inverter and the PEV BMS.

#### 4.8.4.1 Control and Business Deals for DC Power Flow

An external EVSE inverter requires the use of two communication and control structures. The EMS for V2G application communicates with the EVSE inverter to control the functionality of the inverter as a DER device. The EMS can be expected to use a protocol that conforms to the IEC 61850 DER model, such as SEP2. This is all about supplying or absorbing real and reactive power as needed by the V2G application. There is also a DC control process for managing the current flow in and out of the battery as needed by the inverter to perform its DER functions. The communication required for control of DC power flow between the EVSE and the PEV will be discussed in the next section.

The business deals for DC power will vary depending on whether the PEV owner or EVSE owner sign up with the V2G application. If the EVSE owner takes on the business deal for the V2G application, the EVSE owner will need to provide some value for the PEV owner (PEV DC deal). If the PEV owner takes on the business deal for the V2G application, the PEV owner will need to provide some value for the EVSE owner (EVSE DC deal). The control communication for the external EVSE inverter to interact with the PEV is the same for both DC deals. It is only the compensation flow that is different depending on whether the PEV owner or EVSE owner gets paid by the V2G application operator. The information exchange between the PEV and EVSE need to support both business cases.

The enrollment in the DC deals could be very simple. If the EVSE and PEV are owned by the same entity, there is no need for a business deal; only the control capability is needed. In a commercial parking facility, both deals could end up being reflected in the charges for access to the EVSE. The access fee to the EVSE would be lower if the EVSE was providing the V2G service and would be higher if the PEV was providing the V2G service using the EVSE inverter.

4.8.4.2 SAE J2847/2 and the External Inverter

The power electronics of an onboard charger is designed to transfer energy to the battery as controlled by the battery management algorithms that define the charging profile. An objective is to charge in the shortest time, subject to the available external power and the rating of the charger, while protecting battery life. The charger may operate in a constant current mode or constant voltage mode. The charger power electronics is the slave of the PEV charging algorithms. The AC current drawn by the charger from the grid at any instant is a direct consequence of the current flowing into the battery and any losses due to charger efficiency or other vehicle loads. The battery requirements lead, and the grid current follows.

An onboard inverter functions more like the PEV traction drive than the onboard charger. The traction drive uses the battery as a source of power for acceleration and regenerative braking and of energy for range during cruise. The current flow in and out of the battery is as required for vehicle operability, subject to protective limits set by the BMS. The inverter must respond to the power needs of the grid in some applications in much the same way that the traction drive responds to the vehicle driver needs for acceleration and braking. The current flowing in and out of the battery is a consequence of the required AC current flow requirements of the V2G application.

An onboard charger/inverter will need two distinct modes of operation. In the charger mode, the current flow is controlled as needed by the battery. This mode could be used with use case U5, where the V2G application is only concerned with limiting the rate of charging. In the inverter mode, the DC current flow is a result of the inverter providing or absorbing a specific target value of real and reactive power to the grid. This mode would be used with use case U6 and U7. There is a difference between forward power flow to a target value (U6) and permissive charging to a set upper limit (U5). The PEV algorithms for control of the power electronics and the relationship to the BMS for the inverter function and charger function will be different.

An external inverter will also need to have both a pure charger mode and an inverter mode. SAE J2847/2 was created to define the communications between the PEV and an external DC fast charger. SAE J2847/2 will need to be extended to provide for the DER mode operation. The purpose and functionality of an inverter and a charger are very different, and changes will be needed to accommodate the DER requirements.

4.8.4.3 SAE J2847/3 and the External Inverter

Use cases U5, U6, and U7 define the inverter functionality and information exchange requirements between the EMS and the PEV onboard inverter to allow many V2G applications to be performed. SAE J2847/3 defines the actual communications that the PEV will use. It is expected that the PEV will use SEP2.

The V2G application EMS may or may not use SEP2 to communicate with PEVs. If the EMS does not use SEP2, there will be a need to translate between the native EMS protocol and SEP2 somewhere in the physical communication channel between the EMS and the PEV. It is possible that multiple translations may be required. This is a generic problem and not specific to PEVs, and protocol translators will be needed on the smart grid. It is likely that the EVSE could perform this function if the premises network does not use SEP2.

The bidirectional protocol translation will be needed. The EVSE may be the device that performs it. None of this is related to the scope of vehicle communication. The expectation is that the vehicle sends and receives information in only SEP2 protocol, and it is the responsibility of some entity outside the PEV to do the translation.

The relationship between SAE J2847/3 and an external inverter is less clear. The external EVSE inverter is connected directly to the premises network. If the network supports SEP2, the EVSE inverter could use SAE J2847/3 for guidance. However, the external inverter could implement its functionality based on the network protocol. It is only relevant that the PEV be able to provide DC power flow as needed by the EVSE inverter. SAE J2847/2 will govern this exchange. The external EVSE serving as a DER can directly follow the IEC 61850 object model and the local network protocol.

