



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.

TABLE OF CONTENTS

1.	SCOPE.....	5
1.1	Purpose.....	5
2.	REFERENCES.....	7
2.1	Applicable Documents	7
2.1.1	SAE Publications.....	7
2.2	Related Publications	7
2.2.1	SAE Publications.....	7
2.2.2	ANSI Accredited Publications	8
2.2.3	EPRI Publications	8
2.2.4	IEC Publications.....	8
2.2.5	IEEE Publications.....	8
2.2.6	NFPA Publications	9
2.2.7	NYSERDA Publications	9
2.2.8	SunSpec Alliance Publications	9
2.2.9	UL Publications	9
3.	DEFINITIONS	10

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2024 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE J2836_3_202402

For more information on this standard, visit
https://www.sae.org/standards/content/J2836/3_202402

Documents

Document Sharing Hub

4.	TECHNICAL REQUIREMENTS.....	13
4.1	Relationship of SAE J2836/3 to SAE J2836/1	14
4.2	Types of Reverse Power Flow	16
4.2.1	Use of EPP (V2L-EPP, V2V-EPP, V2H-EPP).....	18
4.2.2	Vehicle-to-Grid Using Onboard Inverter (V2G-AC).....	22
4.2.3	Vehicle-to-Grid Using DC Reverse Power Flow (V2G-DC)	22
4.2.4	Vehicle-to-Grid (Home) Using Wireless Power Transfer (V2G-WPT, V2H-WPT).....	24
4.2.5	DC Reverse Power Flow for Off-Grid Applications (V2H-DC, V2L-DC, V2V-DC).....	25
4.2.6	Vehicle-to-Home (Load or Vehicle) Using Modified EVSE (V2H-AC, V2L-AC, V2V-AC))	26
4.2.7	Vehicle to Microgrid (V2M-AC, V2M-DC).....	27
4.2.8	DC Microgrids (V2D-DC).....	27
4.2.9	Use Case PR2 - Customer Discharges the PEV	28
4.3	Communications for Reverse Power Flow.....	29
4.3.1	Data Entry, Customer Communications, and Sources of Information	30
4.3.2	Manual Control of Reverse Power Flow	30
4.3.3	Examples of Manual Control Data Entry.....	31
4.3.4	EMS Control of Power Flow.....	33
4.3.5	Electronic Communication With the Inverter.....	34
4.3.6	Communication Between EVSE and PEV for V2G-DC	35
4.3.7	Information Exchange Considerations	38
4.4	Inverter-Based Distributed Energy Resources	39
4.4.1	Integration of DER With the Feeder.....	39
4.4.2	Smart Inverter Functions.....	41
4.4.3	Direct Control Functions.....	42
4.4.4	Autonomous Functions	43
4.4.5	Abnormal Voltage and Frequency Ride Through	44
4.5	Use Cases and V2G Applications.....	44
4.5.1	V2G Application Domains	45
4.5.2	Use Cases and Power Transfer Capability	46
4.5.3	Operational Bandwidth.....	47
4.5.4	Examples of V2G Applications.....	49
4.5.5	Balancing Area (Bulk Power) Applications.....	50
4.5.6	Distribution System Applications.....	51
4.5.7	Customer Applications	52
4.6	Considerations for Utility Use Case U6 - Basic Distributed Energy Resource	52
4.6.1	Maximum Forward Power and Maximum Reverse Power.....	53
4.6.2	EPRI and IEC Direct Charge/Discharge Storage Function.....	54
4.6.3	Target Setpoint Versus Limit Setpoint	56
4.6.4	Understanding PEV Charging Requirements	57
4.6.5	Duration at Maximum Forward Power Flow.....	59
4.6.6	Duration at Maximum Reverse Power Flow.....	60
4.6.7	Time of Reference.....	62
4.6.8	Recommended Information Available to EMS from PEV.....	62
4.6.9	Recommended Active Power Command and Command Response.....	62
4.6.10	Levels of EMS Engagement with a PEV.....	63
4.6.11	A V2G Example - Facility Demand Charge Management	64
4.7	Considerations for Use Case U7 - Advanced Distributed Energy Resource.....	65
4.7.1	Reactive Power, Apparent Power, and Power Factor	65
4.7.2	Reference Voltage and Reference Voltage Offset.....	70
4.7.3	Recommendations for U7 Fixed Power Factor Function	71
4.7.4	Recommendations for U7 Fixed VAR Function	72
4.7.5	Autonomous Curve Functions.....	73
4.7.6	Low and High Voltage Ride Through Functions	74
4.7.7	Loading and Executing Autonomous Functions	77
4.8	Considerations for Use Case PEV4 - PEV as a Distributed Energy Resource.....	77
4.8.1	Show Me the Money!	77
4.8.2	The Business Deals	78
4.8.3	Process Flow for the DER Direct Scenario	79
4.8.4	Process Flow Differences for EVSE Direct Scenario.....	79

