

Assessment of Interoperability Achieved through IEEE Std 1547-2018 and IEEE P1547.1

Results from EPRI Interoperability Testing and Market Research

3002013473

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Technical Update, December 2018

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ABSTRACT

Integration of Distributed Energy Resources (DERs) can be expensive; relying on software development to create interfaces in utility control systems, utility personnel to analyze feasibility and integration approaches, and program design processes to analyze the cost and benefit to utilities and customers. Research can help avoid costly mistakes by identify potential issues to interoperability and integration and provide solutions before the issues are experienced in the field. EPRI has been conducting interoperability testing dating back to 2016 to identify these issues and develop solutions before they occur in the field. Interoperability testing of DER provides feedback to utilities about how well standards are being implemented in products today and help identify the source of conflicts so feedback can be provided to manufacturers and standards bodies.

In 2018 EPRI's interoperability testing efforts scored a big technology transfer win. Interoperability issues identified in the past three years of interoperability testing were included in the discussions within IEEE 1547-2018 and IEEE P1547.1 working groups. Not all of the interoperability issues were addressed because of the limited scope of IEEE 1547-2018 however many were. In light of this new test procedure, EPRI's 2018 interoperability testing was designed to evaluate how many of the known interoperability issues were addressed. The results of this test inform utilities about which interoperability issues can be evaluated in IEEE 1547-2018 certification testing and which may need to be addressed through other means. It also provides an opportunity to provide the IEEE P1547.1 working group with comments on the effectiveness of the test procedure to help improve its ability to identify interoperability issues.

The 2018 testing is conducted as a joint program effort between EPRI's PS161D and PS174B because of the inherent link between functional and communications performance in the scope of interoperability testing within IEEE 1547-2018 and IEEE P1547.1.

Keywords

Inverters

Interoperability

SunSpec Modbus®

Communications

Solar

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PRIMARY AUDIENCE: Utilities focusing on integrating controllable DER as a flexible resource on the grid.

SECONDARY AUDIENCE: Communications engineers working for utilities who are integrated DER into control networks.

KEY RESEARCH QUESTION

IEEE 1547-2018 and IEEE P1547.1 are testing standards that include the technical specification and testing requirements for interconnection and interoperability between power systems and DERs. IEEE P1547.1 provides the steps required to verify that those requirements are met. How effective is IEEE P1547.1 at addressing known interoperability issues?

RESEARCH OVERVIEW

The report consists of two main parts: a summary of the availability of products supporting IEEE 1547-2018 communication requirements and results from testing of the IEEE P1547.1 test procedure against known interoperability issues.

The summary of available products provides the audience with an overview of why interoperability matters, how this is captured in IEEE P1547.1, the availability of IEEE 1547-2018 functionality in each of the smart inverter communication protocols, a survey of certified inverters against each of these protocols, and information about how manufacturers report conformance to these protocols. The test results provide the audience with an understanding of which interoperability and integration issues are addressed by IEEE P1547.1 and which will need to be addressed in complimentary efforts.

KEY FINDINGS

- The approaching update to IEEE 1547-2018 and other grid codes has caused manufacturers to hold off on releasing new product capabilities. Once grid codes are finalized manufacturers will likely release new products that support these requirements. This was also observed in 2017.
- The most prevalent protocol listed in IEEE 1547-2018 continues to be SunSpec Modbus. Modbus is the most popular protocol for smart inverters in both the residential and commercial space. This has streamlined manufacturer support of SunSpec Modbus because the protocol is already in the current line of products. Forty products (twenty inverters) have completed SunSpec Certification, including major manufacturers. This number is expected to rise as IEEE 1547-2018 requirements go into effect.
- The study found that IEEE P1547.1 addresses many interoperability issues but complimentary efforts will be needed to address remaining issues.

WHY THIS MATTERS

IEEE 1547-2018 and California Rule 21 are both requiring communication capabilities to devices. As utilities explore the option of connecting to DER in their service territory it is important that standards implementations are matured to reduce unexpected, costly delays. IEEE P1547.1 is the first interoperability and interconnection test procedure of its kind and addresses many of the known interoperability issues. EPRI's evaluation of this protocol against known interoperability and interconnection issues helps utilities understand which will be addressed by certification to IEEE 1547-2018 requirements and which may need to be handled by complimentary efforts.

HOW TO APPLY RESULTS

Utilities can apply these results by studying the results to inform decision making including timing for new projects and helping to identify key issues that may present themselves. It also provides utilities with information that could be included in RFPs or used to develop robust programs for integrating new resources into a utility's portfolio.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- *IEEE Standard 1547™ — Communications and Interoperability: New Requirements Mandate Open Communications Interface and Interoperability for Distributed Energy Resources*. EPRI, Palo Alto, CA: 2017. 3002011591.
- *Results from Inverter Interoperability Assessment Using the SunSpec Specification: Summary of EPRI's Testing of Communications in Residential Solar Inverters*. EPRI, Palo Alto, CA: 2016. 3002009462.
- *Protocol Reference Guide: Overview of Application Layer Protocols for DER and DR*. EPRI, Palo Alto, CA: 2017. 3002009850.
- *EPRI's DER Integration Toolkit: An Overview of EPRI Tools for Testing and Implementing Open Protocols*. EPRI, Palo Alto, CA: 2017. 3002009853.
- *Assessment of Interoperability Achieved through IEEE Std 1547-2018 and IEEE P1547.1: Results from EPRI Interoperability Testing and Market Research*. EPRI, Palo Alto, CA: 2017. 3002013473.

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PROGRAMS: **Program 161: Information and Communication Technology**, Applied Information and Communication Technology for DER and DR, PS161D, **Program 174: Integration of Distributed Energy Resources**, Smart Inverters and Grid Supportive Devices, PS174B

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1

INTRODUCTION

Standards can help ease integration and interoperability. Modern interoperability and integration standards are robust however even the most thoroughly defined standard are limited by scope. Design choices outside of the standard itself can cause issues that may prevent devices from properly communicating and interacting with each other.

Interoperability is a broad concept describing a system where all devices and systems involved work together seamlessly with no customization to add new devices or systems to the ecosystem. Because of its broad nature it is often difficult to know every barrier to interoperability without experiencing them in laboratory or field environments. Interoperability testing of DER provides feedback to utilities about how well standards are being implemented in products today and help identify the source of conflicts so feedback can be provided to manufacturers and standards bodies.

This project is a continuation of EPRI interoperability testing since 2016. The goal of these projects have been to identify barriers in interoperability and associated business practices needed to successfully integrate smart inverters on the grid and utility programs. Addressing them before they occur in the field can potentially save utilities from having to perform costly updates to smart inverters and associated control systems like Distributed Energy Management Systems (DERMS), Advanced Distribution Management Systems (ADMS), Energy Management Systems (EMS), local controllers like microgrid controllers or site controllers, or any other system involved in orchestrating distributed energy resources dispatch strategies.

Utilities who are aware of these issues and their solutions can include requirements and work with their vendors to reduce the risk of interoperability issues occurring in the field.

In 2018 EPRI's interoperability testing efforts scored a big technology transfer win. Interoperability issues identified in the past three years of interoperability testing were included in the discussions within IEEE 1547-2018 and IEEE P1547.1 working groups. Not all of the interoperability issues were address because of the scope of IEEE 1547-2018 however many were. This includes:

- Incorrect pairing of DER functionality with control parameters.
- Volatility of DER settings.
- Parameters for variations within smart inverters.

In light of this new test procedure, EPRI's 2018 interoperability testing was designed to evaluate how many of the known interoperability issues were addressed. The results of this test inform utilities about which interoperability issues can be evaluated in IEEE 1547-2018 certification testing and which may need to be addressed through other means. It also provides an opportunity to provide the IEEE P1547.1 working group with comments on the effectiveness of the test procedure to help improve its ability to identify interoperability issues.

The 2018 testing is conducted as a joint program effort between EPRI's Applied Information and Communication Technology for DER and DR (PS161D) and Smart Inverters and Grid Supportive Devices (PS174B) project sets because of the inherent link between functional and communications performance in the scope of interoperability testing within IEEE 1547-2018 and IEEE P1547.1. Each program focuses on different aspects of interoperability. Addressing issues from both aspects are what will allow the industry to embrace distributed energy resources (DER) as a key component to maintain a flexible, reliable, and renewable integrated grid by allowing them to be a reliable, efficient, and effective resource to utilities. More on the role each program plays can be found in Next Steps.

