PAVING THE WAY

VEHICLE-TO-GRID (V2G) STANDARDS FOR ELECTRIC VEHICLES

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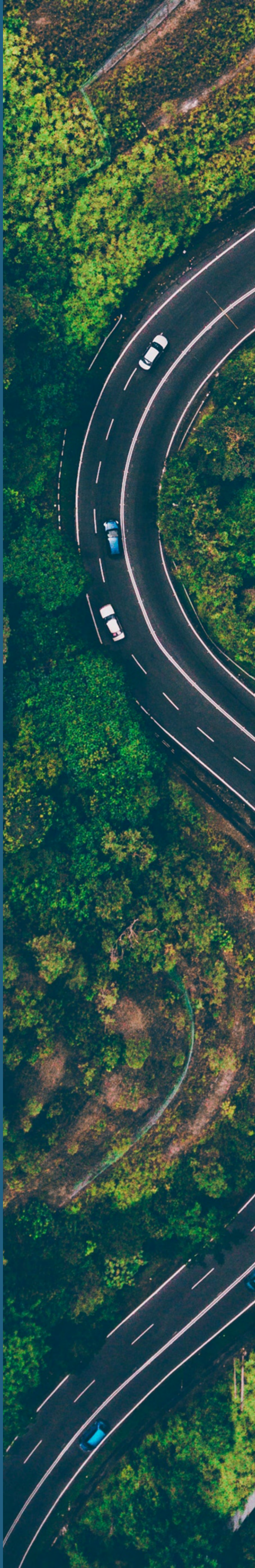


PAVING THE WAY

IREC's ***Paving the Way* series** covers three topics related to electric vehicles (EVs): vehicle-to-grid (V2G) standards, equitable shared mobility programs, and EV charger interconnection timelines. In this series, IREC provides pathways and considerations for transitioning to electrified transportation in a manner that is equitable, efficient, and beneficial to the grid.

- In ***Paving the Way: Vehicle-to-Grid (V2G) Standards for Electric Vehicles***, we review the status of V2G standards and any gaps that need to be addressed to unlock the capabilities of V2G-enabled equipment.
- In ***Paving the Way: Enabling Equitable Electric Vehicle Shared Mobility Programs***, we highlight existing programs that are demonstrating the importance of building equity into shared mobility and EV infrastructure programs.
- In ***Paving the Way: Emerging Best Practices for EV Charger Interconnection***, we discuss the strategies that states and utilities can use to streamline the interconnection of EV charging infrastructure.

A Glossary of Terms can be found on page 21.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

Transportation electrification is essential to helping states and the federal government achieve their energy and climate targets. Electric vehicles (EVs) can provide a myriad of benefits, from reduced air pollution and greenhouse gas emissions to vehicle-to-grid (V2G) services that can support the more efficient operation of the electric grid. In order to scale transportation electrification, regulators, electric utilities, the EV industry, and other stakeholders engaged in the regulatory process will have to work through a number of technical and regulatory issues. In particular, the various technical standards that govern the integration of V2G-enabled EVs through the interconnection process will need to be incorporated into state-level rules.

Technical standards are essential to certifying new equipment and ensuring its safe operation on the grid. The certification process is especially important for electric utilities and distribution system operators that need to be able to trust that any equipment connected to the grid will operate in a predictable way. V2G technologies introduce additional complexity to grid-integrated equipment, due to the variety of inverter configurations possible, including:

- V2G-DC (direct current): In this configuration, power conversion and smart functions are located within the electric vehicle supply equipment (EVSE). Here the EVSE acts as and resembles a stationary smart inverter (a device which goes beyond the basic inverter function of converting power into a usable electric current to also offer grid-support benefits and communication functions).
- V2G-AC (alternating current): In this configuration, the EV houses both the power conversion and smart functions. Here the EV acts as and resembles a smart inverter, albeit a mobile one.
- V2G-Split Inverter: In this configuration, power conversion is located within the EV and smart functions are housed within the EVSE. Here neither the EV nor the EVSE resembles a smart inverter on its own.

V2G-applicable standards cover a wide range of certification topics (such as interconnection, EVSE safety, vehicle functionality, communications), and there is no one standard that holistically captures all of the ways that V2G systems will interact with the grid. There are a number of V2G-applicable standards by different standards organizations, including UL (formerly Underwriters Laboratories), SAE International, the Institute of Electrical and Electronics Engineers (IEEE), among others. Below is a summary of how current standards and protocols apply to V2G equipment:

Interconnection matters fall under IEEE 1547™ series of standards and documents.
EVSE safety and functionality is covered by UL standards.
EV standards and vehicle functions are addressed by SAE.
Testing can be done by third parties (such as Nationally Recognized Testing Laboratories using applicable UL documents) or manufacturers *can self-certify* using SAE documents.
Communications (interoperability) is an evolving area for EVs and, given its wide applicability (demand response, distributed energy resource interface, SAE references), it can be a confusing realm for EVs.

Before V2G can be implemented across the country, states will have to navigate the evolving landscape of applicable standards and integrate them into their rules and technical documents. At this time, we offer the following guidance for certifying V2G equipment to ensure that it will operate in a safe and reliable manner on the grid:

- For V2G-DC, certify the EVSE to UL 1741 to ensure grid conformance (i.e., fulfillment of requirements)
- For V2G-AC, certify the EVSE to UL 1741 SC (once published) and certify the EV to SAE J3072
- For V2G-Split Inverter, both the EV and EVSE should be tested to IEEE 1547.1

II. INTRODUCTION

Electric vehicles were originally designed to draw power from the electric grid as needed to keep them running, similar to a cell phone or other device with a rechargeable battery. However, as EV technologies have evolved over the years, so too has the vision for their use and value to the grid. Policymakers have begun to reimagine the EV as a grid resource in addition to its role as a zero- or low-emissions mode of transportation. Additionally, manufacturers are beginning to transform the way EV charging infrastructure is designed and how it interacts with EV batteries. For example, with the help of smart inverters[1], EVs are capable of acting as mobile energy storage units (i.e., batteries) and providing beneficial services to the electric grid. This concept of enabling EVs to export power to the grid is generally referred to as "vehicle-to-grid."

Policymakers, manufacturers, utilities, and other stakeholders are exploring V2G implementation in at least seven states through pilot programs or discussions in regulatory proceedings.[2] One of the initial challenges has been determining the current technical standards that may apply to V2G and any gaps that may exist. Standards serve many purposes related to the interconnection of energy resources to the grid, including defining technical specifications for equipment, certifying new technologies and functions, and providing assurance to utilities that new resources can be safely operated on the grid. As new grid technologies and functionalities emerge, technical standards must evolve to specify any required technical settings and operational capabilities. For example, existing interconnection standards cover stationary energy storage and inverters, but mobile inverters, as are used in EVs, may necessitate additional safety requirements. To ensure that V2G can become a reality, standards must be updated or developed to address mobile inverters and their impacts on grid safety and reliability, as well as their interaction with vehicle charging practices, communication protocols, and managed charging programs.