4.8.5	Simultaneous V2G Applications and Rules of Engagement.....	84
4.8.6	PEV4 Scenario Summary	85
4.8.7	Participation in V2G Applications - Use Cases Are Not Selected by the Driver	85
4.9	Utility Approval of Interconnection of a DER.....	86
5.	NOTES	88
5.1	Revision Indicator.....	88
APPENDIX A	USE CASE PEV4.....	89
APPENDIX B	USE CASE PR2	93
APPENDIX C	USE CASE U6	101
APPENDIX D	USE CASE U7	103
APPENDIX E	INFORMATION DEFINITIONS	107
APPENDIX F	ABBREVIATIONS	110
APPENDIX G	SMART INVERTER FUNCTIONS AND THE ONBOARD INVERTER.....	113
APPENDIX H	SOME V2G-DC AND V2H-DC CONSIDERATIONS	115
APPENDIX I	MEDIUM- AND HEAVY-DUTY VEHICLES.....	117
Figure 1	Purpose of document	6
Figure 2	Summary of detailed use cases	15
Figure 3	Exportable power panel for V2L-EPP	19
Figure 4	V2H-EPP and V2G-AC with onboard inverter	21
Figure 5	System architecture for DC Level 1 V2G-DC.....	23
Figure 6	System architecture for DC Level 2 V2G-DC.....	24
Figure 7	V2H-EPP and V2H-DC reverse power flow	25
Figure 8	DC microgrid (V2D-DC)	28
Figure 9	Interfaces with inverter of a DER device.....	29
Figure 10	Key parameters for manual control.....	31
Figure 11	Options for manually controlling startup.....	32
Figure 12	Options for manually controlling termination.....	32
Figure 13	Relationship of the utility, premises, and PEV	33
Figure 14	Communication with EVSE inverter	34
Figure 15	Communication with PEV inverter	35
Figure 16	External inverter details.....	36
Figure 17	Typical fast charging profile	37
Figure 18	Example of information exchange.....	38
Figure 19	IEEE 1547-2003 limits.....	40
Figure 20	Use cases and V2G applications	45
Figure 21	Elements that define OBW.....	47
Figure 22	Power and battery characteristics.....	53
Figure 23	Basic elements of the power setting command	55
Figure 24	Example of command sequencing.....	56
Figure 25	Parameters that define PEV charging requirements	58
Figure 26	Relationship of charging parameters	59
Figure 27	Forward power flow measures.....	60
Figure 28	Reverse power flow measures.....	61
Figure 29	Effect of inductance and capacitance	66
Figure 30	Components of complex power vector.....	66
Figure 31	Minimum power factor.....	69
Figure 32	VAR and power factor zones	70
Figure 33	Voltage reference offset.....	71
Figure 34	Structure of an autonomous function	73
Figure 35	Array functions	74
Figure 36	LVRT and HVRT concept.....	75
Figure 37	Example of LVRT implementation	76
Figure 38	Business deals associated with V2G applications.....	78
Figure 39	PEV4 DER process chart.....	80
Figure 40	Elements of active session	81

Figure 41	Three tiers of V2G applications.....	84
Figure 42	System concept for use of SAE J3072	88
Table 1	Inverter characteristics	17
Table 2	SAE types of reverse power flow	18
Table 3	Scenarios for use case PR2	29
Table 4	Utility use cases	47
Table 5	Examples of OBW.....	48
Table 6	Examples of V2G applications	49
Table 7	Recommended PEV information for U6.....	62
Table 8	Active power setpoint command parameters.....	63
Table 9	Levels of engagement.....	64
Table 10	Power factor sign conventions	68
Table 11	Recommended PEV information for fixed power factor.....	72
Table 12	Fixed power factor setpoint command parameters.....	72
Table 13	Recommended PEV information for fixed VAR function.....	72
Table 14	Fixed VAR command parameters.....	73
Table 15	Characteristics of PEV4 scenarios.....	85

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.

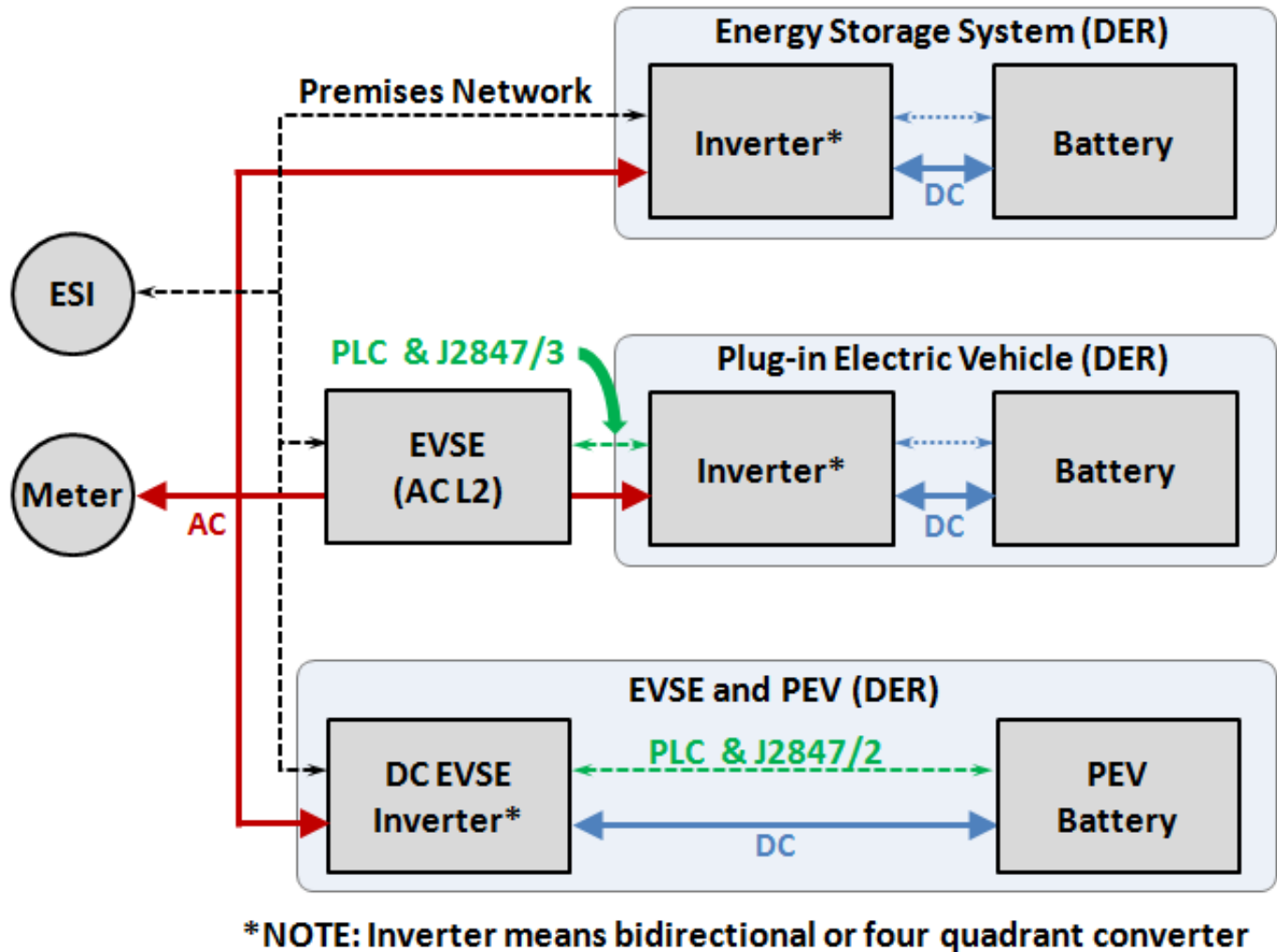


Figure 1 - Purpose of document

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 1547™, 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.nyserdera.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)

Distributed 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 through 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.

