BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Continue the Development of Rates and Infrastructure for Vehicle Electrification.	Rulemaking 18-12-006 (Filed December 13, 2018)

FINAL REPORT OF THE VEHICLE TO GRID ALTERNATING CURRENT INTERCONNECTION SUBGROUP

Alex J. Morris
Executive Director

Jin Noh
Senior Policy Manager

CALIFORNIA ENERGY STORAGE ALLIANCE
2150 Allston Way, Suite 400
Berkeley, California 94704
Telephone: (510) 665-7811 x110
Email: cesa_regulatory@storagealliance.org

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Pursuant to the Joint Administrative Law Judges' Ruling Establishing Subgroup and Schedule to Develop Proposal on Mobile Inverter Technical Requirements for Rule 21 and Noticing Workshop ("Ruling") issued on August 23, 2019 and the e-mail Ruling issued by Administrative Law Judge ("ALJ") Sasha Goldberg e-mail Rulig on November 22, 2019 in R.17-07-007 and R.18-12-006, California Energy Storage Alliance ("CESA") hereby submits the attached subgroup report on behalf of the Vehicle-to-Grid Alternating Current ("V2G AC") Interconnection Sub-Group.

Respectfully submitted,

Alex J. Morris
Executive Director
CALIFORNIA ENERGY STORAGE ALLIANCE

December 11, 2019

ATTACHMENT

Vehicle-to-Grid (V2G) AC Interconnection Technical Sub-Group Report

Gaps Analysis and Recommendations

December 11, 2019

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1. Executive Summary

Mobile energy storage resources from the batteries of plug-in electric vehicles (PEVs) interconnected to the electric grid could be a major renewable integration resource. The resources though face Rule 21 interconnection barriers when it comes to allowing discharge from the PEV battery. In the Rule 21 Interconnection proceeding (R.17-07-007), the California Energy Storage Alliance (CESA) and other stakeholders worked through Working Group 3 to frame the vehicle-to-grid (V2G) interconnection issue and associated proposals into two main use cases:

- **V2G Direct Current (DC)** systems with bidirectional stationary inverter on electric vehicle supply equipment (EVSE), also referred to herein as direct current fast chargers (DCFCs); and
- **V2G Alternating Current (AC)** systems with bidirectional mobile inverter in the PEV.

Working Group 3 participants determined that Rule 21, as written, sufficiently addresses the V2G DC configuration, but found there was a general lack of understanding of the V2G AC use case in the electric industry and thus no confidence that an assessment was even possible given the time constraints in the original working group. The V2G AC Interconnection Subgroup was formed as a joint effort in the Rule 21 Interconnection proceeding and the Development of Rates and Infrastructure for Vehicle Electrification (DRIVE) proceeding (R.18-12-006) to discuss and assess the ability of existing standards to fulfill safety and operational requirements for the interconnection of a V2G AC systems, including the various smart inverter requirements adopted in Rule 21. The objective of this subgroup was two-fold:

1) To understand how existing standards can apply and be mapped together to potentially create a pathway for V2G AC interconnections at one fixed point for one or more PEVs and present recommendations if existing standards are sufficient for safe interconneciton; and
2) If existing standards are not sufficient for safe interconnection, the subgroup was tasked with detailing the gaps in the standards in order to inform standard development organizations (SDOs) in updating or modifying applicable standards to address these gaps, thus creating a potential future pathway for interconnection.

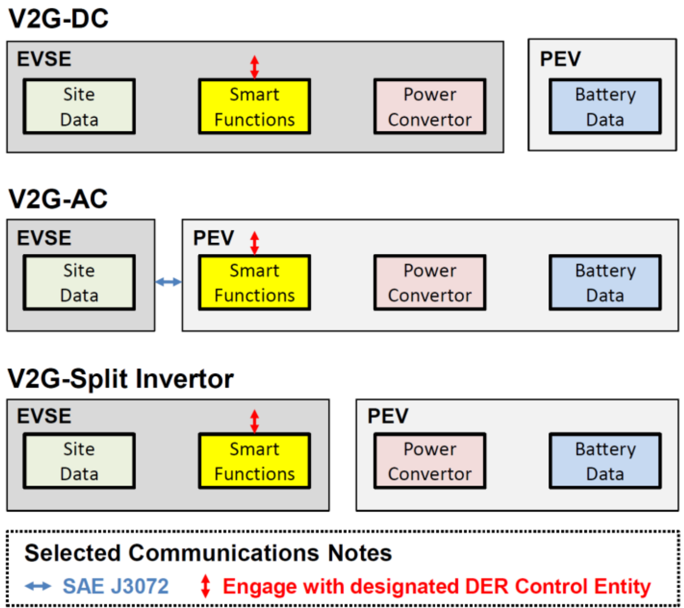
Meetings were held from September to December 2019 to discuss available standards, including those from Society of Automotive Engineers (SAE), Underwriters Laboratories (UL), and Institute of Electrical and Electronics Engineers (IEEE). This report is being filed on December 11, 2019 per Administrative Law Judge (ALJ) Sasha Goldberg e-mail Ruling on November 22, 2019 in R.17-07-007 and R.18-12-006.

First, the subgroup discussed applicability and appropriateness of the current UL 1741 requirements to V2G AC systems, considering all distributed energy resources (DERs) seeking Rule 21 interconnection are subject to these requirements. While UL 1741 is the testing standard that applies more reasonably to stationary inverters, the automotive industry stakeholders in the subgroup explained that the UL 1741 standard has certain requirements that would make the automobile components unreasonably big and heavy that would not be possible for a vehicle or mobile inverter to comply with. This raised a threshold gap around if or how current standards that are generally applicable to stationary DERs may not apply to mobile DERs like V2G AC resources:

> **Gap 1:** Updates are needed to UL 1741 to make it applicable to vehicles.

However, related to this first gap, modifications or updates to UL 1741 may not address the automotive industry's view that mobile inverters should be self-certified by the automotive manufacturers, rather than being third-party tested by a Nationally Recognized Testing Laboratory (NRTL), which points to a broader practice gap around self- versus third-party certification. This practices-related gap is discussed later.

After considering the first gap, the subgroup then discussed two approaches for V2G AC systems to consider how "smart inverter components" are differentiated from a DC stationary inverter configuration in being certified to and demonstrating smart functions. A "mobile inverter" can be thought to consist of two primary components: (1) a computer that implements the smart inverter functions; and (2) a power conversion device that converts an AC current to DC and back to AC again. Considering these two primary components, V2G AC interconnections were differentiated in this subgroup along two different approaches: (1) single onboard inverter configuration; and (2) split inverter configuration.



The main discussion of the gap analysis centered on SAE J3072, which establishes interconnection requirements for a utility-interactive inverter system which is integrated into a PEV and leverages a single onboard inverter configuration where all smart inverter functions, except for the Site Data[1] that is housed in the EVSE, are built into the PEV. SAE saw UL 1741 as insufficiently addressing the unique aspects of a PEV and created J3072 so that the inverter requirements of a V2G AC resource would be enabled through the operationalization of the EVSE and PEV as the DER. Per J3072, while the smart inverter functions are executed by the PEV, the EVSE provides the site settings and authorizes the PEV for discharge. The model numbers of the EVSE and PEV are thus not paired for certification but only PEV models authorized to discharge at the location are allowed by the EVSE to discharge. Importantly, J3072 creates flexibility for the inverter function to be a distributed system within the vehicle and not an integrated removable device produced by a single manufacturer. J3072 outlines an inverter system model (ISM) process definition but does not prescribe the exact configuration because this will vary based on the design of every vehicle.

The subgroup was able to gain a better understanding of how J3072 works. However, another gap was identified because J3072 currently references the inverter requirements in IEEE 1547-2003 and Amendment 1 (January 2014) and inverter testing requirements in IEEE 1547.1-2005:

[1] Site Data includes default settings for curves, ride-through, etc. that are applicable to the site.

> **<u>Gap 2</u>:** Updates are needed to SAE J3072 and other applicable automotive standards to align with IEEE 1547-2018 and IEEE 1547.1-2020.

The subgroup also observed that no EVSE requirements or certification currently exists in J3072 except that it must be able to communicate to some entity to receive settings and operational requirements as required by Rule 21. J3072 implies the existence of other architectures and communication capabilities to get site settings, get default settings, get lists of certified PEVs, and perform capabilities as required by IEEE 1547. This analysis led to the following gap:

> **<u>Gap 3</u>:** Standards and certifications for J3072 mobile inverters to receive default settings need to be defined.

To overcome this gap, two options were discussed to have the EVSE pass along Rule 21 default settings (*e.g.*, ride-through settings) to the PEV. An EVSE standard to enable these capabilities has not been developed, and thus further development of standards are needed to make the two options below achievable:

- **Option 1:** Have EVSEs pre-programmed where the installer implements location-specific operational settings upon installation.
- **Option 2:** Have some external system(s) pass on default settings: (a) to EVSE to be stored and later communicated to PEVs; or (b) to PEV directly (bridged by the EVSE).

Furthermore, as PEVs cross different jurisdictions, the subgroup identified a gap in the standards to ensure that the PEVs are enabled to the correct default settings, which is not discussed in IEEE 1547 and IEEE 1547.1:[2]

> **<u>Gap 4</u>:** IEEE 1547 and IEEE 1547.1 do not account for default Rule 21 settings to be delivered to the inverter at each site.

Finally, a gap was identified around how EVSEs would recognize that the PEV being connected to it would be properly certified. This type of query of a list of certified PEVs would need to occur on a dynamic, ongoing basis, not just at the point of interconnection application to enable interconnection of PEVs:

[2] The standards were designed around stationary inverters that have these default settings pre-programmed at the manufacturing stage prior to installation, at installation, or subsequently using a designated local DER communication interface.

> **Gap 5:** Lists to authenticate and authorize certified PEVs for discharge are needed.

While the focus of the subgroup was around the single onboard inverter configuration leveraging J3072 combined with EVSE specifications that require definition, several vehicle manufacturers expressed a preference for split-inverter configurations using, for example, UL 9741 combined with other communication protocols. UL 9741 (2014 edition) covers the requirements for bidirectional PEV charging equipment that charge PEVs from the electric grid but also includes the functionality to export power from a PEV to the grid or to common loads when commanded to do so. In supplement to the IEEE 1547 and IEEE 1547.1 requirements, UL 9741 would ensure that the PEV complies with grid interconnection requirements by having the EVSE "shut it down" if it does not. However, UL 9741 would need to be aligned with UL 1741 and other applicable standards, leading to the following identified gap:

> **Gap 6:** Updates are needed to UL 9741 to align with UL 1741.

Whether using UL 9741 or some other combination of standards for split inverter configurations, a broader issue of matched-pair certification was identified as a gap given the differing deployment timelines and certification processes of EVSEs and PEVs and the end-to-end verification conducted through IEEE 1547.1:

> **Gap 7:** Matched pair certification for EVSEs presents business and implementation challenges that require further consideration.

Over the course of this subgroup, a key difference in perspective was identified between automotive industry participants in the subgroup and the investor-owned utilities (IOUs) around certification practices, with the former seeking to continue with its industry's practices of self-certification to standards and requirements while the latter seeking to maintain the current electric industry practice of approving interconnections to its distribution grid that leverage third-party-certified generation and storage resources. This represented a "gap" or difference that could affect the interconnection of V2G AC systems for either the single onboard inverter configuration or the split inverter configuration:

> **Gap 8:** The utility processes on third-party certification for storage and generation resource interconnection and automotive industry norms for internal testing presents a key barrier to V2G AC interconnections.

In summary, parties have concluded that there are gaps in the existing standards; and if standards are revised and/or updated to fill these gaps, the standards could be combined to fulfill interconnection requirements for a mobile inverter at one fixed point. As a result, per the ALJ's Ruling requirements, this report cannot not offer any recommended changes to Rule 21 that are needed at this time to enable V2G AC interconnection. However, the subgroup members generally agreed on one key procedural recommendation for the Commission that could ensure a follow-up forum and discussion that builds on this subgroup's efforts:

> **Recommendation 1:** Reconvene subgroup or some other group upon completion of updates to automotive and other applicable standards (*e.g.*, J3072, UL 9741) to assess gaps and consider Rule 21 changes to interconnect V2G AC systems, if such standards have been updated. The scope of this new group will be to re-assess updated national standards and determine whether these standards can be combined to fulfill safety requirements for interconnection of a mobile inverter at one fixed point. Upon completing this review and if gaps are not identified, the group shall recommend language citing existing standards to enable Rule 21 interconnection. PEV industry stakeholders proposed this follow up work should commence July 2020. IOU representatives proposed the follow up work should commence only after the following events have occurred: (1) NRTL testing has been performed to determine exactly which parts of UL 1741 cannot be met by V2G AC inverters; and (2) IEEE 1547.1 has been revised.

Furthermore, a key practices-related gap was identified around the automotive industry's norms around self-certification for safety and reliability versus the utility process of safe and reliable DER interconnections. The difference in automotive internal testing norms and utility processes for third-party certifications need to be reconciled. The PEV industry stakeholders offered the following recommendation:

> **Recommendation 2a:** Consider jurisdictional question of PEV equipment requirements as well as policy issues around self-certification. The scope of this follow-up effort could be considered in R.17-07-007 and R.18-12-006. Meanwhile, the utility industry stakeholders proposed an alternative recommendation related to this practices gap:

> **Recommendation 2b:** Identify, evaluate, and determine solutions to the challenges faced by the PEV industry that prevent it from

complying with third-party testing, which the stationary inverter manufacturers now perform. If challenges remain that prevent all stakeholders from agreeing to third-party testing, then it may be appropriate to consider the jurisdictional question of PEV equipment requirements as well as policy issues around self-certification.

This effort would have important impacts on the appropriate approach to take and would invite the appropriate expertise that was not present in this technically focused subgroup.

2. Introduction

In response to a Motion filed by the California Energy Storage Alliance (CESA),[3] a Ruling was issued on August 23, 2019 that established the Vehicle-to-Grid Alternating Current (V2G AC) Interconnection Subgroup to discuss and identify existing standards to fulfill safety requirements for the interconnection of a mobile inverter.[4] This subgroup was formed to follow-up on one of the issues (Issue 23) initiated in Rule 21 Working Group 3 in January 2019:

> **Issue 23:** *"Should the Commission consider issues related to the interconnection of electric vehicles and related charging infrastructure and devices and, if so, how?"*

Unlike "bare bone" plug-in electric vehicle (PEV)[5] charging or managed/smart PEV charging (V1G), V2G systems are capable of discharging from the PEV battery to serve customers onsite load and/or export to the grid.[6] In Working Group 3, CESA set the interconnection issue into two main use cases:

- **V2G Direct Current (DC)** systems with bidirectional stationary inverter on electric vehicle supply equipment (EVSE), also referred to herein as direct current fast chargers (DCFCs); and
- **V2G Alternating Current (AC)** systems with bidirectional mobile inverter in the PEV

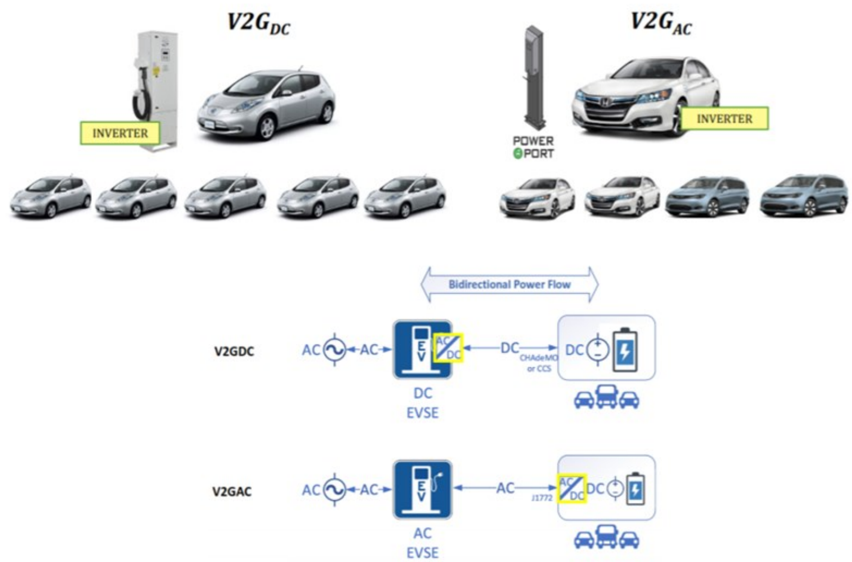
[3] *Motion of the California Energy Storage Alliance to Establish Sub-group and Schedule Joint Workshop in Rulemakings 17-07-007 and 18-12-006 to Introduce Sub-group Proposal on Mobile Inverter Technical Requirements for Rule 21 Interconnection* filed by CESA on May 29, 2019 in R.17-07-007 and R.18-12-006.
http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M294/K992/294992989.PDF

[4] *Joint Administrative Law Judges' Ruling Establishing Subgroup and Schedule to Develop Proposal on Mobile Inverter Technical Requirements for Rule 21 and Noticing Workshop* issued on August 23, 2019 in R.17-07-007 and R.18-12-006.
http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M311/K582/311582954.PDF

[5] In California, PEV has generally been the terminology used to capture both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

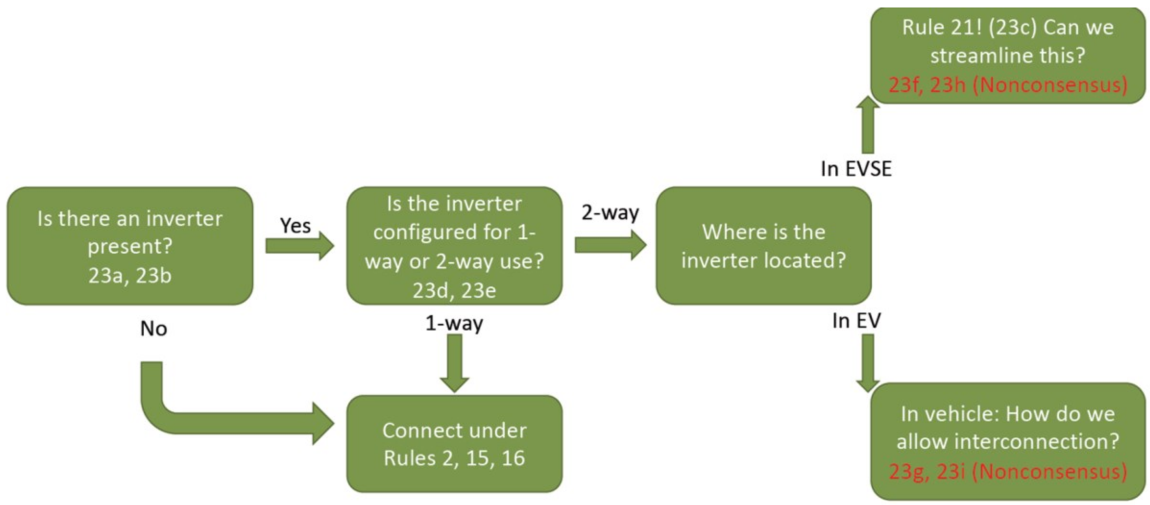
[6] Note that, for the purposes of this report, "V2G" refers to any configuration where the PEV discharges energy and not just to V2G exports to the grid. This includes vehicle-to-home (V2H) and vehicle-to-building (V2B) configurations where there is discharge but no export to the grid through the point of common coupling (PCC) – *i.e.*, similar to a non-exporting stationary battery storage system – as well as V2G exporting configurations.

Figure 1: Graphical Representation of V2G DC and V2G AC Differences



The Working Group 3 Final Report was published on June 14, 2019. For Issue 23, consensus was reached on many of the technical proposals related to V2G DC use case interconnections, where existing standards, such as UL 1741 and UL Power Controls System (PCS) Certification Requirement Decision (CRD), and Rule 21 interconnection processes could be applied to V2G DC stationary inverters. Many of the non-consensus items were procedural in nature (*e.g.*, update to the interconnection portal) or related to specific updates or modifications to Rule 21. A Proposed Decision (PD) is expected in Q1 2020 regarding the range of Issue 23 proposals. With the technical Issue 23 proposals in general consensus, V2G DC systems may have its *technical* barriers to interconnection addressed.

Figure 2: Mapping of Rule 21 Working Group 3 Issue 23 Proposals



However, no consensus was reached, and no significant discussions were held on proposals related to mobile inverters (*i.e.*, V2G AC use case). Unlike the V2G DC use case, V2G AC interconnections required an understanding and review of automotive standards, for which the utilities and other stakeholders have less or no familiarity, as well as an understanding of how these automotive standards may address Rule 21 interconnection requirements. All parties generally agreed that more discussion was needed since there was not enough time devoted to this topic in Working Group 3.

A. Meetings

Per the Ruling, Energy Division scheduled biweekly meetings starting on September 11, 2019, with agenda development and note-taking responsibilities being shared by CESA, Nuvve, and the investor-owned utilities (IOUs). The following meetings were held.

Table 1: Subgroup Meeting Schedule

Date	Purpose
September 11, 2019	Kickoff, logistics, Working Group 3 recap, and scope
September 25, 2019	Rule 21 overview and V2G vision
October 9, 2019	Rule 21 inverter requirements matrix

October 25, 2019	Industry response to matrix and self-certification proposal
November 6, 2019	Preliminary gaps analysis and draft report outline
November 12, 2019	Communication protocols and interoperability requirements
November 20, 2019	Updated gaps analysis and draft report review
December 4, 2019	Updated draft report review and recommendations discussion

Following the submission of this report to the Commission on December 11, 2019,[7] the Ruling scheduled a workshop on December 17, 2019 to discuss the workshop report and set a schedule for parties to offer formal comments in January 2020.

B. Participants

Stakeholders who participated in this subgroup in one or more calls, included:

- 33 North Energy
- Aeych, LLC
- Alphabet
- Audi of America / Volkswagen
- Auto Alliance
- California Electric Transportation Coalition (CalETC)
- California Energy Commission (CEC)
- California Energy Storage Alliance (CESA)
- California Independent System Operator (CAISO)
- California Public Utilities Commission (CPUC) Energy Division
- ComRent
- CWB Solutions

[7] The report was due, per ALJ Sasha Goldberg's e-mail Ruling on December 6, 2019. The Commission granted an extension for submittal of the report to December 11, 2019 on DATE.

- Electrify America
- Enel X North America
- Fermata Energy
- Fiat Chrysler (FCA)
- Ford
- General Motors (GM)
- Green Power Institute (GPI)
- GridComm
- Honda
- Interstate Renewable Energy Council (IREC)
- Liberty Utilities
- Mercedez Benz
- Monterey Bay Community Power (MBCP)
- Nuvve
- Pacific Gas & Electric Company (PG&E)
- PowerHub
- Public Advocates Office (PAO)
- QualityLogic
- Sacramento Municipal Utility District (SMUD)
- San Diego Gas & Electric Company (SDG&E)
- SGS
- Siemens
- Small Business Utility Advocates (SBUA)
- Society of Automotive Engineers (SAE)
- Southern California Edison Company (SCE)
- Tesla
- Underwriters Laboratory (UL)
- Union of Concerned Scientists (UCS)
- University of Delaware (UDel)
- Vehicle-Grid Integration Council (VGIC)

With over 60 individuals on every call, the affiliation of every call participant was not recorded, especially as some just joined via phone dial-in. In other words, participation in this subgroup may have been broader than the list of organizations and companies above.

3. Background and Vision

Significant amounts of grid-connected energy storage resources will be needed to integrate large penetrations of variable and intermittent generation (*e.g.*, solar, wind). In addition to stationary energy storage resources, mobile energy storage resources from the batteries of PEVs interconnected to the electric grid, when parked and available, could offer a major renewable integration resource. According to several studies, V2G has the potential to provide significant grid value and benefits that could be realized by enabling their interconnection.[8] In addition, V2G AC systems potentially provide resiliency value to customers as backup power resources that can move to where the resiliency is needed.[9]

CESA and the automotive stakeholders shared a vision where V2G AC systems, if allowed to interconnect under Rule 21, would enable a number of different use cases that would support customer choice and vehicle-grid integration (VGI) as the state pursues its transportation electrification and decarbonization goals. These VGI use cases include but are not limited to:

- **Just-in-time or just-the-amount charging:** The battery life of PEVs can be preserved or extended by having smart charging profiles that learn a driver's travel schedule.
- **Grid services to the ISO or RTO:** Wholesale capacity or ancillary services can be provided from aggregated V1G and/or V2G resources while providing customer bill savings.
- **Renewables integration:** V1G and V2G resources can help to integrate variable renewables generation and mitigate the "duck curve" through charging and discharging at the appropriate times.

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[8] For example, *Evaluating California's Vehicle-Grid Integration Opportunities: A Framing Document* published by Gridworks on August 2019 at 7-8. https://gridworks.org/wp-content/uploads/2019/08/Gridworks-VGI-Initiative-Framing-Document.pdf.

See also, Noel, Lance, Joseph F. Brodie, Willett Kempton, Cristina L. Archer, and Cory Budischak, 2017, "Cost minimization of generation, storage, and new loads, comparing costs with and without externalities." Applied Energy, Volume: 189, Pp 110-121. DOI: 10.1016/j.apenergy.2016.12.060

[9] *Enhancing Grid Resilience with Integrated Storage from Electric Vehicles: Recommendations for the U.S. Department of Energy*, report prepared by the Electricity Advisory Committee on June 25, 2018.
https://www.energy.gov/sites/prod/files/2018/06/f53/EAC_Enhancing%20Grid%20Resilience%20with%20Integrated%20Storage%20from%20EVs%20%28June%202018%29.pdf

- **Grid services to the distribution utility:** Congestion relief and distribution investment deferral can be provided from V1G and/or V2G resources while providing customer bill savings.

Automotive stakeholders also assert that there have been advances in the ability to manage the state of charge of the PEV battery, communicate to/from the PEV and/or EVSE to modulate power flow, and meter and settle resource dispatch support the V1G and V2G resources in providing customer and grid services. Furthermore, to prolong the battery life of a PEV, the state of charge (SOC) of PEV batteries can be managed within a “mid-range” (*e.g.*, 30% to 60% SOC)[10] such that utilization of “idled” V2G resources serves both the grid and the customer. Other than when drivers require a full SOC for a long trip, battery life is increased by this type of battery management, a side effect of trip prediction and battery management for V2G resources.

V2G benefits and values can be realized through either AC or DC charging. While a pathway for interconnections of V2G DC systems was developed through the Rule 21 Working Group 3 process,[11] mobile inverters present a potential lower-cost alternative to realize V2G applications. V2G AC systems use a combination of hardware and software components that interoperate with the EVSE to provide smart inverter functionality.[12] To illustrate, University of Delaware compiled a “quantity 10” pricing comparison of AC and DC systems at power levels from 6.6 kW to 66 kW (see Table 2) using quotations, published prices, and informed estimates and found that V2G DC systems can be 60% to 120% more costly relative to V2G AC systems.[13]

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[10] Evelina Wikner and Torbjörn Thiringer, 2018, Extending Battery Lifetime by Avoiding High SOC, Appl. Sci. 8, 1825; doi:10.3390/app8101825

[11] As of the submission of this report, tote that the Commission has yet to seek stakeholder comment and make any determinations on the Rule 21 Working Group 3 Issue 23 proposals or the Final Report more generally.

[12] During the subgroup call held on September 25, Willet Kempton (from the University of Delaware), whose group has developed both AC and DC charging for V2G, estimated that V2G AC charging systems could be about half the cost of V2G DC systems. Mr. Kempton prepared the Table 2 estimates for the subgroup based on experience with all systems listed. Citations and background calculations are available on request.

[13] University of Delaware’s analysis assumes a base case of a small unidirectional AC charger with small Level 2 EVSE. For V2G systems, the cost of a V2G-capable EVSE is only incremental and does not include a separate installation cost. Price quotes came from different vendors and may not be precisely comparable. Full data is not available on OEM quantities. The component costs

Table 2: Cost Comparison for V2G-Capable AC and DC Bidirectional Chargers

	AC Cost				DC Cost			
kW	**Onboard[a]**	**Offboard[a]**	**Install[b]**	**Total**	**Onboard[c]**	**Offboard**	**Install**	**Total**
6.6	2,600	900	0	**3,500**	750	3,900[d]	1,000	**5,650**
10	2,580	900	0	**3,480**	750	6,000	1,000	**7,750**
20	5,000	900	0	**5,900**	750	8,000	2,000	**10,750**
66	20,000	3,000	1,000	**24,000**	1,500	50,000[e]	5,000	**56,500**

Keys for sources: [a] Quoted by vendors at quantity of 10; [b] base case; [c] commercial onboard CCS add-on option price for GM Bolt, where the estimate is doubled for 66-kW heavy vehicle; [d] Icaro Gomes talk at CentraleSupélec International Conference on Mobility Challenges, Dec 2019; [e] Simon Funke, Franhofer

The cost-comparison estimate shows that V2G AC systems incur a greater portion of its costs in the vehicle ("onboard") while V2G DC systems incur a greater portion of its costs "offboard". University of Delaware claims that at mass-produced quantities, the cost gap would be larger given that onboard V2G AC systems are a globally and mass-produced product, installed on assembly line.