This paper provides a brief overview of V2G, reviews the existing standards related to V2G and identifies gaps that need to be addressed before it can be fully implemented. As regulators and other stakeholders pursue V2G implementation in their states, this paper is intended to be used as a starting point for regulatory discussions related to the incorporation of V2G standards into interconnection rules.

> **Vehicle-to-Everything (V2X) is the broader term used to describe the storage of energy within an EV and its ability to supply power for particular end uses, including buildings (V2B), homes (V2H), load (V2L), and the grid (V2G).**

III. WHAT IS VEHICLE-TO-GRID TECHNOLOGY?

Vehicle-to-grid (V2G) envisions EVs as mobile energy storage units that can be configured as distributed energy resources (DERs) similar to stationary energy storage systems. Instead of solely drawing power from the grid when plugged-in, V2G allows EVs to communicate with and provide power and other services to the grid or connected loads when needed, through bidirectional (or reverse) power flow. This two-way power flow between the EV and the grid can help balance fluctuations in energy demand since EVs have the capability to charge during periods of low demand and send power to the grid when demand is high.

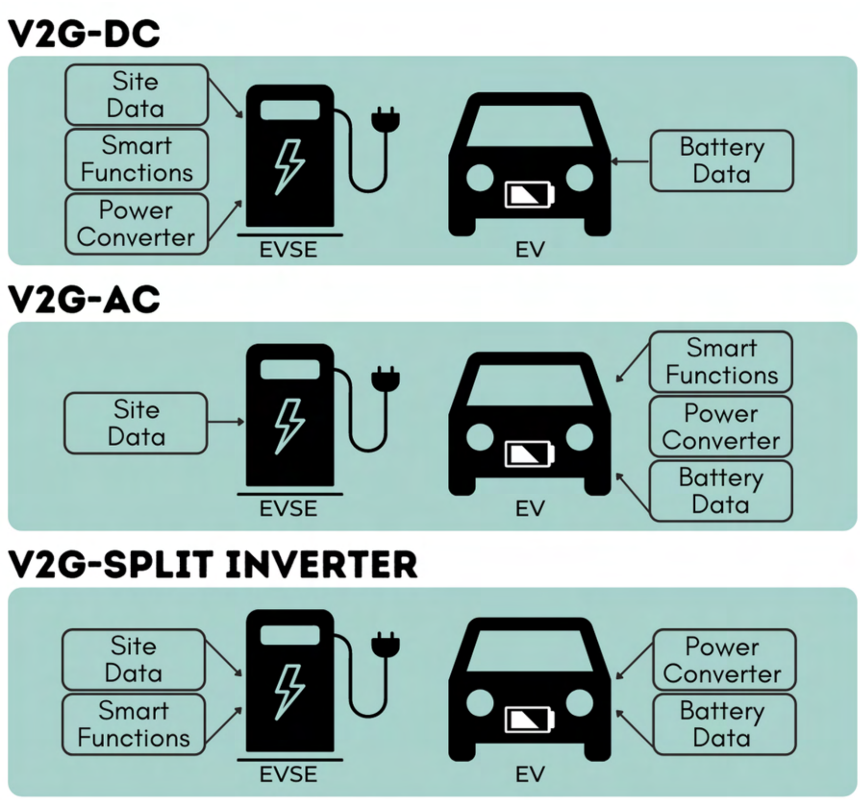
The potential benefits of V2G are substantial, especially when EVs are viewed in aggregate. The Electric Power Research Institute found that V2G could provide $1 billion in annual grid benefits in California alone if the state reaches its goal of 5 million EVs by 2030 and half of the EVs are V2G-enabled.[3] By providing grid services, such as peak shaving (reducing load consumption for a small period of time) and load shifting (moving load consumption to off-peak periods of time), V2G-enabled EVs could offer states and utilities a new grid resource to help meet clean energy policy goals and provide ratepayer and system benefits. In addition, EV adopters could derive new revenue streams from any grid services their vehicles provide.

For V2G-enabled EVs to become effective customer and grid assets, updated standards that govern their interaction and communication with the grid are critical. In particular, communication protocols that govern communications between the EV, the customer, and the grid must be established and enabled to ensure that the EV can provide power and other services to the grid. The interaction between the grid and EVs will vary based on the configuration of the inverter. The different types of inverter configurations are described below.

A. Types of V2G Inverter Systems

There are three types of V2G inverter configurations: V2G-DC, V2G-AC, and V2G-Split Inverter. The main difference between the three configurations is where the power converter and smart functions reside.[4] As shown in the first two configurations in Figure 1 below, the power converter and smart functions can be housed solely within the EV charger (V2G-DC) or within the EV (V2G-AC). In the third configuration (V2G-Split Inverter), the EV charger includes the smart functions, however, its corresponding power converter is located on-board the EV. At this point, it is unclear how the third configuration will be implemented or if such application will have any traction in North America.

Figure 1: V2G Inverter Configurations[5]



> **The EV battery energy can be converted to AC power inside the charge station (V2G-DC) or onboard the vehicle (V2G-AC)—these are vastly different approaches.**

Given that stationary inverter configurations, such as V2G-DC, more closely resemble the inverter configurations and functionality of those connected to stationary DERs, they may fall under current interconnection rules and technical standards. For configurations with mobile inverters, however, equipment certification and technical standards will need to be developed or modified to ensure safe grid operation.

B. V2G Challenges & Status

Vehicle-to-grid is still in the early stages of development in the U.S. While some states are beginning to explore the capabilities of V2G, and V2G-enabled equipment is currently being developed and commercialized, the technology is not yet in widespread use,[6] and several challenges must be addressed in order to scale this technology. One of the initial hurdles for states is determining how to safely and cost-efficiently interconnect new V2G technologies, such as mobile inverters, to the grid, given that many state interconnection rules have not been updated to reflect the unique attributes of energy storage, whether mobile or stationary. Other V2G barriers and concerns (beyond the scope of this paper) include: the high cost of V2G-enabled equipment; battery degradation and charging management; customer awareness and buy in; value streams for grid services; and potential grid impacts.[7]

Stakeholder[8] discussions underway in California, for example, provide a glimpse into the technical and regulatory issues that states must address when updating their interconnection rules to enable V2G. In a working group focused on V2G-AC interconnection, discussions have centered on how the current standards—which are discussed in Section IV below—may address mobile inverter functions. There is some disagreement over which entity should be responsible for testing equipment and how to fill in any gaps related to technical standards.[9] Fortunately, V2G-DC stationary inverters can be connected to the grid under California's current interconnection rule (Rule 21) as long as the installer receives explicit utility permission to switch to bidirectional charging (i.e., the charger is first deployed with V2G mode turned off, then the V2G-DC charger is issued an interconnection agreement by the same process as any other DER inverter).[10]

> **Vehicle-to-grid is still in the early stages of development in the U.S. While some states are beginning to explore the capabilities of V2G, and V2G-enabled equipment is currently being developed and commercialized, the technology is not yet in widespread use, and several challenges must be addressed in order to scale this technology.**

IV. V2G-APPLICABLE STANDARDS

Standards are utilized for many types of equipment and services offered across the world, covering devices like cellphones, networking equipment, computers, electric outlets, and many more common items we use daily. Standards establish a consistent and predictable framework for product testing and development for manufacturers that focuses on reliability and safety, which can enhance consumer confidence in new products and help to establish new markets.[11] Standardization, which is the process of making products, services, or processes conform to a standard, is advanced by thousands of engineers and experts worldwide.[12] Standards are especially important because of the interrelated nature of consumer products. For example, USB ports on laptops and other products are standardized so that manufacturers only need to create one type of port and users do not have to purchase additional cords to connect their products via USB.