2

INTEROPERABILITY AND STANDARDS

Utilities worldwide are challenged by the technical and business decisions to embrace distributed energy resources (DER) as a key component to maintain a flexible, reliable, and renewable integrated grid. The design and implementation of capabilities for robust and interoperable communications between DER technologies and other grid systems are at the heart of addressing many of these challenges. Communications can enable advanced capabilities needed to maintain a reliable and secure grid including dynamic control of DER^{1,2,3}; system analytics to improve efficiency and effectiveness; and optimized dispatch of DER to improve utilization^{4,5}. However, utilities are presented with a challenge of integrating multiple disparate technologies from multiple manufacturers into both the grid and their communication and control architectures. Integration of these systems can be expensive; relying on software development to create interfaces in utility control systems, utility personnel to analyze feasibility and integration approaches, and program design processes to analyze the cost and benefit to utilities and customers. Standards can help reduce these burdens by easing interoperability of these systems.

Interoperability in Distributed Energy Resources

Interoperability is the ability of two or more systems to exchange information and to use the information that has been exchanged. The benefits of interoperability can include reducing the cost and effort of system integration, improving grid performance and efficiency, facilitating more comprehensive grid security and cybersecurity practices, increasing customer choice and participation, establishing industry-wide best practices, and provides a catalyst of innovation.⁶ There are two main components to interoperability in DERs. 1) The ability to exchange information. This is the capability of two systems to connect with each other and exchange information. This requires systems follow different communication standards across Open

¹ *Common Functions for Smart Inverters: 4th Edition*. EPRI, Palo Alto, CA: 2016. 3002008217.

² *Common Demand Response Functions for Heating, Ventilating, and Air Conditioning (HVAC): A Summary of Demand Response Functionality Discussed in the Industry to Date*. EPRI, Palo Alto, CA: 2017. 3002011045.

³ *Applying Standards-Based Demand Response to Support Solar Integration: A Summary of EPRI Testing at the National Renewable Energy Laboratory (NREL)*. EPRI, Palo Alto, CA: 2017. 3002009849.

⁴ *DER Grouping Methods and Considerations for Operations: A Study on the Different Approaches for Creating and Managing Groups of DER and the Impact on Operations*. EPRI, Palo Alto, CA: 2017. 3002009857.

⁵ *Common Functions for DER Group Management, Third Edition*. EPRI, Palo Alto, CA: 2016. 3002008215.

⁶ *Interoperability Strategic Vision. A GMLC White Paper*. Grid Modernization Laboratory Consortium. U.S. Department of Energy. March 2018. <https://gridmod.labworks.org/sites/default/files/resources/InteropStrategicVisionPaper2018-03-29.pdf>

Systems Interconnection model (OSI model⁷). This includes standards like IEEE 802.11 (Wi-Fi), Modbus TCP IP / RTU, IEEE 2030.5, IEEE 1815/DNP3, and others. 2) The ability to use the information being exchanged. This refers to understanding the meaning (or semantics) of the data exchanged over the protocol and acting on it appropriately. This is defined through information models and performance standards. Information models include definitions like naming, functional descriptions aligned with standardized data models or functional descriptions, and data syntax information. These information models vary by protocol. In IEC-61850 it is captured in the IEC-61850-7-420 document. In DNP3 it is captured in application notes like AN-2013-001 DNP3 Profile for Advanced Photovoltaic Generation and Storage. In modbus it is captured in the SunSpec Specification. In 2030.5 it is captured in XML schemas. There are also functional standards and requirements that define how the device should respond when it receives these standardized commands. In the smart inverters domain these are standardized through grid codes – specifications defining safe, secure, and economical operation.

Interoperability and IEEE 1547-2018

IEEE 1547-2018 is a standard that includes the technical specification and testing requirements for interconnection and interoperability between power systems and DERs. The requirements cover performance, operation, testing, safety, and maintenance of the connection to the grid. It is maintained by IEEE Standards Association and was created and is maintained by IEEE working groups.

In the 2018 revision to IEEE 1547, there was a paradigm shift in the expectations for DER. IEEE 1547-2013 required that DER disconnect from the grid if grid conditions went outside of a tolerance band. In IEEE 1547-2018, DER are recognized as an important resource in maintaining grid stability. As part of this, communications are needed to provide dynamic control of DER. The standard defines functional and communications requirements. In communications, it requires standardization at the DER's interface. DER may support more interfaces; however, at least one of the three named protocols (IEEE 2030.5, IEEE 1815-DNP3 using Application Note 2018-001, SunSpec Modbus) must be supported. IEEE 1547-2018 also has an associated test procedure, IEEE P1547.1, which defines the testing criteria for certifying to IEEE 1547.

⁷ The OSI model is a mode that characterizes and standardizes the different communication functions in systems.

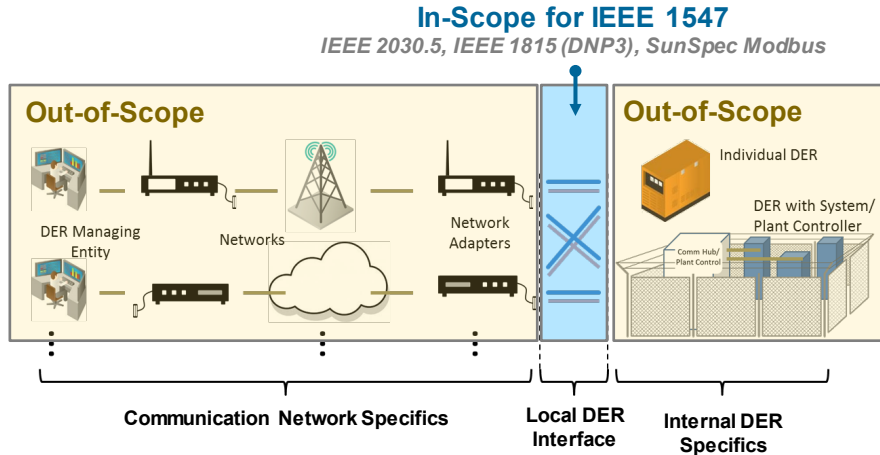


Figure 2-1
Placement of Communications Requirements in IEEE 1547-2018

IEEE P1547.1 is directly related to IEEE 1547. IEEE P1547.1 is the test procedure required for evaluating DER compliance with IEEE 1547-2018 requirements. IEEE P1547.1 provides the steps required to verify that those requirements are met – a more difficult task because of the procedures and details required. While not used directly in product certification, 1547.1 is referenced extensively in the DER test requirements of Nationally Recognized Testing Laboratories (NRTL). Examples of a NRTL include Underwriters Laboratory (UL), Canadian Standards Association (CSA), TUV, and others.⁸ NRTLs take IEEE 1547.1 and create test standards like UL1741 which include testing for compliance with IEEE 1547-2018 (following IEEE 1547.1) requirements along with other safety requirements. Local electrical inspectors in the United States will then verify compliance to IEEE 1547-2018 requirement through certification from a NRTL.

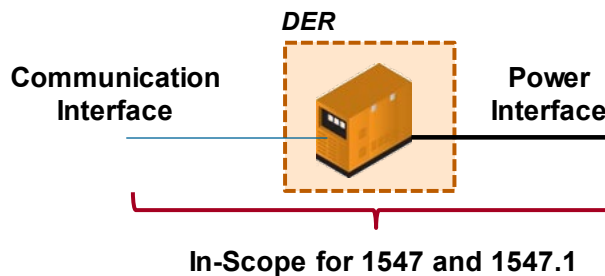


Figure 2-2
Interfaces in Scope for IEEE 1547-2018 and IEEE 1547.1

⁸ *Current List of NRTLs*. Occupational Safety and Health Administration, United States Department of Labor, www.osha.gov/dts/otpca/nrtl/nrtllist.html.

Defining interoperability requirements and validating they are met is important to identify technical issues that may prevent systems from properly communicating with each other but also equally important are the process related questions that can help guide utility program design so that DER can be efficiently integrated into the grid and utility programs. The most recent revision of IEEE 1547-2018 provides a framework for utilities to define the requirements to achieve interoperability and identifies some key functionality of smart inverters.

At the time of this study IEEE P1547.1 is in a closed comment period. Members of the different working groups within the IEEE P1547.1 process are reviewing the document as a whole and submitting comments. The review process will close on October 26th. The working groups will take these comments and address each of them in November. Following comment resolution, the working groups will vote in December 2018 on whether to take it to ballot. If it proceeds to ballot the estimated schedule is to initiate the ballot in Q1 2019, ballot resolutions Q2 2019, IEEE review committee Q3 2019, and 1547.1 publication in Q4 2019 – Q1 2020. Once completed UL will update UL-1741 to reflect IEEE 1547-2018 requirements.