4.8.5 Simultaneous V2G Applications and Rules of Engagement

Much of the discussion has been about a PEV engaging in a V2G application. But it may be possible to engage in parallel applications and at different tiers. Figure 41 shows three tiers of V2G applications running in parallel across three domains. A PEV may be engaged with a facility EMS to help manage peak demand charges during charging. It may also be engaged with a distribution utility providing VAR support for the feeder using an autonomous volt-VAR function. And a system level aggregator may be using the PEV as part of a fleet to perform frequency regulation. If the facility EMS is only interested in limiting the rate of charging of the PEV, this may not be a conflict if the aggregator actually sets the charging or discharging rate. However, allowing simultaneous applications can create conflicts and rules of engagement will be needed to arbitrate the conflicts.

Safety is the highest priority. Zero reverse flow or zero voltage applied is safe. Utility-interactive inverters are designed to trip within specified clearing times if the measured grid voltage or frequency fall out of specified limits. If there is any conflict between commands from any source, zero reverse flow must always take priority.

The PEV must always protect itself from damage. There may be lower or upper limits on the battery SOC that must be protected.

The facility limits must always be respected in both directions. The power levels defined by the EVSE control pilot must never be exceeded for either charging or discharging. If a premises EMS provides a lower forward or reverse flow target or limit than any external EMS, or even the control pilot, the premises EMS limit shall always apply.



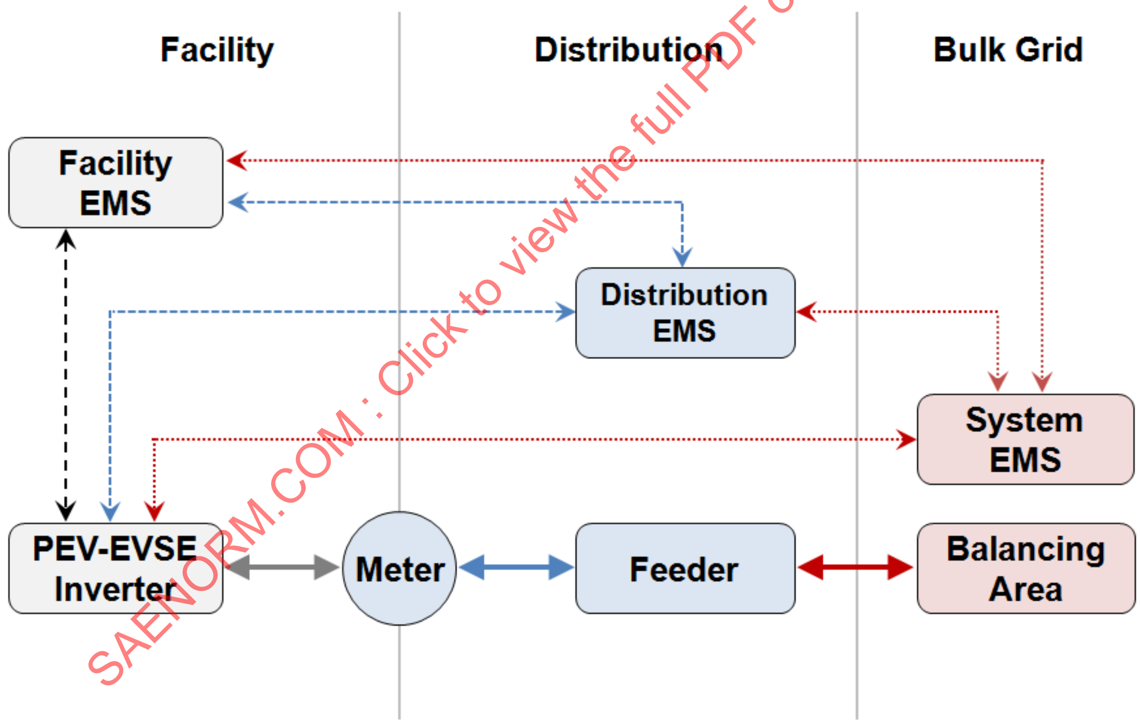



*Figure 41 - Three tiers of V2G applications*

The PEV must also protect the capability to achieve the target energy state by the expected time of disconnect from the EVSE. There will be a disengage time from any reverse flow action based on the state of charge of the battery, the target state of charge at the expected time of disconnect from the EVSE, the power rating of the onboard or external charger, the time needed for conditioning, PEV hotel and parasitic loads, charger efficiency, and other factors known to the PEV that the PEV will demand that the PEV disengage from reverse flow and resume charging under its own control.

#### 4.8.6 PEV4 Scenario Summary

The characteristics of each of the four PEV4 scenarios are listed in Table 15. The process flows for each are defined in Appendix A.

***Table 15 - Characteristics of PEV4 scenarios***

| PEV4 Scenario Characteristics | PEV4 Scenario Name | |
|---|---|---|
| | **PEV Direct** | **EVSE Direct** |
| Inverter location | PEV | EVSE |
| V2G deal with | PEV owner | EVSE owner |
| DC value received by | | PEV owner |
| EMS communicates with | PEV | EVSE |



#### 4.8.7 Participation in V2G Applications - Use Cases Are Not Selected by the Driver

Advanced inverter functions that could be used by a DER device to support the grid were discussed in 4.4. The relationship of SAE use cases U5, U6, and U7 to potential V2G applications of a DER device was reviewed in 4.5. Information exchange considerations between the PEV or EVSE inverter and the EMS of a V2G application were explored in 4.6 for U6 and in 4.7 for U7. A PEV or EVSE inverter is not required to implement all of the functionality defined by IEC 61850-90-7, as reflected by U6 or U7. Much of what is defined in these sections has been implemented in the DER function of SEP2.