This report does not focus on explaining or justifying the value and benefits of V2G use cases in detail. A separate Commission working group in the DRIVE rulemaking (R.18-12-006) is tasked with quantifying value of various VGI use cases and prioritizing the state's focus on these use cases. Instead, this report aims to review the barriers to interconnection for V2G AC use cases.

There are, however, a number of pilots in California seeking to understand the value and use case of V2G AC systems. Pilots are seeking a pathway to reach the broad deployment of the use cases for V2G AC resources.

Table 3: Existing Pilots Seeking V2G AC Interconnection

Project Name	**Funding Source**	**Funding Total**	**CA IOU Territory**	**Timeline**
Cajon Valley V2G School Bus Project	US EPA, CARB, CEC, SDG&E	TBD	SDG&E	August 2019 – TBD

columns show that the AC charging incurs more cost on the vehicle, while DC is more costly offboard. The DC systems are 60% to 120% more costly. We do not have full data for OEM quantities, but the comparison gap would be larger because the onboard converter is a globally mass-produced, integrated product (OEM quantity quotations for onboard are 40% of quantity 10 prices shown). Conversely, the offboard DC charger is more likely a regional product sold by installers or retail outlets, and the DC installation does not become substantially lower cost with volume.

Electric Vehicle Storage Accelerator (EVSA)	NRG-EVgo Settlement	$1 million	SDG&E	2015 – June 2019
Intelligent Electric Vehicle Integration (INVENT)	California Energy Commission	$4 million	SDG&E / others	October 2017 – December 2020
Marine Corps Air Station (MCAS) Miramar V2G Microgrid	California Energy Commission	$2.9 million	SDG&E	July 2017 – June 2020[14]
Rialto V2G Electric School Bus	US DOE, SCAQMD	$6.8 million	SCE	June 2017 – 2021

4. Scope

The objective of this subgroup was to understand how existing standards can apply and be mapped together to potentially create a pathway for V2G AC interconnections at one fixed point for one or more PEVs, if gaps with the standards are not identified. However, if gaps are identified with existing standards, the subgroup was tasked with detailing these gaps in order to inform standard development organizations (SDOs) in updating or modifying applicable standards to address these gaps, thus creating a potential future pathway for interconnection. Specifically, the Ruling provided guidance on the appropriate scope of this subgroup:

- Mapping of existing national standards that can be tested by NRTLs;
- Determination of how well the existing standards can be combined to fulfill safety requirements for interconnection of a mobile inverter at one fixed point; and
- Recommend language citing existing standards to enable Rule 21 interconnection, or if existing standards are insufficient, then notify the SDOs to inform them of gaps in standards.

Consequently, this report has been structured to narrowly identify gaps in the existing standards. While there may be a difference in perspectives on interconnection practices, this report is not seeking to develop consensus and non-consensus technical proposals and solutions that address V2G AC interconnections for the Commission's consideration, unless existing standards can readily meet smart

[14] A 12-month, no-cost time extension is pending CEC approval to mitigate delays in permission-to-operate AC bidirectional inverters and approval of vehicle on-board inverters following a request letter to CPUC for the applicability of UL 1741-SA under Rule 21. See Appendix I.

inverter and other interconnection requirements and enable interconnection through some tariff changes to the Rule 21 tariff (*e.g.*, references to these existing standards if they are not already in the tariff). Any identified gaps can inform updates or modifications to standards by nationally recognized SDOs such as UL, IEEE, SAE, and ISO.[15]

In conducting this gaps analysis, the subgroup discussed, to differing extents, two approaches for V2G AC systems to consider how "smart inverter components" are differentiated in being certified to and demonstrating smart functions. A "mobile inverter" can be thought to consist of two primary components: (1) a computer that implements the smart inverter functions, as outlined in IEEE 1547-2018,[16] and creates an active power setpoint, a reactive power setpoint, and a convert on/off signal; and (2) a power conversion device that creates an AC current that synchronizes to the frequency of the grid voltage waveform with an amplitude and phase required to meet the two setpoints. For V2G DC systems, both components are in the EVSE.

Considering these two primary components, V2G AC interconnections were differentiated in this subgroup along two different approaches:

- **Single onboard inverter configuration:** SAE J2836/3 defines V2G AC to require both components to be entirely onboard the EV. This configuration was the subject of the majority of the subgroup discussions, leading to the analysis of this report to dive deeper into the gaps.
- **Split inverter configuration:** The smart inverter functions could be placed in the EVSE with the power converter in the PEV. Some stakeholders expressed an interest and/or preference in this configuration, which was discussed to some degree in the subgroup but was not explored to the same depths in the gap analysis. While certain gaps were identified to the conceptual interconnection and testing pathway, standards related to this configuration were not sufficiently covered in this subgroup. In the future, the Commission and stakeholders may revisit this configuration, as it is an interconnection pathway that is preferred by certain automotive OEMs.

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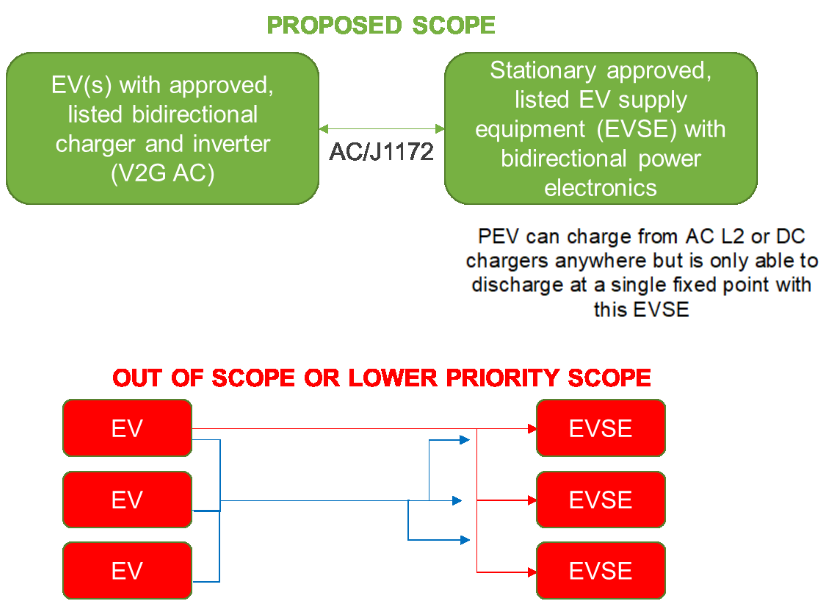
[15] While international standards can be used for reference, California does not rely on international standards for DER interconnections to its distribution electric power grids.

[16] As will be discussed in Section 5, the computer will be required to perform all functions outlined in IEEE 1547-2018 – *e.g.*, reactive power capabilities, Volt/Var and Volt/Watt functions, detection of grid abnormal conditions, unintentional islanding, interoperability, etc.

There are many different use cases for V2G AC systems that could potentially prolong and complicate the technical discussions in the subgroup. For the purposes of efficient time management and to align with the minimum requirements of the Ruling,[17] the subgroup focused the scope on the technical discussions to the interconnection of a mobile inverter at one fixed point. Some parties emphasized that while the initial focus should be on enabling a single fixed point, such standards should be developed with the end goal of enabling multiple fixed points. The use cases covered in this subgroup included one or many EVs interconnecting at one location. As shown in the diagram below, the out-of-scope items for the purposes of this report included the interconnection of one PEV with a mobile inverter to multiple EVSEs (red arrows) as well as the interconnection of multiple PEVs with mobile inverters to multiple EVSEs (blue arrows). In other words, interconnection approval of a PEV at multiple fixed points would require more extensive discussions, as it represents a significant change from the current status quo of Rule 21 studies and processes that approve interconnections at one fixed point at a time.

Figure 3: Graphical Representation of Scope



While still being within scope of the subgroup, there was limited time to discuss the gaps for the use case where many different PEVs interconnect at one fixed point.

[17] Ruling Ordering Paragraph (OP) 2.

Future discussions may be needed on the use case of mobile inverters at multiple interconnection points, which could build off the insights and gaps analysis produced in this subgroup report. Potentially, the interconnection solution for one situation could be used to fulfill the interconnection requirements for another (*e.g.*, multiple connections) as site and default settings, EVSE requirements, and communications become standardized. However, the IOUs expressed that these use cases do not change the fact that Rule 21 interconnection applications will, under current rules, need to be submitted and studies conducted at one fixed point. Each Rule 21-jurisdictional DER submits an application for interconnection at a single location that comes in the form of an account number. As part of the study process, DERs at each location are then studied for the maximum discharge rate for safe interconnection and a determination is made whether any upgrades are necessary. EVSEs are stationary and are tied to a specific account or meter location in the interconnection application, thus meeting the single-location requirement. In other words, the current Rule 21 rules and processes dictate that an interconnection application and study cannot be done for multiple interconnection points and that discharge can only be approved for one fixed point at a time.

There is no question that the site owner applies for interconnection with the utility and is responsible for ensuring that the site operates within agreed site constraints at the point of common coupling (PCC). A question that needs to be explored is what role the utilities want to play in pre-approval of specific PEV models that could connect over the life of the site. One option would be for the utility to not directly approve each EV model at each location and rely on the integrity of the PEV certification tag,[18] which can be queried by the EVSE; thus, the EVSE would be responsible for allowing interconnection. A second option would be for the EVSE to access to the PEV inverter model number and verify that such model number has received certification using an online database of approved PEV models, equivalent to how currently the utility approves inverter models via the usage of CEC-approved inverter listing. The least complexity may be for the utility to approve the site owner for V2G AC interconnection and only require the EVSE to check that any connected PEV self-designates to the EVSE that it has been certified, thus preventing any unauthorized operations (*e.g.*, discharge). However, the utilities have raised that this may potentially compromise grid safety and reliability as no verification is being made that only certified systems are allowed to interconnect with the grid. As a result, the subgroup determined that

[18] As discussed later in Section 6.1, the certification tag verifies whether the PEV has a certified inverter system model that would authorize it for discharge.

this gap analysis may most easily address the use case one EVSE and one EV interconnection.

Other stakeholders raised that interconnection at multiple locations may be a business issue as opposed to a technical interconnection issue. The interconnection agreement will always be between the utility and the account holder for the site. A site owner may have business relationships with an EVSE operator and EV operators to setup the location for V2G AC systems and for their operation.

5. Rule 21 Interconnection & Smart Inverter Requirements

A key development in Rule 21 has been the incorporation of smart inverter requirements. Rule 21 adopted Phase 1 smart inverter requirements in 2017 and some Phase 3 functions in 2019, with additional functions and requirements to be implemented in the future.[19] Operating and metering requirements are covered by Rule 21, while communication and interface requirements are covered mostly by IEEE 1547.[20]

SCE developed a Utility Interconnection Requirements Matrix (referred to hereafter as "Matrix" and attached in Appendix B) that highlighted the applicable major functional Rule 21 smart inverter requirements with document section references to UL and IEEE standards. For each function, SCE outlined the current/future testing standard, future test procedure, default settings, and whether NRTL certification is required. There were certain functions in the Matrix that were not covered by current standards – *e.g.*, fault or open phase detection. The table below summarizes some of the key functional requirements of inverters, but Attachment B provides a more detailed list of these requirements and the specific current and future standards and test procedures.

[19] Phase 3 Functions 5 and 6 became effective in February 2019. Phase 2 requirements and Phase 3 Functions 1, 2, 3 and 8 will be effective in January 2020. Phase 3 Functions 4 and 7 from Phase 3 will be implemented in the future. For the Phase 3 function activation status and effective dates, they can be found in Rule 21 Section Hh.2.o and H.h.2.p., for example, in PG&E's Rule 21 tariff sheet: https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_RULES_21.pdf

[20] Institute of Electrical and Electronics Engineers (IEEE) establishes criteria and requirements for interconnection of DERs with electronic power systems (EPS) and associated interfaces, which are updated every five years.

Table 4: Rule 21 Interconnection Requirements & Functions

Interconnection Functional Requirement	Function
Protective / Voltage Ride Through	Overvoltage / Undervoltage trip and ride-through
Protective / Frequency Ride Through	Overfrequency / Underfrequency trip and ride-through
Reactive Power	Fixed Power Factor
Reactive Power	Dynamic Volt/Var Operations
Power Quality	Operation Ramp Control
Power Quality	Reconnect Ramp Control
Grid Stability	Frequency-Watt
Voltage Limit / Safety	Volt-Watt
Communication Requirements	Inverter Phase 2 Communication
Communication / Scheduling	Scheduling Requirements (Phase 3 Function 8)
Communication / Information Exchange	Monitoring / Telemetry (Phase 3 Function 1)
Control	Connect / Disconnect (Phase 3 Function 2)
Control	Limit Real Power (Phase 3 Function 3)
Protective	Unintended Island
Protective	Fault & Open Phase Detection
Protective	Reclose Coordination
Protective	Fault Current Characterization
Protective	Overvoltage Limitations
Disconnecting Means	Isolation Verification
Voltage Control	Voltage Regulation
Power Quality	Flicker
Power Quality	Harmonics

Generally, as detailed in the Matrix in Attachment B, Rule 21 Section Hh *Smart Inverter Generating Facility Design and Operating Requirements* is the source document that points to the current standards for each of the inverter requirements, with the IEEE 1547-2018 standard or Rule 21 specifying the default settings and/or activation status of specific functions. Since 2005, UL 1741 has been the certification standard for IEEE 1547 and IEEE 1547.1 and is the testing standard used by NRTLs to certify this equipment meets the operating and metering requirements outlined in Rule 21 as well as the National Electric Code (NEC) requirements in Article 705 for Interconnected Electric Power Production Sources.[21] UL 1741 SA was published to

[21] The NEC requirements apply to most all installations not operated, owned and maintained by an electric utility.

provide a certification means and became the national standard for grid-interactive inverters, converters, and interconnection systems equipment and filled the advanced inverter void while IEEE 1547 and IEEE 1547.1 were being revised.

Rule 21 will be updated to account for the updates[22] in IEEE 1547-2018 and IEEE 1547.1-2020 once IEEE 1547.1-2020 is approved, which will likely happen in 2020. These updates are being made to add new features and requirements and to develop testing procedures to certify inverter products to the new IEEE standards. Meanwhile, UL1741 will be revised to replace the Supplement SA tests with references to the published IEEE 1547-2018 and pending in IEEE 1547.1. The revision of UL1741 to replace Supplement SA with the references to the new IEEE 1547-2018 and IEEE 1547.1-2020 should address the utility interconnection guidelines and requirements that already reference UL 1741.

The default communication protocol, as stated in Rule 21 Section Hh.5, is IEEE 2030.5, which defines the functions that can be transmitted, but does not specify the communication gateway. Alternative architecture and communication requirements exist for interconnection, along with functional capabilities. Rule 21 currently only requires the default settings be programmed at installation.[23]

The IOUs added a disclaimer that the Matrix does not contain all of the requirements in UL 1741 and thus sought to better understand the specific gaps of UL 1741 as well as the "magnitude" of these gaps that cannot be met by current V2G AC inverter capabilities. In other words, even if SAE J3072 is mapped onto the Matrix, the IOUs expressed that they would like to better understand the specific requirements in UL 1741 (some of which may not be captured in the Matrix) that cannot be met by V2G AC systems in order to assess whether such systems can interconnect pursuant to Rule 21. The IOUs believe a gap analysis is needed on the portions of UL 1741 that mobile inverters cannot meet beyond the gaps identified in mapping automotive standards to the Matrix.

[22] IEEE 1547-2018, *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*, will require DERs to have specific grid-supportive functionalities and capabilities, including voltage and frequency ride-through, as well as communications and control functionality, which tie into the Rule 21 smart inverter requirements adopted by the Commission.

[23] For V2G AC systems, default settings must be provided to the EV when it connects to the EVSE at each location. Additionally, IEEE 1547-2018 allows the onboard inverter to communicate using IEEE 2030.5. IEEE 2030.5 defines the functions that can be implanted.

A. Applicability of UL 1741 to V2G AC Interconnections

UL 1741 is the grid interconnection standard for inverter systems used in many states and referenced by multiple UL standards and utilities looking to validate a product as being reviewed, tested, and certified for grid interconnection. This is primarily accomplished by UL 1741 directly requiring that the unit meets the IEEE 1547-2018 and IEEE 1547.1-2020 requirements. There may be some other operability requirements that are included beyond the IEEE documents. UL 1741 is also used as an electrical product safety standard by local code inspectors responsible for approving the installation of equipment in accordance with the National Electrical Code (NEC). The NEC specifically excludes installations in automotive vehicles from its scope in section 90.2 (B) (1), so local code enforcement does not extend to any onboard equipment, but requirements that impact safety and operability at the PCC apply to utility approval under Rule 21.[24]

While UL 1741 is the testing standard that applies more reasonably to stationary inverters, the automotive industry stakeholders explained that the UL 1741 standard has certain requirements that would make the automobile components unreasonably big and heavy or would not be applicable to a vehicle. For example, they argued that certain equipment (*e.g.*, switches and relays) being required in the same inverter enclosure would reduce the effectiveness of the EV to serve off-grid functions for the customer. Additionally, UL 1741 provides specific design requirements that have mechanical attributes that are appropriate for stationary facility equipment (*e.g.*, facility or appliance wiring) that may not be applicable to vehicles (*e.g.*, automotive wiring). Similarly, UL 1741 is devoted to physical design requirements for stationary electrical equipment, which is inapplicable to EVs because NEC excludes equipment installed in automotive vehicles. By contrast, SAE explained that J3072 was written to allow every manufacturer to follow their own methodology to build their vehicle, so no standards around automotive wiring were established. See Appendix E for a breakdown of non-applicable components of UL 1741 to vehicles, as identified by a collection of automotive stakeholders.

None of the automotive OEMs present in the subgroup expressed that they have gone through the UL 1741 mechanical and product design requirements to understand the specific inspections and environmental tests that the V2G AC systems could not meet. While meeting the functional requirements of UL 1741 is

[24] SAE representatives indicated that such clarifications to the scope can be explicitly added to SAE J3072 as part of their planned 2020 updates to incorporate key Rule 21 inverter functional requirements (rather than having to utilize UL 1741).

a relatively low hurdle, the automotive OEMs find testing every model year to certification standards to be a challenge. It is important to distinguish between operability requirements and other requirements, such as rain tests, which require testing. Beyond the IEEE 1547.1 testing, there are very few actual test requirements in UL 1741 and these tests need to be performed. The automotive concern is with the design and construction requirements.

UL clarified that UL 1741 does not require all inverter functionalities and components to be contained within a "box" like with solar or stationary storage and explained that certification to a different form factor could be done if smart inverter functions, via a mix of hardware and software components, fit into different equipment. Various UL 1741 functionalities are allowed to be built into different host products, such as a generator or EV.[25] For this reason, UL explained that UL 1741 could be adapted to capture mobile inverter functionalities and validate, for example, that mobile inverters meet the appliance wiring criteria rather than the strict appliance wiring requirements. UL said that it is fully willing to work with industry to make the necessary revisions to UL 1741 to better align with the form factors of automakers.

Lastly, as discussed in the next section, automotive representatives explained how a number of SAE standards cover many of the UL 1741 functional requirements.

6. Existing Automotive and Other Applicable Standards

For stationary storage systems, the "inverter" is often a self-contained device with a model number assigned by a single OEM. The inverter "device" may contain hardware and software components from many other sources, but the integrated inverter entity has a model number supplied by the OEM. The device can be sent to a NRTL to be tested using UL 1741 SA and eventually IEEE 1547.1-2020 tests and then listed to UL 1741 SA, SAE J3072, and/or other relevant standards as defined by Rule 21.

The subgroup focused on SAE J3072 (2015 edition) as part of this gap analysis, which was also the subject of a prior comparison analysis in Rule 21 Working Group 3. The focus on SAE J3072 was driven by stakeholder interest, which was identified by Issue 23 sponsoring stakeholders (*e.g.*, CESA and others) from the previous Rule 21

[25] UL explained that UL 1741 was written as a consensus standard to meet most of the electric industry's needs but not be adapted to every single technology. As such, UL said that UL 1741 was not written with automotive applications in mind at the time, but it can be modified to consider how to make it applicable for V2G AC use cases.

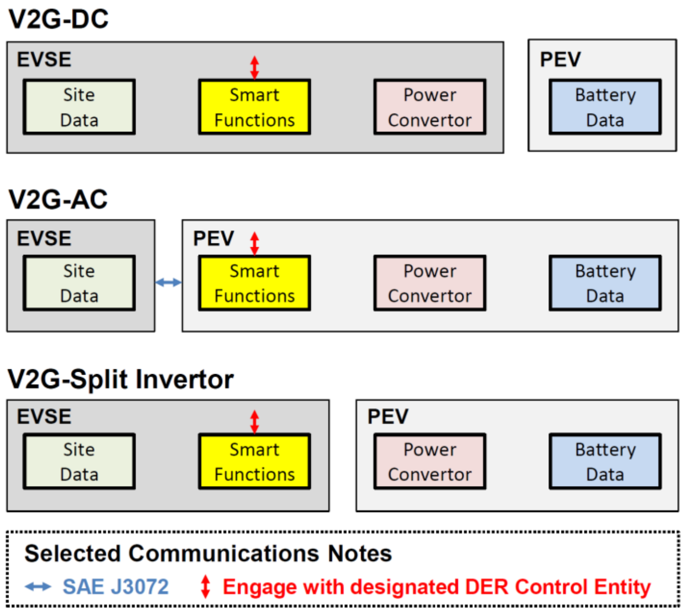
Working Group 3 as an existing automotive standard that should be reviewed and assessed for the purposes of this subgroup. The automotive industry expressed that they are ready to make the necessary updates and modifications based on the gaps assessment (see Appendix D). However, it is important to note that SAE J3072 may not be the only potential pathway for V2G AC interconnections. SAE precisely defines Type V2G-AC in SAE J2836/3 to require the complete inverter system to be located onboard the vehicle. Others consider the case where inverter functionality is split between the EVSE and the PEV to be a form of V2G AC. There may be other automotive or related standards that could be used for this split inverter V2G AC interconnections (for example, see Appendix H for IEC 61850-90-8), but only a few other standards were raised for brief consideration as part of this subgroup effort. As a result, the majority of the focus of this report is on understanding SAE Type V2G-AC and SAE J3072 and assessing the gaps in relation to current and future inverter and interconnection requirements.

The automotive OEMs, for example, presented a straw proposal to allow for self-certification to relevant SAE automotive standards to provide smart inverter functionality while leveraging UL 9741, an existing standard for bidirectional EVSEs that was not published and needs to be completed and updated, to serve as a "gatekeeper" to ensure Rule 21 compliance and meet the IOUs' need for third-party certification for grid interconnections.

In considering the existing automotive and other applicable standards as part of this gap analysis, the subgroup identified how there are two general approaches for V2G AC interconnection based on "where" the smart inverter system functionality is "housed" between the EVSE and the PEV. The smart inverter system functionality can be separated into the following broad categories: Site Data, Smart Functions, Power Converter, and Battery Data.[26] In the following figure, the two approaches to V2G AC interconnection are differentiated based on the allocation of these functionalities. For V2G DC systems, all system functionality is performed by the EVSE, except for the Battery Data function. For SAE Type V2G-AC systems, these functionalities can be allocated where everything except the Site Data is performed by the PEV. SAE J3072 was written exclusively for such a single onboard inverter configuration.

[26] PG&E presented a use case of a "standalone mobile inverter" that is not located in the car or in the EVSE, but such configurations will likely fall under V2G DC configurations and requirements.

Figure 4: V2G Smart Inverter Configuration Types



By contrast, split inverter configurations – which is supported through the use of UL 9741– may have the smart function processing performed by the EVSE – *e.g.*, have the EVSE send a setpoint for active power and a setpoint for reactive power to the power converter onboard the PEV. Similarly, some stakeholders raised the potential for IEC 61850-90-8 in conjunction with ISO 15118 to support a split-inverter configuration for V2G AC interconnections (see Appendix H).

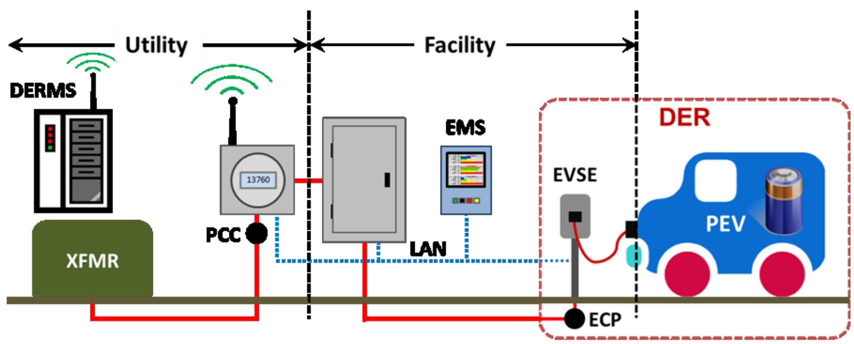
Differentiation of these two approaches supports the understanding of the gaps analysis, as the different approaches have implications for the PEV and EVSE designs, communication protocols used (*e.g.*, IEEE 2030.5 for single onboard inverter configuration per J3072 versus ISO 15118 for split inverter configurations), and testing and certification to the smart inverter requirements. UL 9741 is a system specification for a combined EVSE model and PEV model operating as a bidirectional converter and is not structured to test an PEV with a reference model EVSE, and vice versa. On the other hand, SAE J3072 applies to the EV onboard inverter and allows a reference model EVSE to be used and does not require an actual EVSE model to be tested with the PEV as a system.

Different automotive stakeholders prefer one approach over the other, and both approaches can coexist. However, the approach to utility approval and certification will be different. In the subsequent sections, an overview of the SAE J3072 and UL 9741 is presented to set the foundations for the two approaches.

1. SAE J3072 Interconnection Requirements for Onboard, Utility-Interactive, Inverter Systems

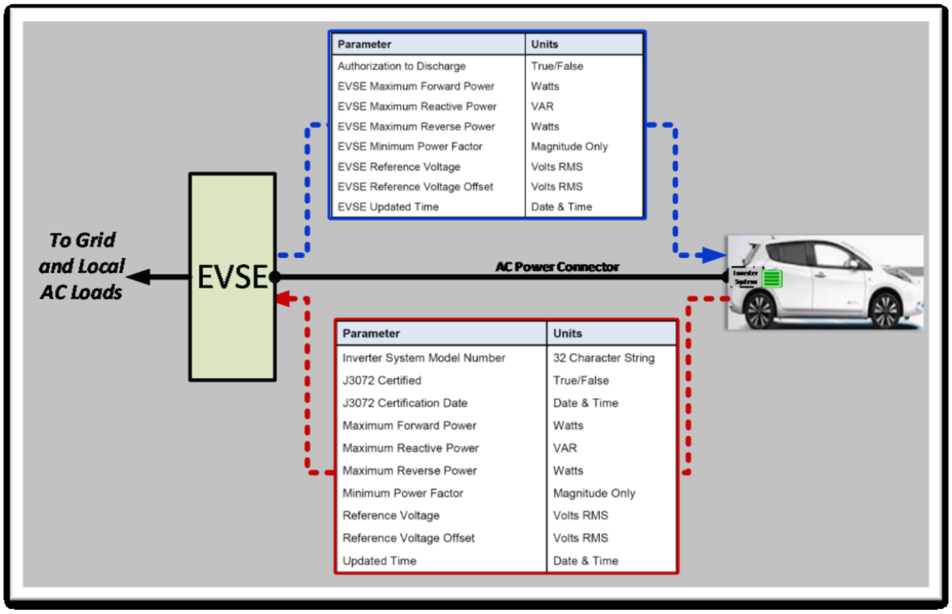
To develop a standard for SAE Type V2G AC onboard inverter system in J3072 (2015 edition), SAE directly references utility interaction requirements of IEEE 1547-2003 *Standard for Interconnecting Distributed Resources with Electric Power Systems*, and IEEE 1547.1-2005 *Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*. J3072 establishes interconnection requirements for a utility-interactive inverter system which is integrated into a PEV and connects in parallel with an electric power system (EPS) by way of conductively coupled EVSEs. This standard also maps the communication between the PEV and the EVSE required for the PEV onboard inverter to be configured and authorized by the EVSE for discharging at a site.