3

AVAILABILITY OF PRODUCTS SUPPORTING COMMUNICATIONS STANDARDS

The first step in performing interoperability testing is identifying products to be tested. In this step EPRI performed an assessment of available products on the market today to understand the current state of smart inverter functionality and open protocols in the market. This includes an assessment of support of IEEE 1547-2018 functionality across each of the three open protocols cited in IEEE 1547-2018, an assessment of certified products to each protocol, background knowledge to identifying support of open protocols in DER, and EPRI’s experience on activating the open protocol in DER.

Functionality Across Protocols

The functionality supported over IEEE 2030.5, IEEE 1815/DNP3, and SunSpec Modbus vary but are similar. They are all based on the same IEC-61850-7-420 information models and their revisions have stayed relatively harmonized over the years. The efforts to capture smart inverter functionality in each of these protocols tends to be forward looking. This is important because a protocol must support the capabilities of the system for it to be used to manage that system. The protocols can stay somewhat future proof by being forward looking and supporting use cases that may have been discussed in working groups but have not yet been implemented in the field.

Function Name*	IEEE Std 2030.5™-2018	IEEE Std 1815™ - 2015 DNP Users Group - AN2018-001	SunSpec Modbus Updated Inverter Information Model Pending Publication
Basic settings	✓	✓	✓
Monitoring information	✓	✓	✓
Management information	✓	✓	✓
Nameplate data	✓	✓	✓
Adjustable constant PF	✓	✓	✓
Voltage-reactive power	✓	✓	✓
Active power-reactive power	✓	✓	✓
Adjustable constant reactive power	✓	✓	✓
Voltage-active power	✓	✓	✓
Voltage trip / freq trip	✓	✓	✓
Enter service	✓	✓	✓
Limit maximum active power	✓	✓	✓

*P1547.1™/D7 Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces. Sept. 2018

Figure 3-1
Support of IEEE 1547-2018 functions in IEEE 2030.5, IEEE 1815/DNP3, and SunSpec Modbus

Out of over twenty-five smart inverter functions identified,⁹ IEEE 1547-2018 requires twelve of them. As shown in Figure 3-1 the functionality required by IEEE 1547-2018 can be found in

⁹ *Common Functions for Smart Inverters: 4th Edition*. EPRI, Palo Alto, CA: 2016. 3002008217

each of the standards. All were recently revised (or are currently being revised) to meet these requirements.

Availability of Products

The following section provides an overview of the protocols and the availability of products on the market today. More information about these and other smart inverter protocols can be found in EPRI's Protocol Reference Guide. It is published and updated yearly by EPRI's Information and Communications Technologies (P161) research program.¹⁰

Assessing availability of products can be difficult. Protocols like SunSpec Modbus have a formal certification program so the number of certified products can be a metric for the amount of support of that protocol. However, it is estimated that there are also large numbers of non-certified products on the market that support open protocols which makes it difficult to get a holistic view of the support of the protocol in DER. Certification is important for increasing the confidence that interoperability can occur seamlessly so this report focuses on the number of certified products on the market.

Overall, adoption is low for most protocols in this domain however the numbers are increasing.

State of the Art – IEEE 2030.5

IEEE 2030.5 is an application layer specification formerly referred to as SEP 2.0 (Smart Energy Profile 2.0). It was developed as a communication protocol to securely integrate consumer's smart devices into the smart grid including smart loads, electric vehicles, and distributed energy resources (DER). This summary will focus on its application to DER. The protocol reduces communications architectural challenges by using the widely used Internet Protocol (IP) at the internet layer and supporting a variety of protocols at the physical layer (including Ethernet, Wi-Fi, powerline communications and different low-power radio technologies).

IEEE 2030.5 has a dedicated function set for management of DER including solar and energy storage systems. Its information model is derived from IEC 61850-7-420 and the Common Functions for Smart Inverter (EPRI 3002008217, 2017).

There are no known certified smart inverters to IEEE 2030.5 but this is because no comprehensive certification process exists yet. However, there is an IEEE 2030.5 certification process developed for validation of Rule 21 (CSIP¹¹) requirements but no products have been certified yet. IEEE is in the process of developing a full certification process for IEEE 2030.5. EPRI is aware of multiple vendors that intend to support IEEE 2030.5 in the near-future.

In California, IEEE 2030.5 has been called out as the default application-level protocol in its grid code, Rule-21. Other Application-Level protocols may be used by mutual agreement, including IEEE 1815/DNP3 for SCADA real-time monitoring and control and IEC 61850. Currently, many DER stakeholders in California including solar and storage vendors, commercial energy

¹⁰ *Protocol Reference Guide: Understanding the Characteristics of Communications with Distributed Energy Resources*. EPRI, Palo Alto, CA: 2018. 3002013621.

¹¹ *Electric Rule No. 21. – GENERATING FACILITY INTERCONNECTIONS*. Pacific Gas and Electric Company. 8 June, 2017. https://www.pge.com/tariffs/tm2/pdf/ELEC_RULES_21.pdf

management system providers, the IOUs and DER operators who manage their customer's DER though cloud servers are planning to develop IEEE 2030.5 compliant interfaces in their devices. The requirements for IEEE 2030.5 communication capability in devices will go into effect throughout 2019.

State of the Art – IEEE 1815/DNP3

IEEE 1815, also known as DNP3, was created to standardize communications between substation equipment, RTUs, IECs, and control systems. The protocol is largely used in utility and energy industries including water, waste water, transportation, and oil/gas industry. It was created in 1993 and is largely based on work in IEC-61850.

DNP3 was a big step forward from Modbus because it supported new, important features to support communications to devices over long distances. It preserves chains of events, event storage, delivery confirmation, and event timestamping; none of which are in Modbus. It also supports event reporting and storing information collected for later transmission. This contrasts to Modbus where only instantaneous data is transmitted, without a timestamp, and without means for event reporting.

DNP3 is similar to Modbus in that it can be implemented using a standardized points configuration (application notes) or a customized points configuration for the specific application. This document focuses on the application note for solar and storage systems named DNP Application Note AN2018-001 – DNP3 Profile for Communications with Distributed Energy Resources.

There are no known certified smart inverters to IEEE 1815/DNP3 but this is because no comprehensive certification process exists yet. EPRI is working with SunSpec on a CEC funded project that will create a framework to test inverters to the requirements captured in AN2018-001. EPRI does not know of any DNP3 smart inverters that currently support AN2018-001 however EPRI is aware of manufacturers who intend to release products soon.

State of the Art – SunSpec Modbus

SunSpec Modbus™ is a standardized implementation of the Modbus protocol for DER. SunSpec supports DER – including solar and energy storage systems – and contains models for exchanging meter data between devices within the same Modbus network.

SunSpec Modbus was created by a group of industry stakeholders to address a need for a standardized approach to Modbus in the solar industry. Modbus was the dominant choice for communications because of its simplicity, stability, and support. However, without a standardized approach, manufacturers and contractors used customized register maps, requiring engineers to modify products and/or control systems to match these custom mappings. In 2009 a set of large players in the industry formed the SunSpec Alliance to address this.

SunSpec Modbus uses the Modbus protocol but specifies a standardized point map for interoperability. SunSpec has different point maps – also called models – for inverters, meters, energy storage, panels, and more. The functionality defined in the inverter models are based on IEC 61850 and the Common Functions for Smart Inverters (EPRI 3002008217, 2017). The information models are designed to include detailed DER internal information (battery

information, cell voltage, etc.) but also includes higher-level grid controls to allow a site management system, owner, or utility to manage the system as a single DER. This simplifies the integration of different components of large, multi-component DER but also allows grid to control the DER as a whole.

The SunSpec protocol is still the only non-proprietary protocol known to EPRI that is being implemented by residential and commercial scale solar inverter manufacturers and being certified. It is likely there are more that are not certified.

Adoption is low for most protocols in this domain however the numbers are increasing. SunSpec Modbus is one of the protocols with the most adoption because many solar inverters and site controllers already support the Modbus protocol which streamlines the adoption of the SunSpec specific implementation of Modbus. Because these protocols are new, manufacturers are learning how to implement SunSpec Modbus in their products and market it to their customers.