When a PEV is enrolled in a V2G program and it has the inverter functionality to enable it to perform the V2G application by engaging with the EMS for the application, the driver does not select a use case, such as U6. These are only for the purpose of defining the communication messages required to be exchanged between the PEV and the EMS. It guides the details of the communication protocol. SAE J2847/3 will use the information from this document to define the messaging required to allow a PEV to engage with an EMS to perform as a DER device in a V2G application.

This top-level use case, PEV4, explores the steps from enrollment to termination. A PEV may be enrolled in different V2G programs, and some may be expected to happen simultaneously during one connection interval as described in 4.8.5. Depending on how the PEV is set up, the PEV may automatically just start to engage with a V2G application during a session, or it may take a specific action by the driver to enable participation during that session.

Some form of data entry will be required for every session. This is discussed in 4.3.1 and other sections within 4.3. As a minimum, the driver must define when the vehicle plans to disconnect from the EVSE. As described earlier in this document, the “source” for the “time charge is needed” is always the PEV, but the actual data entry could be at the PEV, the EVSE, or even by a remote device. When data is entered using vehicle controls and displays, this will most likely be done using proprietary hardware and software, and the look and feel may vary between VMs. Vehicle navigation systems perform the same basic functions, but the controls and displays vary widely by manufacturer. SAE J2847/5 is expected to govern how remote data entry on a portable device or EVSE could be received and used by the PEV in place of a direct entry at the vehicle. For the purpose of this document, it is assumed that any manual entry and selection can be made and accepted by the inverter.

For participation in a V2G application, it is expected that the PEV will display information to allow the PEV operator to designate, for example, that it is desired for the vehicle to engage with a specific frequency regulation aggregator during the session. The driver enters that the PEV will depart at 5:00 p.m. and needs a 100% SOC at departure. The enrollment application with the aggregator may have required that the V2G application engage cooperatively and use the PEV for frequency regulation but also ensure that it is charged by departure. Maybe this is a selectable option. Maybe the PEV selects participation from 1:00 p.m. to 2:00 p.m. The data entry within the PEV or between the PEV and an alternate manual entry device is not governed by SAE J2847/3, only the exchange of information between the PEV and the EMS. The term U6 will not appear to the driver in any implementation because it is only a reference for defining inverter functionality and messaging between the EMS and PEV inverter to make use of the functionality. Once the messages exist in the communication protocol, the name U6 or even IEC names like INV4 are not relevant.

In summary, operationally a driver will apply to participate in a program with a V2G application provider and receive the necessary information to allow the PEV to actually engage with the EMS as a DER device. This may require a onetime initialization process to be performed with manual data entry at the PEV and downloads to the PEV from the V2G EMS or back-office systems. There will be standard controls and displays provided by the VM that allow the vehicle to use its inverter functionality as a DER device with some EMS. There may be options to do this data entry using the EVSE or a remote device as defined by SAE J2847/5. The specific functions that the EMS requests the PEV inverter to use do not have to be designated. The V2G application will command whatever inverter functions are needed and implemented in the PEV using the communication protocol.

The objective is to define the inverter functionality and the communication capability to allow the PEV to be used as a DER device by a wide range of V2G applications: at the bulk system level, the distribution feeder, and behind the meter.

## 4.9 Utility Approval of Interconnection of a DER

Two approvals are needed before a PV system can be used. A building permit must be secured from the municipality, and their code enforcers inspect the installation to ensure that it meets the appropriate NEC requirements. An application to interconnect to the grid must also be made with the electric utility for both business reasons (such as net metering) and grid safety (which is based on meeting IEEE 1547). If the inverter unit is listed by a Nationally Recognized Testing Laboratory (NRTL) as conforming to UL 1741, this generally satisfies both the local code enforcement and utility technical requirements. The application forms request the model number of the inverter unit, and many states maintain a data base of state approved listed models. Because the PV system is fixed to the site, it is easy to program site-specific settings (such as the reference voltage) directly into the inverter unit. For a V2G-DC application, where the inverter is installed in the EVSE, the EVSE can be listed to UL 1741, and the simple application used with PV systems can be used for the EVSE.

However, a roaming PEV inverter (V2G-AC type) creates some unique technical and interconnection approval issues. A PEV can easily cross utility service areas and state lines and connect at locations with different site settings. For example, one EVSE could be connected to 208 VAC service and another EVSE could use 240 VAC service. For an onboard inverter that needs respond to an abnormal voltage event, such as a voltage increase to 120% of the reference voltage, the inverter needs to know the reference voltage for the specific site where the EVSE is installed. It is not safe to expect the vehicle operator to update the site-specific information whenever the PEV connects to an EVSE. These site-specific settings need to be stored in the EVSE and transferred to the PEV when it connects to the EVSE. This requires a special EVSE for V2G-AC. This technical issue can be easily solved.