Figure 5: Representation of SAE J3072 Inverter Functionality Components



Fundamentally, J3072 was written so that the inverter requirements of a V2G AC resource would be enabled through the operationalization of the EVSE and PEV as the DER (see Section 4.2). While the smart inverter functionalities are executed by the PEV (see Section 3.11), the EVSE provides the site settings and authorizes the PEV for discharge. The model numbers of the EVSE and PEV are thus not paired for certification but only PEV models authorized to discharge at the location are authorized by the EVSE to discharge. More than 22 standards are referenced within J3072.

Figure 6: Representation of SAE J3072 Parameter Setting



This standard is structured to follow the steps below:

- **EVSE provides site settings to PEV and confirms these settings:** Local facility information, such as reference voltage and maximum reverse power, and various site constraints are passed from EVSE to PEV at the time it connects to the EVSE (see Section 4.6). These site settings set the constraints for the PEV that the site can accept in terms of, for example, reverse power flow. This is in contrast to stationary inverters that can be pre-programmed prior to installation. Certain parameters defined by IEEE 1547-2018 are made available to PEV by explicitly defined communications between EVSE and PEV in J3072. Other parameters are provided to PEV from a designated DER Control Entity, which could be the EVSE.
- **EVSE verifies PEV J3072 certification:** EVSE could query a list of authorized mobile inverters from an external list to confirm certification (*i.e.*, allowed to discharge at the site) and recognizes the nameplate information of the PEV (*e.g.*, maximum power). EVSE is also verifying that the configuration setting on the PEV is appropriate for the site (*i.e.*, properly set up to discharge at site).
- **EVSE authorizes PEV to discharge:** EVSE authorizes the PEV to discharge up to limit provided by EVSE and monitors and disconnects if PEV violates the limits.
- **PEV inverter controlled by designated DER control entity:** A controlling entity is responsible for the DER commands. While the EVSE is able to

authorize or de-authorize the PEV, the DER control entity ultimately determines whether the PEV discharges, executes operations within the parameters of the curve data, and sets functions on and off. In other words, unless designated as a control entity, the EVSE plays no part in the inverter functionality, just the authorization and possibly validating communications (if the default settings are stored in the EVSE). But the EVSE could be authorized as a control entity for the connected PEV. A site EMS could pass commands to the EVSE which the EVSE then passes to the connected PEV. Alternatively, the site could be designed such that the EMS directly engages the PEV

J3072 does not define the exact component hardware and software parts of the core "Inverter System Model" (ISM) or an exact management process. J3072 creates flexibility for the inverter function to be a distributed system within the vehicle and not an integrated removable device produced by a single manufacturer. Each OEM may have different approaches to identifying hardware and software components in an EV that constitute the core ISM configuration. Section 4.3 and 4.4 requires the automotive OEM to have a process for defining the ISM and assigning a unique inverter system model (ISM) number.

Figure 7: SAE J3072 Inverter System Model Definition Process

Inverter System Model Number		
A141J4aaa	A141J4bbb	A141J4ccc

Top Assembly	Inverter System Models						
	xxxG01			xxxG02		xxxG03	
Revision	-	A	B	-	A	-	A

	Description	Core Inverter System Configurations							
Core Inverter System	Part A	A1	A1	A1	A1	A1	A2	A2	Inverter System
	Part B	B1	B1	B1	B1	B1	B1	B1	
	Part C	C1	C2	C2	C2	C3	C3	C4	
	Part D	D1	D1	D2	D2	D2	D2	D2	
	Part E	E1	E1	E1	E2	E2	E2	E2	
	Part F Part G ... Part ZZ	COMPONENTS NOT SELECTED BY VM TO BE PART OF INVERTER SYSTEM MODEL							

NOTE: All Changes are Class I at Part Level
C2 are Class II at Top Assembly Level (Rev Letter)
E2 are Class I at Top Assembly Level (Group Change)

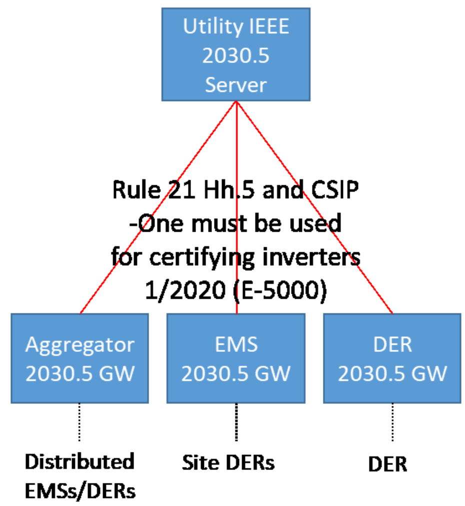
J3072 calls out IEEE 1547 (2003 version) and IEEE 1547.1 (2005 version) for utility interaction requirements and conformance testing; there are plans to revise the standards to the 2018 and 2020 versions (see Appendix D). Testing of the ISM to IEEE 1547.1-2020 will most likely be performed using a complete vehicle. However, certain components of the "complete vehicle" (*e.g.*, seats and mirrors) have no functions relevant to IEEE 1547.1 testing and these vehicle parts would not be considered to be part of a "core" inverter system. Other parts, like a bracket holding down a wire harness, may be relevant but does not have any meaningful role regarding the testing, whereas the software implementing a Volt-VAR function is relevant.

SAE J3072 outlines an ISM process definition but does not prescribe the exact configuration because this will vary based on the design of every vehicle. The importance of the J3072 ISM requirement is to define the primary components of the complete vehicle that are relevant to the IEEE tests. While it may be possible to remove all the hardware and software components within the vehicle for testing, it may be much easier to use the complete vehicle. As a result, some OEM system is needed to define what parts in the vehicle were primarily relevant to the test and assign that configuration a model number, but there are certain components (*e.g.*, rear view mirror) that obviously should not be on the list. One of the primary purposes of J3072 is to deal with defining the embedded hardware and software components that constitute the "inverter" and assign it a unique number.

For the EVSE, the only J3072 requirement is for the EVSE model to be listed by a NRTL to UL 2594 and J3072 Section 4.5, though J3072 could be updated to require a different UL listing for EVSEs (*e.g.*, UL 9741 as discussed in this subgroup). No other EVSE requirements or certification currently exists in J3072 except that it must be able to communicate to some entity to receive settings and curves as required by Rule 21, or in the future, dynamically from the IOUs. A standard is needed to define this V2G AC EVSE. This is a significant gap because this requires a very comprehensive specification which would go beyond what is typically included in UL safety standards. The EVSE must act as an IEEE 2030.5 servers for a client PEV. It must provide a MAC/PHY bridge function to allow the PEV to directly engage the site network. It has very specific J3072 functions with the PEV. It also has functions upstream with the site EMS and possibly to utility. There may be different models within the specification.

Currently, architecture requirements in Rule 21 Section Hh.5 set the architecture requirements in IEEE 1547-2018 and the default protocol as IEEE 2030.5 for communication of the IOU interface to the inverter control, EMS, or aggregator gateway, though other protocols may be used with agreement. IEEE 2030.5 defines the functions that can be transmitted, but the communication gateway is not specified. Separate architecture and communication requirements exist for interconnection, along with functional capabilities. Meanwhile, Resolution E-5000 was recently adopted that established communication capability certification requirements and required the IEEE 2030.5 gateway to attest to the ability to communicate to the connected inverter.[27]

Figure 8: Rule 21 Architecture Requirements



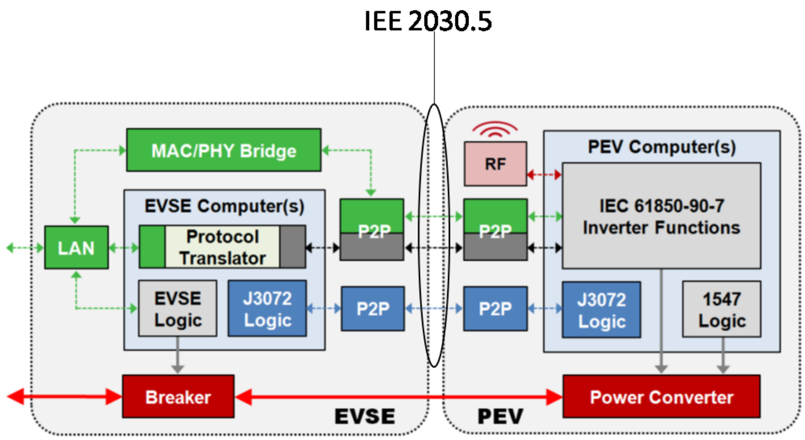
J3072 Section 4.6 defines very specific communication between the EVSE and PEV for the purpose of exchange and confirmation of certain site information and the EVSE providing authorization to discharge to the PEV. The published 2015 version defines System Type A1, which requires IEEE 2030.5 to be used on the J1772 control pilot signal for this communication (see blue boxes in figure below). At the time, this was the only protocol[28] being considered for use with PEVs that supported the International Electrotechnical Commission (IEC) 61850-7-420 DER functionality.[29]

[27] See Appendix C of Resolution E-5000 where testing for Function 1 and 8 gateway and inverter testing is defined. *Resolution E-5000. Clarifies smart inverter communications requirements in response to the Petition of the California Solar & Storage Association for Modification of Resolution E-4832 and Resolutions E-4898*, issued on July 12, 2019. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M309/K713/309713654.PDF

[28] ISO 15118 was discussed as not having this DER functionality, though it may include such functionality at a future date when ISO 15118-20 replaces ISO 15118-2 2014. If ISO decides to have its protocol conform to the IEC 61850-7-420 model, SAE could add the ISO standard as System Type A2. ISO 15118-20 is not currently planning to include onboard smart functions.

[29] IEC 61850-7-420 is an international standard defining communication protocols for intelligent electronic devices at electrical substations. IEC Committee Draft (CD) 61850-7-420 will soon be available for comment at https://www.iec.ch/comment/.

Figure 9: SAE J3072 System Concept Example



This communication information defined in J3072 Section 4.6 between the EVSE and PEV includes local facility information (*e.g.*, reference voltage, maximum reverse power flow), PEV parameters (*e.g.*, certification information, ISM number), discharge authorization, and certain utility default settings. This information is expected to come from the EVSE, but how the EVSE gets this information is not specified in J3072. A new specification and standard are needed for an EVSE which supports V2G-AC and SAE J3072.

Figure 9 shows several options by which the PEV could engage with a designated DER Control Entity. The 2015 version only defines the point-to-point (P2P) communication between the PEV and EVSE on the J1772 control pilot. The figure shows other possible communication between the PEV and a designated DER Control Entity.

One approach is for the PEV to directly engage a site EMS by way of a MAC/PHY bridge within the EVSE using IEEE 2030.5. This allows the PEV to get the volt-VAR curve data and other Rule 21 data directly from the site EMS at the time of connection. This is different than the very specific data prescribed for J3072 Section 4.6 exchange. The EVSE itself could be designated as the DER Control Entity for the site and this P2P link (not the blue one) would be used for this purpose. It could be the same hardware but the role of an EVSE serving as a DER Control Entity and as a J3072 Section 4.6 communicator are different roles.

Some vehicle manufacturers want to use telematics or maybe WiFi to reach a site EMS. This is shown by the red “RF” box. There are complex systems needed to support this to get back to a site EMS, but this concept has been demonstrated. There are other protocols designated by IEEE 1547-2018, such as DNP3 and

SunSpec Modbus, that could be used. These are not designated for J3072 purposes at this time. But if a PEV used one of these the EVSE would need to perform protocol translation with IEEE 2030.5, if the site EMS engaged in that protocol. This is shown by the gray portion of the P2P box. It is much less complex for the EVSE if the PEV and site EMS all engage using IEEE 2030.5 and the EVSE provides the bridge.

The EVSE design to engage with a V2G AC vehicle is not defined and a detailed specification is needed. J3072 only defines interface requirements for a limited communication regarding certain site parameters, so it should not be expected that the onboard inverter will behave differently than a stationary storage system inverter for equipment failures. If the onboard inverter is rated to 20 Watts and it accepted a facility limit of 10 Watts, the inverter would be tested to ensure that it does not operate beyond 10 Watts. But if the software failed because of some latent design flaw, it might go to 20 Watts. In this case, if the EVSE directly measured the output it could detect the excess power and disconnect the EV. This is part of EVSE system design if this is a desired safety feature. Generally, IEEE 1547.1 defines normal operation and not behavior following failures of certain hardware or software or independent monitor and shutdown procedures.

2. UL 9741 Bidirectional EV Charging System Equipment

UL 9741 (2014 edition) covers the requirements for bidirectional PEV charging equipment that charge PEVs[30] from an EPS but also includes the functionality to export power from a PEV to the grid or to common loads when commanded to do so. In supplement to the IEEE 1547 and IEEE 1547.1 requirements, UL 9741 would ensure that the PEV complies with grid interconnection requirements by having the EVSE "shut it down" if it does not when required (*e.g.*, at locations that are not capable of receiving backfeed power). Such EVSEs are required to be installed in accordance with the requirements of NFPA 70.

A standard is needed for the EVSE only which does not require a specific PEV model to be matched to it. UL 9741 might be able to serve as a standard for the SAE V2G-AC J3072 EVSE but more likely a new standard would be needed to preserve use with V2G split inverter configurations. UL 9741 does not include the design detail needed to define requirements for the EVSE acting as an IEEE

[30] This standard also apples to hybrid electric vehicles (HEVs) or plug-in hybrid electric vehicles (PHEVs).

2030.5 server for the PEV and operation of the MAC/PHY bridge, and all of the other operational functions of the EVSE.

EVSEs that perform control and oversight of PEV grid export can be evaluated by UL 9741 and UL 1741, as well as equipment that include the power conversion equipment to facilitate the grid export functions. If the EVSE acts as an IEEE 2030.5 server for a client PEV, these requirements will need to be provided and all the associated testing. A design standard to define the protocols and those functions can be validated through the use of the UL 9741 standard that addresses safety and performance functionality.

UL 9741 was raised as part of the subgroup discussions because third-party certification of EVSEs to UL 9741 played a role in allowing PEVs with mobile inverters to be self-certified to SAE J3072. The EVSE would be certified to UL 9741 for all grid interconnection requirements, as required and desired by the IOUs, while the PEVs would be self-certified to SAE J3072 as necessary for the industry to be flexible. However, UL 9741 does not define the functionality required to create the server for IEEE 2030.5 or operate as a bridge or operate as a DER Control Entity.

UL 9741 anticipated inclusion of an inverter/converter to perform the bidirectional charging and grid export. Inverters and converters are comprised of power conversion electronics and grid interconnection controls. The electronics that perform grid interconnection control functions are covered by the UL 1741 requirements for Interconnection Systems Equipment (ISE). The following definition is from the published version of UL 1741:

> *2.1.20 INTERCONNECTION SYSTEM EQUIPMENT (ISE) – A component or system of components that performs protective and control functions used to interconnect a distributed resource to an EPS.*
>
> *The (ISE) controls portion are a subset of inverters and converter equipment specified in UL9741. UL9741 includes the (ISE) definition. UL9741 includes the following requirement for grid interconnection functionality to be tested per UL1741.*
>
> *90.2.1.1 A utility interactive inverter or subassembly of a unit shall comply with the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741 including all references to IEEE 1547,*

> *Interconnecting Distributed Resources with Electric Power Systems and IEEE 1547.1, Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems. Theses utility interactive products may also include additional Special Purpose Utility Interactive features and/or functions that may be enabled in accordance with local utility interconnection protection requirements.*

It would beneficial to add the EVSE definition to UL 9741 and align the requirements with (ISE) and compliance with UL 1741. While it is already covered, this change would be clearer that EVSEs that do not include the power conversion inverters or converters are also evaluated by the existing published (ISE) requirements in UL1741.

7. Gaps Analysis

The subgroup identified many gaps, which are categorized based on whether the gaps are related to automotive and other related standards that must be modified or updated, further differentiated by whether they support single onboard inverter or split inverter configurations, and those that are related to certification and testing practices.

A. Standards: UL 1741

As a threshold issue, the subgroup sought to understand why the current UL 1741 requirements were inapplicable to V2G AC systems, considering all DERs seeking Rule 21 interconnection are subject to these requirements. Prior to considering the use of automotive and other applicable standards, the subgroup discussed why and how UL 1741 was applicable to vehicles, and whether alternative approaches are needed to enable V2G AC interconnections

1) Gap 1: Updates are needed to UL 1741 to make it applicable to vehicles

UL 1741 was identified by the automotive stakeholders as having requirements that are inapplicable to onboard vehicle inverters and to vehicles in general. UL explained that changes could be made to make the standard more applicable and in line with the “spirit” of certain requirements. For example, appliance wiring requirements could be adjusted or modified to create criteria-based requirements that are applicable to vehicles. The types of criteria that could be applied to bridge the gap were not specified.

However, as explained in the subsequent section on the gap in practices, modifications or updates to UL 1741 may not address the automotive industry's view that mobile inverters should be self-certified by the automotive manufacturers, rather than being third-party tested by a NRTL. As a result, even if UL 1741 is updated to accommodate the automotive industry's concerns with the applicability of the requirements, the automotive industry may still opt to self-certify to SAE J3072, which references IEEE 1547-2018 and IEEE 1547.1-2020, suggesting that the fundamental gap may be one of practices, as opposed to standards.

B. Standards: Single Onboard Inverter Configuration

The main focus of the gap analysis was SAE J3072, which leverages a single onboard inverter configuration where all smart inverter functions, except for the Site Data that is housed in the EVSE, are built into the PEV. Several automakers plan to use this type of configuration, which has advantages in not requiring a matched-pair certification, so long as the gap around defining certain key EVSE specifications are resolved. Other gaps are also identified herein related to this V2G AC interconnection approach.

1) Gap 2: Updates are needed to SAE J3072 and other automobile standards to align with IEEE 1547-2018 and IEEE 1547.1-2020

J3072 currently references the inverter requirements in IEEE 1547-2003 and Amendment 1 (January 2014) and inverter testing requirements in IEEE 1547.1-2005, which were issued at the time J3072 was published. As a result, there are certain functions, such as limiting real power and voltage/frequency ride-through settings, that is required in Rule 21 today but was not included as a function in IEEE 1547-2003. To comply with the latest Rule 21 requirements, J3072 will need to be updated to reflect the inverter requirements of IEEE 1547-2018 as well as the new inverter testing requirements of IEEE 1547.1-2020, which incorporate many of the new Phase 2 and 3 inverter functions as adopted by the Commission. Other SAE standards cited by J3072 as requirements will also need to be updated accordingly. If there is any conflict with the authority of J3072. Informational documents may be updated on a normal refresh cycle.

SAE indicated that it could modify and update its standards to address the gaps within a six-month timeframe after completion of a revised document by the working group for the document revision. If this revision process begins in January 2020, SAE outlined how J3072 can go through its balloting and formatting process to publish a standard that addresses the gaps by June 2020 (see Appendix D), highlighting how J3072 can be updated in an expeditious fashion upon publication of the new IEEE standards that will be available in early 2020.[31] After the standards update, the automotive industry will begin to update their equipment based on the new standards.

There are outstanding questions about whether the mobile inverters can actually execute the required smart inverter functions (*e.g.*, default curves), not just receive the settings from the EVSE. The utilities, for example, are concerned that the onboard inverter can correctly receive the curves but may not be able to correctly execute these curves.

SAE will require the PEV to meet the requirements of IEEE 1547-2018 and IEEE 1547.1-2020. This is no different than for any other inverter based DER under Rule 21.

2) **Gap 3: Standards and certifications for J3072 mobile inverters to receive default settings need to be defined**

There are a number of gap areas related to how mobile inverters will receive the default settings, especially in cases where the IOU does not communicate with the EVSE.[32] The key gaps include:

- Defining how the J3072 required communication protocol between the EVSE to the PEV (IEEE 2030.5) is used to send Rule 21 default curves and ride-through settings to the PEV and confirmation back to the EVSE
- Defining how the EVSE gets the Rule 21 (or other jurisdiction's) default curves and ride-throughs[33]
- Defining and implementing the external system by which EVSEs would receive default settings and curves

SAE standards suggest that IEEE 1547 functionalities are executed in the PEV for V2G AC interconnections using IEEE 2030.5 communication protocols.

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[31] As part of this update process, the IOUs also recommended that language align with those in IEEE 2030.5 and the new standards to be published next year.

[32] Currently, note that the California IOUs do not communicate with the EVSE or other DERs. Instead, the default settings and profiles are programmed in at manufacture and set by the installer.

[33] For example, the EVSE specs have not been defined to set how often the stored settings and curves are updated. Note that, in using IEEE 2030.5, J3072 allows for the EVSE to store not only default curves/settings but also alternate ones.

There are other approaches for the PEV to receive the default settings necessary for interconnection. If an PEV wishes to communicate with the electric utility directly, for example, inverters must communicate with the certified IEEE 2030.5 port at the PEV, though the California IOUs indicated that they do not intend to communicate directly with the PEVs. Alternatively, an aggregator or site EMS (*i.e.*, DER controlling entity) could use IEEE 2030.5 and telematics to make that transfer. Regardless of the point of interconnection, in California, Appendix C of Resolution E-5000 sets the testing requirements to ensure the onboard inverter is able to communicate.[34]

To overcome these gaps, two options were discussed to have the EVSE pass along Rule 21 default settings (*e.g.*, curves, ride-through) to the PEV. An EVSE standard to enable these capabilities has not been developed, and thus further development of standards are needed to make Option 1 and 2 achievable:

> **Option 1: Have EVSEs pre-programmed where the installer implements location-specific operational settings upon installation.** This option only involves communication protocols between the EVSE and PEV and would apply a process similar to other stationary inverters that are pre-programmed to jurisdictional default settings (*e.g.*, Hawaii's Rule H, California's Rule 21). Utility commissioning testing may be needed, and Resolution E-5000 requirements would still apply. In essence, Option 1 would be defining the EVSE as the "DER controlling entity" since default settings are already programmed in the EVSE – *i.e.*, it does not have to dynamically get these settings from an external system, as in Option 2 below. The EVSE can be a gateway for this where a facility EMS could be used to manage the EVSEs, though the EV could also be allowed to directly bridge the EVSE and get curves from a site EMS.
>
> Taking into account the normal pace of regulatory processes, the default settings, as defined in the Rule 21 Handbook, are only modified on a multi-year basis. As a result, Option 1 has appeal in that communication protocols only defined between the EVSE and PEV, though the utilities still have

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[34] Resolution E-5000. Clarifies smart inverter communications requirements in response to the Petition of the California Solar & Storage Association for Modification of Resolution E-4832 and Resolutions E-4898 was issued on July 12, 2019 that clarified the implementation details of the smart inverter Phase 2 communications requirements and of Phase 3 Functions 1 (Monitor Key Data) and 8 (Scheduling), among other things, and can be found here: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M309/K713/309713654.PDF

cybersecurity concerns. However, in the future, curves could be modified dynamically by season or daily by the utility, and have DERs revert back to default settings at other times, but the IOUs indicated that this is an operational issue separate from the default settings issue that would need to be addressed for either Option 1 or 2.[35] All Rule 21 interconnected resources are subject to the same default settings (*e.g.*, curves, ride through).

<u>Option 2</u>: Have some external system(s) pass on default settings: (a) to EVSE to be stored and later communicated to PEVs; or (b) to PEV directly (bridged by the EVSE). This option would require implementation and certification of the external system (*e.g.*, database of default settings),[36] definition of a communication protocol from the external system to EVSE, and consideration of cybersecurity issues. Importantly, considering IEEE 1547-2018 (Section 10.7) sets the architecture requirements that apply to the local DER communication interface, industry would need to develop standards that identify the local DER interface.

Several stakeholders expressed that many different protocols identified in IEEE 1547 should be allowed, so long as the semantic model,[37] including the nameplate, operational settings, monitored data, mode parameters, controls, etc. is well defined. For example, this would include SunSpec Modbus, IEEE 1815 (DNP3) protocol, which uses the IEC 61850 semantic model, or in the future, ISO 15118. Also, SAE J3068 could be used with the added semantic definitions as noted above, which would also facilitate harmonization with IEC 61851-1, Annex D. Some cautioned against having to support all protocol options in order to support some level of standardization.[38] On the other hand, since automobile manufacturing is a global industry, it makes little sense to exclude major protocols from other

[35] This is an issue that may need to be addressed in the Common Smart Inverter Profile (CSIP) Working Group process.

[36] The IOUs expressed that they may not have interest in maintaining a dynamic database of settings to pass onto an EV every time it connects with an EVSE. This is a role that the CEC expressed that they are open to considering.

[37] A semantic data model defines the capability to express information that enables information exchange to interpret meaning (semantics).

[38] One stakeholder commented that was also some early work on V2G in IEEE P2030.1 which was not approved or published.

regions such as IEC 61851-1, Annex D and the harmonized SAE J3068. Whatever protocol is used, it should be specified and account for the multiple translations that may be necessary.

The IOUs expressed that they may not have interest in maintaining a dynamic database of settings to pass along time- or location-based curves onto an PEV every time it connects with an EVSE. UL 1741 SA made these curves optional.

3) **Gap 4: IEEE 1547 and IEEE 1547.1 do not account for default Rule 21 settings to be delivered to the inverter at each site**

Given the mobile nature of PEVs to move across different utility service territories, PEV inverters must be capable of safely and securely discharging electricity, where and when appropriate. Each time a PEV plugs into a new location, default settings (*e.g.*, curves, ride-through) need to be delivered to the inverter that is applicable to the site and in compliance with local grid codes and operational requirements while erasing the inverter default settings when not connected to an EVSE. As PEVs cross different jurisdictions, this will pose a problem to ensure that the PEVs are enabled to the correct default settings, which is not contemplated in IEEE 1547 and IEEE 1547.1, which were designed around stationary inverters that have these default settings pre-programmed at the manufacturing stage prior to installation. IEEE 2030.5 supports loading multiple curves for each function and provides commands to change between curves, but IEEE 1547 does not deal with the loading and switching curves, just the ability to test specific curves. As a part of this effort, it may be necessary to identify the authority having jurisdiction over these multi-utility and cross-state electrical and certification issues, or to delineate and address the areas where multiple authorities exist. Furthermore, stakeholders have raised how IEC 61850-7-420 and EPRI CFSI all allow the various functions to be changed, but how these would address the gap was not discussed.

4) **Gap 5: Lists to authenticate and authorize certified PEVs for discharge are needed**

Currently, the CEC maintains a list of certified smart inverter manufacturers and models that have been tested and certified to Rule 21 inverter and interconnection requirements. The California IOUs use the CEC-maintained list to populate each of their Rule 21 online interconnection application portals. The interconnection application process is clarified and streamlined by having a third-party maintained list for the whole industry to refer to. For example, net energy metering (NEM) generators must use CEC-listed equipment to be eligible for interconnection. This list is "static" in the sense that inverters apply to be listed and the CEC staff goes through an application review and approval process before updating the list.

For locations with only a few PEVs (*e.g.*, home, certain workplace settings), this gap may be addressed by having the EVSE to have model numbers placed directly into the EVSE by design, but there would need to be a process where the site owner looks at a CEC list and exact PEV data to load the EVSE list. This may be one approach for certain use cases, but it would have to also provide an update process solution to ensure PEVs do not "fall off" the list as standards are updated.

However, for V2G AC systems, a gap was identified around how EVSEs would recognize that the PEV being connected to it would be properly certified. This type of query of a list of certified PEVs would need to occur on a dynamic, ongoing basis, not just at the point of interconnection application. With different types of PEVs likely connecting to an EVSE at any point in time, the EVSE must recognize whether a certain EV is certified and authorized for discharge, thus requiring an EVSE to query an approved list of mobile inverters on an operational basis. One option could be to find it sufficient to recognize an onboard J3072 software tag, where PEV indicates that it is certified and the EVSE "trusts the system". Alternatively, an EVSE could search an ISM database to confirm J3072 certification, although not having a verified list to allow interconnection may pose safety/reliability questions that should be evaluated. Furthermore, the required protocol, which has not been defined, between the EVSE and PEV list database should be standardized, as well as other data elements for the PEV. Finally, a mechanism needs to be developed by which an OEM or PEV dealer could submit certification information to the CEC, IOU, or some third-party entity – whichever entity assumes this role of maintaining a certification list – as well as could submit updated certification information to ensure PEVs do not fall off the list as standards are updated over time.

The CEC currently does not have the capability at this time to manage a live, transaction-like database with constant communications but indicated in the subgroup that they may be open to building up the capability to maintain a dynamically accessible list. The CEC stated that it would need to conduct additional future internal investigation between its staff and IT division for further understanding. Such a list could facilitate mobile inverters not only in California but nationally.