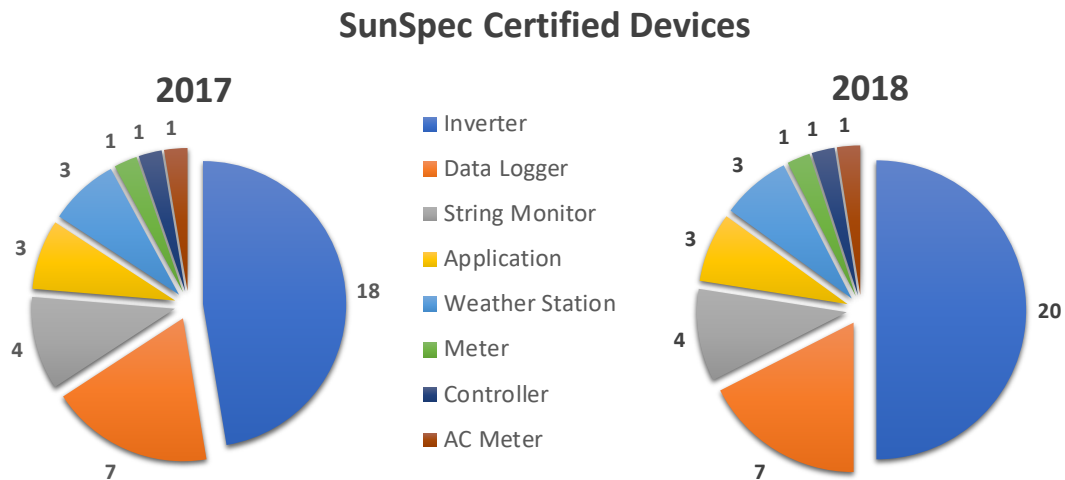


Figure 3-2
Breakdown of devices listed as SunSpec compliant (July 2018)

Modbus is popular with inverter manufacturers because support for the Modbus protocol is already in their current line of products. Forty DER-related product families are listed on SunSpec’s website as having completed SunSpec Certification, including major manufacturers. This includes twenty solar inverters (Figure 3-2). The number of certified inverters is likely to rise as updated IEEE 1547-2018 requirements go into effect.

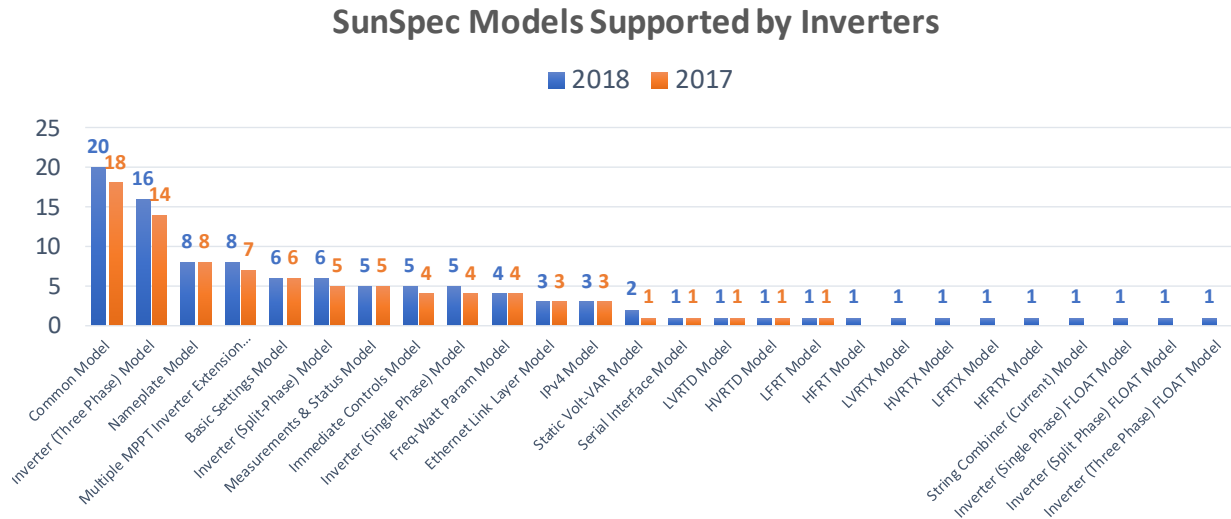


Figure 3-3
Breakdown of models supported by SunSpec compliant inverters (July 2018)

The supported functionality varied across the twenty supported models. As shown in Figure 3-3, the majority supported read-only type information like monitoring points, nameplates, and state information. Inverters from four manufacturers supported control parameters. Generation curtailment was the most popular control followed by frequency-watt (parameter based). The number of parameters for each function varied across models.

Navigating Conformance

Standards for smart inverter communications are relatively new to the industry but are rapidly gain popularity as utilities are seeing benefits in controlling smart inverters to provide visibility in generation of DER and providing controllability of these resources. Many of the standards used have been around for a long time. Modbus has been used since 1979 and DNP3 and IEC-61850 are used across the world for managing distribution system equipment. However, their application to smart inverters is fairly new. This means that the industry is learning how to apply these technologies in the smart inverter domain. The following chapter provides an overview of lessons learned in navigating manufacturer conformance to these standards.

The following example is from the 2017 study of SunSpec Modbus. SunSpec Modbus is used because of the low number of certified products in other protocols.

Manufacturer Marketing and Technical Support

EPRI researchers reached out to manufacturers with certified solar inverters to see if any additional capabilities were available in newer releases of their firmware. In this process it became quickly apparent that most manufacturers did not list SunSpec Modbus as one of their product features even though they had their certification listed on the SunSpec website. Out of the eighteen manufacturers listed in 2017, only two mentioned SunSpec Modbus on their product page at the time of writing. Firmware upgrades were sometimes required to add the SunSpec Modbus capabilities. One manufacturer provided the firmware on their website but the others either did not support firmware upgrades by users or required the firmware to be provided by technical support staff.

Technical support familiar with SunSpec Modbus was often difficult to find. EPRI reached out to multiple manufacturers to confirm their SunSpec Modbus capabilities and found that most of the time their questions had to be escalated multiple times before either a sales team member or technical support team member could answer their question. Sometimes a question would take days to get an answer. In comparison, questions about proprietary modbus mappings were often answered the same day. Typically, once EPRI researchers found the correct person in the technical support team questions could be answered quickly and efficiently. The tricky part was getting to that person.

Documentation was also lacking. EPRI reached out to a couple of the manufacturers to get information about their SunSpec Modbus support and found that most did not have documentation on the point maps. This is not as critical if the user is familiar with the SunSpec protocol and knows how to read the SunSpec compliance documents on the SunSpec Alliance website. Two manufacturers did have point mapping documents available however only one was product specific. Instead this manufacturer provided a master list of all parameters supported across all their products but it did not identify which was supported by each model.

Why does this matter: This may be important to utilities because utilities may need to be able to support their customers or help customers activate their SunSpec Modbus capabilities in products. If the support architecture from manufacturers is in development, then this may make it more difficult for utility customers or contractors to support the interoperability needs of utility programs. It is likely this capability will improve with time.

Asking the Right Questions

Solar inverters and other SunSpec Modbus compatible devices can support a variety of smart inverter functions and associated parameters through their SunSpec Modbus connection. Through experience with speaking with manufacturers, EPRI found that the following questions helped to get the most accurate responses from sales and technical staff at utilities regarding which smart inverter functions and parameters were supported by a specific model. The questions increase in specificity.

Does the product support SunSpec Modbus?

This question addresses whether the product supports the underlying protocol. The following questions will reveal what is supported through SunSpec Modbus.

What functions does the product support using that protocol?

Smart inverters for solar or storage can support any number of the over twenty smart inverters functions identified to date. This may include volt/var curves, remote disconnect, power curtailment, etc. EPRI found that the list of functionalities supported through SunSpec Modbus is a subset of the functional supported through proprietary means.

What parameters does the product support for those functions, through the protocol?

Smart inverter functions define the high-level capability of the system. Each smart inverter function consists of a group of individual parameters. For example, the volt-var function. A volt-var function has parameters including ability to turn on/off the function, x and y coordinates of the volt-var array, which curve is active if the device supports more than one, and others. Like the previous question, the list is often a subset of what is supported through proprietary means. The reason the question is important is that solely asking what functions are supported may not give enough information to know whether the product matches the desired application. Supporting the volt-var function could mean the device supports turning on or off a preset, fixed volt-var curve or it could mean that the function is fully configurable.

Why does this matter: This is important to utilities because utility customers may need support selecting compliant products. The test procedure for IEEE 1547-2018 (IEEE 1547.1) will help with this because it will provide testing companies like Underwriter Laboratories (UL) with a specific test procedure to certify products. The resulting certification will make it easier for utilities and utility customers to select compliant products. However, IEEE 1547-2018 only requires a subset of smart inverter functions and does not include many of the energy storage capabilities. Utilities interested in using functions not listed in IEEE 1547-2018 will need to manually select products and reach out to manufacturers to learn about their capabilities.