V2G applicable standards are still in the early stages of development and involve multiple standards organizations, such as: UL (formerly Underwriters Laboratories), SAE International, the Institute of Electrical and Electronics Engineers (IEEE), Open Charge Alliance (which advances the Open Charge Point Protocol, OCPP), Open Automated Demand Response (OpenADR) Alliance, and the International Organization for Standardization (ISO). Table 1 lists the standards and protocols reviewed in this document, along with the specified certification topic to which they apply.

Table 1: V2G-Applicable Standards by Certification Topic

Scope	Standards & Protocols
Interconnection	IEEE 1547-2018
	IEEE 1547.1-2020
EVSE Safety & Functionality	UL 1741
	UL 9741
Vehicle Functions	SAE J2836/3
	SAE J3072
Communication	IEEE 2030.5-2018 (SAE J2847/3)
	OCPP
	OpenADR
	ISO 15118

To understand why there are many standards applicable to V2G, it is helpful to review the recent evolution of standards. Figure 2 highlights the development and revision of many of the V2G-applicable standards since 2010.

Figure 2: V2G Standards Development Timeline

2010	**UL 1741**	Second edition of this UL standard is published to support interconnection and listing of inverters. Conformance testing utilizes IEEE 1547-2003 and IEEE 1547.1-2005 (more applicable to stationary inverters).
2013	**SAE J2836/3 & SAEJ847**	First publication of these SAE standards, which expected inverters to be listed to UL 1741. Additionally, IEEE adopts SEP 2.0 application protocol as IEEE 2030.5.
2014	**UL 9741**	UL publishes first edition of this standard, outlining the investigation of bidirectional EVSE.
2015	**SAE J3072**	This SAE standard is published, specifically targeting mobile inverters. The document references IEEE 1547-2003 and IEEE 1547.1-2005.
2016	**OpenADR**	OpenADR is published to standardize and simplify demand response (and DER) two-way information exchange.
2017	**UL 1741 SA, SAE J2836/3**	UL publishes supplement SA, allowing states like California and Hawaii to activate smart inverter controls when grid-connected. Additionally, SAE revises its J2836/3 to recognize J3072 in place of UL 1741 for mobile inverters.
2018	**IEEE 1547-2018, IEEE 2030.5-2018, OCPP 2.0**	IEEE 1547 and IEEE 2030.5 are revised, opening industry-wide adoption of DERs and interoperability. Similarly, OCPP 2.0, an application protocol between EVSE and central management systems is launched.
2020	**IEEE 1547.1-2020, OCPP 2.0.1**	1547.1 is published, establishing conformance testing procedures to IEEE 1547-2018 for DERs. Additionally, OCPP 2.0 is revised to OCPP 2.0.1 with added smart charging features.
2021	**SAE J3072 & SAE J2836/3, UL 9741**	SAE standards are revised to support IEEE 1547-2018, IEEE 1547.1-2020, and IEEE 2030.5-2018. UL 9741 publishes its second edition. Third edition of UL 1741 is published, which includes revision to UL 1741 SB.

In the sections that follow, the applicable V2G standards are explained in more detail, along with any gaps that may impact their effectiveness. The standards are intended to enable the safe integration of DERs onto the grid, and ultimately must be applied by public utility regulators for specific DER interconnection use cases. In addition to being aware of what those standards are, Public Utility Commissions (PUCs) must make many technical and regulatory decisions regarding standards adoption. These range from the effective date of compliance requirements to determining which sections and sub-sections are applicable to which use cases. This paper does not aim to answer all these questions, but rather to identify the applicable standards that regulators should consider for enabling V2G functionality in a brief "snapshot" format that can serve as a concise reference point.

A. IEEE 1547

The Institute of Electrical and Electronics Engineers (IEEE) is "the largest technical professional organization," covering aspects of electrical, electronics, and computing fields around the world.[13] *IEEE Standard 1547™-2018 for Interconnection and Interoperability of DER with Associated Electric Power Systems (1547-2018 or the standard)* is the base 1547 standard that supports the proliferation of DERs, as well as the added smart features, grid support capabilities, and interoperability requirements of those DERs. V2G configurations, whether they are stationary or mobile systems, involve an Electric Vehicle Supply Equipment (EVSE) interface and a battery that can interact with the distribution system. Because of this, V2G is within the scope of IEEE 1547.

IEEE Standard 1547-2018 is supported by other documents in the 1547 series of standards that provide clarity and guidance to implement the baseline requirement.[14] As such, regulators seeking to adopt *IEEE Standard 1547-2018* in their interconnection regulations should not view it in isolation; they should consider its interactions and interdependencies with other sections of the 1547 series, based on the unique needs and characteristics of each jurisdiction. For example, IEEE 1547.1-2020, the conformance test procedure for DER equipment interconnecting with the grid, specifies the type tests, production tests, commissioning tests, periodic tests, and evaluations that equipment shall conform with to meet IEEE 1547 requirements. IEEE P1547.9, the draft guide for energy storage interconnection, is a new document in the 1547 series that is currently in development and includes guidance (recommended practice) that is specific to energy storage, as well as an Annex dedicated to the interconnection of bidirectional EVSE. Table 3 provides an overview of the technical gaps in IEEE 1547 identified in a California Public Utilities Commission ruling in 2020.[15] However, it's important to note that IEEE 1547.1 has no specific provisions for testing of DERs (or EVSE/EV in this case) that are not stationary. Conformance related concerns including commissioning tests for V2G-AC may be addressed by the upcoming UL 1741 supplement SC.

Table 2: Overview of 1547 Applicable Standards, Gaps, and Status Update

IEEE 1547-2018	**Title**	IEEE Standard for Interconnection and Interoperability of DER with Associated Electric Power Systems (EPS) Interfaces
	Scope	A technology-neutral standard that applies to interconnection and interoperability of DERs.
IEEE 1547.1-2020	**Title**	IEEE Standard Conformance Test Procedures for Equipment Interconnecting DER with EPS and Associated Interfaces
	Scope	This standard describes the tests to be conducted to ensure compliance with IEEE 1547.
IEEE P1547.9/D5.1	**Title**	(NEW) Draft Guide to Using IEEE 1547 for Interconnection of Energy Storage DER with EPS
	Scope	Introduced to bolster energy storage-specific content missing in IEEE 1547-2018. Guidance is also provided for EV charging stations with V2G capability.
Gaps Identified in 2020		No specific gaps identified within IEEE 1547 standard related to V2G.
2021 Status Update		P1547.9/D5.1 Annex B covers the expected conformance for DC and AC charging stations. For DC, the EVSE should be listed to UL 1741. For AC, the EVSE can be listed to UL 1741 (for the EVSE) and SAE J3072 for the onboard inverter.