There are no established procedures in the electric power industry for handling a DER interconnection application without providing the actual inverter model to be used on the application form. The PV inverters are always fixed to the site, and the exact model number is known. However, the PEVs roam, and there could be many different PEV models that could possibly connect to a site EVSE over time, particularly at public sites. The facility owner could provide the model number of the EVSE, but it does not contain an inverter and is not by itself a DER, so there is no basis to apply for interconnection of a DER. Except for a homeowner for one specific EVSE and EV model, the existing single DER approval processes cannot be used. And even for a homeowner, it is not possible for the vehicle OEM to have the onboard inverter listed by a NRTL to UL 1741.

A standard was needed to which a VM could certify conformance by analyses, inspections, and tests that a specific model of a utility-interactive inverter system, which is integrated into the PEV, could be interconnected in parallel with an EPS by way of compatible, conductively coupled, electric vehicle supply equipment. This new standard would require conformance of the onboard inverter to IEEE 1547 and IEEE 1547.1, just as in done by UL 1741. The standard would also define the exact communication required for the EVSE and PEV to coordinate site settings and for the site EVSE to authorize the PEV to discharge.

The facility owner applies to the utility using the EVSE model number which is certified as conforming to the new standard. The vehicle OEMs certify the “inverter system model” onboard the PEV to the new standard, which includes functional testing of the inverter itself. The EVSE serves as the gatekeeper to only authorize those vehicles which are approved by the utility to be able to discharge in their service area. A utility could just authorize the EVSE to verify that the connected PEV has been certified to the standard or may require that the EVSE check the actual model number against a utility approved list for the service area. If a utility plans to maintain an active database, the vehicle OEMs would need a process with those utilities to submit certification information for each service area.

SAE created SAE J3072 as a standard for this purpose. SAE J3072 assumes that utilities will establish procedures by which a site could be approved for the interconnection of PEVs with onboard inverters on the basis of an application form that requests EVSE model numbers but does not request PEV information. The interconnection agreement for the site would require an EVSE to only authorize a connected PEV to discharge if the EVSE confirms that the inverter system model has been certified as conforming to SAE J3072.

It is expected that a VM will perform the analyses, inspections, and tests to ensure that each inverter system model that is authorized by the VM to be installed in one of their PEV models conforms to the requirements of SAE J3072. The VM will issue a certificate of conformance to SAE J3072 for each authorized inverter system model.

It is expected that an EVSE manufacturer (EVSE OEM) will perform the analyses, inspections, and tests to ensure that each EVSE model that is authorized by the EVSE OEM to be used with a PEV with an onboard inverter system conforms to the requirements of SAE J3072. The EVSE OEM will issue a certificate of conformance to SAE J3072 for each authorized EVSE model. There is an ongoing UL standard development, i.e., UL 1741 SC, to embrace SAE J3072 requirements. This envisions that the UL 1741 SC to be incorporated into a utility's grid interconnection agreement process, such as Rule 21 in California, such that the EVSE will be tested by a NRTL.

SAE J3072 defines firm requirements for different system types. The original 2015 release only defines System Type A1 which is defined as follows. The EVSE and PEV conform to the requirements of SAE J1772 which apply to AC Level 2 Transfer. The PEV can provide either an SAE J1772 C1 or C1 Combo receptacle (in which case, only pin 1 [L1] and pin 2 [L2/N] of the coupler are used to transfer AC power between the EVSE and PEV). The facility reference (nominal supply) voltage will not be less than 208 VAC or greater than 240 VAC. The facility maximum continuous AC charging current will not be more than 80 A rms. Information which is defined by this standard to be directly exchanged between the EVSE and PEV will be transferred using PLC over the SAE J1772 control pilot in accordance with SAE J2931/4. The higher OSI-layers follow SAE J2931/1 and IEEE 2030.5 to the extent needed to meet the requirements of SAE J3072.

Figure 42 shows an EVSE and PEV operating as SAE J3072 System Type A1. The blue boxes designate the communication required by SAE J3072. This link is used by the PEV to get local settings from the EVSE at the time of connection and for the EVSE to confirm that the PEV is using acceptable settings. The EVSE also retrieves the model number of the inverter system and certification status to SAE J3072. The inverter in a PEV is not just a box, and SAE J3072 defines a process by which the vehicle OEM designates the inverter system and defines its model number. The EVSE is responsible for verifying that the local utility approves that this model can discharge in their service area. This could be as simple as the EVSE just checking to see that the model has been certified to SAE J3072 by software tag. A utility might require the EVSE to check a database of approved models. When the EVSE confirms the PEV is using appropriate local settings and is approved for use in the service area, it authorizes the PEV to discharge. The standard defines specific requirements for this process.

The green boxes in the figure designate communication between a DER control entity and the PEV for engagement with smart inverter functions for which the EVSE is not designated as the exclusive DME. This explicitly includes the Coordinated Charge/Discharge Management Function. This approach provides a MAC/PHY bridge to allow direct IEEE 2030.5 communication between a DER controller and a smart inverter onboard the PEV. SAE J2847/3 provides guidance for the use of IEEE 2030.5 for this purpose.