Certification and Firmware Versions

Manufacturers perform certification testing with SunSpec however this certification is not always updated after the initial certification. In addition, manufacturer advertise support of SunSpec modbus but do not advertise which functions and parameters are supported. This makes it difficult to understand what is supported by industry products. There was one case where a manufacturer had added functionality to their product but had not repeated the certification. This made it difficult to know exactly what the product could do. Therefore, it would not be considered. It is important to note that updates to firmware may or may not impact the SunSpec Modbus implementation in the product so firmware updates are not always an indication that the interface has been modified. This is why firmware is not always identified in the SunSpec certification documents.

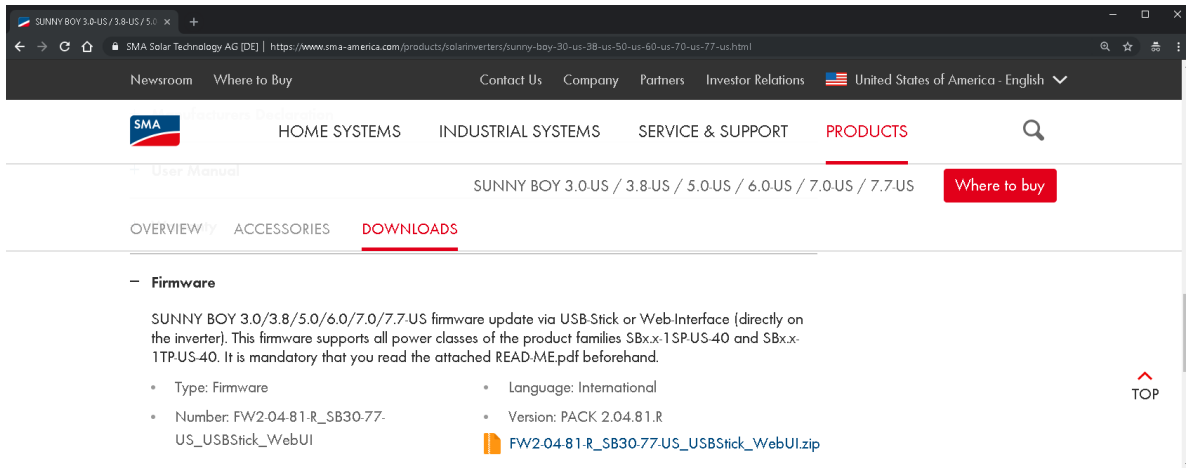


Figure 3-4
Example of smart inverter firmware update.

In many solar inverters, the firmware can be updated to add functionality. In these cases, the model number may not be the only information needed to identify functionality supported. The EPRI team found that firmware version was only sometimes noted in the certification process however multiple manufacturers supported firmware updates. At least one had updated their firmware multiple times since their certification. EPRI researchers could tell because the firmware release date was later than the certification date and EPRI was aware of multiple firmware releases since the certification date. This doesn't mean that the SunSpec Modbus interface was modified but EPRI has seen cases where it has been. In this case EPRI interoperability testing revealed that they had added additional capabilities. It is important to note that most manufacturers do not post their firmware on their website making it difficult to tell if it has been updated since certification. An example of one manufacturer who does post firmware on their website is shown in Figure 3-4. This mixed with the lack of marketing of these capabilities make it difficult to determine what capabilities had been added without physically testing the system

Why does this matter: As mentioned in “Asking the Right Questions”, utilities may need to help guide their products to smart inverters that comply with interoperability requirements. IEEE 1547-2018 compliance testing may help with basic applications however more advanced applications including energy storage or solar systems using functionality not defined in IEEE 1547-2018 may create a need to navigate the process manually. There is also an issue with owners of DER updating firmware and possibly changing the inverter functionality without the utility knowing. Often firmware updates also address cyber security issues so proper firmware management will be necessary.

Certification processes can help by ensuring protocols have been implemented properly and reducing the risk of interoperability issues caused by improper implementations of protocols. Understanding that firmware may be an important trait when determining the capabilities of the system will be important to matching inverters to applications.

Activating Protocols – Example of SunSpec Modbus

Once the correct firmware is installed on the inverter the process for activating SunSpec Modbus in a product varied between manufacturers. Some manufacturers have it available by default. Some require activation of the physical communication ports through internal parameters. Others require specifically activating SunSpec Modbus. Once activated the process is straightforward aside from some generic network setup. A couple examples of the differences.

One manufacturer required the use of a separate Bluetooth dongle to connect a mobile device to the inverter. Alternatively, an installer could use an Android phone (only Android) and a USB cable to turn on SunSpec Modbus through their smart phone app. Another manufacturer required users to open the manufacturer's free software to configure the inverter initially, turn on networking, and enable advanced control. Neither of these were difficult but just highlight the differences in the process and the variety of approaches that installers will need to know.

There was also a manufacturer that required users to enter an unlock code through a proprietary mechanism to unlock the smart inverter functions. This had to be entered every 10 hours through the proprietary mechanism. This is mentioned separately from the activation observations above because EPRI believes it is a barrier to interoperability because it is required every 10 hours and is not solely an initialization process. EPRI has informed the manufacturer and the SunSpec Alliance to help overcome this potential barrier before it is encountered in demonstrations. Similar unlock codes have been observed in the field. Another manufacturer used a custom code that expired every 10 days. Users must reapply for a new, unique code each time.

Why does this matter: Installers may need to become familiar with multiple processes to active SunSpec Modbus capabilities in multiple product families. It is possible that manufacturer will start to offer these products with SunSpec enabled out of the package or with very clear processes as the market matures. In California many manufacturer ship products preconfigured with Rule 21 Phase 1 (autonomous functions, no communications) requirements active so that minimal configuration is needed at installation.

4

TEST RESULTS

The process of defining an interoperability test procedure within IEEE 1547.1 presents an opportunity to address many of the interoperability issues EPRI and the industry have identified through projects dating back to 2016.^{12,13,14,15,16,17} EPRI's goal in this project was to assess how many of these interoperability issues have been addressed by this new test procedure, provide comments back to the IEEE 1547.1 working groups to improve the test procedures ability to capture interoperability issues before they occur, and identify which may need to be addressed in future activities.

EPRI procured a SunSpec-certified inverter from a distributor and installed it in the EPRI Knoxville Laboratory. The inverter was updated with firmware provided by the manufacturer. The inverter was connected to the local grid and a solar inverter simulator. Meters were installed on the input and output of the inverter so researchers could monitor the behavior of the inverter. A photo of an example of EPRI laboratory setups is shown in Figure 4-1. The specific test setup is not shown to obfuscate the make and model of the inverter.

¹² *Standard Communication Interface and Certification Test Program for Smart Inverters*. California Solar Initiative: Research, Development, Demonstration, and Deployment Program. California Public Utilities Commission. August 2016. http://www.calsolarresearch.ca.gov/images/stories/documents/Sol4_funded_proj_docs/EPRI4_Seal/2_CSI-RDD_Sol4_EPRI-Seal_StdCommInt_CertTestProg_FinalRpt_2016-08.pdf

¹³ *Results from Inverter Interoperability Assessment Using the SunSpec Specification: Summary of EPRI's Testing of Communications in Residential Solar Inverters*. EPRI, Palo Alto, CA: 2016. 3002009462.

¹⁴ *Evaluation of SunSpec Modbus for Distributed Energy Resources: Results from EPRI Interoperability Testing and Market Research*. EPRI, Palo Alto, CA: 2017. 3002009854.

¹⁵ *Parallel Operation of Multiple Smart Inverters*. EPRI, Palo Alto, CA: 2016. 3002008218.

¹⁶ *Smart Inverter Active Energy Loss in Volt-Var and Power Factor Control Modes*. EPRI, Palo Alto, CA: 2017. 3002012134.

¹⁷ *DC-Coupled PV plus Energy Storage Integration Technology Evaluation*. EPRI, Palo Alto, CA: 2017. 3002011891.



Figure 4-1
DER installed in EPRI's Interoperability Laboratories in Knoxville, TN.

EPRI's testing followed the test steps in P1547.1TM/D7 – September 2018. The following chapters from the draft test procedure were followed. EPRI tested a subset of the tests within IEEE P1547.1 because no inverter was available that supported all of the functions required by IEEE 1547-2018 over one of the three approved communications protocols.