C. Standards: Split Inverter Configuration

Several auto OEMs expressed a strong preference for the use of UL 9741 (in lieu of UL 1741) as the primary standard for mobile inverters under the Rule 21 framework. In addition, several stakeholders raised other interconnection pathways leveraging a split-inverter configuration, such as through IEC 61850-90-8 and ISO 15118, and expressed how this subgroup should allow for different configurations and approaches to be allowed for V2G AC interconnections. In the following gaps analysis, the gap is analyzed for UL 9741, which was one part of one approach to enable a split-inverter configuration, as well as the broader challenge and "gap" of matched-pair certification that would be created through interconnection via a split-inverter configuration.

1) Gap 6: Updates are needed to UL 9741 to align with UL 1741

UL 9741 was identified as a potential standard by which third-party certification could be done on the stationary EVSE that interacts with external systems to receive default settings and curves and/or to access an online database of J3072 certified EVs and their associated inverter model number. As published today, UL 9741 does directly reference and require UL 1741 compliance for grid interconnection evaluations. This provides a useful linkage so that EVSEs could be evaluated to UL 9741 and the UL 1741 required grid interconnection requirements would allow EVSEs to comply with California Rule 21, which already requires a UL1741 and UL1741 Supplement SA certification.

Both UL 9741 and UL 1741 would benefit from updates to fill gaps and better clarify the evaluation for this specific purpose, but the necessary linkages are already in place between UL 9741, UL 1741 and California Rule 21. A UL 1741 Certification Requirement Decision (CRD) is being published to cover equipment installed in mobile vehicles and this CRD includes a reference to UL 9741 for EV-related grid interconnection aspects. While joint certification concerns were raised about the use of UL 9741 for EVSEs and SAE J3072 for PEVs, the use of EVSEs as a pass-through to the mobile inverters via IEEE 2030.5 may address these concerns.

2) **Gap 7: Matched pair certification for EVSEs presents business and implementation challenges that require further consideration**

Under the straw proposal, EVSEs would store commands and curves and play gatekeeper to inverter functionalities, which would require the UL-certified EVSE and SAE-certified PEV to be certified together as a matched pair, or joint system, at the site with two-part numbers since the EVSE cannot execute the commands and in accordance with prescribed curves. EVSE-PEV matched pair testing presents some challenges in certifying every combination and would require EVSE and EV businesses to come together to validate the combination, unless a company offers the pairing together.

The split system presents some issues for SDOs and utilities if specific EVSE models and specific EV models are deployed independently. If this can be done, the split system may have cost advantages. Separating the smart function computer from the power conversion unit between the EVSE made by one company and the PEV made by another company may complicate certification. For example, the EVSE and PEV could be produced during different years and there is no single entity that could manage the process of testing the two products, and today, there is no standard that supports separately certifying the EVSE and PEV because IEEE 1547.1 is based on an end-to-end verification of each smart function through actual delivered power and not just a setpoint.

Matched-pair certification may be more viable for certain one-to-one residential use cases but presents challenges for many-to-one use cases (*e.g.*, public or workplace charging). Even for many residential applications, OEMs expressed that they may not want to pair an EVSE to a specific EV, even though it would provide interoperability clarity from an IEEE 1547 perspective.

Given the challenges with paired certification, the subgroup found that the simplest path forward would be to have a UL-listed EVSE that that leverages a protocol which is capable of implementation in SAE J3072 and IEEE 1547 certified EV communicates with the EVSE, which passes through settings and commands from an external system to deliver inverter functions.[39] The gap to

[39] Similarly, SAE previously considered whether the EVSE should implement some smart inverter functions, such as sending active and reactive power setpoints to an onboard power converter and have this combined and integrated EVSE and EV perform the IEEE 1547-2018 functions. However, due to joint certification challenges, SAE was designed to have either the EVSE OEM (V2G DC) or

address in this case is to define the EVSE and external system requirements and communication protocols. If the other gaps are addressed, closing this gap may not be necessary.

D. Practices

Over the course of this subgroup, a key difference in perspective was identified between the automotive industry and the IOUs around certification practices, with the former seeking to continue with its industry's practices of self-certification to standards and requirements while the latter seeking to maintain the current electric industry practice of approving interconnections to its distribution grid that leverage third-party-certified generation and storage resources. This represented a "gap" or difference that could affect the interconnection of V2G AC systems for either the single onboard inverter configuration or the split inverter configuration.

1) Automotive Industry Norms on Internal Testing

Automotive OEMs explained that they operate in a different environment where they self-certify compliance to Federal Motor Vehicle Safety Standards (FMVSS) for each vehicle produced. In accordance with the U.S. Vehicle Safety Act, OEMs are required to document and archive requirements, test methods, responsibilities, and evidence required to demonstrate compliance to the complete set of applicable legal requirements mandated by the U.S. government that impose criteria on vehicles to enhance safety protection. Test plans, test results, and other evidence of compliance is stored in a long-term vault for legal purposes. Methods to validate that a vehicle has been designed to requirements include physical testing, inspections, and demonstrations via sampling in addition to computer-aided engineering (CAE) and analysis. The National Highway Transportation Safety Administration (NHTSA) may perform audit enforcement testing to verify compliance after the vehicle is in the market. While the approval authority for vehicle safety has generally been NHTSA, there is an open question as to who would be the approval authority for vehicle grid interconnection given the open jurisdictional issue of PEVs.

the EV OEM (V2G AC) be 100% responsible for the smart inverter certification. Such a structure also creates clear lines of accountability. Thus, J3072 does not allow any of the smart inverter functionality to be executed by the EVSE.

Table 5: Comparison of Self-Certification versus Third-Party Certification

	Self-Certification	Third-Party Certification
Vehicle OEM	• Ensure compliance with regulatory requirements • Document evidence to demonstrate compliance • Ensure that products continue to meet regulatory requirements for the lifecycle of the vehicle	• Submit product samples for testing • Prove compliance through witnessed testing • Demonstrate ability to build compliant vehicles, systems or components
Approval Authority	• May audit production vehicles • Can open investigation • Can take legal actions based on results of investigation	• Review test plans • Conduct or witness tests • Grant approvals

Third-party certification can be an added layer (and could be pursued as part of federal safety testing) but may be unnecessary and prove to be burdensome. Vehicle manufacturing is a continually updated process with "running changes" that are frequently made as production lines are retooled for new products. Internal testing procedures are preferred to external third-party "type approval" certification processes to prevent lengthy delays that could halt production lines. The product development process for new automotive technology typically begins between four and five years before production.

During the first two years of pre-production, a product may undergo substantial design and engineering changes. Testing of pre-production vehicles often takes place between 18 to 36 months before production. About 18 months prior to production, OEMs wrap up the testing and design of pre-production vehicles, placing a "design freeze" on any further changes. At this point, OEMs will validate their product to ensure they can achieve the relevant certification by meeting all FMVSS, EPA, and other standards and requirements. This self-certification step is typically a continual, 18-month process spanning from the design freeze until the beginning of production.

An OEM's ability to develop and fully test products internally is core to the advancement of products over a short product development cycle time. This is done for electromagnetic compatibility (EMC) testing, crash testing, and other items where OEMs establish internal capability instead of supporting outside testing for validation of changes during the development cycle. These internal testing capabilities are heavily focused on safety:

- In the case of crash testing, any change to the vehicle architecture and/or structure that requires retesting is done internally with the proper documentation and record retention.
- In the case of PEV charging tests, any change to the vehicle architecture and/or structure that requires retesting is done internally with the proper documentation and record retention. OEMs implement major changes to system software in this testing phase as frequently as every month. In the case of V2G AC charging, this process can contain around 300 DVP&R tests that include communication identified in SAE J1772 and grid quality items in SAE 2894 that are fully detailed in SAE J2953 for interoperability. There is also regression testing to ensure that all items changed in software update are still functional and in compliance with testing standards.[40]

The magnitude of effort, internal support resources, and test facilities to perform validation and revalidation is significant, as this process occurs as frequently as each month during the product development cycle. The nature of these advanced vehicle products being retained in an internal secure site is also a concern for OEMs with respect to the competitive information that can be made public during the product development phase.

Currently, one approach around internal testing is for outside facilities with the appropriate expertise to validate what the OEM does internally and reports. For example, the Intertek lab was used to validate the J2953/1 and J2953/2 for AC charging and grid quality testing that was developed by Argonne National Labs (ANL). Sixteen OEMs and 16 EVSEs were tested, and changes needed for compliance were identified. Each OEM and each EVSE manufacturer had access to specific results, and an overall summary was published. Since then, some testing was directed back to Intertek until internal test capabilities were obtained for all items. A vehicle manufacturer may prefer to have such a lab perform the testing for them under a services contract since they may face lower costs to develop a third-party lab for this very specialized testing access, even during the R&D phases.

[40] Since V2G AC requires both software and functional conformance, the updates to J3072 will reference the IEEE and other specifications required that have been updated in the last five years since the initial publication of J3072.

In the example of OEM's compliance to FMVSS 305, internal testing is based on these SAE standards:

1. J2344 - Guidelines for Electric Vehicle Safety
2. J2578 - Recommended Practice for General Fuel Cell Vehicle Safety
3. J1766 - Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing

These identify that the high-voltage system on the vehicle must meet the three items below and were used in FMVSS 305 requirements.

1. FMEA – No single point failure will cause an issue
2. Monitoring of the system is required
3. Fail safe

Since the vehicle high-voltage system is isolated from the vehicle chassis, if any of the safety items are not met, it is immediately disconnected from any other high-voltage components and isolated. Testing is done after crash to ensure collision impacts do not alter these conditions. Additional safety considerations are included in J1772 for charging standards, including the following:

1. Vehicle ground circuit is sized to meet the short circuit testing value and duration in UL 2251 that is identified in J1772.
2. The EVSE generates a pilot circuit that identifies the Available Line Current to the vehicle in case the vehicle can draw more current than the facilities is sized for (circuit breaker and wiring), the vehicle will not exceed this value transmitted by the pilot circuit PWM value.

The EVSE pilot circuit uses the ground circuit as the return path so any disruption of this (open circuit) results in the vehicle immediately shutting off charging current.

According to automotive OEM participants, internal testing to J3072 and third-party certification of the EVSE follows the above pattern and presents a lower-cost alternative to interconnection compared to full third-party certification of the PEV while ensuring that the controls and capabilities are in place to provide smart inverter functionalities, ensure grid reliability, and guarantee safety. Requiring third-party certification of particular inverter models used in the PEV creates a new interconnection application process that can be burdensome to homeowners and lead to complexities for workplace charging, where specific vehicles could change from day-to-day and require frequent updates to the application every time a new and different PEV connects to the EVSE site. A new PEV inverter model may not be able to discharge until the site owner updated the site application and received utility approval to interconnect the new PEV type. With such an approach, barriers to V2G interconnection at public sites (*i.e.*, many-to-one V2G) would be created since site owners will never know which PEV models will connect to the EVSE. Instead, the concept for the J3072 updates is to allow the site owner to apply for interconnection based on the EVSE model numbers and have certain site constraints governed by J3072.

Importantly, there is a jurisdictional question regarding PEV equipment, which is beyond the scope of the National Electric Code (NEC). EVSE installations, by contrast, are subject to NEC 625.48. It is sufficient for the automotive standards to reference the required electrical requirements. PEVs will need another method of assurance of conformance to allow, for example, out-of-state vehicles to connect and operate in California. Automated functions may need to be configured on a national basis to avoid these issues.

In sum, automaker representatives in this subgroup believe that self-certification is a rigorous process, achieves the same outcome as third-party verification, and allows for continuous improvement. The self-certification process is held up to the highest standards. Leveraging this self-certification proposal balances the need for flexibility and innovation with the ability to add V2G functionality via onboard inverters that can be executed safely. Considering self-certification is performed as a means of compliance to regulatory requirements for many other industries (*e.g.*, aerospace, defense), V2G AC interconnections should not have to deviate from such processes.

International Electrotechnical Commission (IEC) standards were highlighted as not prohibiting self-certification, which could present a potential pathway for establishing standards conformance since IEC is more interested in performance. However, this pathway was not detailed during the subgroup discussions and presented potential hurdles if requirements differ among countries.

2) Utility Process on Third-Party Certification

Testing and certification are performed by an accredited NRTL in accordance with Rule 21 Section L. Certification ensures Generating Facility equipment will not adversely affect the distribution or transmission system.

The CEC gets documentation from the NRTL that the inverter has been tested to comply with these requirements and then creates a dataset of the entities and the ISMs that are in compliance. The IOUs seek to maintain the requirement of third-party certification for V2G AC systems as it has worked well for other DER interconnections under Rule 21. For example, electric industry standards cover a number of risk factors that may not be covered elsewhere, such as cybersecurity protocols. From the IOU's perspective, an energy storage located in an PEV provide the same level of risks to safety as stationary inverters. This is because at the time that PEV connects to the grid via an EVSE, the storage system injects real power to the customer/grid and thus these systems must follow the same rigor of certification to ensure that safety to not only the interconnection customer as well the rest of the customer in the grid is maintained.

8. Conclusion

Stakeholders gained a deeper understanding of both the Rule 21 interconnection requirements and smart inverter standards as well as the various applicable automotive and electrical standards for V2G AC systems. However, over the course of the subgroup, parties have concluded that there are gaps in the existing standards that could, if standards are revised and/or updated to fill these gaps, be combined to fulfill interconnection requirements for a mobile inverter at one fixed point. As a result, per the Ruling's requirements, this report does not offer any recommended changes to Rule 21 that are needed at this time to enable V2G AC interconnection.

At the same time, the gaps analysis included as part of this report has highlighted key areas where existing standards need to be updated or modified by testing laboratories and standards bodies to in order to support V2G AC interconnections. The IOUs have emphasized that addressing these gaps are not recommendations or solutions to allow for V2G AC interconnections but would constitute merely "notification" of gap areas that entities like UL and SAE could seek to address. According to the IOUs, whether these updated or modified standards will be sufficient for Rule 21 interconnection requires additional or follow-up stakeholder discussion.

To this extent, the subgroup members generally agreed on one key procedural recommendation for the Commission to consider.

> **Recommendation 1:** Reconvene subgroup or some other group upon completion of updates to automotive and other applicable standards (*e.g.*, J3072, UL 9741) to assess gaps

and consider Rule 21 changes to interconnect V2G AC systems, if such standards have been updated. The scope of this new group will be to re-assess the updated national standards and determine whether these standards can be combined to fulfill safety requirements for interconnection of a mobile inverter at one fixed point. Upon completing this review and if gaps are not identified, the group shall recommend language citing existing standards to enable Rule 21 interconnection. PEV industry stakeholders proposed this follow up work should commence July 2020. IOU representatives proposed the follow up work should commence only after the following events have occurred: (1) NRTL testing has been performed to determine exactly which parts of UL 1741 cannot be met by V2G AC inverters; and (2) IEEE 1547.1 has been revised.

In ruling on Recommendation 1, the Commission will ensure that there is a follow-up forum and discussion that builds on this subgroup's efforts in order to allow for V2G AC interconnection without undue delays. By July 2020, UL and SAE indicated that they will have made the revisions to potentially address the gaps identified in this subgroup.[41] This group would resemble many aspects of this sub-group, with a similar scope and similar "cross-listing" of this group in both the R.17-07-007 and R.18-12-006 proceedings to ensure the appropriate representation and participation. The IOUs indicated that such reconvening of the group should be contingent upon UL 1741 testing data and publication of IEEE 1547.1.

Furthermore, a key practices-related gap was identified around the automotive industry's norms around self-certification for safety and reliability versus the utility process of safe and reliable DER interconnections. The difference in automotive internal testing norms and utility processes for third-party certifications need to be reconciled. As the automotive industry highlighted, there is not a FMVSS published for V2G AC inverter systems, but this could be appropriate if a federal standard was needed. This standard could also define the approach to testing onboard inverter equipment, which may or may not use OSHA authorized NRTLs or rely on OEM testing. However, as the utilities have noted, energy storage located in an PEV provide

[41] These revisions do not mean that the standards have gone through balloting and have been published and finalized. However, at this point, the significant revisions will be made to be able to make an assessment of the updated standards, which the utilities and stakeholders would need to review for their adequacy in meeting Rule 21 interconnection requirements.

the same level of risks to safety as stationary inverters, such that third-party certification requirements and processes should be followed just as with any other DER interconnection. The PEV industry stakeholders offered the following recommendation:

> **Recommendation 2a:** Consider jurisdictional question of PEV equipment requirements as well as policy issues around self-certification. The scope of this follow-up effort could be considered in R.17-07-007 and R.18-12-006.

Meanwhile, the utility industry stakeholders proposed an alternative recommendation related to this practices gap:

> **Recommendation 2b:** Identify, evaluate, and determine solutions to the challenges faced by the PEV industry that prevent it from complying with third-party testing, which the stationary inverter manufacturers now perform. If challenges remain that prevent all stakeholders from agreeing to third-party testing, then it may be appropriate to consider the jurisdictional question of PEV equipment requirements as well as policy issues around self-certification.

This effort would have important impacts on the appropriate approach to take and would invite the appropriate expertise that was not present in this technically focused subgroup. However, SCE highlighted that the Commission or the utilities may not have jurisdiction over electric codes, thus raising questions as to whether the Commission could reconcile and/or resolve this practices gap.

9. Appendices

A. J3072 Table of Contents

B. Rule 21 Inverter Requirements Matrix

Inverter Requirements

<table>
<tr><th rowspan="3">Interconnection Functional Requirement</th><th rowspan="3">Function</th><th>Current Standard</th><th>Current Testing Standard</th><th>Future Standard</th><th>Future Test Procedure</th><th colspan="6" rowspan="2">Default Settings</th><th rowspan="3">NRTL Certification Required?</th></tr>
<tr><th rowspan="2">Rule 21 Section</th><th rowspan="2">UL1741 / UL1741SA or Other as Specified</th><th rowspan="2">IEEE1547-2018</th><th rowspan="2">IEEE1547.1-2020 Under UL1741</th></tr>
<tr><th colspan="2">Ride-Through</th><th colspan="2">Trip</th><th colspan="2">Reconnect</th></tr>
<tr><td>Protective / Voltage Ride Through</td><td>Overvoltage / Undervoltage trip and ride-through</td><td>Hh.1.a / Hh2.b.ii</td><td>UL1741SA – SA09</td><td>Section 6.4</td><td>Section 5.4</td><td colspan="2">Table 16 (IEEE1547-2018), Table Hh-1 (Rule 21)</td><td colspan="2">Table 13 (IEEE1547-2018), Table Hh-1 (Rule 21)</td><td colspan="2">300 seconds (IEEE 1547-2018), 15 seconds (Rule 21</td><td>Yes</td></tr>
<tr><td>Protective / Frequency Ride Through</td><td>Overfrequency / Underfrequency trip and ride-through</td><td>Hh.1.a</td><td>UL1741SA – SA10</td><td>Section 6.5</td><td>Section 5.5</td><td colspan="2">Table 19 (IEEE1547-2018), Table Hh-2 (Rule 21)</td><td colspan="2">Table 18 (IEEE1547-2018), Table Hh-2 (Rule 21)</td><td colspan="2">301 seconds (IEEE 1547-2018), 15 seconds (Rule 21</td><td>Yes</td></tr>
<tr><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th colspan="6">Default Activated / Deactivated</th><th rowspan="2"></th></tr>
<tr><th colspan="3">IEEE1547-2018</th><th colspan="3">Rule 21</th></tr>
<tr><td>Reactive Power</td><td>Fixed Power Factor</td><td>Hh.2.i</td><td>UL1741SA – SA12</td><td>Section 5.2 & 5.3</td><td>Section 5.14.3</td><td colspan="3">Activated</td><td colspan="3">Deactivated</td><td>Yes</td></tr>
<tr><td>Reactive Power</td><td>Dynamic Volt/Var Operations</td><td>Hh.2.j (Table Hh-4)</td><td>UL1741SA – SA13</td><td>Section 5.3</td><td>Section 5.14.4</td><td colspan="3">Deactivated</td><td colspan="3">Activated</td><td>Yes</td></tr>
<tr><td>Power Quality</td><td>Operation Ramp Control</td><td>Hh.2.k</td><td>UL1741SA – SA11</td><td></td><td></td><td colspan="3">Not Included</td><td colspan="3">Activated (100%/Second)</td><td>Yes</td></tr>
<tr><td>Power Quality</td><td>Reconnect Ramp Control</td><td>Hh.2.k</td><td>UL1741SA – SA11</td><td>Section 4.10.3</td><td>Section 5.6</td><td colspan="3">Rate of Change / Enter Service Period</td><td colspan="3">2% Maximum Current/Second</td><td>Yes</td></tr>
</table>

Grid Stability	Frequency-Watt	Hh.2.l	UL1741SA – SA14	Section 6.5.2.7	Section 5.15	Activated	Activated		Yes
Voltage Limit / Safety	Volt-Watt	Hh.2.m	UL1741SA – SA15	Section 5.4	Section 5.14.9	Deactivated	Activated		Yes
Communication Requirements	Inverter Phase 2 Communication	Hh.5	E-5000 Appendix C	Section 10 (Interoperability)	Section 6 (Interoperability)	Capability Verified / Deactivated for Interconnection			Require E-5000 Attachment C (Approved Testing Pathway)
Communication / Scheduling	Scheduling Requirements (Phase 3 Function 8)	Hh.6	Inverter Manufacturer Attestation	Section 10 (Interoperability)	Section 6 (Interoperability)	Capability Verified / Deactivated for Interconnection			Temporarily No, but Yes 12 Months after Publication of National Standard
Communication / Information Exchange	Monitoring / Telemetry (Phase 3 Function 1)	Hh.7	Inverter Manufacturer Attestation	Section 10 (Interoperability)	Section 6 (Interoperability)	Capability Verified / Deactivated for Interconnection			Temporarily No, but Yes 18 Months after Publication of National Standard
Control	Connect / Disconnect (Phase 3 Function 2)	Hh.8 a & b	UL1741SA – SA17*	Section 10 (Interoperability)	Section 6 (Interoperability)	Capability Verified / Deactivated for Interconnection			Yes
Control	Limit Real Power (Phase 3 Function 3)	Hh.8.c.e	UL1741SA – SA18*	Section 10 (Interoperability)	Section 6 (Interoperability)	Capability Verified / Deactivated for Interconnection			Yes
Protective	Unintended Island	Hh.1.a	UL1741SA – SA08	Section 8.1	Section 5.10				Yes
Protective	Fault & Open Phase Detection	Hh.1.a	UL1741 / IEEE1547.1	Section 6.2	Section 5.11				Yes (Open Phase)
Protective	Reclose Coordination	Hh.4.c	Impact Study	Section 6.3	Section 8.0				
Protective	Fault Current Characterization	Impact Study	Impact Study	Section 11.4.2	Section 5.18				
Protective	Overvoltage Limitations	Hh.2.a (ANSI C84.1.1-1995)		Section 7.4	Section 5.17				

Disconnecting Means	Isolation Verification	Hh.1.c		Section 4.8					No
Voltage Control	Voltage Regulation	Hh.2.a (ANSI C84.1.1-1995)							No (Evaluated vis Impact / Monitoring)
Power Quality	Flicker	Hh.2.d (IEEE519-1992)		Section 7.2.3					No (Evaluated via Impact Results, Commissioning, and Monitoring)
Power Quality	Harmonics	Hh.2.g (Table Hh-3)	UL1741 Section 40 (IEEE1547-2005)	Section 7.3	Section 5.12				Yes

* In progress via UL CRD

Disclaimer: The IOUs state that this list represents a list of the major functional requirements, but it does not represent a complete set of requirements. See Rule 21, IEEE 1547, IEEE 1547.1, and UL 1741 for complete set of requirements.

Automotive Industry's Mapping of Applicable V2G AC Standards

The capabilities to meet utility requirements are generally indicated in J3072 Sections 4.7 "Smart Inverter Functions and 4.8 "Utility Interactions" where Section 4.7 points to the J2836/3 "Use Cases for PEV Communication as Distributed Energy Resource" while Section 4.8 references IEEE 1547-2003 and IEEE 1547.1-2005 with a few modifications. Section 4.7 notes that, as certain smart inverter functions become mandatory for approval of interconnection of PEVs with onboard inverter systems, this standard will be revised to include requirements for implementation and conformance testing.

Interconnection Functional Requirement	**Function**	**IEEE 2030.5**	**SunSpec**			**Equivalent SAE Source & Certification Standards**	**Equivalent IEC 61850 Source**
			CSIP Implementation Guide v2.103-15-2018	**SunSpec CSIP Conformance Test Procedures v1.2**	**2.2EPC-14-036 Smart Inverter Evaluation Report**		
Protective / Voltage Ride Through	Overvoltage / Undervoltage trip and ride-through	1 Low Voltage Ride Thru Must Trip Curve P1 - Low Voltage Ride Through opModLVRTMustTrip	opModLVRTMUSTTrip opModLVRTMAYTrip opModLVRTMomentaryCessation	BASIC-004 - Basic Inverter Control (Low/High Voltage	Table 1. Criteria for Low and High Voltage Ride-Through Tests	J3072 Section 4.7, J2836/3	IEC61850-7-420

		2 High Voltage Ride Thru Must Trip Curve P1 - High Voltage Ride Through opModHVRTMustTrip 3 Low Voltage Momentary Cessation Curve P1 - Low Voltage Ride Through opModLVRTMomentaryCessation 4 High Voltage Momentary Cessation Curve P1 - High Voltage Ride Through opModHVRTMomentaryCessation	opModHVRTMUSTTrip opModHVRTMAYTrip opModHVRTMomentaryCessation	Ride-Through) [C, A, S]		Sections 4.4.5, 4.7.6	
Protective / Frequency Ride Through	Overfrequency / Underfrequency trip and ride-through	5 Low Frequency Ride Thru Must Trip Curve P1 - Low Frequency Ride Through opModLFRTMustTrip 6 High Frequency Ride Thru Must Trip Curve P1 - High Frequency Ride Through opModHFRTMustTrip	opModLFRTMustTrip opModHFRTMustTrip	BASIC-005 - Basic Inverter Control (Low/High Frequency Ride-Through) [C, A, S]	Table 2. Criteria for Low and High Frequency Ride-Through Tests	J3072 Section 4.7, J2836/3 Section 4.4.5	IEC61850-7-420
Reactive Power	Fixed Power Factor	Fixed Power Factor P1 - Fixed Power Factor opModFixedPFInjectW, opModFixedPFAbsorbW	opModFixedPFInjectW opModFixedPFAbsorbW	BASIC-008 - Basic Inverter Control (Fixed Power Factor)	Table 5. Criteria for Determining Power Factors for Specified Power Factor Tests	J3072 Section 4.7, J2836/3 Sections 4.4.3, 4.7.3	IEC61850-7-420
Reactive Power	Dynamic Volt/Var Operations	Volt-Var Curve P1 - Volt-Var opModVoltVar	opModVoltVar	BASIC-006 - Basic Inverter Control (Volt-Var)	Table 6. Criteria for Calculating Volt-VAr Curve Parameters Figure 3. “Most Aggressive” Volt-VAr Curve Figure 4. “Average” Volt-VAr Curve Figure 5. “Least Aggressive” Volt-VAr Curve	J3072 Section 4.7, J2836/3 Sections 4.4.4.1, 4.7.5	IEC61850-7-420
Power Quality	Operation Ramp Control	Ramp Rate Setting P1 - Ramp Rate setGradW	setSoftGradW	BASIC-007 - Basic Inverter Control (Ramp Rates)	Table 3. Criteria for Normal Ramp Rates Table 4. Criteria for Soft Start Ramp Rates	J2894/1, /2	IEC61850-7-420