While System Type A1 requires IEEE 2030.5 for SAE J3072 purposes, a future version could introduce a new System Type based on a different protocol. However, this becomes a concern over EVSE models and PEV models which are electrically compatible but can't communicate, which would allow charging but prevent any discharging.

Appendix G provides some guidance on the use of other protocols for communication between the DER control entity and a PEV onboard inverter. California selected IEEE 2030.5 as the first protocol to be used by utilities to communicate with facility management systems, DER aggregators, and individual DER devices. The utilities would not likely engage small DER directly. Other protocols, such as DNP3, could be used with utility equipment and by agreement with DER operators, but the utilities are required to always have IEEE 2030.5 capability.

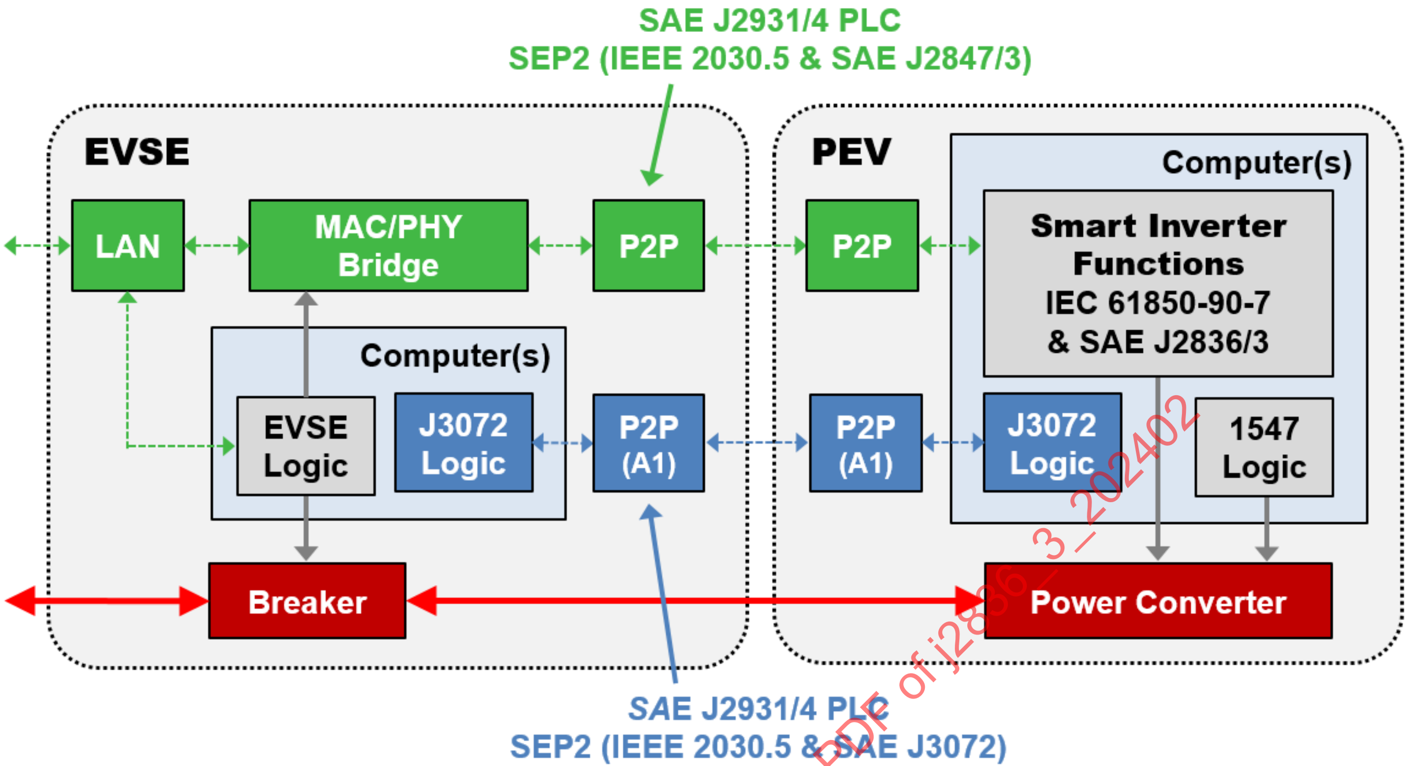



*Figure 42 - System concept for use of SAE J3072*

## 5. NOTES

### 5.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE HYBRID-EV COMMITTEE

# APPENDIX A - USE CASE PEV4

## A.1 USE CASE NAME

Use case name PEV as a distributed energy resource (PEV4).

## A.2 USE CASE SUMMARY

This use case describes the process steps needed to enroll a PEV or EVSE as a DER in a V2G application (or program), perform the initial setup of the PEV or EVSE, engage in one or more sessions, be compensated for participation, and terminate the participation in the V2G program sometime in the future.