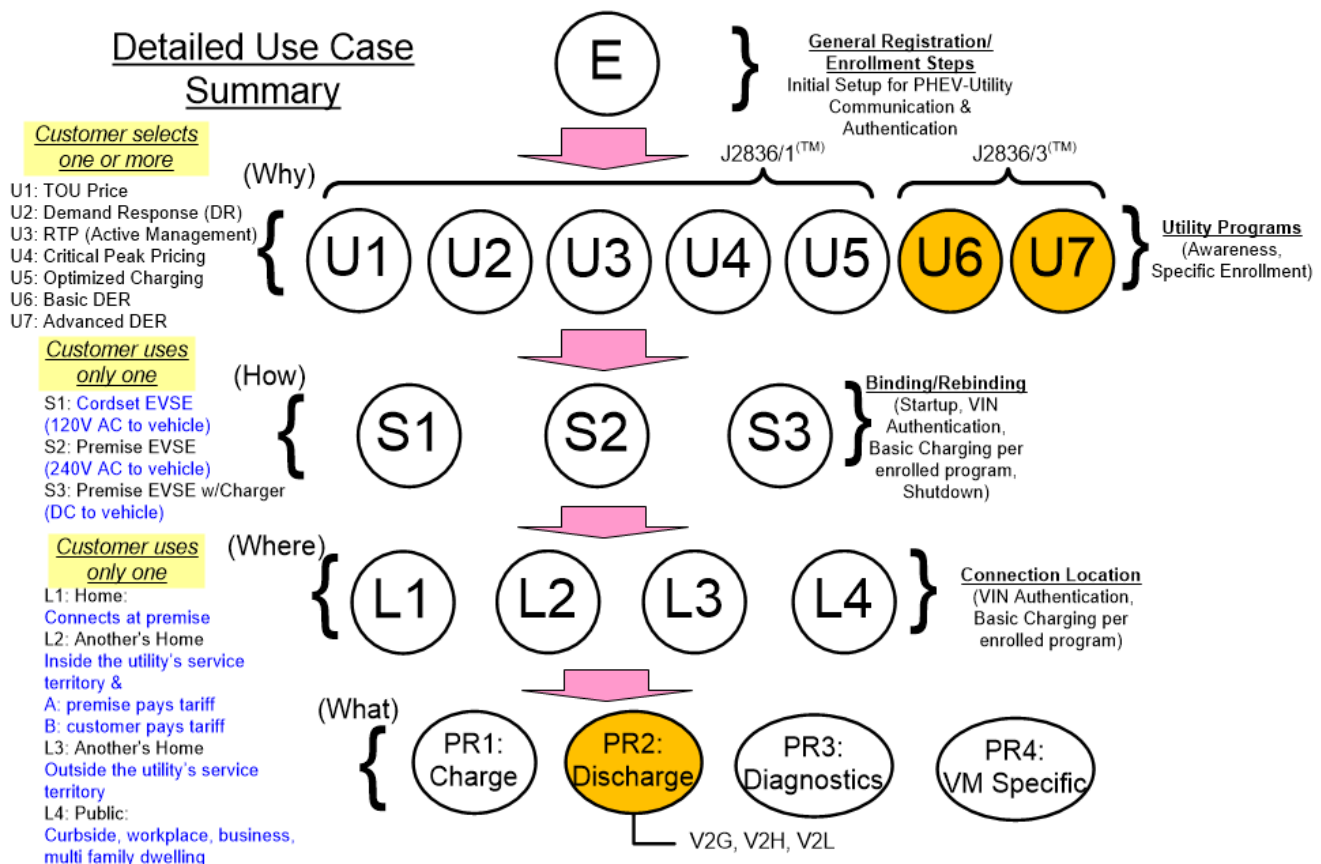


Figure 2 - Summary of detailed use cases

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 4.2.5 J2847/2	V2L-AC 4.2.6 J2847/5	V2L-EPP 4.2.1	
Charge another electric vehicle; special V2L	V2V	V2V-DC 4.2.5 J2847/2	V2V-AC 4.2.6 J2847/5	V2V-EPP 4.2.1	
PEV is only source of backup power for islanded home (NEC 702)	V2H	V2H-DC 4.2.5 J2847/2	V2H-AC 4.2.6 J2847/3	V2H-EPP 4.2.1	V2H-WPT 4.2.4 J2847/6
Connected in parallel with utility grid (NEC 705) or to islanded AC microgrid with strong VF source	V2G	V2G-DC 4.2.3 J2847/2	V2G-AC 4.2.2 J3072		V2G-WPT 4.2.4 J2847/6
Connected to a “weak” islanded AC microgrid; special case of V2G	V2M (V2G)	V2M-DC 4.2.7	V2M-AC 4.2.7		
Connected to a DC microgrid which could be in islanded facility; special case of V2G	V2D (V2G)	V2D-DC 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.