B. UL Standards

UL has developed over 1500 standards and is an accredited standards development organization in the U.S. and Canada.[17] UL also partners with other national bodies around the world and is a leading entity when it comes to certifying product safety, especially in North America. Unlike IEEE 1547, which is a standard adopted by public utility regulators as part of the interconnection rulemaking process, UL standards apply to manufacturers through product certification. They can be incorporated by reference into interconnection rules as a jurisdiction's approved method of certifying that a given technology meets the necessary operating requirements. There are two UL standards that apply to V2G technologies: UL 1741 and UL 9741. The former applies to all types of generation equipment, while the latter applies only to vehicles and associated supply equipment.

UL 1741

UL 1741 is widely used for grid interconnection. This UL standard provides guidance for evaluating inverters with specific grid compliance requirements (i.e., compliance with California's Rule 21, Hawaii's Rule 14H, and other interconnection rules). Stationary inverters, such as those accompanying PV systems, have been certified to UL 1741 for years, and utilities have strong familiarity and experience with its testing and certification protocols. Table 3 provides an overview of the UL 1741 gaps identified in 2020 in a ruling by the California Public Utilities Commission.[19]

In a V2G-DC system, the EVSE can be considered a stationary inverter, and therefore, interconnection requirements, including conformance to grid integration, can be met when the V2G-DC EVSE is certified to UL 1741.[18]

UL1741 cannot be directly used to certify equipment installed in an electric vehicle (for a V2G-AC system) because many of the requirements in UL 1741 relate to safety and construction requirements for stationary electrical equipment and are not appropriate, as written, to be used with automotive equipment. A new automotive version of UL 1741 could have been created by UL, but this would not have addressed other requirements unique to the onboard inverter. SAE developed J3072 to address those onboard inverter issues.

Table 3 provides an overview of the UL 1741 gaps identified in 2020 in a ruling by the California Public Utilities Commission.[19]

Table 3: Overview of UL 1741 Applicable Standards, Gaps, and Status Update

<table>
<tr><td rowspan="2">UL 1741</td><td>Title</td><td>Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources</td></tr>
<tr><td>Scope</td><td>These requirements cover inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems. Interactive inverters, converters, and ISE are intended to be operated in parallel with an EPS to supply power to common loads.[20]</td></tr>
<tr><td rowspan="2">UL 1741 SA*</td><td>Title</td><td>UL 1741 Supplement SA used with IEEE 1547-2003[21]</td></tr>
<tr><td>Scope</td><td>An add-on to the UL 1741 with grid support smart features.</td></tr>
<tr><td rowspan="2">UL 1741 SB*</td><td>Title</td><td>UL 1741 Supplement SB used with IEEE 1547-2018</td></tr>
<tr><td>Scope</td><td>An add-on to the UL 1741 with grid support smart features realized in IEEE 1547-2018.</td></tr>
<tr><td rowspan="2">UL 1741 SC*</td><td>Title</td><td>UL 1741 Supplement SC (forthcoming)</td></tr>
<tr><td>Scope</td><td>An add-on to the UL 1741 with V2G-AC support realized in SAE J3072.</td></tr>
<tr><td>Gaps Identified in 2020</td><td colspan="2">UL 1741 standard(s) needs updating to properly account for V2G integration.

Utilities may prefer to use an updated UL 1741 because of their familiarity with it. However, most requirements cannot be used for automotive electronics and an automotive version would be needed (SAE J3072 was created for this purpose).</td></tr>
<tr><td>2021 Status Update</td><td colspan="2">A new revision to UL 1741 was published on September 28, 2021. This new version (also referred to as UL 1741 Edition 3), includes a revision to Supplement SB and other updates. The UL 1741 SC task group held their first meeting in Q1 2021 to support the use of SAE J3072 for V2G-AC. In 2021, California customers can purchase a V2G-DC system that has the EVSE certified with UL 1741 + SA. In 2022, California residents should be able to purchase UL 1741 + SB certified EVSEs for V2G-DC applications.</td></tr>
</table>

*Supplement is contained within the UL 1741 standard

UL 9741

UL 9741 covers bidirectional EVSE and applies to V2G-DC as well as V2G-AC systems. As written, the standard relies on UL 1741 for guidance, evaluation, and testing to meet grid integration requirements. Unlike UL 1741 which only applies to discharging, UL 9741 could be used for charging and discharging. Perhaps, the best way to understand UL 9741 is by envisioning its practicality to grid interconnection, as stipulated below:

- UL 9741 is changing and will likely continue to evolve (e.g., to align with UL 1741 revisions).
- Currently, the power industry does not recognize UL 9741 as a substitute for UL 1741 for use with interconnection of EVs as generating facilities.
- Where grid connection is involved, UL 9741 could be used to support the local building code for EVSE installation but would rely on UL 1741 for grid interconnection requirements. IIn that case, the EVSE would be dual listed (to UL 9741 and UL 1741).
- However, for UL 9741 to apply to V2G-AC, the standard also needs to align with UL 1741 SC which calls out conformance to SAE J3072 (as captured in the Section IV. C. SAE).
- The new version of UL 9741 may also include requirements for off-grid power generation (e.g., V2H, V2L).

Table 4 provides an overview of the gaps identified in 2020,[22] and the present status of the standard. It can be noted that a revision was released in 2021, however, alignment with the evolving UL 1741 has yet to be achieved.

Table 4: Overview of UL 9741 Standard, Gaps, and Status Update

Title	Outline of Investigation for Electric Vehicle Power Export Equipment (EVPE)
Scope	These requirements cover bidirectional electric vehicle charging equipment that charge electric vehicles from an electric power system and also include functionality to export power from the electric vehicle to an electric power system.[23]
Release	March 2014 (original issue), May 2021 (revised issue). Prior to the 2021 release, the title was “Outline of Investigation for Bidirectional Electric Vehicle (EV) Charging Equipment.”
Gaps Identified in 2020	Updates to UL 9741 are needed to align it with the evolving UL 1741.
2021 Status Update	The new release covers both unidirectional and bidirectional equipment connected to EV. This also includes bidirectional equipment that is configured to operate in “unidirectional mode.”

C. SAE Standards

SAE International develops standards and best practices for several transport industries, including aerospace, automotive, and commercial vehicles.[24] The three V2G-related SAE standards that support mobile systems and define the interaction between the vehicle and the grid include J2836/3, J2847/3, and J3072.

SAE J2836/3 is a broad information report (not a standard) that explains different approaches for using the energy of an EV battery to power remote loads (V2L), to serve as a backup generator for a home (V2H), or to engage in smart functions with the utility grid (V2G). J2836/3 defines use cases for how smart inverter functions can be supported.[25] When first published in 2013, it was assumed that onboard inverter (V2G-AC) could be listed to UL 1741 because UL 1741 seemed to be a universal standard. When the need for J3072 arose, J2836/3 was revised in January 2017 to reflect the use of J3072 in place of UL 1741 for V2G-AC.