## A.3 USE CASE NARRATIVE

This is intended to be a high-level overview of the processes used for a PEV or EVSE to engage as a DER device in a V2G application. The inverter is the core of a DER device. However, only a few of the process steps involve actual use of the functionality of the inverter and active communication between the inverter and the EMS controlling the V2G application. Many of the process steps in PEV4 involve electronic communications for purposes other than the control of the inverter. This is true of the processes involved with establishing secure communications and authorizing the PEV to participate with the V2G application EMS. There may be other processes associated with providing meter information and conducting business transactions. Some of the data entry functions will be provided using proprietary vehicle software and equipment.

This use case is at a summary level, and it is not intended to be a guide for any specific communication standard. SAE J2847/3 will address the communication needs between the PEV and EMS for use cases U6 and U7. Similarly, SAE J2847/2 will deal with the EVSE inverter to PEV communications required for the EVSE inverter to be able to operate with a PEV battery.

## A.4 OVERVIEW OF SCENARIOS

Four scenarios will be described in this appendix. The names of each scenario and the key characteristics of each scenario are listed in the Table A1.

***Table A1 - Overview of PEV4 scenarios***

| PEV4 Scenario Characteristics | PEV4 Scenario Name | |
|---|---|---|
| | **PEV Direct** | **EVSE Direct** |
| Inverter location | PEV | EVSE |
| V2G deal with | PEV owner | EVSE owner |
| DC value received by | | PEV owner |
| EMS communicates with | PEV | EVSE |



## A.5 SCENARIO NAME: PEV4 - PEV DIRECT

### A.5.1 Scenario Narrative

An owner of a PEV with an onboard inverter wishes to enroll and participate in a V2G application (program). This scenario describes the process steps to enroll in the program, perform the initial setup of the PEV, engage in one or more sessions, be compensated for participation, and terminate the participation in the V2G program sometime in the future.

Two business arrangements are required to engage in the V2G program: one between the PEV owner and V2G owner (PEV as DER), and one between the PEV owner and the EVSE owner (EVSE use). These agreements could be very formal agreements, or they may be very informal. For example, the use of the PEV behind the meter by a home EMS would not require any business deals between the PEV and home EMS or between the PEV and EVSE. But there would need to be some setup information entered into both the home EMS and the PEV, and possibly even the AC EVSE. At a public parking garage, the PEV would require a formal business arrangement with a frequency regulation aggregator and would have a simple payment plan of some sort with the garage (EVSE) owner for the use of the equipment, parking space, and energy.

### A.5.2 Preconditions

The PEV has an onboard inverter, and it is capable of communicating with the EMS of the V2G application (program) owner. The inverter has the required functionality to perform the intended V2G application.

### A.5.3 Scenario Step-by-Step Description

***Table A2 - PEV direct scenario***

| Process Step | Actor(s) | Description |
|---|---|---|
| 1 - Enrollment | V2G owner<br>PEV owner | V2G owner promotes a V2G program and makes enrollment materials available to PEV owners. PEV owner provides completed enrollment information to V2G owner. V2G owner accepts the application and provides setup materials to the PEV owner. V2G owner sets up the PEV in the EMS and other back-office systems. |
| | EVSE owner<br>PEV owner | EVSE owner promotes use of EVSE for DER use and makes enrollment materials available to PEV owner. PEV owner provides completed enrollment information to EVSE owner. EVSE owner accepts the application and provides setup information to PEV owner. EVSE owner sets up the PEV in the EVSE and any back-office systems. |
| 2 - Initial setup | PEV owner<br>PEV | The appropriate settings are manually entered using PEV controls and displays to allow the PEV to participate as a DER device in the enrolled V2G program using the AC EVSE. This can be done as a background update during another charging event or at the start of the first session during which the PEV will participate in this new V2G program. |
| 3 - Session | | |
| 3.1 - Plug-in PEV | PEV owner | PEV is connected to an AC Level 2 EVSE that allows the PEV to participate as a DER. |
| 3.2 - Session setup | PEV owner<br>PEV | PEV owner enters session settings using PEV controls and displays to allow the PEV to participate as a DER device in the enrolled V2G program. Communication may need to be established to complete the activity. It may be started before plugging connecting to the EVSE. |
| 3.3 - Establish communication | PEV<br>EMS | PEV and EMS establish secure communications and enable the PEV to engage as a DER device under control of the EMS for the enrolled V2G program. |
| 3.4 - Initialize V2G | PEV<br>EMS | Prior to or immediately at the start of the active V2G engagement of the PEV as a DER, the PEV and EMS exchange information that is expected to remain constant during the execution phase.<br>Execute SAE J3072 4.6 |
| 3.5 - Execute V2G | PEV<br>EMS | EMS receives state information from PEV and provides DER control commands to PEV continually during the active engagement.<br>Execute SAE J3072 4.7 |
| 3.6 - Wrap up V2G | PEV<br>EMS | EMS receives final state information from PEV. PEV may acquire information from meter or other devices to relay to EMS, or EMS may directly engage other systems. |
| 3.7 - Updates | PEV owner<br>PEV<br>EMS | PEV owner may perform data entry that is needed for a future V2G session. Automatic updates by the EMS of parameters or curves for a future session may also occur. If required for the current session, this must have been done during a prior session or during the session setup phase. |
| 3.8 - Unplug PEV | PEV owner<br>PEV | The PEV is disconnected from the EVSE. The PEV should terminate and wrap up any V2G program that has not already ended before disconnecting. If final information exchange with EMS has not been completed, information must be saved and provided to EMS during a future connection event. |
| 4 - Post session | EMS<br>V2G owner | EMS provides V2G engagement information for PEV to the V2G owner's back-office systems for performance assessment and compensation of PEV owner. |
| 5 - Termination | PEV owner<br>V2G owner<br>PEV<br>EMS | PEV owner provides request to V2G owner to no longer participate in the enrolled V2G program in accordance with terms of enrollment. V2G owner accepts termination and resets EMS. PEV owner resets PEV to disable V2G program. This could be automatic for single event enrollments. |