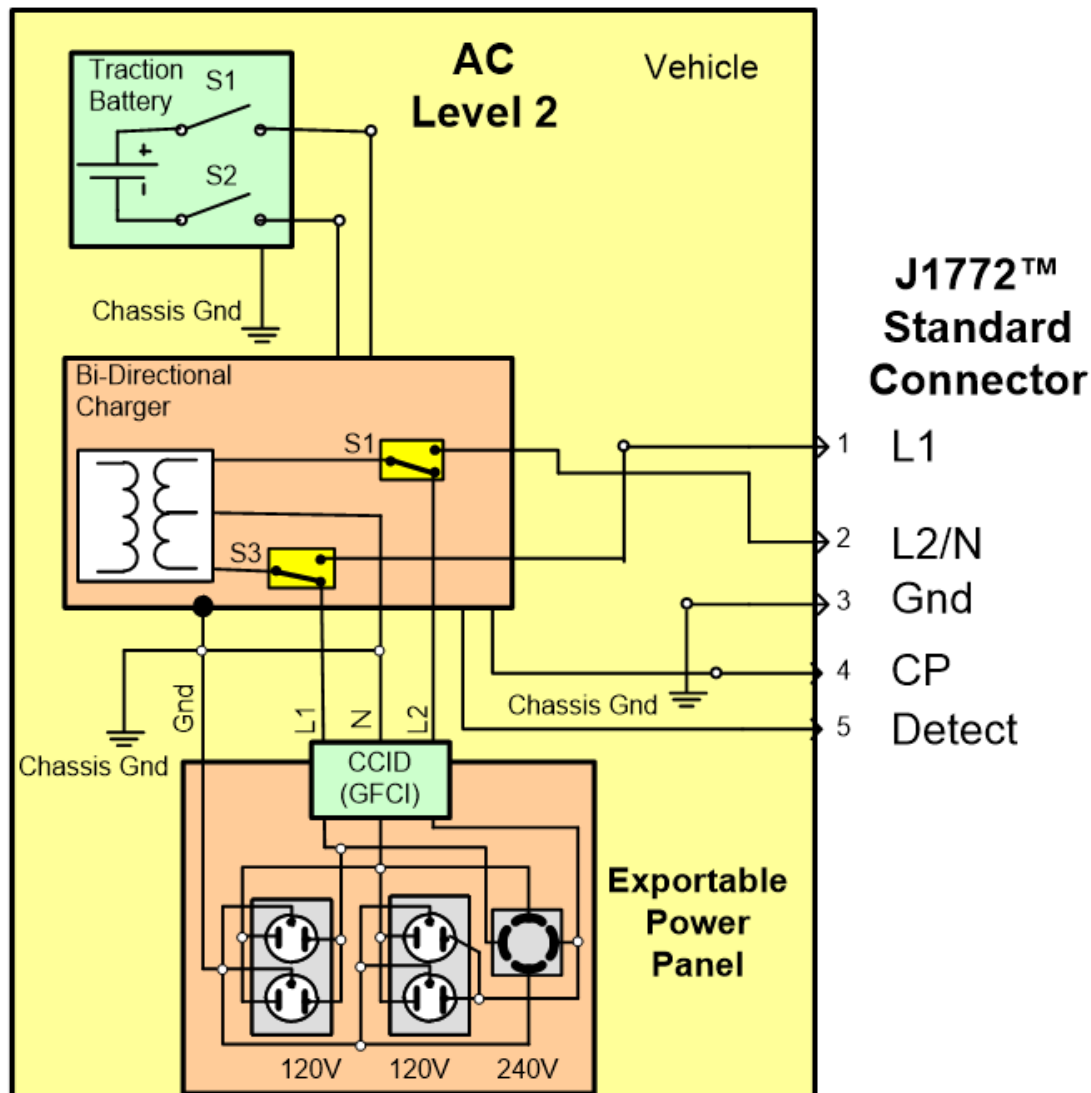


Figure 3 - Exportable power panel for V2L-EPP

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.

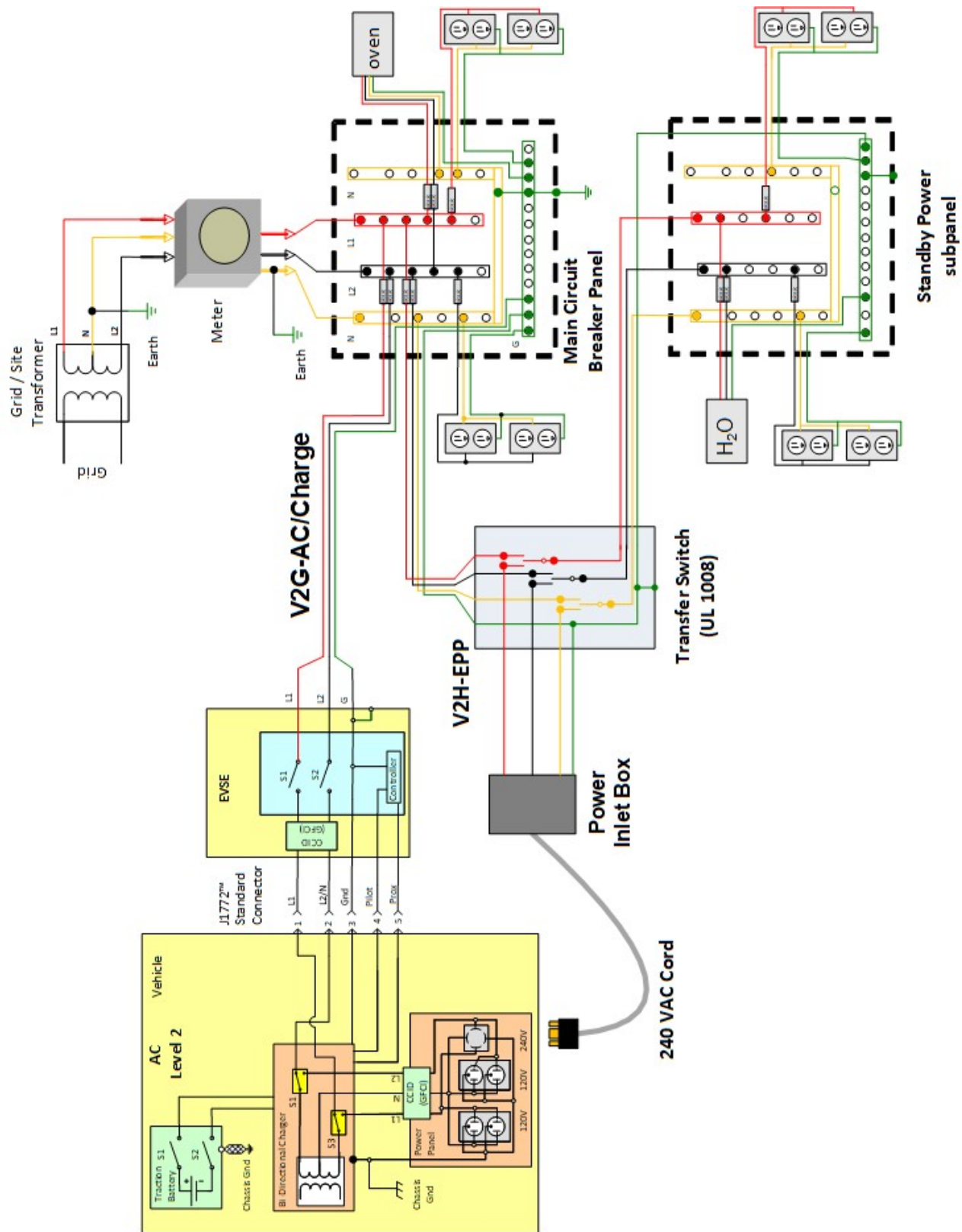


Figure 4 - V2H-EPP and V2G-AC with onboard inverter

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.