SAE J2847/3, first released in December 2013, is a recommended practice (not a standard) that provides guidance for using the *IEEE 2030.5-2013, the IEEE Standard for Smart Energy Profile Application Protocol* (discussed in greater detail in section IV.D. Communications Protocols) DER Function Set on V2G applications. This is a supplement to using IEEE 2030.5 standard.[26] J2847/3 was revised March 2021 to update it for the 2018 update of IEEE 2030.5. Several significant DER-related deficiencies were corrected by IEEE.[27] J2847/3 is a good explanation of the use of the DER function set for people who understand smart inverters but are not communication experts.

SAE J3072, on the other hand, is an actual standard that provides interconnection requirements for onboard inverters systems and serves three primary purposes listed in Table 5 below.

Table 5: Three Key Purposes of SAE J3072

Inverter Within an EV Is a Function Integrated Into the EV	EV Roams and It Is Installed Automatically When It Connects to an EVSE at a Facility	Testing Shall Be Performed by a Qualified Entity
Inverter is not a removable device that can be sent to the lab for testing. The standard requires the vehicle manufacturer to define an “Inverter System Model Number” to uniquely identify the onboard hardware and software that implement the functionality to be certified.	The exact process used by the EV to get site specific information and settings from the EVSE is defined. Similarly, the approach used by the EVSE to authorize the EV to discharge is exactly defined.	The inverter system model shall be tested and certified to IEEE 1547-2018, as tested by 1547.1-2020. Testing must be performed by an authorized entity. There is debate as to whether this would be an OSHA NRTL (such as UL), or whether a vehicle manufacturer could perform the certification, if properly “qualified.”

The original version of J3072, released in May 2015, did not require any smart inverter functions because it was based on certification to IEEE 1547-2003 and IEEE 1547.1-2005. After the publication of IEEE 1547-2018 and IEEE 1547.1-2020, SAE revised J3072 to reflect the updated DER requirements and interoperability reflected in the newer IEEE standards. In short, SAE J3072 can be thought of as the UL 1741 equivalent in terms of grid integration, providing a certification path to mobile inverters. **Therefore, for V2G-AC, regulators should consider a suite of standards that incorporates: 1547 compliant inverters, J3072 certified EVs, and UL 1741 stickered EVSEs.[28] Tables 6-8 provide overviews of each SAE standard, and the gaps identified in 2020.[29]**

Table 6: Overview of SAE J2836/3 Standard

Title	Use Cases for Plug-In Vehicle Communication as a DER
Scope	This SAE Information Report establishes use cases for a plug-in electric vehicle (PEV) communicating with an Energy Management System (EMS) as a DER which must be supported by SAE J2847/3.
Release	January 2013 (original issue), January 2017 (revised issue).[30]
Gaps Identified in 2020	No specific gaps identified within SAE J2836/3 document related to V2G.

Table 7: Overview of SAE J2847/3 Standard, Gaps, and Status Update

Title	Communication for Plug-In Vehicles as a DER
Scope	Applies to a PEV which is equipped with an onboard inverter and communicates using IEEE 2030.5-2018 (the IEEE Standard for Smart Energy Profile Application Protocol). It is a supplement to the IEEE 2030.5 Smart Energy Profile (SEP) 2 standard, which supports the use cases defined by SAE J2836/3. It provides guidance for the use of the SEP2 distributed energy resource function set with a PEV. It also provides guidance for the use of the SEP2 flow reservation function set, when used for discharging. It is not intended to be a comprehensive guide to the use of SEP2 in a PEV.[31]
Release	December 2013 (original issue), March 2021 (revised issue).
Gaps Identified in 2020	Updates were needed to SAE J2847/3 to support communication specifications provided in IEEE 2030.5-2018.
2021 Status Update	The revised issue complements and harmonizes with communication requirements (messages/signals) established in IEEE 2030.5-2018.[32]

Table 8: Overview of SAE J3072 Standard, Gaps, and Status Update

Title	Interconnection Requirements for Onboard, Grid Support Inverter Systems
Scope	This standard establishes requirements for a grid support inverter system function which is integrated into a PEV, and which connects in parallel with an EPS via EVSE. This standard also defines the communication between the PEV and the EVSE required for the PEV onboard inverter function to be configured and authorized by the EVSE for discharging at a site. Its requirements are intended to be used in conjunction with IEEE 1547 and IEEE 1547.1.[33]
Release	May 2015 (original issue), March 2021 (revised issue). The 2021 release changed the title from “Utility-Interactive Inverter Systems” to “Grid Support Inverter Systems” following IEEE 1547-2018.
Gaps Identified in 2020	Updates were needed to SAE J3072 to harmonize it with IEEE 1547-2018 and IEEE 1547.1-2020.[34]
2021 Status Update	The new release: • Supports IEEE 1547-2018 and IEEE 1547.1-2020, but also offers optional support to IEEE 1547-2003 and IEEE 1547.1-2005. • Offers a path to certification for on-board inverters, based partially on testing and certifying SAE J3072 with other required standards.[35]

D. Communication Protocols

In addition to the standards described above, communication protocols (also known as interoperability protocols) represent another critical element of DER integration. Communication protocols provide a channel through which information is exchanged with DERs in a consistent manner.[36] Such information exchange can be applicable to all DERs (such as inverters) or could be specific to certain DER types (such as energy storage). As an example, communication protocols make it possible to identify the present status of a DER and manage associated assets (such as scheduling of charge and discharge, demand response, and following price signals).

There is much ongoing discussion regarding utility-to-DER communications, including the use of one of the three communication protocols specified in 1547-2018,[37] and the use of Distributed Energy Resource Management Systems (DERMS) to manage DER assets (including V2G EVs). This section does not focus on the use of DERMS or utility-to-DER communications. Instead, the V2G related protocols discussed here may encompass use cases outside the utility-DER interface.

There are several communication protocols utilized in the industry. Some protocols are proprietary (made by a single company with access restricted), and some are open (available to anyone for use, although there may be an associated cost). Table 9 provides an overview of applicable V2G communication protocols and trends, covering open protocols that have an impact on V2G maturity and establishment. These protocols are rapidly evolving, and significant changes are expected in the future. Some of these anticipated changes relate directly to V2G implementation (such as charge, discharge, scheduling, management, etc.) and some relate indirectly (such as cyber security).

The interoperability and communication domain is a confusing area for EVs. For traditional stationary DERs, communication standards encompass a variety of applications, such as communication to individual smart inverters, communications to aggregators, settings communications, energy usage communications, and pricing communications. However, SAE is the organization people go to for EV standards. So, an already confusing areas now cross-references with SAE standards. Regulators should be aware of these protocols to make informed decisions regarding the interconnection of V2G.

Notably, IEEE 2030.5 is expected to have immediate impacts on DERs by establishing channels for communications between EVs and EVSE, between EVSE and energy management systems, and between EVSE and DER aggregators (particularly in the U.S.[39]). Additionally, due to the applicability of IEEE 2030.5 in the SAE J3072 certification process and IEEE 1547-2018 DER interfaces, this communication protocol is likely to play a crucial role in V2G adoption. Similarly, SunSpec Modbus and DNP3 AN2018-001 (both of which apply to DER interface, as allowed for in IEEE 1547-2018), are likely to interact with SAE standards in the near future.