## A.6 SCENARIO NAME: PEV4 - EVSE DIRECT

### A.6.1 Scenario Narrative

An owner of an EVSE with an inverter wishes to enroll and participate in a V2G application (program). This scenario describes the process steps for the EVSE owner to enroll in the program, perform the initial setup of the EVSE, engage in one or more V2G sessions, be compensated for participation, and terminate the participation in the V2G program sometime in the future.

Two business arrangements are required to engage in the V2G program: one between the EVSE owner and V2G owner (EVSE as DER), and one between the EVSE owner and the PEV owner (PEV use). Just as with the PEV direct scenario, these agreements could be very formal agreements, or they may be very informal. The owner of the EVSE receives value from the owner of the V2G program for participation. The owner of the PEV in turn receives some value from the owner of the EVSE, and this could be as simple as a preferred rate for parking and charging at a commercial parking garage.

If a commercial parking facility signs up to use all of its EVSEs to perform a DER application, this would be considered to be a B2G program. In this case, it would use a facility EMS to manage the individual EVSE units. Each EVSE is enrolled with the facility EMS under this scenario. The facility itself is enrolled as a B2G provider using its EMS to communicate with the utility EMS. The individual V2G enrollments tier to a single B2G enrollment. The B2G enrollment for the facility with the utility would be formal. The internal agreements between the many EVSE units and the building EMS would be informal; just what is needed to set up the communication. Each PEV would have an arrangement with the facility, which operates the EVSE units, for the DC power transfer.

### A.6.2 Preconditions

The EVSE has an inverter that is capable of communicating with the EMS of the V2G application (program) owner. The inverter has the required functionality to perform the intended V2G application. The PEV is capable of engaging with an external inverter for DC power flow.

### A.6.3 Scenario Step-by-Step Description

***Table A3 - EVSE direct scenario***

| Process Step | Actor(s) | Description |
|---|---|---|
| 1 - Enrollment | V2G owner<br>EVSE owner | V2G owner promotes a V2G program and makes enrollment materials available to EVSE owners. EVSE owner provides completed enrollment information to V2G owner. V2G owner accepts the application and provides V2G setup materials to the EVSE owner. V2G owner sets up the EVSE in the V2G EMS and other back-office systems. |
| | EVSE owner<br>PEV owner | EVSE owner promotes use of DC power flow and makes enrollment materials available to PEV owner. PEV owner provides completed enrollment information to EVSE owner. EVSE owner accepts the application and provides DC flow setup materials to the PEV owner. EVSE owner sets up the PEV in the EVSE and any back-office systems. |
| 2 - Initial setup | EVSE owner<br>EVSE | The appropriate settings are manually entered using EVSE controls and displays to allow the EVSE to participate as a DER device in the enrolled V2G program. This can be done as a background update during another charging event or at the start of the first session for this new V2G program. |
| | PEV owner<br>PEV | The appropriate settings are manually entered using PEV controls and displays to allow the PEV to participate in DC charging, DC forward power flow, and DC reverse power flow with the designated EVSE inverter. |
| 3 - Session | | |
| 3.1 - Plug-in PEV | PEV owner | The PEV is connected to the DC EVSE. |
| 3.2 - Session setup | PEV owner<br>PEV<br>EVSE | PEV owner enters session settings using PEV controls and displays and allows the PEV battery to be used by the EVSE inverter for DC power flow. EVSE retrieves information from PEV, as needed, to perform session setup of the EVSE for the V2G program. |