The diagram illustrates the electrical architecture for a vehicle-to-grid (V2G) system. It is divided into three main sections: Vehicle, EVSE, and the J1772 Standard Connector.

- Vehicle Section (Light Green):** Contains the **Traction Battery** and a set of switches labeled **S1**, **S2**, **S3**, and **S4**. The battery is connected to S1 and S2, while S3 and S4 are connected to the EVSE lines.
- Charger Section (Orange):** Labeled **AC Level 2, DC Level 1** and **Charger**. It has two input lines from the vehicle (S3 and S4) and two output lines (S5 and S6) connected to the EVSE.
- EVSE Section (Light Blue):** Contains the **EVSE** unit, a **PLC** (Programmable Logic Controller), a **Bi-Directional Charger**, and an **IBS** (Intelligent Battery System). The EVSE has two input lines (S1 and S2) from the vehicle and two output lines (S5 and S6) to the charger. It also has a **Controller** and a **CP Detect** line.
- J1772 Standard Connector:** A dashed line separates the vehicle and EVSE sections. It shows the connection points for **L 1/DC+**, **L 2/DC-**, **Ground**, **CP Detect**, and **Ground**.

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.

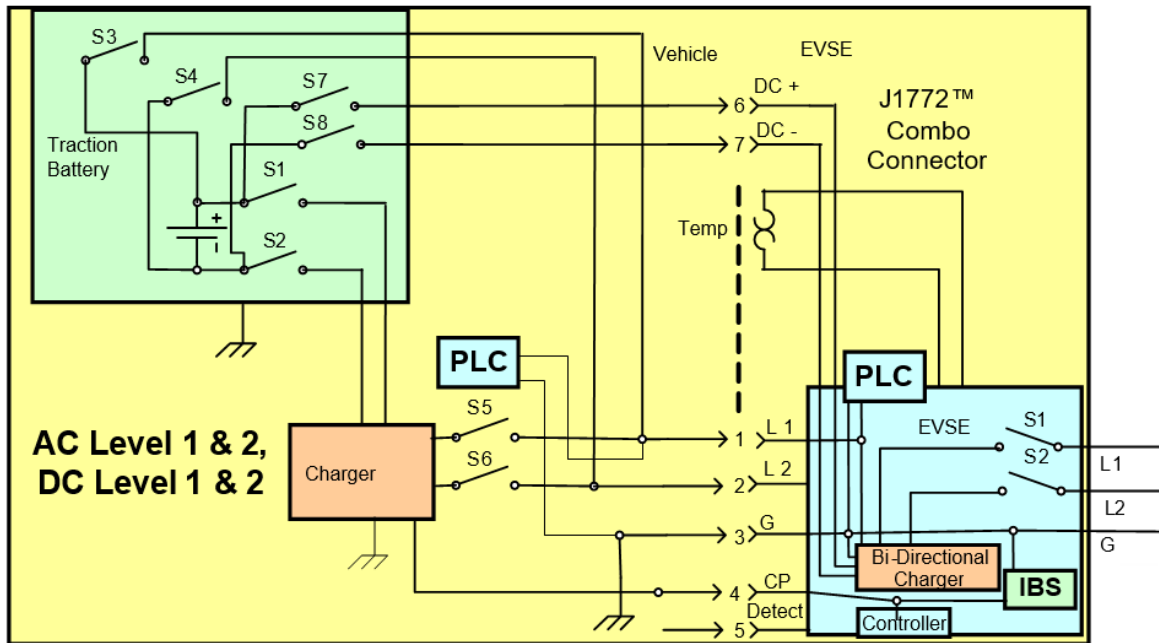


Figure 6 - System architecture for DC Level 2 V2G-DC

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.

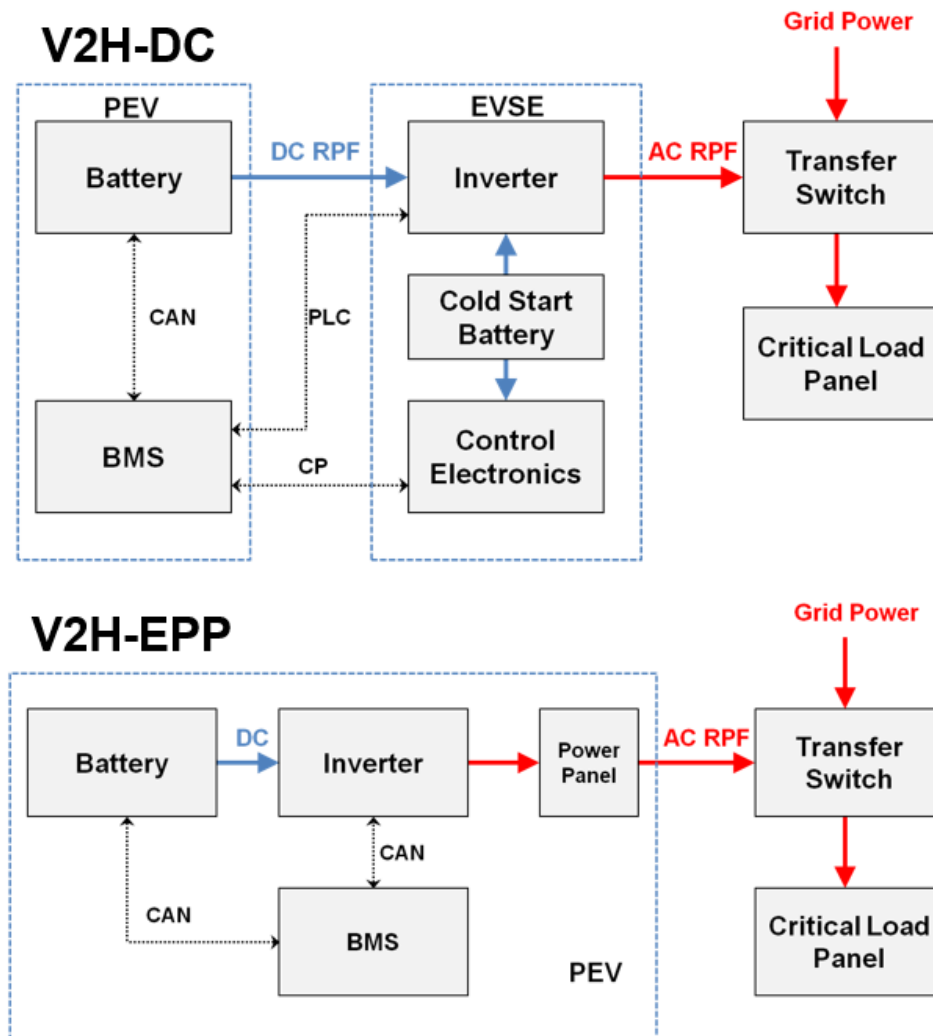


Figure 7 - V2H-EPP and V2H-DC reverse power flow

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.