Table 9: Overview and Trends of V2G Applicable Communication Protocols

<table>
<tr><th colspan="4">Trends</th></tr>
<tr><td rowspan="2">IEEE 2030.5</td><td>Title</td><td>IEEE Standard for Smart Energy Profile Application Protocol</td><td rowspan="2">IEEE 2030.5 was adopted by IEEE in 2013. In 2016, the California Public Utilities Commission selected the standard as the default communication protocol between utilities and DER in the state’s interconnection rules (California Rule 21).

The latest version of the standard (IEEE 2030.5-2018) incorporates IEEE 1547-2018 and California Rule 21 features and is also the core messaging protocol for SAE J3072.[40]</td></tr>
<tr><td>Scope</td><td>The application layer with TCP/IP providing functions in the transport and internet layers to enable utility management of the end user energy environment, including demand response, load control, time of day pricing, management of distributed generation, electric vehicles, etc. is defined in this standard. For V2G applications, the protocol can be used for EVs to communicate with EVSE, and/or EVSE communication with a DER aggregator or DER management system.</td></tr>
</table>

Continued on next page

Table 9: Overview and Trends of V2G Applicable Communication Protocols *(Cont.)*

			Trends
OCPP 2.0.1	**Title**	Open Charge Point Protocol 2.0.1	OCPP 2.0 was launched in 2018. OCPP 2.0.1, an updated version of the protocol, was released in 2020. The new release did not add new functionalities. However, issues identified in the prior release were addressed; improvements in security, support of ISO 15118, and smart charging were also added in the new release.[41]
	Scope	**An application protocol for communication between EVSEs and a central management system, allowing charging stations and central management systems from different vendors to communicate with each other.**	
OpenADR	**Title**	Open Automated Demand Response	This popular demand response protocol was made available in 2013. In May 2021, for the first time, OpenADR was written into a standard outside the U.S., opening a new market in Europe.[42] It is also included in California's Title 24 Building Energy Efficiency Standards, published in 2020.
	Scope	A standardized demand response protocol that encompasses EV charging and DER programs, facilitating a common information exchange between utilities, aggregators, and customers. **For V2G applications, the standard can be used between the EVSE and DER management systems.**	
ISO/DIS 15118	**Title**	Road vehicles — Vehicle to grid communication interface	First published in 2013 and accompanied by a series of documents over the years (ISO 15118.1:2013, ISO 15118.2: 2014, ISO 15118-3; ISO 15118-4: 2018 etc.), ISO 15118 provides the basic framework, conformance test, and details on communications between EVs and EVSE. The ISO 15118.1 was revised in 2019.[43] ISO 15118-20, the 2nd generation network and application layer, is currently under development.[44]
	Scope	**Specifies the communications between EVs and EVSE, and provides a common understanding on charge/ discharge, payments, cybersecurity, and privacy.**	

V. CONCLUSION

Standards are integral to the safe and efficient integration of DERs on the electric grid. Therefore, it is crucial for regulators, utilities, and manufacturers to understand the various standards and protocols that can enable grid integration of new technologies and capabilities, such as V2G. Given the diversity of V2G-applicable standards, the industry is likely to develop multiple certification approaches, such as third-party certification through Nationally Recognized Testing Laboratories, self-certification through SAE, or possibly a hybrid approach. Table 10 provides an overview of the expected grid conformance standard based on the configuration of the inverter.

Table 10: Overview of V2G Technology Type and Expected Grid Conformance Standard

Technology/Inverter System	Expected Grid Conformance Standard
V2G-DC (Stationary)	The EVSE needs to be tested to IEEE 1547.1, and such testing is called out in UL 1741. Given that the inverter is housed within the EVSE, conformance to UL 1741 would be sufficient to meet grid requirements. **Expected conformance: EVSE is listed to UL 1741.**
V2G-AC (Mobile)	The EV is tested to SAE J3072 which requires testing to IEEE 1547.1. The EVSE is listed to UL 1741 SC as interconnection system equipment. **Expected conformance: EV is certified to J3072 and the EVSE is listed to UL 1741 SC.**
V2G-Split Inverter	No standard has been established for this system configuration. However, in practice, to achieve grid integration, the EVSE and the EV power converter will need to be tested to IEEE 1547.1. To implement this option, it would not only require a system integrator (that can test the EVSE and the power converter), but also parties (EVSE and EV) may need to agree with the arrangements.

The V2G-DC inverter configuration interacts with the grid in a manner essentially identical to existing storage inverters. As such, the integration of stationary V2G-DC systems is far more mature compared to mobile V2G-AC or V2G-Split Inverter systems. For the latter system configurations, there are several considerations that will impact how they are tested and certified. First, the existence of multiple configurations at the early stages of industry adoption adds complexities to the certification process. Second, depending on the design configurations of the mobile systems, partial certification (as opposed to full system certification) may be necessary. Additionally, utilities may be uncomfortable evaluating systems that have not been fully certified by a third party. Finally, there are several communications protocols applicable to V2G technologies and this is an area likely to experience significant evolution in the industry.

States seeking to enable V2G functionalities should consider the above standards to both ensure the safe integration of V2G-enabled EVs and maximize the benefits of V2G for the grid, customers, and the environment.

> **“Standards are integral to the safe and efficient integration of DERs on the electric grid. Therefore, it is crucial for regulators, utilities, and manufacturers to understand the various standards and protocols that can enable grid integration of new technologies and capabilities, such as V2G.”**

GLOSSARY

Demand Response	Demand response refers to initiatives that reduce customers' electricity usage during times of high demand for electricity on the grid, such as by adjusting a thermostat, turning on a battery, or temporarily turning off or reducing power demand from devices like washers and dryers, electric vehicle chargers, or industrial machinery. Often, demand response is achieved via automated signals from the utility to a customer's connected devices. Many utilities offer voluntary, opt-in demand response programs that compensate participating customers.
DERMS	Distributed Energy Resource Management Systems, or DERMS, are software programs that allow utilities to manage the operations of an aggregation of distributed energy resources (DERs), like solar PV systems, energy storage systems (ESS), or electric vehicles.
DERs	Distributed Energy Resources (DERs) are small-scale energy generation and storage technologies, such as solar PV systems, energy storage systems (ESS), electric vehicles, small wind turbines, and other technologies. They are characterized by being sited at or near the customer's location on the distribution grid (i.e., "behind-the-meter"), as distinguished from large-scale utility-operated power sources that are connected to the transmission grid.
EPS	An Electric Power System (EPS) is a facility that delivers electric power to a load.
EV	Electric vehicles (EVs) are all-electric vehicles that have a battery that is charged by plugging in to charging equipment.
EVSE	Electric Vehicle Supply Equipment (EVSE) refers to the charging equipment used to transfer energy from the electric grid to the vehicle battery or vice-versa, in the case of vehicle-to-grid (V2G) applications.
Inverter	An inverter is a device that connects to a distributed energy resource for the purpose of converting power into a usable electric current (e.g., converting direct current produced by solar panels to alternating current for use in homes and businesses).
ISE	Interconnection system equipment (ISE) refers to equipment that connects an electric generator with a local electric power system (i.e, the electric grid), such as switchgear, protective devices, inverters or, other interface devices.
NRTL	A Nationally Recognized Testing Laboratory (NRTL) is an independent organization that certifies products for the U.S. market. NRTLs are recognized by the Occupational Safety and Health Administration (OSHA) under Federal Code 29 CFR 1910.7 for products to be used in U.S. workplaces.
PEV	Plug-in electric vehicle (PEV) is another term for electric vehicles that charge by plugging into charging equipment; the term encompasses both plug-in hybrid electric vehicles, which have both an internal combustion engine and an electric motor that uses energy stored in a battery, and all-electric EVs.
Power Converter	The power converter is a device that transforms alternating current (AC) to the direct current (DC) needed to charge the EV battery, and that converts DC to AC when discharging the EV battery.