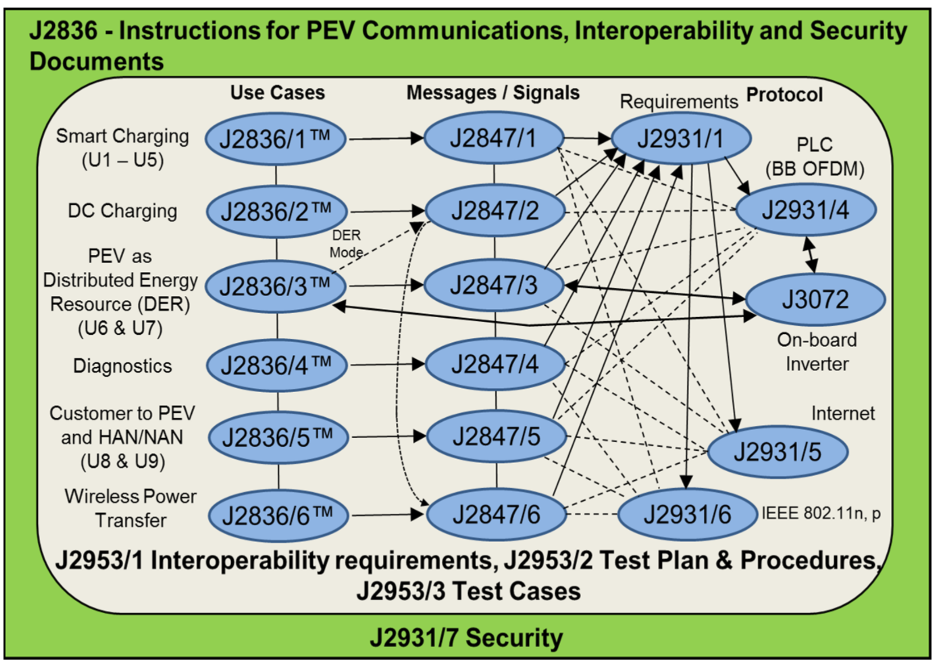
Power Quality	Reconnect Ramp Control	Soft-Start Ramp Rate Setting P1 - Ramp Rate setSoftGradW	setGradW	BASIC-007 - Basic Inverter Control (Ramp Rates)	Table 3. Criteria for Normal Ramp Rates Table 4. Criteria for Soft Start Ramp Rates	J2894/1, /2	IEC61850-7-420
Grid Stability	Frequency-Watt	Frequency-Watt Curve P3 - Function 5: Frequency Watt Mode opModFreqWatt	opModFreqWatt	BASIC-012 - Basic Inverter Control (Frequency-Watt)	Table 2. Criteria for Low and High Frequency Ride-Through Tests Figure 2. Graphical Representation of Low and High Frequency Ride Through Criteria	J3072 Section 4.7.5, J2836/3 Section 4.4.4.3	IEC61850-7-420
Voltage Limit / Safety	Volt-Watt	Volt-Watt Curve P3 - Function 6: Volt Watt Mode opModVoltWatt	opModVoltWatt	BASIC-011 - Basic Inverter Control (Volt-Watt)	Table 6. Criteria for Calculating Volt-VAr Curve Parameters Figure 3. “Most Aggressive” Volt-VAr Curve Figure 4. “Average” Volt-VAr Curve Figure 5. “Least Aggressive” Volt-VAr Curve	J3072 Section 4.7.5, J2836/3 Section 4.4.4.2	IEC61850-7-420
Communication Requirements	Inverter Phase 2 Communication		IEEE2030.5	All Tests		J3072 Section 4.7, J2836 Section 5.5	IEC61850-7-420 mapped to DNP3 (MESA Profile) as IEEE2030.5 alternative
Communication / Scheduling	Scheduling Requirements (Phase 3 Function 8)	All DER Controls are schedulable	All DER Controls are schedulable	BASIC-016 to BASIC-026			IEC61850-7-4
Communication / Information Exchange	Monitoring / Telemetry (Phase 3 Function 1)	Metering Mirror Function Set DER Info resources	Real Power, Reactive Power, Frequency, Voltage, Nameplate Ratings, Status	BASIC-027 (Alarms) BASIC-028 (Inverter Status) BASIC-029 (Inverter Meter Readings)			IEC61850-7-420

Control	Connect / Disconnect (Phase 3 Function 2)	P3 Function 2 - opModEnergize (Anti-Islanding function and confirmation) Set DER as energized (true) or de-energized (false). Used in conjunction with ramp rate when reenergizing. opModEnergize P3 Function 2 - opModConnect	opModEnergize opModConnect	BASIC-009 - Basic Inverter Control (Connect/Disconnect)		J3072 Section 4.7, J2836/3 Sections 4.4.3.5, 5.5.6	IEC61850-7-420
Control	Limit Real Power (Phase 3 Function 3)	P3 Function 3 - opModMaxLimW	opModMaxLimW	BASIC-010 - Basic Inverter Control (Limit Max Active Power Mode)		J3072 Section 4.7, J2836/3 Sections 4.6.2, 5.5.6	IEC61850-7-420
Protective	Unintended Island					J3072 Section 4.8	IEC61850-7-4
Protective	Fault & Open Phase Detection					J3072 Section 4.8	IEC61850-7-4
Protective	Reclose Coordination					J3072 Section 4.7, J2836/3 Section 5.5.6	IEC61850-7-4
Protective	Fault Current Characterization					J3072 Appendix C	IEC61850-7-4
Protective	Overvoltage Limitations					J3072 Section 4.7, J2836/3 Section 4.7.5	IEC61850-7-4
Disconnecting Means	Isolation Verification					J3072 Section 4.8	IEC61850-7-420
Voltage Control	Voltage Regulation					J3072 Section 4.8	IEC61850-7-420
Power Quality	Flicker					J2894/1, /2	IEC61850-7-420
Power Quality	Harmonics					J2894/1, /2	IEC61850-7-420

C. Applicable SAE Standards Referenced by SAE J3072

SAE J2836 Communications and Interoperability

J2836 outlines the various V2G applications and use cases and addresses the common smart inverter functions adopted in Rule 21. J2836/3 maps the capacities of the EVs and what DER commands need to be received and decoded for these specific applications. The PEV communicates point-to-point with the EVSE, where the PEV can have a WiFi bridge and communicate with an EVSE port, facility's energy management system (EMS), IOU's distributed energy resources management system (DERMS), or from an aggregator. SAE document interaction is shown below.[42]

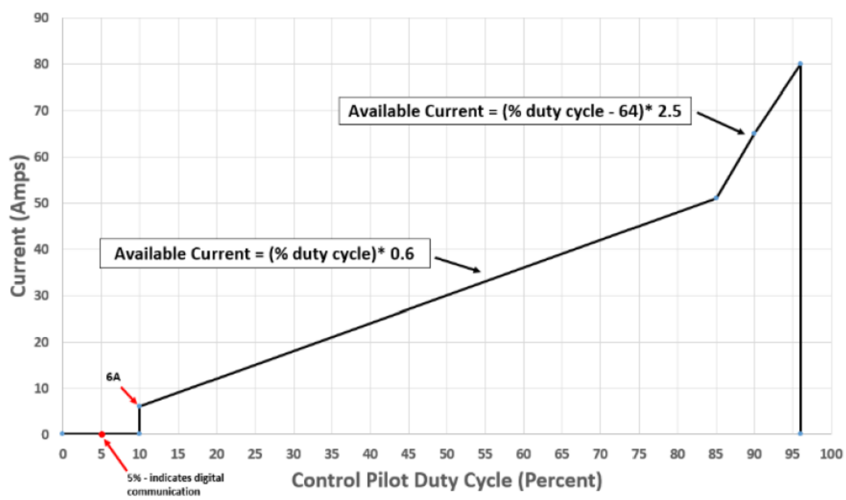


Meanwhile, EVSE communication with the PEV is currently defined in accordance with SEP2 and IEEE 2030.5.

[42] J2836 documents can be found for free here: https://www.sae.org/search/?qt=j2836

SAE J1772 Charging Standard

J1772 is the SAE standard that explains how the EVSE, once installed, will determine the maximum line current that the EVSE can provide the PEV using pulse width modulation (PWM).[43] The EVSE generates a Control Pilot PWM value that identifies to the vehicle the "Available Line Current" (ALC) since the premise has the circuit breaker and wiring sized for the charging current. The vehicle reads the EVSE PWM and ensures that it does not exceed that current. If the onboard inverter could accept more current, it will always limit the charge current to this PWM value. The vehicle also uses this for AC L1 cordsets, where a 20% PWM identifies 12A is the max ALC, as connected to a premise 15A outlet and CBR. The PWM range is 10% to 96% for 6A to 80A range.



J1772 AC L2 SEP2 is referenced in J3072 to ensure that the model number is unique. The J1772 connector is defined as part of the core ISM and references UL 2202, UL 2231, and UL 2551.

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[43] PWM is a current control technique that enables control of the speed of motors, heat output of heaters, etc., which can be applied to hybrid and EV motor drive circuits to ensures that only the amount of power as needed is consumed. Rather than restricting the flow of current using resistance, PWM circuits turn the current on/off and vary that amount of time that it is "on". For any EVSE, as part of the connection process, a safety lock-out exists, preventing current from flowing when the charger is not connected to the car. It ensures that if a cable is not correctly inserted, power will not flow through it. EVSEs can also detect hardware faults, disconnecting the power and preventing battery damage and electrical shorts.

SAE J2847 Messages and Diagrams

Below is an example of how J2847 enacts IEEE 2030.5 and how the information is put into the server. J2847/3 provides guidance to the system design engineer on how to use the IEEE 2030.5 DER function set but is not a substitute for the actual standard. It maps terminology used by the SAE for parameters to the terminology used by IEEE 2030.5. Notably, EPRI Common Functions for Smart Inverters, IEC 61850-7-420, IEEE 2030.5, IEEE 1547-2018, and SAE J2836 documents often use different terms for the same parameters

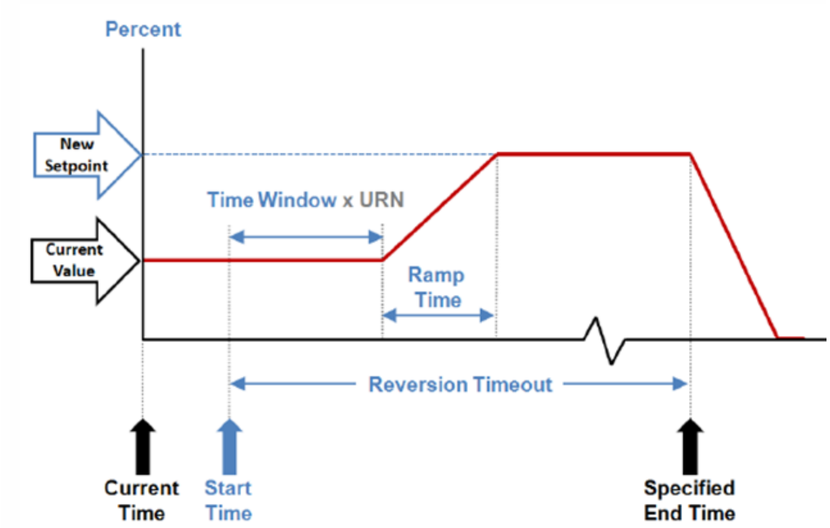


FIGURE 15 - DER CONTROL EVENT

D. Planned Updates to SAE Standards

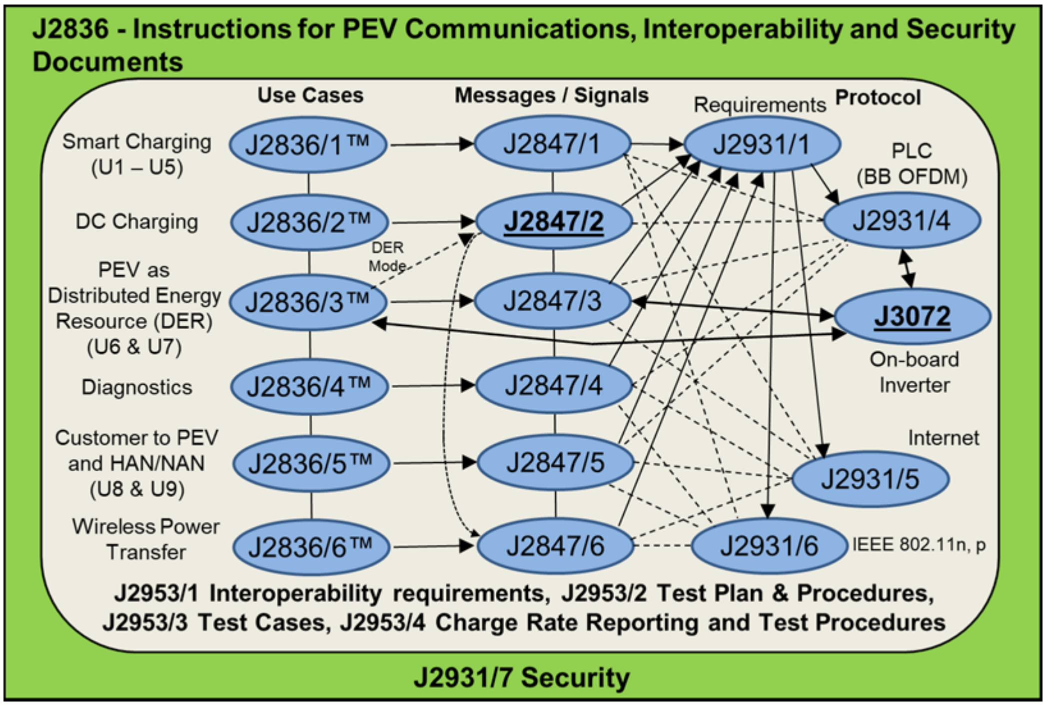
The automotive industry expressed that they are ready to make the necessary updates and modifications based on the gaps assessment. For example, SAE standards will be updated to the new IEEE 1547-2018[44] and IEEE 1547.1 once published to ensure that all power, communications, and interoperability requirements are consistent and in agreement. SAE also plans to update the standards to look beyond Rule 21 functions to other "desirable" requirements, such as around power quality and charging/discharging under external command.

SAE Communication Background – Major Documents and Functions

- J2836™ - Instructions and Use Cases (establishes requirements)
  - Technical Information Report (TIR)
- J2847 – Messages, diagrams, etc. (derived from the use case requirements)
  - -2 is a Standard, others are Recommended Practice (RP)
- J2931 – Communication Requirements, Protocol & Security
  - TIR
- J2953 – Interoperability
  - RP
- J3072 – Interconnection Requirements for Onboard, Utility-Interactive, Inverter Systems
  - Standard

SAE Hybrid Communication and Interoperability Task Force – Interaction of 23 Documents

[44] IEEE 1547-2018 should include updated commands for DERs that can be incorporated into J3072.



Documents Planned for Updates for AC DER

- J2836/3 - Use Cases for Plug-In Vehicle Communication as a Distributed Energy Resource
  - No need to update until California decides on Rule 21
- J2847/3 - Communication for Plug-in Vehicles as a Distributed Energy Resource
  - This should be updated to IEEE 2030.5-2018 but is not a trivial update and would be best done by a developer of IEEE 2030.5-2018
- J3072 - Interconnection Requirements for Onboard, Utility-Interactive Inverter Systems
  - Update with current references and include new items: Point to IEEE 1547-1 and IEEE 1547.1
  - Point to other SAE standards: J2836/3, J2847/3, J2953/1, and J2953/2 (Use Cases, Messages, and Interoperability)
- J2953/1 - Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)
  - Add conformance to J2953/1 for SunSpec communication testing (of IEEE 2030.5)
  - Add IEEE 1547.1 functional tests

- J2953/2 - Test Procedures for the Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)
    - Add conformance test procedures and plan

Timeline

SAE will continue with background effort and start updates in mid January 2020, with expected completion in June 2020, according to Rich Scholer, Chair of the SAE Hybrid Communication and Interoperability Task Force, and Hank McGlynn, Leader of V2G Working Group. The ballot to task force will be done in mid July 2020 (14 days), followed by a ballot to the Hybrid Committee in August 2020 (28 days). SAE formatting will be completed in one month in September 2020, with MVC ballot in October 2020 (28 days). The updated SAE standards will be published in early November 2020.

E. UL 1741 Application to PEV Onboard Inverters

The following table provides VGIC's assessment of which elements of the UL 1741 standard are applicable to PEV onboard inverters and which are not. This was intended to help differentiate between elements that may be appropriate for stationary inverters (*e.g.*, mounted on the side of a building) and those that are not appropriate in a vehicle due to space constraints or other existing design requirements. Sections SA11-16 were not evaluated to time constraints.

Key:

- H in NA column = Heading only (no requirements)
- D = deleted
- X in MOD column = needs modified

2018	UL 1741 Section (Second Edition, Dated January 28, 2010)	NA	NO	YES	MOD	Comments
	INTRODUCTION	**H**				
	1 Scope 7				**X**	Add scope statement for PEVs
	2 Glossary 7				**X**	Add terms for PEVs
X	PV rapid shutdown equipment and systems					
	3 General 12	H				
	3.1 Components 12		X			
	3.2 Units of measurement 13			**X**		
	3.3 References 13			**X**		
	CONSTRUCTION					
	4 General 13		X			
	5 Frame and Enclosure 13	H				
	5.1 General 13		X			
	5.2 Access covers 14		X			
	5.3 Cast metal enclosures 15		X			
	5.4 Sheet metal enclosures 15		X			
	5.5 Nonmetallic enclosures 18		X			
	5.6 Openings covered by glass 18A		X			

	5.7 Openings for wiring system connections 18A		X			
	5.8 Openings for ventilation 20		X			
	5.9 Environmental rated enclosures 26		X			
	6 Protection Against Corrosion 29		X			
	7 Mechanical Assembly 29		X			
	8 Mounting 30		X			
	9 Protection of Users — Accessibility of Uninsulated Live Parts 30		X			SAE J2344 & J2578
	10 Protection of Service Personnel 34		X			SAE J2344 & J2578
	11 Electric Shock 35	H				
	11.1 Voltage 35		X			SAE J2344 & J2578
	11.2 Stored energy 37		X			
	12 Switches and Controls 40A		X			
	13 Disconnect Devices 42		X			SAE J2344
X	General					
X	Provision for locking					SAE J2344
	14 AC Output Connections 43	H				SAE J2344
	14.1 Stand-alone inverters 43		X			
	14.2 Utility-interactive inverters 43		X			
	15 Receptacles 44		X			
	16 Supply Connections 44	H				SAE J2344
	16.1 General 44		X			
	16.2 Wiring terminals 44A		X			
	16.3 Wiring leads 47		X			
	16.4 Wiring compartments 48		X			
	16.5 Openings for conduit or cable connection 48		X			
	16.6 Openings for class 2 circuit conductors 49		X			
	17 Wire-Bending Space 49		X			
	18 Equipment Grounding 55	H				SAE J2344
	18.1 General 55		X			
	18.2 Grounding electrode terminal 57		X			

	19 AC Output Circuit Grounded Conductor 58		X			
	20 Internal Bonding for Grounding 59		X			
	21 Internal Wiring 61	H				
	21.1 General 61		X			
	21.2 Protection of wiring 63		X			SAE J2344
	21.3 Electrical connections 63		X			SAE J2344
	22 Live Parts 64		X			
	23 Separation of Circuits 65	H				
	23.1 Factory wiring 65		X			
	23.2 Field wiring 65		X			
	23.3 Separation barriers 66		X			J1766 (FMVSS 305)
	24 Spacings 66A	H				
	24.1 General 66A		X			
	24.2 Insulating liners and barriers 69		X			
	25 Alternate Spacings — Clearances and Creepage Distances 70		X			
	26 Insulating Materials 71	H				
	26.1 General 71		X			
	26.2 Barriers 72		X			
	27 Capacitors 72		X			
	28 Isolated Accessible Signal Circuits 73		X			
	29 Control Circuits 74		X			
	30 Overcurrent Protection 76	H				
	30.1 General 76		X			
	30.2 Control circuit overcurrent protection 78		X			
	30.3 Output ac power circuit overcurrent protection 79		X			GFCI/CCID in EVSE per J1772 (charging), in PEV for DER
	30.4 Battery circuits 80		X			
	31 DC Ground Fault Detector/Interrupter 80		X			J2344

	32 Printed-Wiring Boards 80B		X			
	32A External Transformers 80B		X			
	PROTECTION AGAINST RISKS OF INJURY TO PERSONS					
	33 General 81		X			
	34 Enclosures and Guards 82		X			J2344
	35 Moving Parts 82		X			
	36 Switches and Controls 82		X			
	37 Mounting 83		X			
	OUTPUT POWER CHARACTERISTICS AND UTILITY COMPATIBILITY					
	38 General 83			**X**		
	39 Utility Interaction 83				**X**	No Adjustments Allowed in PEV
X	~~40 DC Isolation From the Utility 84~~	D				
	PERFORMANCE					
	41 General 84				**X**	EVSE Requirement - SAE J1772
	42 Maximum-Voltage Measurements 85		X			
	43 Temperature 85		X			
	44 Dielectric Voltage-Withstand Test 90	H				SAE J2344 & SAE J2578, Appendix B
	44.1 General 90		X			
	45 Output Power Characteristics 91	H				J2894/1 & /2
	45.1 General 91			**X**		
	45.2 Output ratings 92			**X**		
	45.3 Input range 92			**X**		
	45.4 Harmonic distortion 92			**X**		
X	45.5 DC injection 93	D				
	46 Utility Compatibility 93				**X**	To refer to updated title of IEEE 1547
X	~~46.1 General 93~~			**X**		

X	~~46.2 Utility voltage and frequency variation test 93~~	D				
X	~~46.3 Anti-Islanding test 93~~	D				
X	~~46.4 Loss of Control Circuit 93~~	D				
X	~~47 Abnormal Tests 94~~	H				
	47.1 General 94		X			47.1.4 Unit may not be horizontal on vehicle
	47.2 Output overload test 100		X			
	47.3 Short-circuit test 100A		X			
	47.4 DC input miswiring test 100A		X			
	47.5 Ventilation test 1008		X			
	47.6 Component short- and open-circuit 100B		X			
	47.7 Load transfer test 100C		X			
	47.8 Loss of Control Circuit 100C		X			
	48 Grounding Impedance Test 100C		X			
	49 Overcurrent Protection Calibration Test 100D		X			
	50 Strain Relief Test 100D		X			
	51 Reduced Spacings on Printed Wiring Boards Tests 101	H				
	51.1 General 101		X			
	51.2 Dielectric voltage-withstand test 101		X			
	51.3 Shorted trace test 101		X			
	52 Bonding Conductor Test 101		X			
	53 Voltage Surge Test 102A		X			
	54 Calibration Test 103		X			
	55 Overvoltage Test 104		X			
	56 Current Withstand Test 104A		X			
	57 Capacitor Voltage Determination Test 105		X			
	58 Stability 105		X			
	59 Static Load 105		X			
	60 Compression Test 106		X			
	61 Rain and Sprinkler Tests 106	H				
	61.1 General 106		X			

	61.2 Rain test 106		X			
	61.3 Sprinkler test 109		X			
	RATING					
	62 Details 111				**X**	
	MARKING					
	63 Details 112		X			
	64 Cautionary Markings 120		X			
	65 Equipment Information and Instructions 121	H				
	65.1 Separation of information 121		X			
	65.2 Operating and installation instructions 121				**X**	
	66 Important Safety Instructions 123				**X**	
	MANUFACTURING AND PRODUCTION TESTS					
	67 Dielectric Voltage-Withstand Test 126		X			
	68 Utility Voltage and Frequency Variation Test 128		X			
	CHARGE CONTROLLERS					
	INTRODUCTION					
	69 General 129		X			
	CONSTRUCTION					
	70 General 130		X			
	PERFORMANCE					
	71 General 130A		X			
	72 Normal Operations 130B		X			
	73 Temperature 131		X			
	74 Temperature Compensation 131		X			
	75 Connection Sequence 131		X			
	76 Abnormal Tests 133	H				
	76.1 General 133		X			
	76.2 Input and output faults 133		X			
	76.3 Charge controller miswiring 133		X			
	76.4 Low-voltage disconnect 134		X			
	MARKING					
	77 Cautionary Markings 134		X			
	78 Details 135		X			

	79 Important Safety Instructions 135		X			
	AC MODULES					
	INTRODUCTION					
	80 General 136		X			
	CONSTRUCTION					
	81 General 136		X			
	PERFORMANCE					
	82 General 137		X			
	83 AC Module Inverter Securement Test 137		X			
	RATING					
	84 General 138		X			
	MARKING					
	85 Details 138		X			
	86 Important Safety Instructions 138		X			
X	RAPID SHUTDOWN EQUIPMENT AND SYSTEMS	H				
X	INTRODUCTION	H				
X	General		X			SAE J2344 sec 4.3.3
X	CONSTRUCTION					
X	88 Protection of Emergency Personnel		X			SAE J2344 sec 4.9, 5, SAE J1766. FMVSS305
X	89 Electrical Isolation Systems (EIS)		X			SAE J2344 sec 4.3.1
X	90 Initiators		X			SAE J2344 sec 3.4
X	91 PVRSS that Includes Disconnect Functionality		X			SAE J2344 sec 4.3.3.1
X	92 PVRSS and PVRSE Functional Safety		X			SAE J2344 sec 4.3.3.1
X	92.1 General		X			SAE J2344
X	92.2 Conditions to be addressed for a PVRSS/PVRSE		X			SAE J2344
X	PERFORMANCE	H				
X	93 General	H				
X	93.1 Operational tests for PVRSS/PVRSE verification of levels – controlled conductors		X			SAE J1772, J1673, J 1797, J2344
X	93.2 Verification testing of PVRSS at rated extremes		X			SAE J1772, J1673, J 1797, J2345

X	93.3 Power supply grid support ride through				**X**	IEEE 1547 / 1547.1
X	93.4 Inverters rated as PVRSE				**X**	IEEE 1547 / 1547.1
X	93.5 Other equipment rated as PVRSE	X				
X	94 Functional Safety Evaluation and Environmental Stress Testing For PVRSS/PVRSE		X			SAE J2288, J2380, J2380, J2344
X	RATINGS	H				
X	95 General		X			FMVSS305, IEC60417, ISO2575
X	MARKING	H				
X	96 Details		X			FMVSS305, IEC60417, ISO2575
X	97 Installation Instructions		X			J2344 /OEM Owners manual
X	SUPPLEMENT SA - GRID SUPPORT UTILITY INTERACTIVE INVERTERS AND CONVERTERS					
X	GENERAL					
X	SA1 Scope					
X	SA2 Acronyms					
X	SA3 Definitions				**X**	SA3.19 to refer updated version of IEEE 1547 / 1547.1
X	SA4 Construction		X			SA4.1 being to excessive for auto
X	SA5 Performance – Grid Support Utility Interactive	H				
X	SA5.1 General		X			Marking for rating per SA6 is useless of on-board device
X	SA5.2 Grid support utility interconnection protection performance				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA5.3 Test parameter tolerances					
X	SA5.4 Representative testing					
X	SA5.5 Abnormal tests		X			47.1 may not apply to all vehicle conditions
X	SA6 Ratings, Markings and Instructions		X			Marking for rating is useless of on-board device
X	SA7 Manufacturing and Production Line Testing for Grid Support Utility Interactive Inverters				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	PART 2 – SPECIFIC REQUIREMENTS AND TESTS FOR GRID SUPPORT	H				

	UTILITY NTERACTIVE INVERTERS					
X	SA8 Anti-islanding Protection - Unintentional Islanding with Grid Support Functions Enabled					
X	SA8.1 General				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA8.2 Test procedure				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA8.3 Tests requirements				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA9 L/HVRT Low and High Voltage Ride-Through	H				
X	SA9.1 Function L/HVRT – low and high voltage ride-through				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA9.2 Must trip magnitude and duration				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA10 L/HFRT Low and High Frequency Ride-Through	H				
X	SA10.1 General					
X	SA10.2 Test requirements					
X	SA10.3 Test procedure				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA10.4 Ride-through test signal (step function)					
X	SA10.5 Must trip magnitude and duration				**X**	To refer to updated version of IEEE 1547 / 1547.1
X	SA11 RR – Normal Ramp Rate and SS – Soft-Start Ramp Rate				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/2
X	SA11.1 General				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/2
X	SA11.2 Procedure for normal ramp rate test				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/3
X	SA11.3 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/4
X	SA11.4 Procedure for soft-start ramp rate test				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/5
X	SA11.5 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/6
X	SA11.6 Ramp rate test profiles				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/7
X	SA12 SPF – Specified Power Factor				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J2894 /1&/8
X	SA12.1 General	H				
X	SA12.2 Procedure for specified power factor test				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA12.3 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072

X	SA13 Volt/VAr Mode (Q(V))	H				
X	SA13.1 General				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA13.2 Procedure for Volt-VAr ″Q(V)″ test				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA13.3 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA14 Frequency-Watt (FW) – Optional	H				
X	SA14.1 General				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA14.2 EUT Specified Parameters				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA14.3 Test procedure				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA14.4 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA15 Volt-Watt (VW) – Optional	H				
X	SA15.1 General				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA15.2 EUT specified parameters				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA15.3 Test procedure				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA15.4 Test requirements				**X**	Refer to updated version of IEEE 1547 / 1547.1 / SAE J3072
X	SA16 Ratings for Grid Support Utility Interactive Inverters, Converters		X			

F. Industry's Ride Through Updates Summary

Ride Thru Summary

Note: This document intends to identify the additional information and references for each requirement of this category summation. Each item is linked to all of the subsequent standards text, figures and tables to fully describe each requirement and test from both a software and hardware perspective. SAE J3072:2020 will be updated with the expected publication by June 2020.