General Requirements

- 4.1 – General
- 4.2 – Test result accuracy
- 4.3 – Testing environment
- 4.4 – Measurement accuracy and calibration of the testing equipment
- 4.5 – Product information
- 4.6 – Test reports
- 4.7 – Testing equipment requirements
- 4.8 – Requirements on type test order and selection of DER sample(s)
- 4.9 – Microgrid-capable DER and devices

Type Tests

- 5.15. – Voltage regulation
 - 5.15.1 – Voltage Regulation Overview
 - 5.15.2 Test for constant power factor (PF) mode
 - 5.15.3 Test for voltage-reactive power (volt-var) mode
- 5.18 – Interoperability
 - 5.18.2 – Interoperability Testing Approach
 - 5.18.3 – General Test Procedures
 - 5.18.4 – Nameplate Data Test

- 5.18.5 – Basic Settings Information Test
- 5.18.6 – Monitoring Information Test
- 5.18.2 – Interoperability Testing Approach
- 5.18.3 – General Test Procedures
- 5.18.4 – Nameplate Data Test
- 5.18.5 – Basic Settings Information Test
- 5.18.6 – Monitoring Information Test
- 5.18.7 – Management Information Test
- 5.18.8 – DER settings non-volatility test
- 5.18.9 – Specific Protocol Mappings

The inverter was controlled solely through the SunSpec Modbus interface. Testers evaluated the SunSpec interface by sending commands to the inverter over the SunSpec interface and verifying that the response was appropriate. EPRI used the SunSpec Dashboard (a test tool available from the SunSpec Alliance) to control the smart inverter. This tool supports polling the inverter for all supported parameters. The results from this polling are available in following chapter.

Device Under Test

The pending update to IEEE 1547-2018 has caused many manufacturers to wait on releasing new smart inverter and smart inverter capabilities as they wait to see what the final requirements will be. This was revealed through discussions with manufacturers and the SunSpec Alliance.

EPRI’s interoperability testing is part of an on-going effort dating back to 2016. In 2016 EPRI tested two inverters from major manufacturers. In 2017 EPRI’s researchers selected a previously untested, three-phase smart inverter to be tested in the EPRI lab. In 2018, one of the previous inverters were retested using new firmware. This inverter was chosen because it had the most overlap with the required functionality in IEEE 1547-2018.

The manufacturer allows for new functionalities to be added through a firmware update. The inverter is certified through the SunSpec Alliance however the version of firmware is an older version than the one provided on the manufacturer’s website. More information about each SunSpec Model and its mapping to smart inverter functionality is available through the SunSpec Modbus specifications.¹⁸ The following SunSpec models are supported based on EPRI’s query of device functionality using the SunSpec Dashboard. Only the constant power factor and volt/var mode were tested. Spot testing was performed on the other models to assess potential interoperability gaps. Snapshots of the individual parameters supported in each model can be found in the appendix.

- Model 1 – Common Information
- Model 11 – Ethernet Link Layer
- Model 12 – IPv4

¹⁸ SunSpec Specifications & Information Models. SunSpec Alliance. Accessed November 2017. <https://sunspec.org/download/>

- Model 122 – Measurement Status
- Model 120 – Nameplate Ratings
- Model 121 – Basic Settings
- Model 122 – Measurements and Extended Status Reporting
- Model 123 – Immediate Controls
- Model 124 – Storage
- Model 126 – Volt-VAR Arrays
- Model 127 – Frequency-Watt Control
- Model 128 - Dynamic Reactive Current
- Model 131 - Watt – PF
- Mode 132 - Volt/Watt
- Model 160 - MPPT
- Model 137 - LVRT
- Model 138 - HVRT

Contributions to the IEEE P1547.1 Working Group

The purpose of EPRI’s testing evaluated the IEEE P1547.1 test procedure by applying it in a real testing environment. This allowed EPRI to provide comments back to the working group regarding the feasibility, clarity, and technical comprehensiveness of the procedure. EPRI testing generated 56 comments to the IEEE 1547.1 WG. The comments ranged from editorial issues to technical contributions. Comments were provided for most of the sections tested. Some themes in the comments include:

- More information about why specific target were chosen if no reference to another standard is provided.
- Clarification of terminology to prevent misinterpretations.
- Removing extraneous information that can cause test instructions to be unclear.
- Miscellaneous typos and technical errors.

EPRI also tested the comprehensiveness of the test against EPRI’s on-going list of interoperability issues identified in lab and field testing.^{13,14} IEEE 1547-2018 and IEEE P1547.1 are designed to address a number of interoperability challenges however the requirements defined in IEEE 1547-2018 do not comprehensively cover all interoperability considerations because of a mixture of lack of industry consensus on the procedure and some being application specific. These topics include firmware updates, sampling rates, latency, system decisions, order of operations in control signals, and others can impact the ability for two systems to work together. A summary of this assessment can be found below.

Incorrect Pairing Functionality with Control Parameters

Gap: Multiple implementation issues were discovered in 2017 and 2018 testing. The issues related to matching communications parameters with the correct device behavior.

Potential Impact: Utilities dispatch commands to smart inverters, whether settings for autonomous functions or manual functions, based on system modeling and analysis. This analysis is based on smart inverters following standardized definitions of how smart inverters should interpret information received through their communication interfaces. Deviation from these standards means that utility modeling may not match system performance.¹⁹ On a large scale this may cause significant deviation from expected behavior. EPRI's experience with this interoperability issue found that the issue ranged. Some devices followed functional specification with some deviation where did not follow functional specifications at all or did not respond. Some examples of incorrect pairing include:

- Leading vs lagging power factor can differ depending on the perspective of the measurement and the standard used. EPRI has observed issues where this was implemented backwards in systems from what was expected.
- Sending a request to limit active power to 50% is rejected by an inverter but no error is generated. The inverter continues to output 100% power while a query of active control parameters indicate that it is actively curtailing power.
- Connect/disconnect may set power to zero in some units and operate a physical switch in others.
- An inverter is asked to turn on volt/var with watt priority. Watt priority is not supported so the inverter turns on volt/var with VAR priority.

Is it Addressed by 1547? Yes, but IEEE P1547.1 only covers a subset of all of the smart inverter functions available to the industry. IEEE 1547-2018 requires twelve of the different functions from smart inverters. There are over twenty-five identified.²⁰

In IEEE P1547.1 there are both communication and functional requirements. The interoperability test procedures require that this testing be performed end-to-end so that the approved communication protocols are used to do a subset of the functional testing. The current version of the test procedure does not require that all functional tests be performed through the communication interface. The reason the working group took this approach was to avoid having to make testing for subsequent protocols lengthy and expensive.

¹⁹ 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.” *IEEE Xplore – Digital Library*, The IEEE Standards Association, 6 Apr. 2018, ieeexplore.ieee.org/servlet/opac?punumber=8332110.

²⁰ *Common Functions for Smart Inverters: 4th Edition*. EPRI, Palo Alto, CA: 2016. 3002008217

Parameters for Variations within Smart Inverter Functions

Gap: DER protocols have parameters (DeptRef in SunSpec Modbus) that allows users to change the behavior of a smart inverter function. An example of changing whether the volt/var function prioritizes reactive or active power. This parameter needs to be evaluated for the best way to implement it to avoid confusion on which one is required and which is currently supported by an inverter. The two inverters tested did not always implement the same DeptRef and the behavior when an unimplemented mode was active was mixed and unpredictable.

Potential Impact: The DeptRef parameter allows users to change how some smart inverter functions behave without having to create a whole new information model for each variant. A method is needed to ensure headend and devices are synchronized. For example, if a headend thinks a device is outputting VARs in VAR priority (will provide requested number of VARs) but the device only supports watt priority (inverter continues to follow maximum power point and any remaining capacity is used for VARs) then the response from the device will not match the expected behavior from the headend.

2018 Update: In 2016 EPRI noted that a control system should either make it clear to users what DeptRef is default or provide users with a choice. The inverters should also be able to communicate which functions are supported or provide meaningful error messages back to the user or headend.

Since the testing in 2016 EPRI has discussed this issue with the SunSpec Alliance. There is currently debate on the best approach for addressing this but some of the ideas include embracing the difference in the functions and creating parallel models. This would make the difference between the variants very clear.

The other concept SunSpec is exploring is the addition of error reporting registers. This could potentially address several barriers including this one because the inverter could return meaningful error messages instead of just the generic messages supported by the underlying modbus protocol.

The discussion is ongoing however the issue may be partially solved through new grid codes. It is likely that grid codes and utilities will require specific DeptRef values in interconnection agreements. If this is the case, the supported DeptRefs across management tools and inverters will converge on these requirements. IEEE 1547-2018 states specific modes but allows for other modes to be used upon agreement between parties (owner and utility). This means that both parties would be aware that there was potential that the modes may change.

In 2018 SunSpec launched an effort to update their standard in light of findings from field implementation in addition to new requirements from IEEE 1547. The DeptRef issues was not directly addressed but SunSpec is working on new error codes that provide more meaningful data to upstream systems. This will be helpful in addressing this interoperability issue.