PUC	Public utility commissions (PUCs), also called public service commissions, regulate utilities, including electric, gas, telecommunications, water and wastewater utilities, though in this paper our focus is on PUCs as regulators of electric utilities. PUCs are charged with assuring that utilities provide reasonable, adequate, and efficient service to customers at just and reasonable prices, and providing utilities with a reasonable opportunity to recover the costs incurred providing service, including a fair return to investors.
Smart Inverter	A smart inverter is a type of inverter with additional "smart" capabilities. A smart inverter goes beyond the power conversion function of a traditional inverter to also provide autonomous grid support functions during excursions from normal operating voltage and frequency conditions (simply put, they can support the reliability of the grid). Smart inverters also include communication systems with the ability to accept external commands.
TCP/IP	Transmission Control Protocol/Internet Protocol (TCP/IP) is a set of rules that governs the connection of computer systems to the internet, allowing standardized internet communications over long distances.
V2B	Vehicle-to-buildings (V2B) is a subcategory of vehicle-to-grid (V2G) (defined below), which refers specifically to the use of EVs to power loads in commercial buildings and homes.
V2G	Vehicle-to-grid (V2G) envisions EVs as mobile energy storage units that can be configured as distributed energy resources (DERs) similar to stationary energy storage systems. Instead of solely drawing power from the grid when plugged in, V2G allows EVs to communicate with and provide power and other services to the grid or connected loads when needed, through bidirectional (or reverse) power flow.
V2G-AC	V2G-AC (alternating current) is one of several possible inverter configurations for V2G. In this configuration, power conversion and smart functions are located within the electric vehicle. In this configuration, the EV houses both the power conversion and smart functions. Here the EV acts as and resembles a smart inverter, albeit a mobile one.
V2G-DC	V2G-DC (direct current) is one of several possible inverter configurations for V2G. In this configuration, power conversion and smart functions are located within the electric vehicle supply equipment (EVSE). Here the EVSE acts as and resembles a stationary smart inverter, offering grid-support benefits and communication functions, in addition to the basic inverter function of converting power into a usable electric current
V2G-Split Inverter	An inverter configuration for V2G in which power conversion is located within the EV and smart functions are housed within the EVSE. In this configuration, neither the EV nor the EVSE resembles a smart inverter on its own.
V2H	Vehicle-to-buildings (V2B) is a subcategory of vehicle-to-grid (V2G), which refers specifically to the use of EVs to power loads in homes.
V2L	Vehicle-to-buildings (V2B) is a subcategory of vehicle-to-grid (V2G), which refers to the use of EVs to power loads.
V2X	Vehicle-to-Everything (V2X) is the broader term used to describe the storage of energy within an EV and its ability to supply power for particular end uses, including buildings (V2B), homes (V2H), load (V2L), and the grid (V2G).

ENDNOTES

1. An inverter is a device that connects to a distributed energy resource for the purpose of converting power into a usable electric current (e.g., converting direct current produced by solar panels to alternating current for use in homes and businesses). A smart inverter goes beyond power conversion by also providing autonomous grid support functions during excursions from normal operating voltage and frequency conditions (simply put, they can support the reliability of the grid). Smart inverters also include communication systems with the ability to accept external commands.
2. The list of states with V2G pilots or ongoing regulatory discussions on V2G includes California, Michigan, Minnesota, New York, North Carolina, South Carolina, and Virginia. *See* Connor Smith and Nicole Lepre, *Electric Utility Filing Bi-Annual Update: An update on U.S. investor-owned utility activity on transportation electrification for the second half of 2020*, Atlas Public Policy (Feb. 2021), https://atlaspolicy.com/wp-content/uploads/2021/02/Electric-Utility-Filing-Bi-Annual-Brief-2020b.pdf; *see also*: California Public Utilities Commission (CPUC) Docket 17-07-007, Order Instituting Rulemaking to Consider Streamlining Interconnection of Distributed Energy Resources and Improvements to Rule 21 (hereinafter "CPUC Docket 17-07-007") and Minnesota Public Utilities Commission Docket M-21-101, In the Matter of Xcel Energy's Petition for Approval of Load Flexibility Programs and Financial Incentive Mechanism.
3. Electric Power Research Institute, *Vehicle-to-Grid: $1 Billion in Annual Grid Benefits*, EPRI Journal, https://eprijournal.com/vehicle-to-grid-1-billion-in-annual-grid-benefits/ (accessed Sept. 6, 2021).
4. The power converter is a device that transforms alternating current (AC) to the direct current (DC) needed to charge the EV battery, and that converts DC to AC when discharging the EV battery. Smart functions refer to the control resource that implements the smart inverter roles defined in IEEE 1547-2018.
5. Graphic based on a figure from slide-deck presentation by Hank McGlynn, *SAE J3072 Update for V2G-AC* (July 23, 2020), https://assets.ctfassets.net/ucu418cgcnau/7GQxhGKISFwMP7cZbgEI2j/2359b324fcca6c36b0ad1b265df4e7e7/D2-2_McGlynn_EPRI-IWC-HJM-20200723_V2.pdf.
6. Robert Walton, *2021 Outlook: The future of electric vehicle charging is bidirectional — but the future isn't here yet*, Utility Dive (Jan. 12, 2021), https://www.utilitydive.com/news/2021-outlook-the-future-of-electric-vehicle-charging-is-bidirectional-bu/592957/.
7. Laura Jones et al., *The A to Z of V2G: A comprehensive analysis of vehicle-to-grid technology worldwide*, The Australian National University (Jan. 2021), https://arena.gov.au/assets/2021/01/revs-the-a-to-z-of-v2g.pdf.
8. The integration of V2G technologies involves a number of key stakeholders, including: manufacturers; Electric Vehicle Supply Equipment (EVSE) providers; the standards development industry; state policymakers and regulators; utilities and/or aggregators; and other parties.
9. *See* CPUC Docket 17-07-007, *Final Report of the Vehicle to Grid Alternating Current Interconnection Subgroup – Gaps Analysis and Recommendations* (Dec. 11, 2019).
10. *See* CPUC Docket 17-07-007, *Resolution E-5165, Order Instituting Rulemaking to Consider Streamlining Interconnection of Distributed Energy Resources and Improvements to Rule 21, Approval, with Modifications, of Vehicle-to-Grid Implementation Plans and Technical Requirements in Compliance with Decision 20-09-035*, pp. 4-5 (Nov. 4, 2021). https://docs.cpuc.