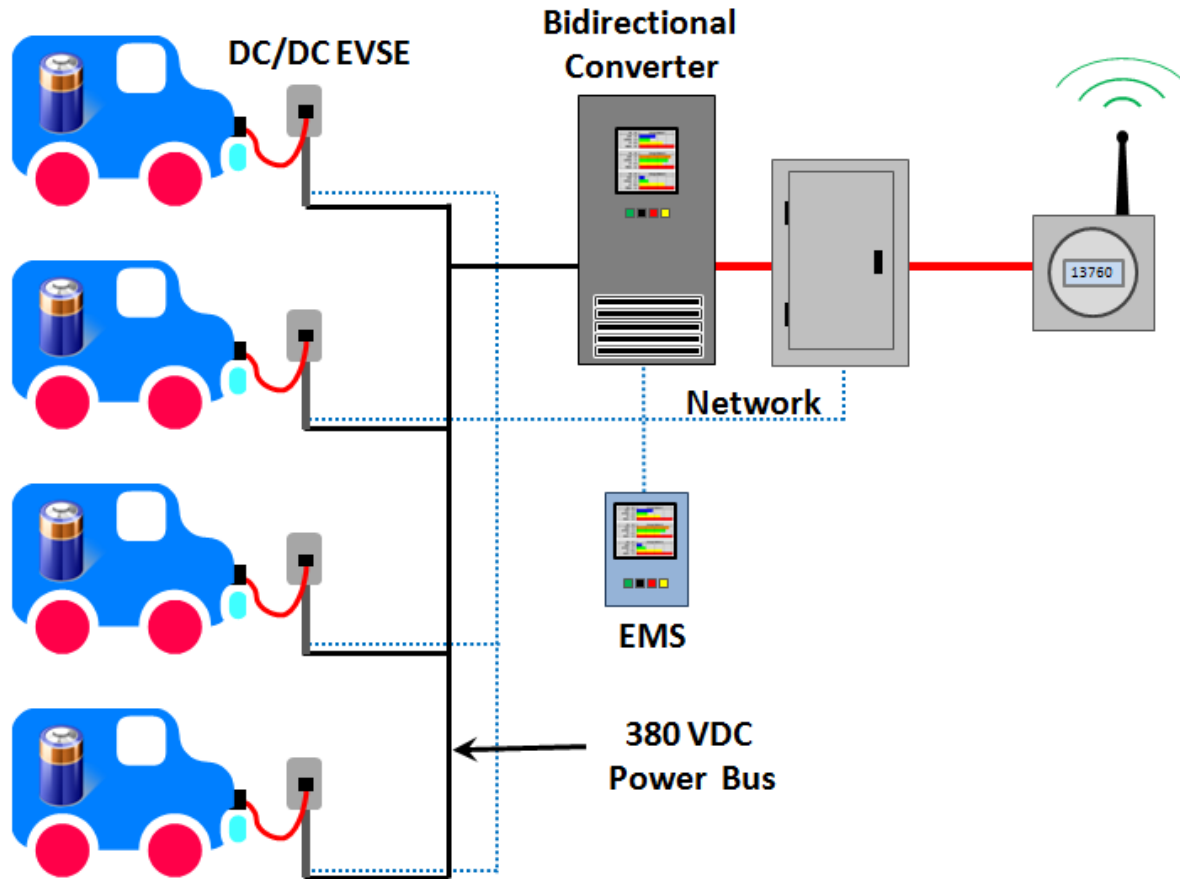


Figure 8 - DC microgrid (V2D-DC)

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

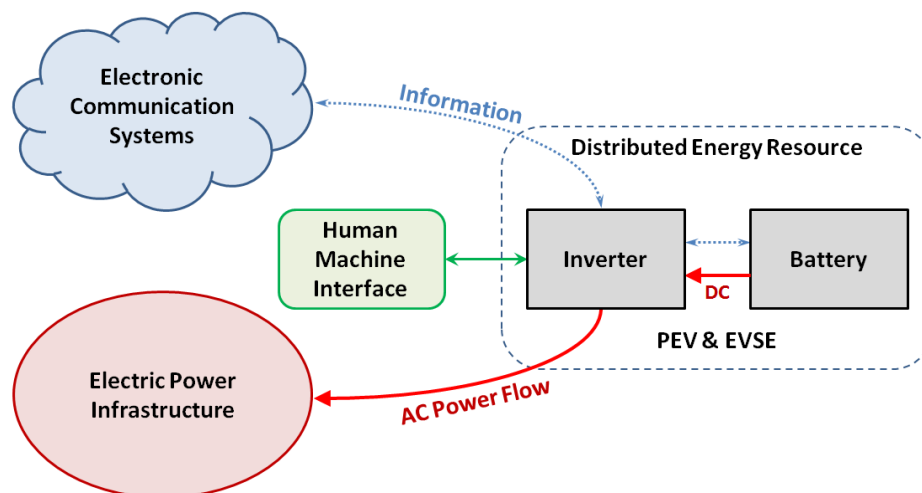
Use Case PR2 Scenario Name	Use Case PR2 Scenarios Characteristics			
	Type	Control	Inverter	Outlet
V2G-DER-AC	V2G-AC	DER	Onboard	SAE J1772
V2G-DER-DC	V2G-DC	DER	External	SAE J1772
V2G-DER-WPT	V2G-WPT	DER	External	Wireless
V2G-MAN-AC	V2G-AC	Manual	Onboard	SAE J1772
V2G-MAN-DC	V2G-DC	Manual	External	SAE 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 converter (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.