1. IEEE 2030.5

Item	Function	Rule 21 Function	IEEE 2030.5 Resource	Rule 21 sections
1	Low Voltage Ride Thru Must Trip Curve	P1 - Low Voltage Ride Through	opModLVRTMustTrip	Hh.1.a/ Hh2.b.ii
2	High Voltage Ride Thru Must Trip Curve	P1 - High Voltage Ride Through	opModHVRTMustTrip	Hh.1.a/ Hh2.b.ii
3	Low Voltage Momentary Cessation Curve	P1 - Low Voltage Ride Through	opModLVRTMomentaryCessation	Hh.1.a/ Hh2.b.ii
4	High Voltage Momentary Cessation Curve	P1 - High Voltage Ride Through	opModHVRTMomentaryCessation	Hh.1.a/ Hh2.b.ii
5	Low Frequency Ride Thru Must Trip Curve	P1 - Low Frequency Ride Through	opModLFRTMustTrip	Hh.1.a
6	High Frequency Ride Thru Must Trip Curve	P1 - High Frequency Ride Through	opModHFRTMustTrip	Hh.1.a

1. Low Voltage Ride Thru Must Trip Curve
    a. IEEE 2030.5 command: opModLVRTMustTrip attribute (DERCurveLink) [0..1] 23
    b. Rule 21 section: Specify curve type == 5. The Low Voltage Ride-Through (LVRT) function is specified by 24 duration-volt curves that define the operating region under low voltage conditions. Each LVRT 25 curve is specified by an array of duration-volt pairs that will be interpolated into a piecewise 26 linear function that defines an operating region. The x value of each pair specifies a duration 27 (time at a given voltage in seconds). The y value of each pair specifies an effective percent 28 voltage, defined as

((locally measured voltage - setVRefOfs) / setVRef). This control specifies 29 the "must trip" region.

2. High Voltage Ride Thru Must Trip Curve
    a. IEEE 2030.5 command: opModHVRTMustTrip attribute (DERCurveLink) [0..1]
    b. Rule 21 section: Specify curve type == 7. The High Voltage Ride-Through (HVRT) function is specified by 1 duration-volt curves that define the operating region under high voltage conditions. Each HVRT 2 curve is specified by an array of duration-volt pairs that will be interpolated into a piecewise 3 linear function that defines an operating region. The x value of each pair specifies a duration 4 (time at a given voltage in seconds). The y value of each pair specifies an effective percent 5 voltage, defined as ((locally measured voltage - setVRefOfs) / setVRef). This control specifies 6 the "must trip" region.
3. Low Voltage Momentary Cessation Curve
    a. IEEE 2030.5 command: opModLVRTMomentaryCessation attribute (DERCurveLink) [0..1] 15
    b. Rule 21 section: Specify curve type == 4. The Low Voltage Ride-Through (LVRT) function is specified by 16 duration-volt curves that define the operating region under low voltage conditions. Each LVRT 17 curve is specified by an array of duration-volt pairs that will be interpolated into a piecewise 18 linear function that defines an operating region. The x value of each pair specifies a duration 19 (time at a given voltage in seconds). The y value of each pair specifies an effective percent 20 voltage, defined as ((locally measured voltage - setVRefOfs) / setVRef). This control specifies 21 the "momentary cessation" region.
4. High Voltage Momentary Cessation Curve
    a. IEEE 2030.5 command: opModHVRTMomentaryCessation attribute (DERCurveLink) [0..1] 38
    b. Rule 21 section: Specify curve type == 6. The High Voltage Ride-Through (HVRT) function is specified by 39 duration-volt curves that define the operating region under high voltage conditions. Each HVRT 40 curve is specified by an array of duration-volt pairs that will be interpolated into a piecewise 41 linear function that defines an operating region. The x value of each pair specifies a duration 42 (time at a given voltage in seconds). The y value of each pair specifies an effective percent 43 voltage, defined as ((locally measured voltage - setVRefOfs) / setVRef). This control specifies 44 the "momentary cessation" region.
5. Low Frequency Ride Thru Must Trip Curve
    a. IEEE 2030.5 command: opModLFRTMustTrip attribute (DERCurveLink) [0..1] 8
    b. Rule 21 section: Specify curve type == 8. The Low Frequency Ride-Through (LFRT) function is specified by a 9 duration-frequency curve that defines the operating region under low frequency conditions. Each 10 LFRT curve is specified by an array of duration-frequency pairs that will be interpolated into a 11 piecewise linear function that defines an operating region. The x value of each pair specifies a 12 duration (time at a given

frequency in seconds). The y value of each pair specifies a frequency, in 13 Hz. This control specifies the "must trip" region.

6. High Frequency Ride Thru Must Trip Curve
    a. IEEE 2030.5 command: opModHFRTMustTrip attribute (DERCurveLink) [0..1] 31
    b. Rule 21 section: Specify curve type == 9. The High Frequency Ride-Through (HFRT) function is specified by a 32 duration-frequency curve that defines the operating region under high frequency conditions. Each 33 HFRT curve is specified by an array of duration-frequency pairs that will be interpolated into a 34 piecewise linear function that defines an operating region. The x value of each pair specifies a 35 duration (time at a given frequency in seconds). The y value of each pair specifies a frequency, in 36 Hz. This control specifies the "must trip" region.

2. Sunspec

1. File: CSIPImplementationGuidev2.103-15-2018

5.2.4 DER Controls and DER Default Control Requirements

DER Clients SHALL use the IEEE 2030.5 mappings for the Grid DER Support Functions shown in Table 9.

Grid DER Support Functions	IEEE 2030.5 DERControls
Low/High Voltage Ride Through	*opModLVRTMUSTTrip* *opModLVRTMAYTrip* *opModLVRTMomentaryCessation* *opModHVRTMUSTTrip* *opModHVRTMAYTrip* *opModHVRTMomentaryCessation*
Low/High Frequency Ride Through	*opModLFRTMUSTTrip* *opModLFRTMAYTrip* *opModHFRTMUSTTrip* *opModHFRTMAYTrip*

2. File: SunSpecCSIPConformanceTestProceduresV1.2

Tests are described in these sections: Purpose, Setup, Procedure, Pass/Fail Criteria

- BASIC-004 - Basic Inverter Control (Low/High Voltage Ride-Through) [C, A, S]
- BASIC-005 - Basic Inverter Control (Low/High Frequency Ride-Through) [C, A, S]

3. File: 2.2EPC-14-036SmartInverterEvaluationReport

1 thru 4: Low and High Voltage Ride-Through (20% & 100% power)

The IUT must not trip (i.e. disconnect from the grid), during AC voltage excursions outside the normal operating range, during a specified time duration. It must either cease output momentarily, or continue outputting power, depending on the severity of the voltage deviation, while sustaining its electrical connection to the grid, according to the criteria set forth in Table 2. The inverter must trip for time durations longer than the ride-through times specified.

Table 1. Criteria for Low and High Voltage Ride-Through Tests

Region	Voltage at PCC (% Nominal Voltage)	Ride-Through Until	Operating Mode	Maximum Trip Time (s)
High Voltage 2 (HV2)	$V \geq 120$			0.16 sec.
High Voltage 1 (HV1)	$110 < V < 120$	12 sec.	Momentary Cessation	13 sec.
Near Nominal (NN)	$88 \leq V \leq 110$	Indefinite	Continuous Operation	Not Applicable
Low Voltage 1 (LV1)	$70 \leq V < 88$	20 sec.	Mandatory Operation	21 sec.
Low Voltage 2 (LV2)	$50 \leq V < 70$	10 sec.	Mandatory Operation	11 sec.
Low Voltage 3 (LV3)	$V < 50$	1 sec.	Momentary Cessation	1.5 sec.

5 & 6: Low and High Frequency Ride-Through

The IUT must continue to output power to the grid during AC frequency excursions of specified duration and deviation from the normal operating frequency of 60 Hz, as set forth in Table 2.

The IUT must trip for time durations longer than the specified ride-through times.

Table 2. Criteria for Low and High Frequency Ride-Through Tests

Region	System Frequency Default Settings	Minimum Range of Adjustability (Hz)	Ride-Through Until (s)	Ride-Through Operational Mode	Trip Time (s)
High Frequency 2 (HF2)	$f > 62$	62.0 – 64.0	No Ride-Through	Not Applicable	0.16
High Frequency 1 (HF1)	$60.5 < f \leq 62$	60.1 – 62.0	299	Mandatory Operation	300
Near Nominal (NN)	$58.5 < f \leq 60.5$	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Low Frequency 1 (LF1)	$57.0 < f \leq 58.5$	57.0 – 59.9	299	Mandatory Operation	300
Low Frequency 2 (LF2)	$f \leq 57.0$	53.0 – 57.0	No Ride-Through	Not Applicable	0.16

3. IEC 61850

IEC 61850 Logical Nodes for Voltage trip

Voltage trip function	IEC 61850 data object (LN.DO)	Clarification and additional test instructions
HV Trip Curve Points	DHVT.TrZnSt PTOV.TmVCrv	Status of high-voltage trip function Trip function *V*-time curve
LV Trip Curve Points	DLVT.TrZnSt PTUV.TmVCrv	Status of low-voltage trip function Trip function *V*-time curve

IEC 61850 Logical Nodes for Frequency trip

Frequency-trip function	IEC 61850 data object (LN.DO)	Clarification and additional test instructions
HF Trip Curve Points	DHFT.TrZnSt PTOF.StrVal	Status of high-frequency trip function Frequency or frequency rate change setting; if this level is exceeded and other settings permit it, the device trips.
LF Trip Curve Points	DLFT.TrZnSt PTUF.StrVal	Status of low-frequency trip function Frequency or frequency rate change setting; if this level is exceeded and other settings permit it, the device trips.

4. UL 1741, 9741

1 thru 4: Protective/Voltage Ride-through - SA09:

Table SA9.1
Example operating parameters that correspond to Rule 21 L/HVRT[a]

Region	Voltage (% Nominal Voltage)	Ride-Through Until	Operating Mode	Maximum Trip Time (s)
High Voltage 2 (HV2)	$V \geq 120$	Not Applicable	Not Applicable	0.16 s
High Voltage 1 (HV1)	$110 < V < 120$	12 s	Momentary Cessation	13 s
Near Nominal (NN)	$88 \leq V \leq 110$	Indefinite	Continuous Operation	Not Applicable

[a] While these operating parameters correspond to the Rule 21 parameters, they may be substituted with operating parameters for other area EPS requirements.
Note 1: Manufacturer may evaluate product over wider ranges of adjustment than those within the table.
Note 2: The table voltage could be either at the PCC or equipment terminals.
Note 3: For LV3 or HV1 the EUT shall cease to energize in not more than 0.16 s (and not trip). This may differ in other SRD(s).

5 & 6: Protective/Frequency Ride-through - SA10:

Table SA10.1
Example operating parameters that correspond to Rule 21 L/HFRT[a]

Region	System Frequency Default Settings	Minimum Range of Adjustability (Hz)	Ride-Through Until (s)	Ride-Through Operational Mode	Trip Time (s)
High Frequency 2 (HF2)	f > 62	62.0 – 64.0	No Ride-Through	Not Applicable	0.16
High Frequency 1 (HF1)	60.5 < f ≤ 62	60.1 – 62.0	299	Mandatory Operation	300
Near Nominal (NN)	58.5 < f ≤ 60.5	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Low Frequency 1 (LF1)	57.0 < f ≤ 58.5	57.0 – 59.9	299	Mandatory Operation	300
Low Frequency 2 (LF2)	f ≤ 57.0	53.0 – 57.0	No Ride-Through	Not Applicable	0.16

[a] While these operating parameters correspond to the Rule 21, 2015 parameters they may be substituted with operating parameters for other area EPS requirements.

Note 1: Manufacturer may evaluate product over wider ranges of adjustment than those within the table.

Note 2: Frequency / Watt functionality is an option under the Rule 21, 2015 filing.

5. IEEE 1547-1

- Ride Thru (voltage: Section 6.4, frequency: Section 6.5):

Table 16—Voltage ride-through requirements for DER of abnormal operating performance Category III (see Figure H.9)

Voltage range (p.u.)	Operating mode/response	Minimum ride-through time (s) (design criteria)	Maximum response time (s) (design criteria)
$V > 1.20$	Cease to Energize[a]	N/A	0.16
$1.10 < V \leq 1.20$	Momentary Cessation[b]	12	0.083
$0.88 \leq V \leq 1.10$	Continuous Operation	Infinite	N/A

[a] Cessation of current exchange of DER with Area EPS in not more than the maximum specified time and with no intentional delay. This does not necessarily imply disconnection, isolation, or a trip of the DER. This may include momentary cessation or trip.
[b] Temporarily cease to energize an EPS, while connected to the Area EPS, in response to a disturbance of the applicable voltages or the system frequency, with the capability of immediate restore output of operation when the applicable voltages and the system frequency return to within defined ranges.
[c] The voltage threshold between mandatory operation and momentary operation may be changed by mutual agreement between the Area EPS operator and DER operator, for example to allow the DER to provide Dynamic Voltage Support below 0.5 p.u.

Table 19—Frequency ride-through requirements for DER of abnormal operating performance Category I, Category II, and Category III (see Figure H.10)

Frequency range (Hz)	Operating mode	Minimum time (s) (design criteria)
$f > 62.0$	No ride-through requirements apply to this range	
$61.2 < f \leq 61.8$	Mandatory Operation[a]	299
$58.8 \leq f \leq 61.2$	Continuous Operation[a,b]	Infinite[c]
$57.0 \leq f < 58.8$	Mandatory Operation[b]	299
$f < 57.0$	No ride-through requirements apply to this range	

[a] Any DER shall provide the frequency-droop (frequency-power) operation for high-frequency conditions specified in 6.5.2.7.

[b] DER of Category I may provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7. DER of Category II or Category III shall provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7.

[c] For a per-unit ratio of Voltage/frequency limit of V/f ≤ 1.1.

- Trip:

Table 13—DER response (shall trip) to abnormal voltages for DER of abnormal operating performance Category III (see Figure H.9)

Shall trip—Category III				
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
OV2	1.20	0.16	fixed at 1.20	fixed at 0.16
OV1	1.10	13.0	1.10–1.20	1.0–13.0
UV1	0.88	21.0	0.0–0.88	21.0–50.0
UV2	0.50	2.0	0.0–0.50	2.0–21.0

[a] The Area EPS operator may specify other voltage and clearing time trip settings within the range of allowable settings, e,g., to consider Area EPS protection coordination.

[b] Nominal system voltages stated in ANSI C84.1, Table 1 or as otherwise defined by the Area EPS operator. The ranges of allowable settings do not mandate a requirement for the DER to ride through this magnitude and duration of abnormal voltage condition. The Area EPS operator may specify the voltage thresholds and maximum clearing times within the ranges of allowable settings; settings outside of these ranges shall only be allowed as necessary for DER equipment protection and shall not conflict with the voltage disturbance ride-through requirements specified in 6.4.2. For the overvoltage (OV) and undervoltage (UV) trip functions clearing time ranges and for the OV trip functions voltage ranges, the lower value is a limiting requirement (the setting shall not be set to lower values) and the upper value is a minimum requirement (the setting may be set above this value). For the UV trip functions voltage ranges, the upper value is a limiting requirement (the setting shall not be set to greater values) and the lower value is a minimum requirement (the setting may be set to lower values).

Table 18 —DER response (shall trip) to abnormal frequencies for DER of abnormal operating performance Category I, Category II, and Category III (see Figure H.10)

Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Frequency[c] (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s)
OF2	62.0	0.16	61.8–66.0	0.16–1 000.0
OF1	61.2	300.0	61.0–66.0	180.0–1 000.0
UF1	58.5	300.0[c]	50.0–59.0	180.0–1 000
UF2	56.5	0.16	50.0–57.0	0.16–1 000

[a] The frequency and clearing time set points shall be field adjustable. The actual applied underfrequency (UF) and overfrequency (OF) trip settings shall be specified by the Area EPS operator in coordination with the requirements of the regional reliability coordinator. If the Area EPS operator does not specify any settings, the default settings shall be used.

[b] The ranges of allowable settings do not mandate a requirement for the DER to ride through this magnitude and duration of abnormal frequency condition. The Area EPS operator may specify the frequency thresholds and maximum clearing times within the ranges of allowable settings; settings outside of these ranges shall only be allowed as necessary for DER equipment protection and shall not conflict with the frequency disturbance ride through requirements specified in 6.5.2. For the overfrequency (OF) and underfrequency (UF) trip functions clearing time ranges and for the OF trip functions frequency ranges, the lower value is a limiting requirement (the setting shall not be set to lower values) and the upper value is a minimum requirement (the setting may be set above this value). For the UF trip functions frequency ranges, the upper value is a limiting requirement (the setting shall not be set to greater values) and the lower value is a minimum requirement (the setting may be set to lower values).

[c] This time shall be chosen to coordinate with typical regional underfrequency load shedding programs and expected frequency restoration time.

- Reconnect
    - Voltage Ride thru: 300 seconds (IEEE1547-2018) 15 seconds (Rule 21)
    - Frequency Ride thru: 300 seconds (IEEE1547-2018) 15 seconds (Rule 21)

Voltage Ride thru: Section 5.4

Table 5—Category III LVRT Test Conditions

Test Condition	Residual Voltage (p.u.)	Minimum Duration [a] (s)	From-To Time	Required DER Mode of Operation [b]
A	0.88–1.00	5	t0–t1	Continuous Operation
B	0.00–0.05	1	t1–t2	Momentary Cessation
C	0.00–0.50	10	t1–t3	Mandatory Operation
D	0.50–0.70	20	t1–t4	Mandatory Operation
E	0.88–1.00	120	t4–t5	Continuous Operation
E'	0.86–0.90	120	t4–t5	Continuous Operation

[a] The minimum duration times are cumulative including all prior test conditions in the sequence at the same or lower magnitude.

[b] During each test condition specified in column 1 the EUT is required to operate in the mode shown in column 5

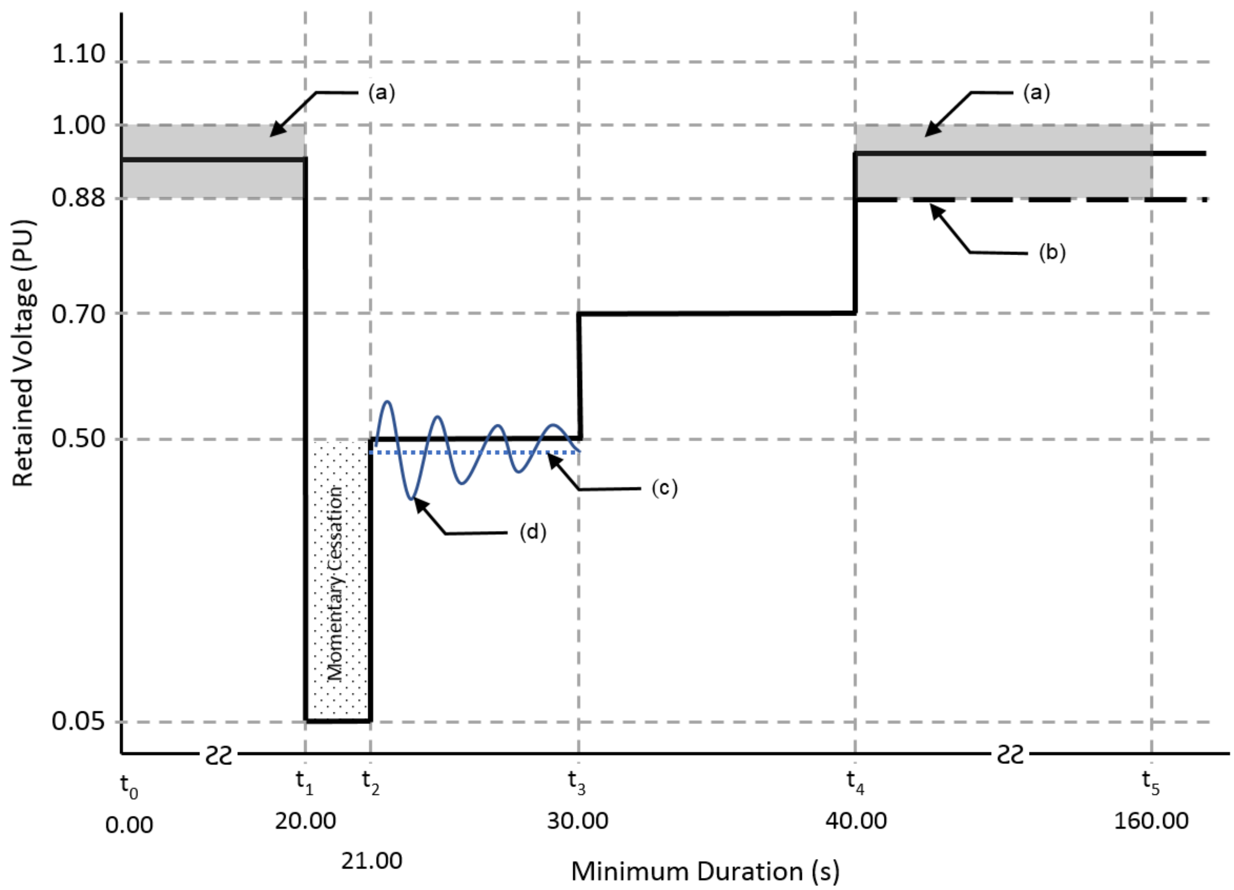
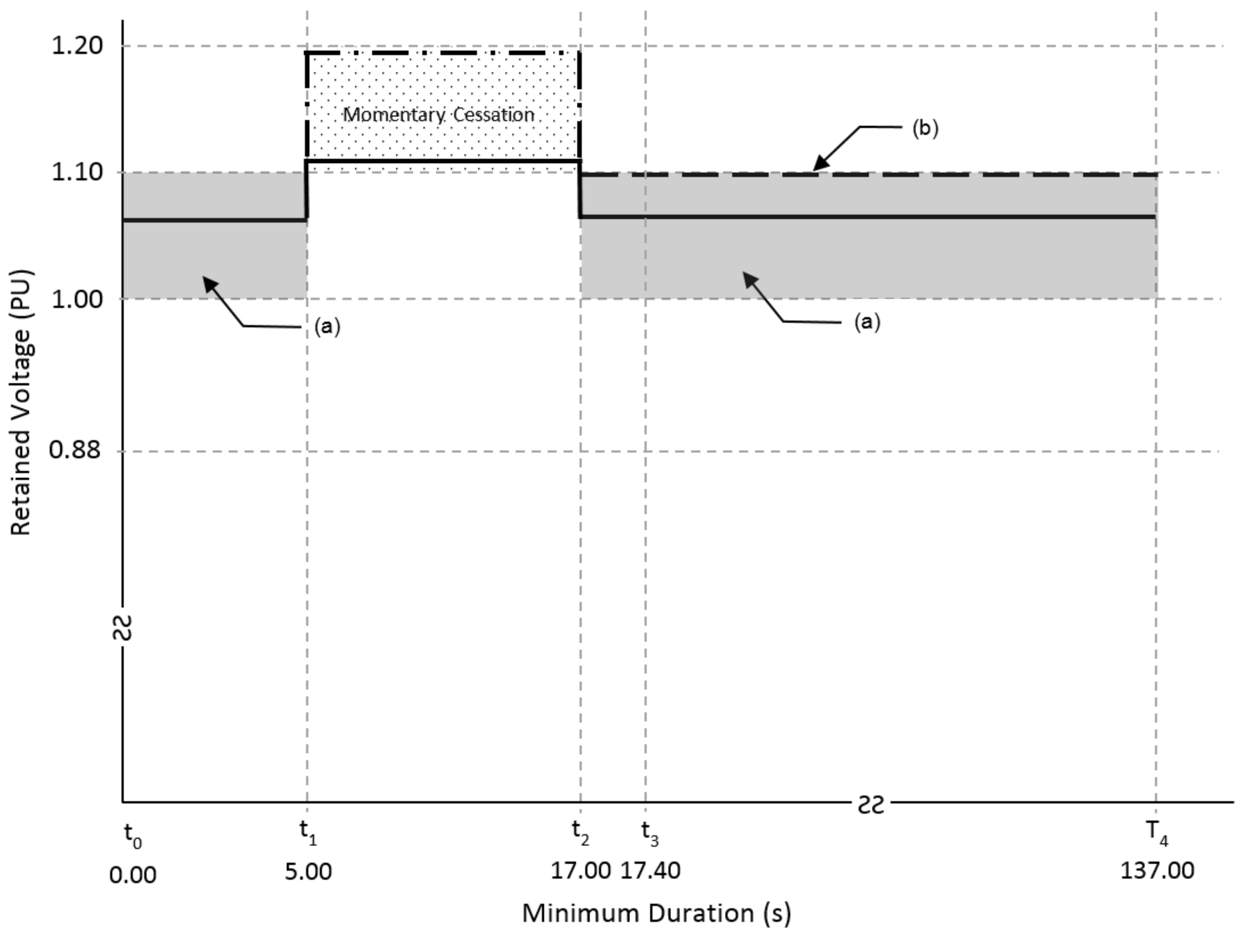


Table 9—Category III HVRT Test Conditions

Test Condition	Residual Voltage (p.u.)	Minimum Duration [a] (s)	From-To Time	Mode of Operation
A	1.00–1.10	5	t0–t1	Continuous Operation
B	1.10–1.12	12	t1–t2	Momentary Cessation
C	1.18–1.20	12	t1–t2	Momentary Cessation
D	1.00–1.10	120	t4–t5	Continuous Operation
D'	1.08–1.12	120	t4–t5	Continuous Operation

[a] The minimum duration times are cumulative including all prior test conditions in the sequence at the same or greater magnitude.



Frequency Ride thru: Section 5.5

G. Industry's Power Stability/Modulation Updates Summary

Power Stability/Modulation Summary

Note: This document intends to identify the additional information and references for each requirement of this category summation. Each item is linked to all of the subsequent standards text, figures and tables to fully describe each requirement and test from both a software and hardware perspective. SAE J3072:2020 will be updated with the expected publication by June 2020.

1. IEEE 2030.5

Item	Function	Rule 21 Function	IEEE 2030.5 Resource	Rule 21 sections
1	Reactive Power	P1 - Fixed Power Factor	opModFixedPFInjectW, opModFixedPFAbsorbW	Hh.2.i
2	Reactive Power	Dynamic Volt/Var Operations	opModVoltVar	Hh.2.j (Table Hh-4)
3	Power Quality	Operation & Reconnect Ramp Control	setSoftGradW setGradW	Hh.2.k
4	Frequency-Watt Curve	P3 - Function 5: Frequency Watt Mode	opModFreqWatt	Hh.2.l
5	Volt-Watt Curve	P3 - Function 6: Volt Watt Mode	opModVoltWatt	Hh.2.m

7. Fixed Power Factor
    a. IEEE 2030.5 command: opModFixedPFInjectW, opModFixedPFAbsorbW
    b. Rule 21 sections: Producer shall provide adequate reactive power compensation on site to maintain the Smart Inverter power factor near unity at rated output or a Distribution Provider specified power factor in accordance with the following requirements:
        i. Default Power Factor setting: Absorbing reactive power at 0.95 lagging power factor.
    c. Aggregate generating facility is greater than 15 kW: 1.0 +/- 0.15 (0.85 Lagging to 0.85 Leading) down to 20% rated power irrespective of real power production.
    d. Aggregate generating facility is less than or equal to 15 kW: 1.0 +/- 0.10 (0.90 Lagging to 0.90 Leading) down to 20% rated power irrespective of real power production.
8. Dynamic Volt/Var Operations

   a. IEEE 2030.5 command: opModVoltVar
   b. Rule 21 sections: The Smart Inverter shall be capable of operating dynamically within a power factor range of +/- 0.85 PF for larger (>15 kW) systems, down to 20% of rated active power, and +/- 0.9 PF for smaller systems (≤15 kW), down to 20% of rated active power, irrespective of real power production. This dynamic volt/var capability shall be able to be activated or deactivated in accordance with Distribution Provider requirements.
   c. The Distribution Provider may permit or require the Smart Inverter systems to operate in larger power factor ranges, including in 4-quadrant operations for storage systems with the implementation of additional anti-islanding protection as determined by the Distribution Provider.
   d. The Smart Inverter shall be capable of providing dynamic reactive power compensation (dynamic Volt/Var operation) within the following constraints:
      i. The Smart Inverter shall be able to consume reactive power in response to an increase in line voltage, and produce reactive power in response to a decrease in line voltage.
      ii. The reactive power provided shall be per the range irrespective of real power production, but the maximum reactive power provided to the system shall be as directed by the Distribution Provider.
      iii. Reduction of real power production is allowed to meet the required reactive power ranges.