Is it Addressed by 1547? Yes, but only for covered functions. IEEE 1547-2018 specifies which of these variants are allowed. The interoperability issue with the parameter is not solved by IEEE 1547-2018 but IEEE 1547-2018 limits the allowable number of options to one which means that this parameter is not needed unless more than one mode will be used.

Proprietary Feature Unlock Key

Gap: Manufacturers have implemented proprietary unlock key on their inverter that are required to make changes to the smart inverter functionality. The key is required to unlock smart inverter capabilities on the device. Manufacturers have indicated that this feature is to protect users and utilities from unintentional activation or modification of smart grid functionality. In one example the key lasted for 10 hours or until the inverter is powered off. The feature is not part of communication standards and required a custom approach to allow uninterrupted access to the inverter.

Potential Impact: It is straightforward to add a capability to send a proprietary feature unlock key to an inverter however there is no capability to do this in any of the protocols cited in IEEE 1547-2018 so it must be done separately. This is a barrier to interoperability because it is a non-standardized approach. If each manufacturer implements something similar but implemented differently then interoperability will fail because communication systems will have to be designed to support specific capabilities in each make or model of inverter defeating the purpose of following a standardized approach.

Exceptions like this one run contrary to the idea of standardization and prevent interoperability because they require case-by-case customization. It is possible protocols may adopt a mechanism to transmit these sort of commands but there are no current plans to do so.

Is it Addressed by 1547? No, this topic was discussed in the IEEE P1547.1 Interoperability working group and conclusion was that this was out of scope for IEEE 1547-2018 and should instead be addressed in utility requirements documents. In the IEEE P1547.1 working group meetings utilities were split on whether this function. Proponents of this function voiced support because it can protect against accidental changes of settings.

The IEEE P1547.1 working group explored standardizing a mechanism to implement these unlock codes but received feedback from some standards groups that the mechanism appears to be a security mechanism but a poor one. There were concerns that implementing it may give a false sense of security and that implementation of user validation is preferred to simple unlock codes.

Utilities who plan to roll out communicable smart inverters should consider requiring inverters in their territory to come “unlocked”.

Varied Support of Modbus Functionality

Gap: EPRI has experienced some implementation issues in the underlying communication protocols unrelated to the DER specific information models. An example is that one inverter only allowed curves to be written one point at a time.

Potential Impact: Control systems will likely follow Modbus best practices and will attempt to minimize traffic over a communication network by grouping multiple commands into a single message. Not supporting this feature of modbus will cause a failure in the interoperability of the control system and the device.

Though feasible, this is not the intent of the standards for wide-scale implementation. Because the inverter will accept the message but only write one of the points this could cause issues where curves are partially written. Furthermore, writing to multiple registers in a single message is required in the SunSpec Modbus specification and should be supported for all curve functions.

Is it Addressed by 1547? Partially. The testing in IEEE P1547.1 is focused on the smart inverter specific parameters but will test some basic protocol support through the exchanging of information with the DER and the test harness. Validation of all parts of the protocol are not tested.

Supplemental protocol certification will continue to be valuable and complimentary to certification to the IEEE P1547.1 requirements. There are requirements in each of the communication protocols that are not verified through the IEEE P1547.1 testing. Interoperability testing in IEEE 1547-2018 will ensure the short list is supported as it related to the IEEE 1547-2018 requirements. Protocol certification could verify additional requirements and parameters not covered in IEEE 1547-2018 and further improve interoperability.

EPRI continues to find similar implementation issues. It is difficult to determine a single correct implementation because often the underlying protocol allows for multiple correct ways to do something which has unintended consequences to the DER domain. More experience is needed to determine the impact this issue can have and the prevalence as numbers of products supporting the protocol rise. If this becomes a significant barrier, solutions will need to be presented to standards groups.

Volatility of DER Settings

EPRI testing found some inverters revert to default settings when power to the inverters is cycled (AC or DC).

Potential Impact: If inverters lose settings where there is low DC power (night, completely overcast) this will cause inverters to forget any settings they have received each day or on overcast days. If it occurs after AC power cycling, then inverters may forget all settings after a power outage or if disconnected from the grid.

Is it Addressed by 1547? Yes, IEEE P1547.1's chapter "5.18.8 DER settings non-volatility test" addresses systems losing settings during a power down. This will test whether DER lose settings overnight.

"Sleep Mode" Communications Capabilities

EPRI testing found that solar inverters are often non-responsive when there is no power from the solar array.

Potential Impact: If inverters are not being responsive at night utilities will be limited when they are able to send signals to smart inverters in their territory. It is possible that utilities may configure inverters at night when system bandwidth may be low, to prepare for conditions expected in the following day, or simply need to send manual dispatch commands for VAR support. If low DC conditions occur during the day (low irradiance conditions) it could block utilities from using manual control of VAR support in inverters which smart inverters can provide even when solar irradiance is low. In summary, the issues will depend on the use cases and the limitations of the inverter.

Is it Addressed by 1547? No, IEEE 1547 does not require that inverters be accessible 100% of the time. It is possible utilities may use network adapters to map between IEEE 1547 protocols and their protocol of choice. If this is the case utilities may be able to embed software in these adapters that allow them to hold parameters received from a utility and send them to the inverter when the communication interface becomes available. This still prevents changes in nighttime VAR support but does provide a mechanism to leverage low bandwidth periods on utility networks.

Maximum Polling Frequency

EPRI has received reports that some inverters behave unexpectedly when polling of data exceeds a manufacturer stated limit. This included inverters locking up or refusing to respond. In response EPRI evaluated the impact of high rates of sampling had on smart inverters by performing a series of sustained 6-hour tests to read a set of thirty monitoring points under a variety of conditions. The data was polled by a modbus datalogger which was scripted to poll the selected monitoring points once a second over the 6-hour period. The tests were designed to emulate different communications requirements in the field. The first looked at a single upstream systems polling data every second. On the device tested the results showed that over 99.5% of the values were received. EPRI ran one set where the vendor dashboard (hosted by the device) was used during testing and the results were similar.

This test is not to be confused with latency. Latency describes how old the data is when it received by the system. Latency is the sum of all delays introduced over the total transmission of the data packet from its origination to its destination.

Potential Impact: The rate that a DER may be polled for data will depend on the application. High polling rates may be used in microgrid or localized applications where systems are designed to respond quickly to changed conditions on the grid or in response to other loads or generators nearby. More work is needed to determine what the requirements are for these applications to help inform whether current limits are appropriate.

Is it Addressed by 1547? No, this is outside of the scope of IEEE P1547.1 and will dependent of the use case.

Interoperability and Control Systems

Protocols have different requirements of upstream and downstream systems. Upstream systems like DERMS often need to be more flexible to support the variety of implementations and features of a protocol. For example, in SunSpec Modbus control systems (or any upstream system) must be able to scan a DER's modbus registers to determine its capabilities as well as the location of key data points for monitoring and control. This feature is to allow manufacturers flexibility to accommodate legacy systems and testing tools that may overlap with SunSpec Modbus point addresses. EPRI testing found that multiple DERMS had not implemented the search function, and instead had to be given the register locations in advance – risking a need for continuous work by software developers and/or DERMS operators.²¹

Potential Impact: Utilities are exploring options for managing large numbers of DER in the field through control systems like DERMS that can provide algorithmic optimization across multiple protocols and types of DER. EPRI testing through Tucson Electric Power's DERMS project²¹ has unveiled some important DERMS specific interoperability gaps related to the translation capabilities in DERMS. Some test tools exist however there are no certification frameworks for testing upstream systems. Interoperability with these systems will become important because the responsibility of translating between the many DER protocols is on these systems. Most existing systems are being built using learnings from SCADA control systems however DER control can be different. There are potentials for a large number of different makes and types of DER that use a variety of protocols to communicate. The control loops may also be different than distribution system equipment because customer operated systems may not always respond as expected depending on local use by the customer.

Is it Addressed by 1547? No, IEEE 1547-2018 scope is limited to the DER interface and does not make any requirements of upstream systems.

Multi-interface Inverters

Some inverters offer multiple interfaces. The interaction between interfaces is unknown and has been known to cause issues. One manufacturer's inverter would lock out users if both Ethernet and Wi-Fi connections were used to connect to the inverter. This is a scenario that may occur in the field if the homeowner accesses the inverter to monitor system performance while the utility has an interface with the inverter to manage it. Another manufacturer throws an error that says that too many users are logged in if users do not log out after use.

Potential Impact: Utilities and equipment owners may both want access to the system. The harmony between the two need to be resolved for utilities to be able to manage the operation of the inverter in parallel with owners (residential or commercial) or local controllers (site controller, microgrid controllers) operating and monitoring the system.