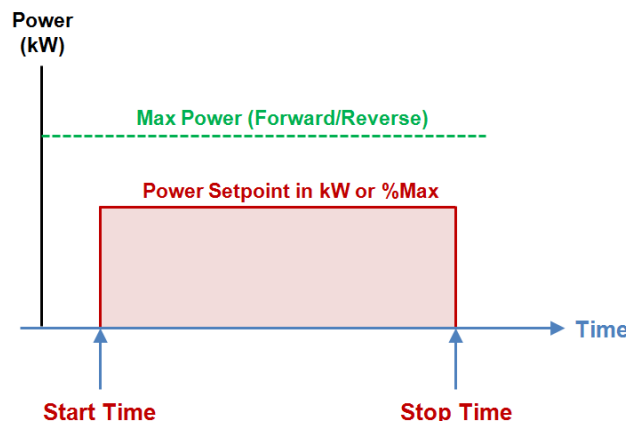


Figure 10 - Key parameters for manual control

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.

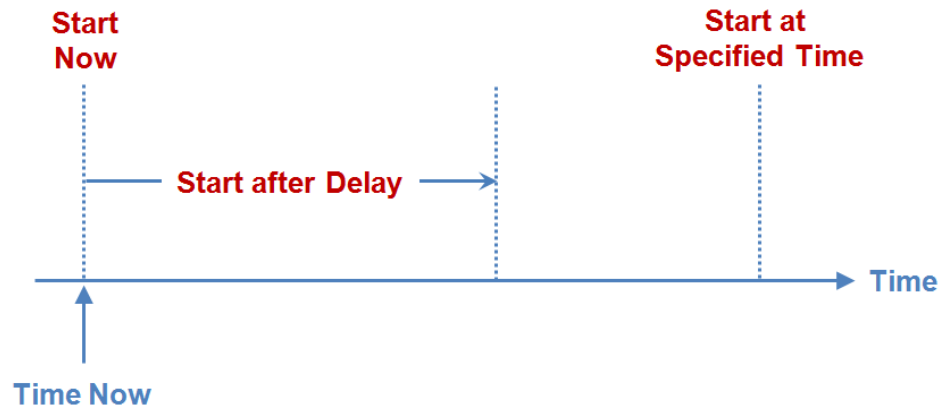


Figure 11 - Options for manually controlling startup

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).

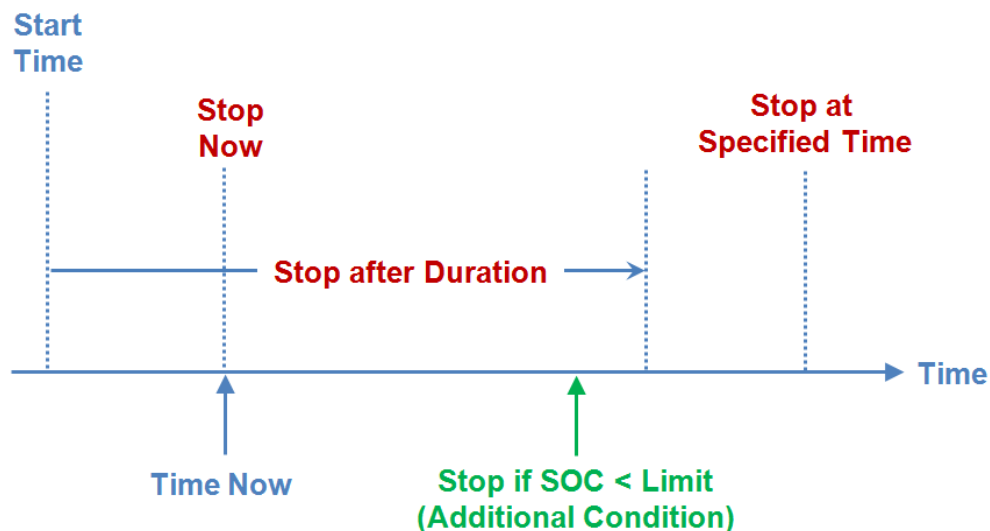


Figure 12 - Options for manually controlling termination

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.

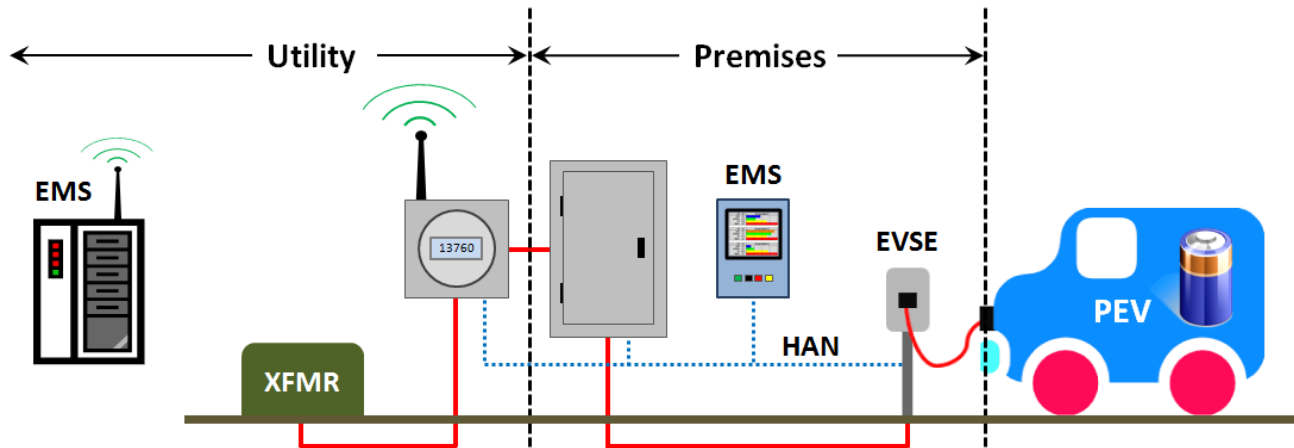


Figure 13 - Relationship of the utility, premises, and PEV

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.