9. Operation & Reconnect Ramp Control
   a. IEEE 2030.5 command: setSoftGradW
   b. Rule 21 section: The Smart Inverter is required to have the following ramp controls for at least the following conditions. These functions can be established by multiple control functions or by one general ramp rate control function. Ramp rates are contingent upon sufficient energy available from the Smart Inverter.
      i. Normal ramp-up rate: For transitions between energy output levels over the normal course of operation. The default value is 100% of maximum current output per second with a range of adjustment between 1% to 100%, with specific setting as mutually agreed by the Distributor Provider and the Producer.
      ii. Connect/Reconnect Ramp-up rate: Upon starting power into the grid, following a period of inactivity or a disconnection, the inverter shall be able to control its rate of increase of power from 1 to 100% maximum current per second. The default value is 2% of maximum current output per second with specific settings as mutually agreed upon by the Distributor Provider and the Producer.

10. Frequency Watt Mode
   a. IEEE 2030.5 command: opModFreqWatt
   b. Rule 21 section: This requirement will become mandatory for Generating Facilities utilizing inverter-based technologies for which an Interconnection Request is submitted beginning February 22, 2019. The utilization of this function is permissible under mutual

agreement between Distribution Provider and the generating facility before the effective date. Smart inverters shall reduce their real power production as a function of system frequency in accordance with the following:

i. When system frequency exceeds 60.036 Hz, the active power output produced by the Smart Inverter shall be reduced by 50% of real power nameplate rating per hertz (5% of real power nameplate rating reduction per 0.1 hertz)
ii. When system frequency moves under 59.964 Hz, the active power output produced by the Smart Inverter shall be increased by 50% of real power nameplate rating per hertz (5% of real power nameplate rating increase per 0.1 hertz) when inverter is capable of increasing real power production.
iii. The default dead-band should be +/- 0.036 Hz from 60 hertz (59.964 Hz to 60.036 Hz). When the system frequency is in range of 59.964 Hz and 60.0364 Hz, the Smart Inverter is not required to increase or decrease power as a function of system frequency.

11. Volt Watt Mode
    a. IEEE 2030.5 command: opModVoltWatt
    b. Rule 21 section: This requirement will become mandatory for Generating Facilities utilizing inverter-based technologies for which an Interconnection Request is submitted beginning February 22, 2019. The utilization of this function is permissible under mutual agreement between Distribution Provider and the generating facility before the effective date. Smart Inverters shall reduce their real power production as a function measured voltage at the inverter terminal or at the Generating Facility Point of Common Coupling (PCC) in accordance with the following:
        i. When the measured voltage is greater than 106% of nominal voltage (Example: 127.2 volts on a 120 volts nominal), the export of active power at the PCC or the production of active power by the Smart Inverter shall be reduced at a rate of 25% of active power nameplate rating per one percent of nominal voltage. Figure Hh-3 Volt-Watt Requirements illustrate the required rate of reduction. When export of active power is controlled, a certified inverter and control system shall be used.
        ii. When the measured voltage is greater than 110% of nominal voltage (Example: 132 volts on 120 volts nominal), the export of active power to the grid at the PCC or the production of active power by the Smart Inverter shall be reduced to 0 watts

2. Sunspec

- **File: CSIPImplementationGuidev2.103-15-2018**

DER Clients SHALL use the IEEE 2030.5 mappings for the Grid DER Support Functions shown in Table 9.

Grid DER Support Functions	IEEE 2030.5 DERControls	IEEE 2030.5 DefaultDERControls
1 - Fixed Power Factor Control	opModFixedPF	opModFixedPF
2 - Dynamic Volt-VAr Operations	opModVoltVar	opModVoltVar
3 – Operation and Reconnect Ramp Rate Setting		*setGradW* *setSoftGradW*
4 - Frequency-Watt Control	*opModFreqWatt*	*opModFreqWatt*
5 - Volt-Watt Control	*opModVoltWatt*	*opModVoltWatt*

Table 9 – Grid DER Support Functions to IEEE 2030.5 Control Mapping.

- **File: SunSpecCSIPConformanceTestProceduresV1.2**

1. Fixed Power Factor

BASIC-008 - Basic Inverter Control (Fixed Power Factor) [C, A, S]

Function	IEEE 2030.5 Control	Control Type
Fixed Power Factor	`opModFixedPFInjectW`	Immediate

Setting	Default	Test Values
opModFixedPFInjectW.displacement	950	900
opModFixedPFInjectW.excitation	false	false
opModFixedPFInjectW.multiplier	-3	-3

Figure 8 Fixed Power Factor Settings

2. Dynamic Volt/Var Operations

BASIC-006 - Basic Inverter Control (Volt/Var) [C, A, S]

Function	IEEE 2030.5 Control	Control Type
Volt-VAr	`opModVoltVar`	Curve

Setting	Default	Test Values
opModVoltVar.DERCurve.CurveData	(9200, 3000), (9670, 0), (10300, 0), (10700, -3000)	(9100, 4000), (9570, 0), (10400, 0), (10600, -4000)
opModVoltVar.DERCurve.openLoopTms	10	5
opModVoltVar.DERCurve.autonomousVrefEnable	false	false
opModVoltVar.DERCurve.autonomousVrefTimeContant	0	0
DERCurve.curveType	11	11
DERCurve.xMultiplier	-2	-2
DERCurve.yMultiplier	-2	-2

Figure 6 Volt-VAr Settings

3. Operation & Reconnect Ramp Control

BASIC-007 - Basic Inverter Control (Ramp Rates) [C, A, S]

Function	IEEE 2030.5 Control	Control Type
Ramp Rate Setting	setGradW setSoftGradW	Default-Only

Setting	Default	Test Values
Default.DERControl.setGradW	10000 (100%)	9000
Default.DERControl.setSoftGradW	200 (2%)	400

Figure 7 Ramp Rates Settings

4. Frequency Watt Mode

BASIC-012 - Basic Inverter Control (Frequency-Watt) [C, A, S]

Function	IEEE 2030.5 Control	Control Type
Frequency-Watt	`opModFreqWatt`	Curve

Setting	Default	Test Values
opModFreqDroop.dBOF	60036 (60.036)	60030
opModFreqDroop.dBUF	59964 (59.964)	59970
opModFreqDroop.kOF	50 (.05)	40
opModFreqDroop.kUF	50 (.05)	40
opModFreqDroop.openLoopTms	500 (5 sec)	600
opModFreqWatt.DERCurve.CurveData		(5900,100), (5950,80), (6050,80), (6200, 0)
DERCurve.curveType		0
DERCurve.xMultiplier		-2
DERCurve.yMultiplier		0
DERCurve.yRefType		1

Figure 12 Frequency-Watt Settings

5. Volt Watt Mode

BASIC-011 - Basic Inverter Control (Volt-Watt) [C, A, S]

Function	IEEE 2030.5 Control	Control Type
Volt-Watt	`opModVoltWatt`	Curve

Setting	Default	Test Values
opModVoltWatt.DERCurve.CurveData	(10000,10000), (10600,10000), (11000, 0)	(10000,10000), (10500,10000), (10900, 0)
DERCurve.curveType	12	12
DERCurve.xMultiplier	-2	-2
DERCurve.yMultiplier	-2	-2
DERCurve.yRefType	1	1

Figure 11 Volt-Watt Settings

- **File: 2.2EPC-14-036SmartInverterEvaluationReport**

1. Fixed Power Factor

Specified Power Factor: The default setting for inverters is a power factor (PF) of 1.0 (i.e., real power only). CA Rule 21 compliant inverters will have the capability to change their power factor from 1.0 to a minimum inductive value, typically about 0.8; and from 1.0 to a minimum capacitive value, typically about -0.8. The IUT should respond to system commands to change its power factor to either output or absorb VARs for according to whether the grid voltage is below the normal range or above it, to help regulate the voltage back to the normal range. Inverters are tested at their maximum and minimum inductive and capacitive points, and at midpoints (halfway between min/max points and 1.0). Table 5 lists the criteria for determining the specified power factor test points.

Test #	PF command	P_X
1	1	P_{rated}
2	$PF_{min,ind}$	$S_{rated} \cdot PF_{min,ind}$
3	$PF_{mid,ind}$	$S_{rated} \cdot PF_{mid,ind}$
4	$PF_{min,cap}$	$S_{rated} \cdot PF_{min,cap}$
5	$PF_{mid,cap}$	$S_{rated} \cdot PF_{mid,cap}$

Table 5. Criteria for Determining Power Factors for Specified Power Factor Tests

2. Dynamic Volt/Var Operations

This function allows the IUT to responds to AC grid voltage fluctuations on a dynamic basis by supplying or absorbing VARs to help maintain AC voltage within specified limits. In other words, when grid voltage goes above the normal range, the inverter should absorb reactive power from the grid to help reduce the system voltage; when voltage is too low, the inverter should export reactive power to help raise the voltage. When the grid voltage is close to or within the normal range (between 90 % and 110% of the nominal voltage), the inverter should operate at 1.0 PF. Rule 21 allows this function to be “most aggressive” (providing fast and strong VAr support), “average” (moderately fast and strong VAr support), or “least aggressive” (slower and lower VAr support), depending on system requirements. Specifications for setting the different types of curve are listed in Table 6.

Test	Characteristic Curve	Volt/Var [V,Q] Array			
1	Characteristic 1 “Most Aggressive” Curve (Figure 11)	V1	$Q_1/K_{VARmax} + V_2$	Q1	$Q_{max,cap}$
		V2	V_{nom} - $Deadband_{min}/2$	Q2	0
		V3	V_{nom} + $Deadband_{min}/2$	Q3	0
		V4	$Q_4/K_{VARmax} + V_3$	Q4	$Q_{max,ind}$
2	Characteristic 2 “Average” Curve (Figure 12)	V1	$Q_1/K_{VARavg} + V_2$	Q1	$0.50*Q_{max,cap}$
		V2	V_{nom} - $Deadband_{avg}/2$	Q2	0
		V3	V_{nom} + $Deadband_{avg}/2$	Q3	0
		V4	$Q_4/K_{VARavg} + V_3$	Q4	$0.50*Q_{max,ind}$
3	Characteristic 3 “Least Aggressive” Curve (Figure 13)	V1	$Q_1/K_{VARmin} + V_2$	Q1	$0.25*Q_{max,cap}$[40]
		V2	V_{nom} - $Deadband_{max}/2$	Q2	0
		V3	V_{nom} + $Deadband_{max}/2$	Q3	0
		V4	$Q_4/K_{VARmin} + V_3$	Q4	$0.25*Q_{max,ind}$

Table 6. Criteria for Calculating Volt-VAr Curve Parameters

Volt-VAr characteristic #1:

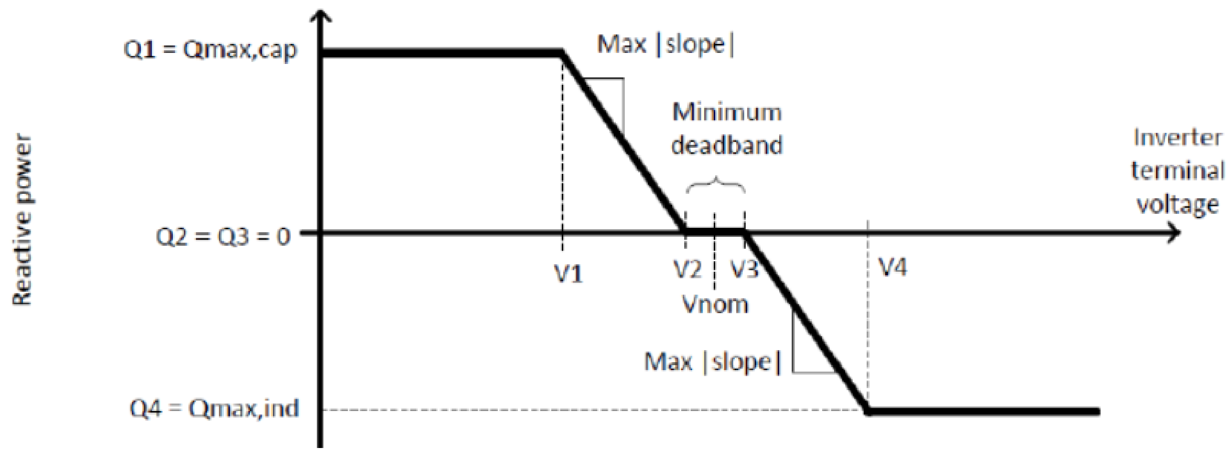


Figure 3. "Most Aggressive" Volt-VAr Curve

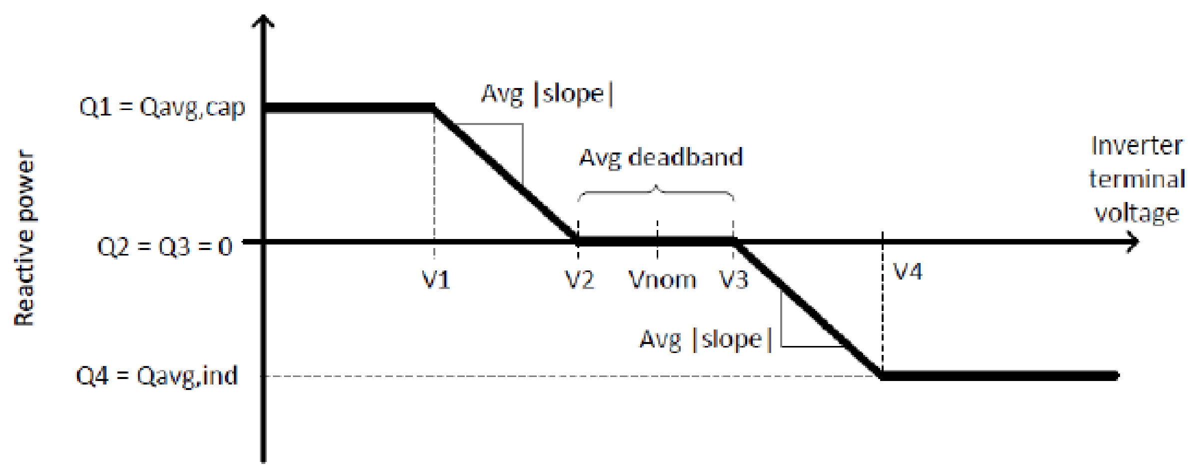


Figure 4. "Average" Volt-VAr Curve

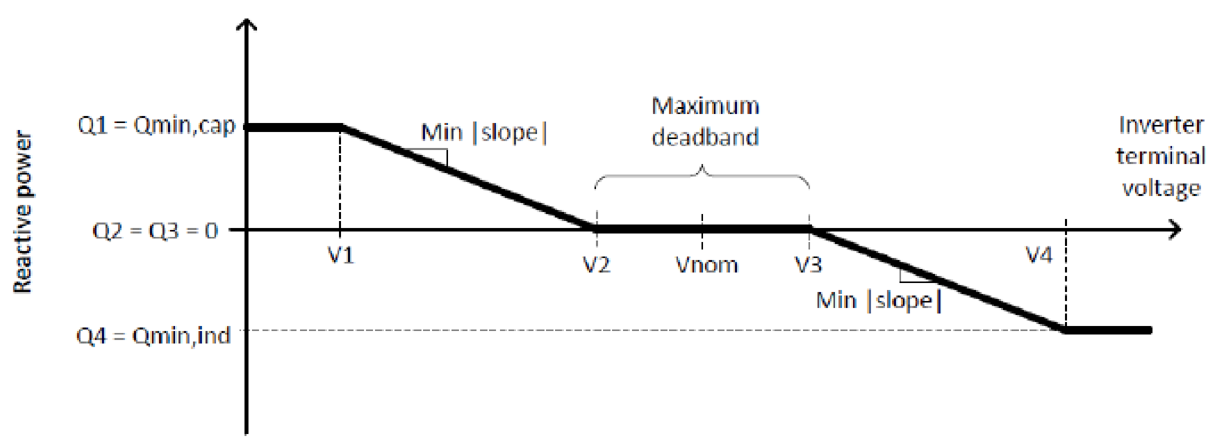


Figure 5. "Least Aggressive" Volt-VAr Curve

3. Operation & Reconnect Ramp Control

Normal and Soft-Start Ramp Rates

Ramping is a measure of how fast the output of the inverter transitions from one power level to another. Under some conditions, such as aggregated DERs which might tend to act as a larger entity than a single DER, it may be desirable to adjust the ramp rates to avoid large, sharp jumps in power level. Such jumps could cause power quality or other issues for the grid.

Normal Ramping is employed for routine operation, as when the inverter is following the output of a PV system. Normal ramping criteria for Rule 21 tests are given in Table 3. Soft-Start Ramping is intended for smoothing transitions from zero power level to the desired power level, a key application being restarting after a grid outage. Soft start ramping criteria for Rule 21 tests are given in Table 4.

Test	Independent Normal Up and Down Ramp Rates		Single Normal Ramp Rate for Up and Down Ramps
	Up Ramp Rate RR_{norm_up} (% nameplate watts/sec)	Down Ramp Rate RR_{norm_down} (% nameplate watts/sec)	Ramp Rate RR_{norm} or RR (% nameplate watts/sec)
1	0 (Disabled)	0 (Disabled)	0 (Disabled)
2	$RR_{norm\_up\_min}$	$RR_{norm\_down\_min}$	RR_{norm_min}
3	$(RR_{norm\_up\_min} + RR_{norm\_up\_max})/2$	$(RR_{norm\_down\_min} + RR_{norm\_down\_max})/2$	$(RR_{norm\_min} + RR_{norm\_max})/2$
4	$RR_{norm\_up\_max}$	$RR_{norm\_down\_max}$	RR_{norm_max}
5[30]	$RR_{norm\_up\_max}$	$RR_{norm\_down\_min}$	N/A

Table 3. Criteria for Normal Ramp Rates

Test	Soft-Start Ramp Rate[32] RR_{SS} ($\%P_{rated}$/sec)
1	0 (Disabled)
2	RR_{SS_min}
3	$(RR_{SS\_min} + RR_{SS\_max})/2$
4	RR_{SS_max}

Table 4. Criteria for Soft Start Ramp Rates

4. Frequency Watt Mode

Low and High Frequency Ride-Through

The IUT must continue to output power to the grid during AC frequency excursions of specified duration and deviation from the normal operating frequency of 60 Hz, as set forth in Table 2.

The IUT must trip for time durations longer than the specified ride-through times.

Region	System Frequency Default Settings	Minimum Range of Adjustability (Hz)	Ride-Through Until (s)	Ride-Through Operational Mode	Trip Time (s)
High Frequency 2 (HF2)	f > 62	62.0 – 64.0	No Ride-Through	Not Applicable	0.16
High Frequency 1 (HF1)	60.5 < f ≤ 62	60.1 – 62.0	299	Mandatory Operation	300
Near Nominal (NN)	58.5 < f ≤ 60.5	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Low Frequency 1 (LF1)	57.0 < f ≤ 58.5	57.0 – 59.9	299	Mandatory Operation	300
Low Frequency 2 (LF2)	f ≤ 57.0	53.0 – 57.0	No Ride-Through	Not Applicable	0.16

Table 2. Criteria for Low and High Frequency Ride-Through Tests

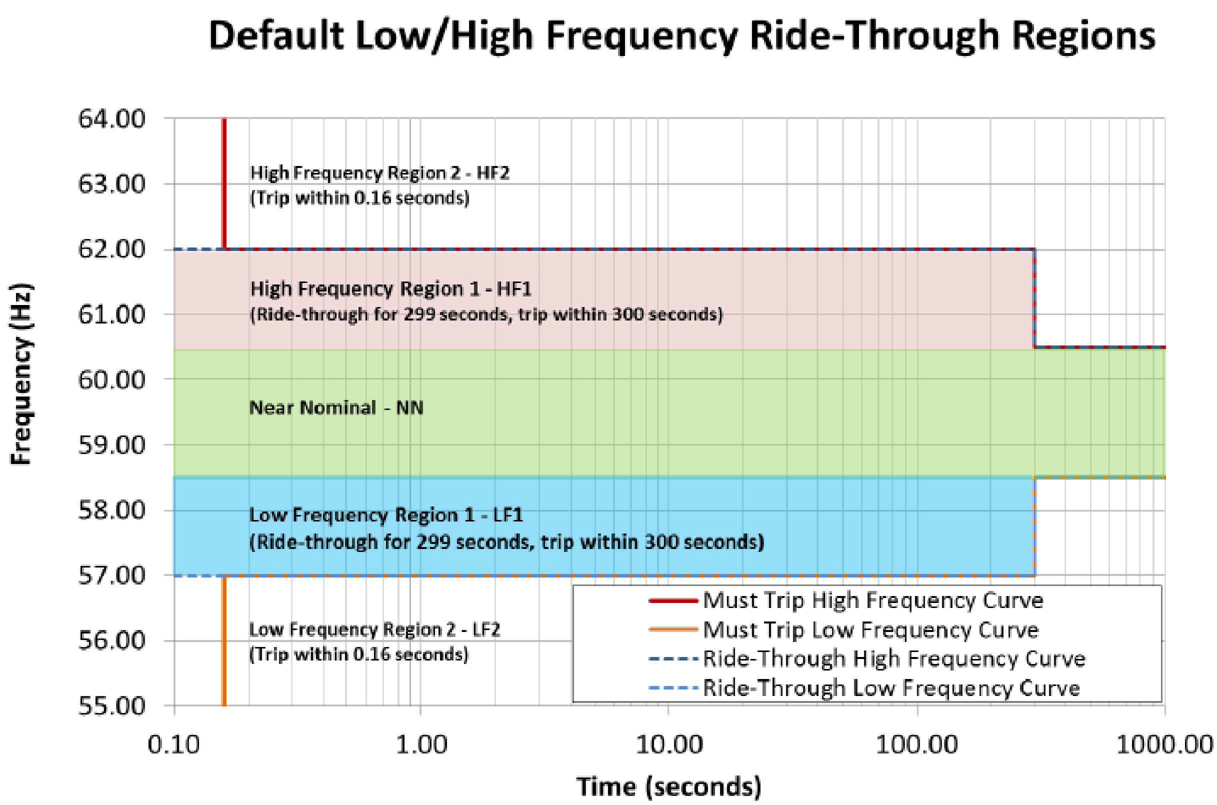


Figure 2. Graphical Representation of Low and High Frequency Ride Through Criteria

HFRT:

1. With the inverter initially at 100% of its rated power, the Grid Simulator is commanded to adjust the AC frequency to 61.985 Hz for 299 sec., followed by 15 seconds at nominal 60 Hz frequency.
2. Step 1 is repeated four additional times.
3. Steps 1 and 2 are repeated with the DC sources adjusted so that the inverter is at 20% rated

power.
4. Test is successful if inverter continues to output power throughout all stages of the test.
LFRT:
1. With the inverter initially at 100% of its rated power, the Grid Simulator is commanded to adjust the AC frequency to 57.115 Hz for 299 sec., followed by 15 seconds at nominal 60 Hz frequency.
2. Step 1 is repeated four additional times.
3. Steps 1 and 2 are repeated with the DC sources adjusted so that the inverter is at 20% rated power.
4. Test is successful if inverter continues to output power throughout all stages of the test.

5. Volt Watt Mode

3. UL 1741, 9741

1 - Fixed Power Factor - SA12 Specified Power Factor

In order to maintain a stable grid voltage, it is desired that inverters be able to supply reactive power to the grid. One way to do this is to have the inverter operate at a specified, non-unity power factor. This test verifies that an EUT operates at a fixed power factor.

2 - Dynamic Volt/Var Operations - SA13 Volt/VAr Mode (Q(V))

In order to maintain a stable grid voltage, it is desired that inverters be able to supply or absorb reactive power to/from the EPS. One way to achieve this is to have the inverter supply or absorb reactive power in response to fluctuations in EPS voltage. The inverter supplies or absorbs reactive power as a function of voltage known as a Q(V) function or Volt-VAr mode. This test verifies that the inverter's Volt-VAr mode implements the reactive power response to fluctuations in EPS voltage.

Inverters can be set to prioritize reactive or active power. This priority setting defines the inverter's behavior when the inverter reaches its kVA limits. Volt-VAr mode can function with active or reactive power priority. When an inverter is set in Volt-VAr mode with reactive power priority and the inverter's apparent power kVA limit is reached, active power is reduced to maintain reactive power production. When an inverter is set in Volt-VAr mode with active power priority and the inverter's apparent power kVA limit is reached, the reactive power is reduced to maximize active power production.

3 - Operation & Reconnect Ramp Control - SA11 SA11 RR – Normal Ramp Rate and SS – Soft-Start Ramp Rate

This test confirms that an inverter meets a given response characteristic for providing ramp rate responses for normal and/or soft-start ramp rate commands. An EUT can change the rate at which they increase their power output. These ramp rates are constrained by what the systems can physically do. For instance, if they are outputting their maximum power, they cannot ramp up, while a completely charged storage system may discharge power into the Area EPS but cannot draw power from the area EPS as it is already completely charged.

The purpose of establishing ramp-up rates for systems is to help smooth transitions from one output level to another output level. Although a single system might not impact the grid through a single sharp transition, aggregated systems responding to a specific event could cause significant rapid jumps in overall output if they do not ramp to the new level. Such sharp transitions could cause power quality issues such as voltage spikes or dips, harmonics, or oscillations.

Table SA11.1 Normal ramp rate test parameters

Test	Ramp-UP Rate RR_{norm_up}(% I_{rated}/sec)
1	$RR_{norm\_up\_min}$
2	$(RR_{norm\_up\_min} + RR_{norm\_up\_max})/2$
3	$RR_{norm\_up\_max}$

Table SA11.2 Soft-start ramp rate test parameters

Test	Soft-Start Ramp Rate RR_{ss}(% P_{rated}/sec)
1	RR_{ss_min}
2	$(RR_{ss\_min} + RR_{ss\_max})/2$
3	RR_{ss_max}

4 - Frequency Watt Mode - SA14 Frequency-Watt (FW)

This test procedure is for the Frequency-Watt function, which is optional, see SA1.7. In order to provide frequency support to the grid, an inverter may change its active power output with changes in grid frequency. As frequency increases, the desired response of the inverter is to decrease active power output. Likewise, as frequency decreases it is desired for the inverter to increase active power output. This increase in power may not always be possible depending on the energy source. This active power response to a change in frequency is referred to as a Freq-Watt or frequency droop function. This test confirms that an inverter meets the Freq-Watt response specifications stated by the manufacturer or as required by a specific SRD.

Depending on the mode of operation and energy source attached to the inverter, both over frequency and under frequency responses may be possible. For energy sources such as solar energy, inverters only export power to the grid. Such inverters may not be capable of increasing active power and so can only provide an over frequency response. Where the inverter output is limited due to a commanded power limit the inverter may be capable of providing both over frequency and under frequency responses.

The Frequency-Watt response tests defined in this supplement are designed only to verify the functionality of the inverter. Performance of an aggregation of multiple inverters may be evaluated but is not mandatory in this test.

5 - Volt Watt Mode - SA15 Volt-Watt (VW)

This test procedure is for the Volt-Watt function, which is optional, see SA1.7. In order to help support the voltage of the grid, an inverter may change its active power output with changes in grid voltage. As voltage increases, the desired response of the inverter is to shed power. Likewise, as voltage decreases it is desired for the inverter to increase power output. This increase in power may not always be possible depending on the energy source and the mode of operation. This active power response to a change in voltage is referred to as a Volt-Watt response function. This test confirms that an inverter meets the Volt-Watt response specifications stated by the manufacturer.

Depending on the mode of operation and energy source attached to the inverter, multiple modes of operation are possible. For limited energy sources such as solar energy, inverters may only provide power to the grid. For inverter applications with energy storage, the inverter may provide or consume power from the grid. These bidirectional inverters add the ability to change from producing power to consuming power in response to grid voltage and vice versa. The bidirectional capability is not covered by this test.

The Volt-Watt response tests defined in this document are designed for verifying the functionality of the inverter. Performance of an aggregation of inverters is beyond the scope of this test.
While these tests verify the inverter's dynamic response, these tests do not address the voltage or frequency stability of the Area EPS.