| Process Step | | Actor(s) | Description |
|---|---|---|---|
| | 3.3 - Establish communication | EVSE<br>EMS | EVSE and EMS establish secure communications and enable the EVSE to engage as a DER device under control of the EMS for the enrolled V2G program. |
| | | PEV<br>EVSE | PEV and EVSE establish secure communications to allow for management and control of DC power flow by the EVSE inverter. SAE J2847/2 governs communication. |
| | 3.4 - Initialize V2G | EVSE<br>PEV<br>EMS | Prior to or immediately at the start of the active V2G engagement of the EVSE as a DER, the EVSE and EMS exchange information that is expected to remain constant during the execution phase. EVSE retrieves information from PEV as needed to provide to EMS or as needed by EVSE to manage DC power flow. |
| | 3.5 - Execute V2G | EVSE<br>PEV<br>EMS | EMS receives state information from EVSE and provides DER control commands to EVSE continually during the active engagement. EVSE retrieves information from PEV as needed to provide to EMS or as needed by EVSE to manage DC power flow. |
| | 3.6 - Wrap up V2G | EVSE<br>PEV<br>EMS | EVSE receives final state information from PEV, and then EMS receives final consolidated state information from EVSE. EVSE may acquire information from PEV, meter, or other devices to relay to EMS, or EMS may directly engage other systems. |
| | 3.7 - Updates | EVSE owner<br>EVSE<br>EMS | EVSE owner may perform data entry that is needed for a future V2G session. Automatic updates by the EMS of parameters or curves for a future session may also occur. If required for the current session, this must have been done during a prior session or during the session setup phase. |
| | 3.8 - Unplug PEV | PEV owner<br>EVSE | The PEV is disconnected from the EVSE. The EVSE should terminate and wrap up any V2G program that has not already ended. |
| 4 - Post session | | EMS<br>V2G owner | EMS provides V2G engagement information for EVSE to the V2G owner back-office systems for performance assessment and compensation of EVSE owner. |
| | | EVSE<br>EVSE owner | EVSE provides PEV engagement information to EVSE owner's back-office systems for performance assessment and compensation of PEV owner. |
| 5 - Termination | | PEV owner<br>EVSE owner<br>PEV<br>EVSE | PEV owner provides request to EVSE owner to no longer participate in the DC flow program in accordance with terms of enrollment. EVSE owner accepts termination and resets EVSE. PEV owner resets PEV to disable DC program. This could be automatic for single event enrollments. |
| | | EVSE owner<br>V2G owner<br>EVSE<br>EMS | EVSE owner provides request to V2G owner to no longer participate in the enrolled V2G program in accordance with terms of enrollment. V2G owner accepts termination and resets EMS. EVSE owner resets EVSE to disable V2G program. This could be automatic for single event enrollments. |

# APPENDIX B - USE CASE PR2

## B.1 USE CASE NAME: CUSTOMER DISCHARGES THE PEV (PR2)

## B.2 USE CASE SUMMARY

This use case describes the specific manual actions required to enable a PEV to transfer energy to a live grid (V2G), to a home following a power failure (V2H), or to a load at a remote location (V2L). The use of one PEV to charge another PEV (V2V) is a special case of V2L. This use case does not describe the electronic communications between an EMS and the PEV/EVSE which is required for a PEV to serve as a DER device. These are described in detailed use cases U6 and U7. It does describe the actions required to enable the PEV to participate as a DER device.

## B.3 USE CASE NARRATIVE

Other detailed use cases may be part of establishing the preconditions for the scenarios in this use case. For example, many V2G applications will require enrollment with a utility or ESCO to be able to participate in a V2G program. This is a precondition for each V2G scenario. The specific controls and displays provided by the vehicle or EVSE manufacturer to set parameters for the inverter and to start and stop the energy transfer are not defined by this use case. The V2G scenarios provide for either manually setting the discharge power or enabling the PEV to participate in a DER program. For the other modes, the inverter is manually activated as a voltage and frequency source. Communication is not required with any EMS for basic discharging. Communication is required with an EMS for the PEV to participate as a DER. Manual operation is performed using vehicle controls and displays.

## B.4 OVERVIEW OF SCENARIOS

The scenarios are listed in Table B1. The naming convention begins with the type of reverse power, followed by whether the power flow is controlled manually (MAN) or as a DER device, and then by whether the transfer of power from the PEV is by EPP, AC port, DC port, or wireless (WPT). Discharging under scenario PR2-V2G-DER-AC is of V2G-AC type, controlled as a DER device, using AC transfer from the vehicle. DC transfer is always from the PEV to an external inverter in the EVSE and uses the conductive coupler.

***Table B1 - Overview of PR2 scenarios***

| Use Case PR2 Scenario Name | Use Case PR2 Scenarios Characteristics | | | |
|---|---|---|---|---|
| | Type | Control | Inverter | Outlet |
| V2G-DER-AC | V2G-AC | DER | Onboard | SAE J1772 |
| V2G-DER-DC | V2G-DC | DER | External | SAE J1772 |
| V2G-DER-WPT | V2G-WPT | DER | External | Wireless |
| V2G-MAN-AC | V2G-AC | Manual | Onboard | SAE J1772 |
| V2G-MAN-DC | V2G-DC | Manual | External | SAE J1772 |
| V2G-MAN-WPT | V2G-WPT | Manual | External | Wireless |
| V2H-MAN-EPP | V2H-EPP | Manual | Onboard | NEMA |
| V2H-MAN-DC | V2H-DC | Manual | External | SAE J1772 |
| V2L-MAN-EPP | V2L-EPP | Manual | Onboard | NEMA |
| V2L-MAN-DC | V2L-DC | Manual | External | SAE J1772 |

## B.5 SCENARIO NAME: PR2-V2G-DER-AC

### B.5.1 Scenario Narrative

A PEV is be used as a DER device for a V2G application. The onboard inverter is connected to the live grid using an AC Level 2 EVSE.