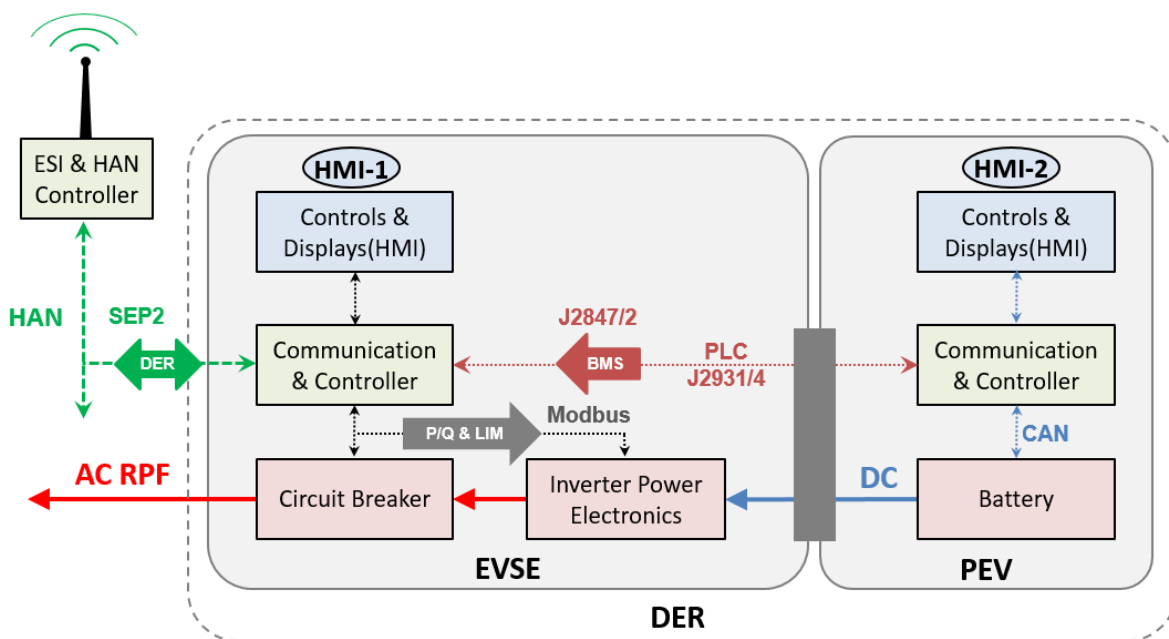


Figure 14 - Communication with EVSE inverter

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.

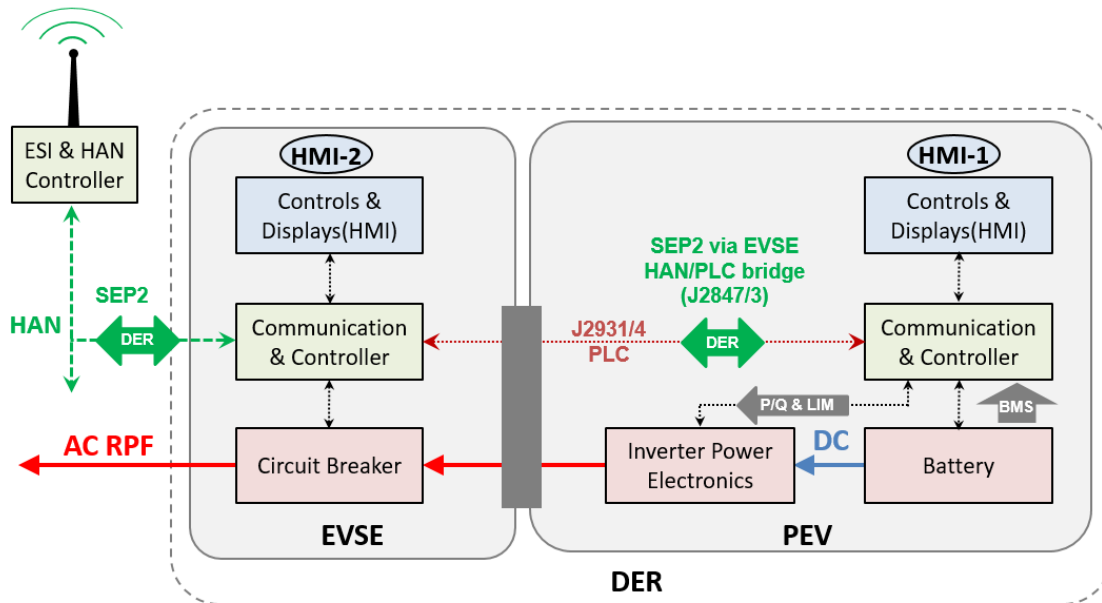


Figure 15 - Communication with PEV inverter

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.

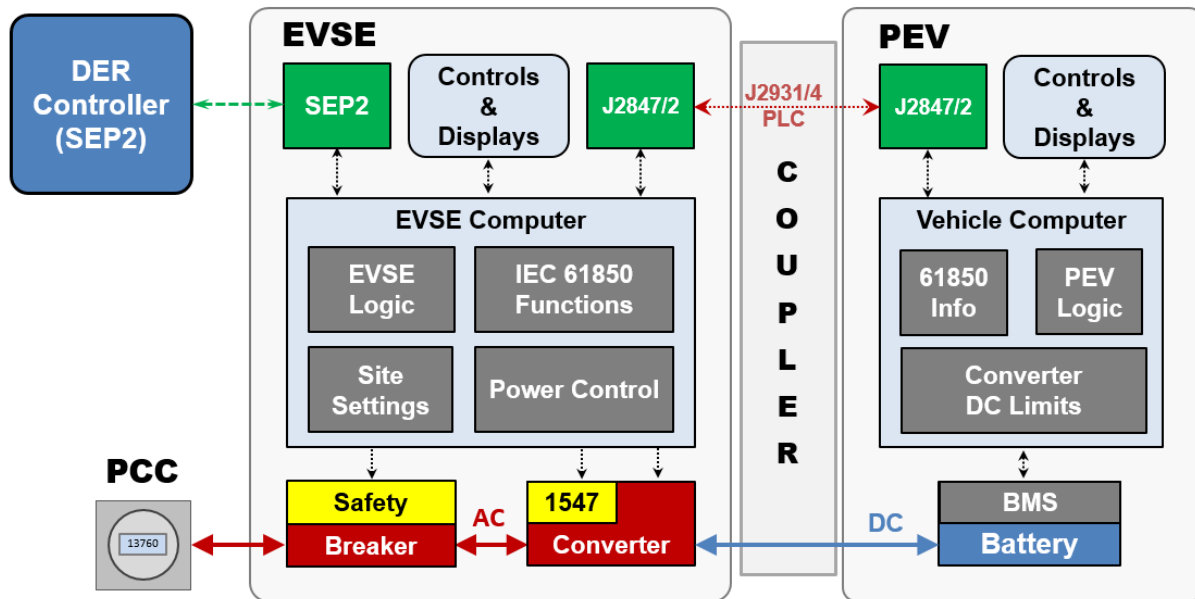


Figure 16 - External inverter details

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.