ca.gov/PublishedDocs/Published/G000/M411/K454/411454854.PDF
11. IEEE Standards Association, *What are Standards? Why are They Important?* (Jan. 11, 2021), https://beyondstandards.ieee.org/what-are-standards-why-are-they-important/.
12. ANSI, *Education & Training in Standardization*, https://www.ansi.org/education/standards-education-training (last accessed Sept. 6, 2021).
13. IEEE, *History of IEEE*, https://www.ieee.org/about/ieee-history.html (last accessed Sept. 6, 2021).
14. To name a few, the 1547 series includes IEEE 1547.1-2020 (conformance testing), IEEE 1547.2-2008 (guide to IEEE 1547 – currently in draft stages of revision) and IEEE P1547.3 (draft providing cyber security details).
15. *See* CPUC Docket 17-07-007 Decision 20-09-035, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M347/K953/347953769.PDF (last accessed Sept. 6, 2021).
16. Subject to change, the scope is from draft 5.1 (updated June 2021) of a proposed IEEE standard.
17. UL Standards, *Standards*, https://ulstandards.ul.com/ (last accessed Sept. 6, 2021).
18. UL 1741 draws upon requirements included in IEEE 1547 that utilities are familiar with related to the grid integration of DERs connected to stationary inverters. Thus, V2G-DC conformance to UL 1741 is achievable through existing practices.
19. *See* CPUC Docket 17-07-007 Decision 20-09-035, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M347/K953/347953769.PDF (last accessed Sept. 6, 2021).
20. UL Standard, *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*, https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL1741 (last accessed Oct. 4, 2021).
21. IEEE 1547-2003 is the first standard in the 1547 series and is the predecessor to IEEE 1547-2018.
22. *See* CPUC Docket 17-07-007 Decision 20-09-035, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M347/K953/347953769.PDF (last accessed Sept. 6, 2021).
23. UL Standards, *UL LLC Outline of Investigation for Electric Vehicle Power Export Equipment (EVPE)*, https://www.shopulstandards.com/ProductDetail.aspx?productId=UL9741_2_O_20210521 (last accessed Sept. 6, 2021).
24. SAE standards embody systems that are on-board the vehicle or connect to the vehicle. *See* SAE, *SAE Standards Development*, https://www.sae.org/servlets/works/ (last accessed Sept. 6, 2021).
25. The specific uses cases serve as a container for the many smart inverter functions defined by the EPRI Common Functions for Smart Inverter document, many of which are now included in IEEE 1547-2018.
26. IEEE 2030.5 is the authoritative document and SAE J2847/3 is the supporting document. In addition to EV functionality discussed in this report, IEEE 2030.5 has applications in several DER and non-DER related communications (such as demand response, energy usage data, pricing, and billing communication) and can be integrated in various devices (such as smart meters, thermostat, EVs, and more recently smart inverters).
27. Issues were found and noted in the original version of J2847/3 (which was based on IEEE 2030.5-2013). These issues were corrected. As an example, there was no way to tell the client (PEV) how often to GET a command from the control entity (i.e., every second or every hour). The 2018 version specifically fixed open issues in DER function set of the 2013 version.
28. Note that J3072 is likely to be revised to reconcile with the updated UL 1741 SB and the forthcoming UL 1741 SC.
29. *See* CPUC Docket 17-07-007 Decision 20-09-035, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M347/K953/347953769.PDF (last accessed Sept. 6, 2021).
30. J2836/3 establishes the use cases which in turn are supported by J2847/3. For additional

information on J2836/3, see SAE, *Use Cases for Plug-In Vehicle Communication as a Distributed Energy Resource, J2836/3_20101* (Jan. 18, 2017) https://www.sae.org/standards/content/j2836/3_201701/.

31. For the recent/updated publication of SAE J2847/3, see SAE, *Communication for Plug-lin Vehicles as a Distributed Energy Source*, J2847/3_202103 (March 23, 2021), https://www.sae.org/standards/content/j2847/3_202103/.
32. The revision aligns with IEEE 2030.5 requirements established in IEEE 1547-2018. For more information, see SAE, *Surface Vehicle Recommended Practice*, *J2847/3* (March 2021), https://www.sae.org/standards/content/j2847/3_202103/preview/.
33. SAE J3072 offers flexibility to use the IEEE 1547-2018 or the IEEE 1547-2003 version. For additional information, see SAE, *Interconnection Requirements for Onboard, Grid Support Inverter Systems, J3072_202103* (March 10, 2021), https://www.sae.org/standards/content/j3072_202103/.
34. *See* CPUC Docket 17-07-007, *Decision Adoption Recommendations From Working Groups Two, Three, and Subgroup* (Sept. 24, 2020), p. 165-171) (discussing subgroups and standards gaps issue).
35. Auto manufacturers can choose to self-certify with the SAE J3072 or utilize a third party such as a Nationally Recognized Testing Laboratory. *See* Justin Falce, *SAE International Releases Updates for Two Major Electric Vehicle Charging Documents* (April 6, 2021), Yahoo! Finance, https://finance.yahoo.com/news/sae-international-releases-updates-two-130000790.html.
36. Messages can be sent and received via appropriate (recognizable) language and physical interface, all of which need to be properly defined.
37. IEEE 1547-2018 requires that DER interface supports at least one of three protocols (SunSpec Modbus, DNP3 AN2018-001, and IEEE 2030.5).
38. The selection of the open communication protocol is adopted from James Mater et al, *Communication Protocols for Managed EV Charging and V2G Applications*, 33rd Electric Vehicle Symposium (June 14-17, 2020), https://na-admin.eventscloud.com/eselectv3/v3/events/474828/submission/files/download?fileID=616229396699750e51070e7de6a93b21-MjAyMC0wOCM1ZjI0NDAxZjZlYzVm.
39. For instance, California has named IEEE 2030.5 as the default protocol for smart inverter communications.
40. *Id.*
41. OCPP 2.0.1 addressed issues identified during Plugfests and in the field. See a description and scope at Open Charge Alliance, *Open Charge Point Protocol 2.0.1*, https://www.openchargealliance.org/protocols/ocpp-201/ (last accessed Sept. 6, 2021).
42. BSI, the UK National Standards Body published new standards that referenced OpenADR. *See* OpenADR Alliance, *BSI Includes OpenADR 2.0 Standard* (May 25, 2021), https://www.openadr.org/index.php?option=com_content&view=article&id=195:bsi-includes-openadr-2-0-standard&catid=21:press-releases&Itemid=121.
43. ANSI Webstore, *International Standard ISO 15118-1:2019 – Road vehicles – Vehicle to grid communication interface - Part 1: General information and use-case definition* (last accessed Sept. 6, 2021).
44. For more information about this upcoming standard, see ISO, *ISO/DIS 15118-20 Road vehicles – Vehicle to grid communication interface – Part 20: 2nd generation network layer and application layer requirements*, https://www.iso.org/standard/77845.html (last accessed Sept. 6, 2021).

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