4. IEEE 1547.1

1 - Fixed Power Factor

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (underexcited) for active power output levels greater than or equal to the minimum steady-state active power capability (P_{min}), or 5% of rated active power, P_{rated} (kW) of the DER, whichever is greater.
When operating at active power output greater than 5% and less than 20% of rated active power, the DER shall be capable of exchanging reactive power up to the minimum reactive power value given in Table 7 multiplied by the active power output divided by 20% of rated active power.
Operation at any active power output above 20% of rated active power shall not constrain the delivery of reactive power injection or absorption, up to the capability specified in Table 7, as required by the active control function at the time, as defined in 5.3. Curtailment of active power to meet apparent power constraints is permissible. These reactive power requirements are illustrated in informative Figure H.3.60

Table 7 —Minimum reactive power injection and absorption capability

Category	Injection capability as % of nameplate apparent power (kVA) rating	Absorption capability as % of nameplate apparent power (kVa) rating
A (at DER rated voltage)	44	25
B (over the full extent of ANSI C84.1 range A)	44	44

1 & 2 - Fixed & Dynamic Power Factor

Table 8 —Voltage-reactive power settings for normal operating performance Category A and Category B DER

Voltage-reactive power parameters	Default settings		Ranges of allowable settings	
	Category A	Category B	Minimum	Maximum
V_{Ref}	V_N	V_N	0.95 V_N	1.05 V_N
V_2	V_N	V_{Ref} – 0.02 V_N	Category A: V_{Ref} Category B: V_{Ref} – 0.03 V_N	V_{Ref} [c]
Q_2	0	0	100% of nameplate reactive power capability, absorption	100% of nameplate reactive power capability, injection
V_3	V_N	V_{Ref} + 0.02 V_N	V_{Ref}[c]	Category A: V_{Ref} Category B: V_{Ref} + 0.03 V_N
Q_3	0	0	100% of nameplate reactive power capability, absorption	100% of nameplae reactive power capability, injection
V_1	0.9 V_N	V_{Ref} – 0.08 V_N	V_{Ref} – 0.18 V_N	V_2 – 0.02 V_N[c]
Q_1[a]	25% of nameplate apparent power rating, injection	44% of nameplate apparent power rating, injection	0	100% of nameplate reactive power capability, injection[b]
V_4	1.1 V_N	V_{Ref} + 0.08 V_N	V_3+0.02 V_N[c]	V_{Ref} + 0.18 V_N
Q_4	25% of nameplate apparent power rating, absorption	44% of nameplate apparent power rating, absorption	100% of nameplate reactive power capability, absorption	0
Open loop response time	10 s	5 s	1 s	90 s

3 - Operation & Reconnect Ramp Control

During entering service, the DER shall be capable of the following:

a) Prevent *enter service* when permit service setting is disabled.

b) DER shall be capable of delaying *enter service* by an intentional adjustable minimum delay when the Area EPS steady-state voltage and frequency are within the ranges specified in Table 4. The adjustable range of the minimum intentional delay shall be 0 s to 600 s with a default minimum delay of 300 s.

Table 4 —Enter service criteria for DER of Category I, Category II, and Category III

Enter service criteria		Default settings	Ranges of allowable settings
Permit service		Enabled	Enabled/Disabled
Applicable voltage within range	Minimum value	≥ 0.917 p.u.[a]	0.88 p.u. to 0.95 p.u.
	Maximum value	≤ 1.05 p.u.	1.05 p.u. to 1.06 p.u.
Frequency within range	Minimum value	≥ 59.5 Hz	59.0 Hz to 59.9 Hz
	Maximum value	≤ 60.1 Hz	60.1 Hz to 61.0 Hz

[a]This corresponds to the Range B of ANSI C84.1, Table 1, column for service voltage of 120–600 V.

c) DER shall increase output of active power,[50] or exchange of active power for energy-storage-DER, during *enter service* as specified. Active power shall increase linearly, or in a stepwise linear ramp, with an average rate-of-change not exceeding the DER nameplate active power rating divided by the enter service period. The duration of the *enter service* period shall be adjustable over a range of 1 s to 1000 s with a default time of 300 s.[51] The maximum active power increase of any single step during the *enter service* period shall be less than or equal to 20% of the DER nameplate active power rating.
Where a stepwise ramp is used, the rate of change over the period between any two consecutive steps shall not exceed the average rate-of-change over the full *enter service* period. This requirement is a maximum ramp rate requirement and the DER may increase output slower than specified.

Exception 1: For Local EPS that have an aggregate DER rating of less than 500 kVA, individual DER units may increase output of active power with no limitation of the rate-of-change, following an additional randomized time delay with a default maximum time random interval of 300 s, and with an adjustable range for the maximum time random interval of 1 s to 1000 s.

Exception 2: Increase of output of active power by Local EPS having an aggregate DER rating of equal to or greater than 500 kVA and increasing output with active power steps greater than 20% of nameplate active power rating shall require

4 - Frequency Watt Mode

Depending on the DER *abnormal operating performance category* as described in Clause 4, the DER shall
have the capability of *mandatory operation* with frequency-droop (frequency-power) during *low-frequency*
ride-through and *high-frequency ride-through* as specified in Table 22.

Table 22 —Requirements of a frequency-droop (frequency-power) operation for low-frequency conditions and high-frequency conditions for DER of abnormal operating performance Category I, Category II, and Category III

Category	Operation for low-frequency conditions	Operation for high-frequency conditions
I	Optional (may)	Mandatory (shall)
II	Mandatory (shall)	Mandatory (shall)
III	Mandatory (shall)	Mandatory (shall)

During temporary frequency disturbances, for which the system frequency is outside the adjustable deadband db_{OF} and db_{UF} as specified in Table 24, but still between the trip settings

in Table 18, the DER shall adjust its active power output from the pre-disturbance levels, according to the formulas in Table 23.
The active power output shall be as defined by the relevant formula in Table 23, plus any inertial response to the rate of change of frequency, until frequency returns to within the deadband.

Table 24 —Parameters of frequency-droop (frequency-power) operation for DER of abnormal operating performance Category I, Category II, and Category III

Parameter	Default settings[a]			Ranges of allowable settings[b]		
	Category I	Category II	Category III	Category I	Category II	Category III
db_{OF}, db_{UF} (Hz)	0.036	0.036	0.036	0.017[c]–1.0	0.017[c]–1.0	0.017[c]–1.0
k_{OF}, k_{UF}	0.05	0.05	0.05	0.03–0.05	0.03–0.05	0.02–0.05
$T_{response}$ (small-signal) (s)	5	5	5	1–10	1–10	0.2–10

Mandatory frequency tripping requirements

When the system frequency is in a range given in Table 18, and the fundamental-frequency component of voltage on any phase is greater than 30% of nominal, the DER shall *cease to energize* the Area EPS and *trip* within a *clearing time* as indicated.[96] Under and overfrequency tripping thresholds and *clearing times* shall be adjustable over the *ranges of allowable settings* specified in Table 18. The underfrequency and overfrequency trip settings shall be specified by the Area EPS operator in coordination with the requirements of the *regional reliability coordinator*. If the Area EPS operator does not specify any settings, the default settings shall be used.

Table 18 —DER response (shall trip) to abnormal frequencies for DER of abnormal operating performance Category I, Category II, and Category III (see Figure H.10)

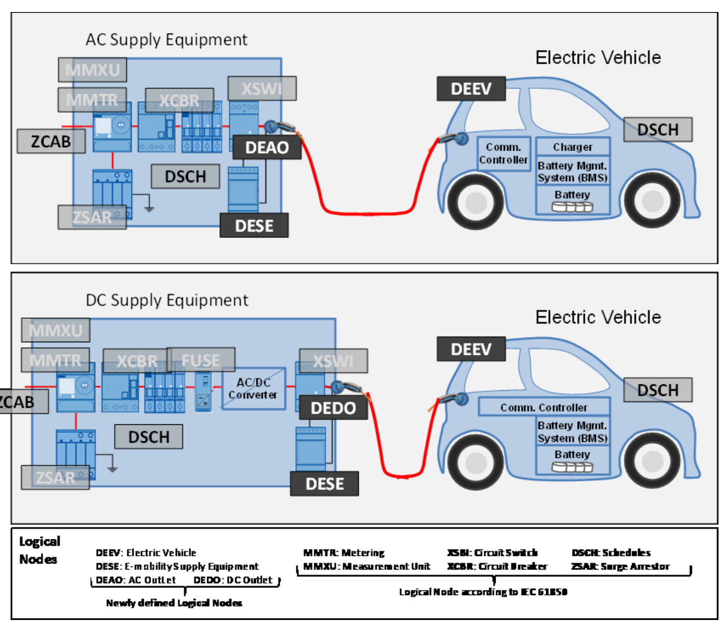
H. IEC 61850-90-8 Object Model for Electric Mobility

IEC 61850-90-8 describes the information model for both DC and AC PEVs connected to EVSEs. The IEC 61850-7-420 standard covers all of the V2G functions.

From a power grid point of view, the operations of AC and DC charging an PEV are very similar. Technically, the difference is in the placement of the charging equipment: on-board for AC charging, off-board for DC charging. This has an influence on the communication requirements between the PEV and the charge spot which is already covered in ISO 15118-2:2014. The real difference is in the services provided to the connected PEV in terms of charging power. Typically, dedicated off-board DC charging equipment provide higher charging power rates.

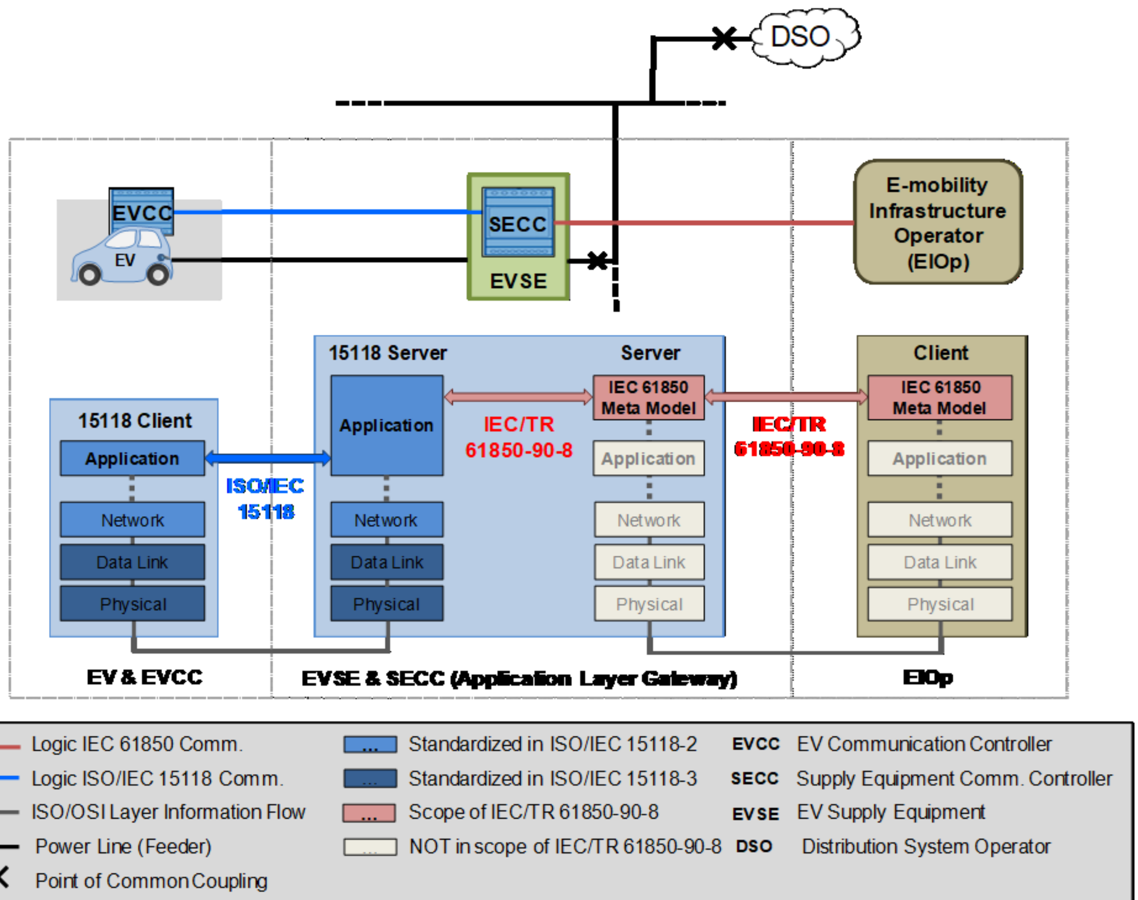
However, from the grid's point of view a PEV connected to an AC or DC EVSE basically has the same need: Power is drawn from the grid connection point based upon requirements of the connected PEV. In that respect it provides the same basic information relevant for power grid operations. Hence this technical report models AC and DC chargers using a very similar LN model shown in the figure below.

Figure H-1: IEC 61850 Logical Nodes overview Based on IEEE VPPC2012



The following is an overview on how charging infrastructure architectures according to ISO 15118-1 may be mapped to an IEC 61850 compliant meta model. This overview is non-exhaustive and only provides a guideline for potential scenarios.

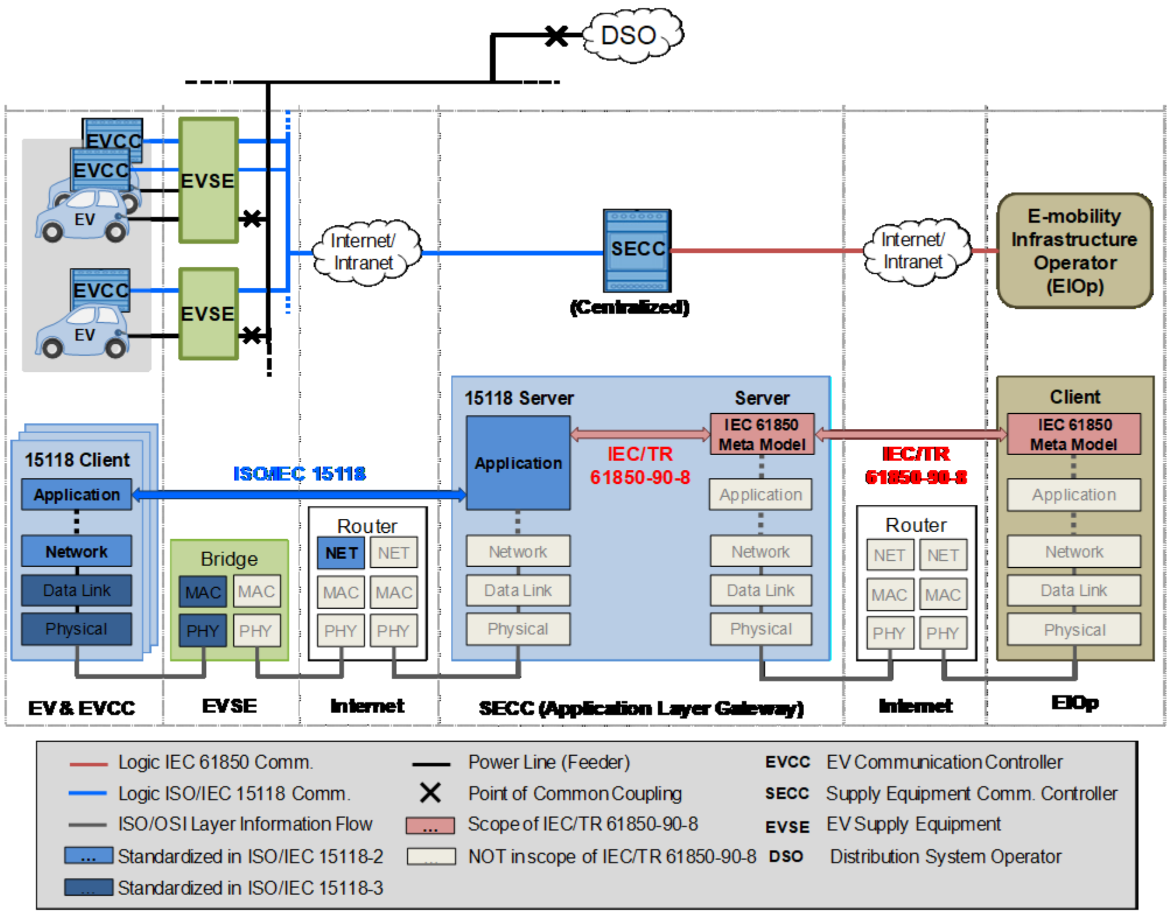
Figure H-2: Basic Concept of Mapping ISO 15118 V2G Communication Interface to IEC 61850 DERs with Dedicated SECC in the EVSE Managing One PEV



In the figures above, the basic architecture concept of the mapping between ISO 15118 and an IEC 61850 meta model is illustrated. According to the ISO 15118-2 V2G communication interface paradigm, the EV Communication Controller (EVCC) is always the client whereas the Supply Equipment Communication Controller (SECC) is always the server. Information provided from the PEV is made available through the V2G communication interface at the ISO 15118 server side. All relevant information is mapped to an IEC 61850 meta model and provided to the client-side (E-mobility Infrastructure Operator).

Note that the above figure only illustrates the mapping between ISO 15118 and IEC 61850 meta model. All other aspects (e. g. IEC 61851-1) are not illustrated.

Figure H-3: Basic Concept of Mapping ISO 15118 V2G Communication Interface to IEC 61850 DERs with Centralized SECC Outside of EVSE Managing a Set of EVs



According to ISO 15118-1, various types of architectures for EVSE and SECC deployment scenarios are possible. The second figure illustrates how a centralized SECC with optional bridges and routers in the communication path between the EVCC and SECC may be deployed in order to manage a set of EVSEs. In this case, each EVSE handles safety related functions (*e.g.*, IEC 61851-1) but the SECC handles all high-level communication for a whole set of EVs being connected to respective EVSEs. The EVCC does not observe any difference compared to the deployment shown in first figure. The basic concept of the mapping between ISO 15118 and IEC 61850 client/server architectures remains the same. According to the V2G communication interface paradigm, the EVCC still is the client and the SECC the server. Information provided from each PEV is made available through the V2G communication interface at the ISO 15118 server side in the centralized SECC. All relevant information is mapped to an IEC 61850 meta model and provided to the client-side (E-mobility Infrastructure Operator).

Note that any combination of the previous architectures (first and second figures) may be implemented. Additionally, the use of a Multi-Use DER (MUDER) interface offered by the E-mobility Infrastructure Operator for the purpose of aggregation/pooling a set of DER units in the context of E-mobility is still under discussion.

I. Letter and Request to the California Public Utilities Commission (CPUC) Regarding the Marine Corps Air Station (MCAS) Miramar Project

To:
Carolyn Sisto
Energy Division
California Public Utilities Commission

December 21, 2018

Dispute Regarding Applicability of Rule 21 requirements to Vehicle-to-Grid Project

Dear Ms. Sisto,

I am Doug Black of Lawrence Berkeley National Laboratories (LBNL) and I am the Principal Investigator to Energy Commission contract ARV-600-13-009. This projects seeks to demonstrate advanced electric vehicle storage functionalities at the Marine Corps Air Station (MCAS) Miramar, CA which is located within San Diego Gas & Electric Company's (SDG&E) service area.

This request identifies a pressing need for the California Public Utilities Commission to clarify and resolve a utility tariff term in dispute between LBNL, on behalf of MCAS Miramar, and their utility, SDG&E. The clarification regards the applicability of the recently-adopted Rule 21 Underwriters Laboratories (UL) 1741- Supplement A (SA) requirements towards Vehicle to Grid (V2G) technologies and to allow a pilot demonstration to evaluate a unique and enabling V2G technology in direct support of the advancement of transportation and microgrid goals identified by the State of California and the Department of the Navy.[45]

1. Background / Overview

[45] Memorandum of Understanding between the U.S. Department of the Navy and the Energy Commission https://www.energy.ca.gov/releases/2016_releases/2016-10-12_navy_and_energy_commission_partner_nr.html at https://www.energy.ca.gov/business_meetings/2016_packets/2016-09-14/Item_01a.pdf

In direct response to Governor Brown's 2012 executive order to target 1.5 million zero-emission vehicles (ZEVs) on California Roads by 2025[46], the California Independent System Operator (CAISO) worked with the California Energy Commission (CEC), the California Air Resources Board (CARB) and the California Public Utilities Commission (CPUC) to develop California's Vehicle Grid Integration (VGI) Roadmap. The VGI Roadmap accomplishes one of the state's Zero-Emission Vehicle Action Plan[47] activities of mapping a way to develop solutions that enable electric vehicles (EV) to provide grid services while still meeting consumer driving needs. Multiple agencies and organizations throughout California, as well as industry partners across the country, are answering the call to turn the Governor's vision into reality by participating in Working Groups and charting the path forward identified in the VGI Roadmap to: Determine VGI Value and Potential; Develop Enabling Policies, Regulations and Business Practices; and Support Enabling Technology Development.

Working Groups are tasked to develop recommendations to address Identified Barriers and ultimately conduct activities to support the demonstration of enabling technologies and the refinement of existing policies. In some cases, technology development outpaces policy refinement; preventing their demonstration and delaying the benefits enabling technologies can bring unless policy-makers recognize and direct their use. Such is this case with the MCAS Miramar project and why it is brought for review by the CPUC.

2. Vehicle-Grid Integration Working Group

In December 2016, the CEC and CPUC held a joint workshop with experts to discuss the importance of Vehicle Grid Integration (VGI) and concluded a working group (VGIWG) to continue the state's pursuit of bringing VGI to market should be developed[48]. The subsequent VGIWG was organized by the CPUC and CEC and studied the applicability of standards from the Society of Automotive Engineers (SAE), Underwriters Laboratories (UL), the Institute of Electrical and Electronics Engineers (IEEE) as it applies to multiple Use Cases for using EVs as Distributed Energy Resources (DERs). The multiple Use Cases included one for Direct Current (DC) charged EVs and one for Alternate Current (AC) charging of EVs. The DC charging of EVs, identified as Use Case SAE V2G-DC DER (EVSE Direct), utilizes an off-board bi-directional inverter to control charging of the EV and discharging into the electrical grid. The off-board inverter is a permanently-installed facility; using the same approach and therefore rules and regulations, as commonly found for Photovoltaic (PV) and Energy Storage (ES) systems.

[46] California Executive Order B-16-2012

[47] The Governor's Interagency Working Group on Zero-emission Vehicles published a first edition of the ZEV Action Plan in 2013.

[48] December 7, 2016 Vehicle-Grid Integration Communications Standards Workshop, https://www.energy.ca.gov/altfuels/2016-TRAN-01/documents/

However, the AC charging of EVs, identified as Use Case SAE V2G-AC (PEV Direct) uses a very different approach. Instead of permanently installing an off-board inverter facility as commonly found with PV and ES systems, the V2G-AC (PEV Direct) Use Case utilizes an onboard bi-directional charger that is part of an integral and permanently installed system of the EV. Wherever the EV roams, the bi-directional charging system roams with it. Consequently, the working group rightfully states the SAE V2G-AC Use Case of a roaming inverter is unprecedented and for which there is no simplified process for approval[49]. The working group also identified that SAE created Standard J3072, *Interconnection Requirements for Onboard, Utility-Interactive Inverter Systems* to be used for approval of this type of DER. However, Rule 21 was not developed or recently amended with the SAE V2G-AC Use Case in mind.

3. Smart Inverter Working Group

On September 22, 2011, the CPUC initiated Rulemaking (R.) 11-09-011 to review and, if necessary, revise the rules and regulations governing the interconnection of generation and storage facilities to the electrical distribution systems of the investor-owned utilities (IOUs)[50]. In early 2013, parties of this resolution formed the Smart Inverter Working Group (SIWG) to develop proposals that would take advantage of the advanced capabilities of inverters that were rapidly being deployed for PV and ES systems. The SIWG, also funded by the CEC, identified requirements for smart inverter installations to promote grid stability as a distributed resource.

The new smart inverter performance capabilities that resulted from the SIWG are identified in UL 1741-SA, Advanced Inverters and reflect new capabilities that many existing inverters do not have. Some of the advanced inverter capabilities listed in UL 1741-SA have been incorporated into San Diego Gas and Electric (SDG&E) Rule 21 as a requirement for Smart Inverters in anticipating the use of smart inverters at fixed locations to support grid stability. However, performance requirements were only identified for permanently-installed inverter facilities. The separate use case of an onboard vehicle charging systems and the unique aspects with a roaming inverter that is an integral part of an electric vehicle was not separately addressed within Rule 21.

4. SDG&E Rule 21 Applicability

Underwriters Laboratories identifies the UL 1741-SA is not a standalone document, rather, a Supplement to the existing standard, UL 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy*

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[49] V2G Use Case DER V2G-AC, page 4, per http://www.cpuc.ca.gov/vgi/

[50] CPUC Resolution E-4920, http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M212/K527/212527968.PDF

Resources. SDG&E Rule 21 incorporates now invokes performance requirements identified in UL 1741-SA for new inverter installations and is also intended to be harmonized with IEEE 1547-2003, *Standard for Interconnecting Distributed Resources with Electric Power Systems*[51].

However, neither UL 1741 nor IEEE 1547 identify applicability to onboard charging systems for EVs. To the contrary, UL 1741 states products covered by the standard are intended to be installed in accordance with the National Electric Code (NEC), National Fire Protection Association (NFPA) 70[52]. NEC Article 90.2(B), Scope states the NEC does not cover "installations in…automotive vehicles other than mobile homes and recreational vehicles." NEC Article 625, Electric Vehicle Charging System refers to SAE J3072, *Standard for Interconnection Requirements for Onboard, Utility-Interactive Inverter Systems*; which, is the same standard identified by the VGI WG as an applicable standard for the PEV-V2G AC Use Case.

As stated by the VGIWG, the PEV-V2G AC Use Case is unprecedented. Unfortunately, this enabling V2G technology has outpaced policy as Rule 21 was not recently amended with this unprecedented technology in mind. Even though the NEC, IEEE, and UL standards invoked by Rule 21 are intended for fixed installations, SDG&E distribution engineers that are responsible for reviewing the interconnection application for the Miramar project views extending the UL 1741-SA requirements to all inverter-based technologies as "the law"; including mobile charging systems. SDG&E's interpretation has the effect of extending the policy intended only for fixed installations, thereby preventing the completion of Miramar's interconnection application and energization of demonstration of a State and Federally-sponsored project enabling V2G technologies that are available today.

5. Recommendation

Pursuant to VGI Roadmap goals, this request for resolution recommends conducting a 12-month pilot demonstration to enable SDG&E and the VGIWG the opportunity to study this unprecedented enabling V2G technology of the PEV-V2G AC Use Case. The CEC-funded demonstration[53] to be conducted at MCAS Miramar has made steady progress in deploying charging infrastructure independent of the V2G capable PEVs to be delivered. Benefits from conducting this pilot demonstration include:

- Confirming the electrical system impact by demonstrating the PEV-V2G AC Use Case.
- Distinguishing the interconnection needs for V2G using an off-board 2-way inverter versus an onboard 2-way charging system.

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[51] SDG&E Rule 21, Section B, Applicability, http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-RULES_ERULE21.pdf

[52] NFPA 70, Section 1, Scope, https://standardscatalog.ul.com/standards/en/standard_1741_2

[53] Energy Commission Contract ARV 600-13-009 https://www.energy.ca.gov/business_meetings/2017_packets/2017-03-08/Item_14_600-13-009-02.pdf

- Supporting enabling technology development by proving out technical concepts, publicizing the potential of the unprecedented VGI-enabling technology, and guiding research toward areas of high potential for cost reductions and benefits.
- Evolving policy and regulation by clarifying the eligibility and business processes and clarifying technical requirements for VGI products and programs.

LBNL acknowledges that the Commission is currently considering the applicability of Rule 21 for the interconnection of electric vehicles and charging infrastructure in R.17-07-007.[54] While LBNL/Techflow is participating in Rule 21 Working Group 3, our understanding of the proposed timeline for procedural resolution of Issue 23 is mid-2019, with the *potential* thereafter for tariff modifications and subsequent utility/customer implementation. However, the timeline for the expenditure of funds under the Energy Commission Agreement with LBNL is March 2020. Moreover, if interconnection cannot proceed, Miramar's V2G fleet operations cannot commence, delaying the achievement of Department of Defense objectives for energy security, resilience and innovation[55] and prolonging Miramar's use of fossil fuels in transportation.

Thus, we respectfully request that CPUC, in support of advancing the VGI Roadmap and state ZEV and grid reliability goals:

- Resolve that UL 1741-SA certification is inapplicable for the electric vehicles scoped within the project, and
- Advise SDG&E, to collaboratively develop the PEV-V2G AC Use Case demonstration necessary to successfully complete interconnection.

We appreciate your consideration and anticipate your reply. Please contact Doug Black for further discussion about how this project may proceed.

Sincerely,
Doug Black

CC:
<u>Energy Division, California Public Utilities Commission</u>
Jamie Ormond
Judith Ikle'
Edward Randolph

<u>Fuels and Transportation Division, California Energy Commission</u>

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[54] Issue 23 https://gridworks.org/initiatives/rule-21-working-group-3/

[55] https://www.nbcsandiego.com/news/local/MCAS-Miramar-Launches-Self-Driving-Vehicle-Projects-475021463.html

Adeel Ahmad
Noel Crisostomo
Kiel Pratt
Elizabeth John
Kevin Barker