²¹ *Tucson Electric Power Project RAIN*. EPRI, Palo Alto, CA: 2018. 3002014812

Is it Addressed by 1547? No, the IEEE P1547.1 test procedure does not currently test alternative interfaces or the interaction between them. The test harness is developed to be consistent and performed the same way for every inverter so testing of proprietary or secondary interfaces during the test is out of scope.

Communications Requirements in Specifications

Utilities and public entities looking to define requirements for communicating to DER are presented with numerous choices including network layers, functionality communicated over the communications network, and expected functional response when receiving commands. There are numerous choices for communications to DER including network layers, functionality communicated over the communications network, and expected functional response when receiving commands.

Is it Addressed by 1547? Yes, documents like IEEE 1547-2018 can serve as a baseline template for requirements for near-term use cases. Advanced users can append or amend as needed.

5

SUMMARY

It is evident the industry is evolving. The standards themselves continue to develop to meet the applications. Manufacturers continue to move towards adopting these protocols, developing support mechanisms, and incorporating SunSpec Modbus and other protocols in their marketing and other documents. This will continue to advance over time. It is expected that as demand for SunSpec Modbus and other open protocols increases manufacturers will advance their processes. This is likely to happen soon with IEEE 1547-2018 and California Rule 21 both requiring communication capabilities to devices. As utilities adopt these grid codes manufacturers will meet the need for products that comply with rules of grid codes. Utilities may want to continue to monitor the state of the art of these devices so that they can design programs for enrolling these devices that can do so efficiently and cost-effectively.

IEEE 1547-2018 and IEEE P1547.1 focuses on interoperability by including both electrical as well as interoperability and communications requirements. IEEE P1547.1 provides the steps required to verify that those requirements are met – a more difficult task because of the procedures and details required and the first of its kind in the world. EPRI’s evaluation of this protocol against known interoperability issues found that many are addressed by IEEE P1547.1 but some are outside the scope of IEEE 1547-2018 and therefore not tested in IEEE 1547.1.

Key Findings

- The approaching update to IEEE 1547-2018 and other grid codes has caused manufacturers to hold off on releasing new product capabilities. Once grid codes are finalized manufacturers will likely release new products that support these requirements. This was also observed in 2017.
- The most prevalent protocol listed in IEEE 1547-2018 continues to be SunSpec Modbus. Modbus is the most popular protocol for smart inverters in both the residential and commercial space. This has streamlined manufacturer support of SunSpec Modbus because the protocol is already in the current line of products. Forty products (twenty inverters) have completed SunSpec Certification, including major manufacturers. This number is expected to rise as IEEE 1547-2018 requirements go into effect.
- The study found that IEEE P1547.1 addresses many interoperability issues but complimentary efforts will be needed to address remaining issues. A summary of these results can be found on the following page.

<u>Interoperability Issue</u>	<u>Relation to IEEE P1547.1</u>
Incorrect Pairing Functionality with Control Parameters	Yes, but IEEE P1547.1 only covers a subset of all of the smart inverter functions available to the industry. IEEE 1547-2018 requires twelve of the different functions from smart inverters. There are over twenty-five identified.
Parameters for Variations within Smart Inverter Functions	Yes, but only for covered functions. IEEE 1547-2018 specifies which of these variants are allowed. The interoperability issue with the parameter is not solved by IEEE 1547-2018 but IEEE 1547-2018 limits the allowable number of options to one which means that this parameter is not needed unless more than one mode will be used.
Proprietary Feature Unlock Key	No, this topic was discussed in the IEEE P1547.1 Interoperability working group and conclusion was that this was out of scope for IEEE 1547-2018 and should instead be addressed in utility requirements documents.
Varied Support of Modbus Functionality	Partially. The testing in IEEE P1547.1 is focused on the smart inverter specific parameters but will test some basic protocol support through the exchanging of information with the DER and the test harness. Validation of all parts of the protocol are not tested.
Volatility of DER Settings	Yes, IEEE P1547.1’s chapter “5.18.8 DER settings non-volatility test” addresses systems losing settings during a power down. This will test whether DER lose settings overnight.
“Sleep Mode” Communications Capabilities	No, IEEE 1547 does not require that inverters be accessible 100% of the time.
Maximum Polling Frequency	No, this is outside of the scope of IEEE P1547.1 and will dependent of the use case.
Interoperability and Control Systems	No, IEEE 1547-2018 scope is limited to the DER interface and does not make any requirements of upstream systems.
Multi-interface Inverters	No, the IEEE P1547.1 test procedure does not currently test alternative interfaces or the interaction between them. The test harness is developed to be consistent and performed the same way for every inverter so testing of proprietary or secondary interfaces during the test is out of scope.
Communications Requirements in Specifications	Yes, documents like IEEE 1547-2018 can serve as a baseline template for requirements for near-term use cases. Advanced users can append or amend as needed.

6

NEXT STEPS

Integrating DER into the grid and utility control architectures requires continuous work to understand and address research questions around effective and efficient processes. Two key aspects will be understanding and addressing interoperability and integration barriers before they are experienced in the field and validating standards conformance.

Understanding and addressing interoperability and integration barriers before they are experienced in the field. Interoperability testing will continue to be important as utilities ramp up activities around DERMS, DER integration, and microgrids. Standards can help ease integration and interoperability. Modern interoperability and integration standards are robust however even the most thoroughly defined standard are limited by scope. Design choices outside of the standard itself can cause issues that may prevent devices from properly communicating and interacting with each other.

Integration of DER systems can be expensive; relying on software development to create interfaces in utility control systems, utility personnel to analyze feasibility and integration approaches, and program design processes to analyze the cost and benefit to utilities and customers. Research can help avoid costly mistakes by identify potential issues to interoperability and integration and provide solutions before the issues are experienced in the field.

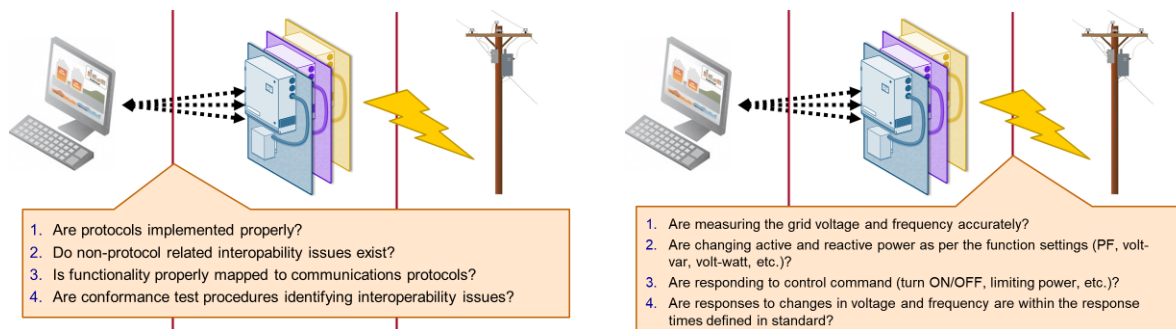


Figure 6-1
Examples of the type of questions answered at each of the different interfaces of a smart inverter.
P161 - Information and Communication Technologies (left) and P174 - Integration of DER (right)

This work will require cooperation between researchers in both EPRI’s Information and Communications Technologies and EPRI’s Integrations of Distributed Energy Resources groups. Each program focuses on different aspects of interoperability and integration (Figure 6-1). Addressing issues from both perspectives will support the industry to embrace distributed energy resources (DER) as a key component to maintain a flexible, reliable, and renewable integrated grid by allowing them to be a reliable, efficient, and effective resource to utilities.

Validating standards conformance. Another important aspect will be validating conformance to different standards in this space. Industry stakeholders like IEEE or others should be engaged and encourage to develop certification processes to validate conformance of each of the standards associated with interoperability. Test tools can help support manufacturers and vendors in performing mid-development testing.²² They can also help utilities test for interoperability while certification processes are being developed.

Communications interoperability events will also play an important role. These events support the industry by providing manufacturers of DER and vendors of DERMS/ADMS systems with an opportunity to test systems against a common test harness. These events provide an opportunity for industry stakeholders to hold discussions about how interoperability can be achieved in these systems. Interoperability events will be particularly important for control systems like DERMS because current no certification testing exists for interfaces in control systems. EPRI testing through Tucson Electric Power's DERMS project (Project RAIN) has unveiled some important DERMS specific interoperability gaps related to the translation capabilities in DERMS. EPRI is exploring expanding their existing DERMS interoperability workshop^{23,24} to include downstream interfaces in 2019.

²² *EPRI's DER Integration Toolkit: An Overview of EPRI Tools for Testing and Implementing Open Protocols.* EPRI, Palo Alto, CA: 2018. 3002013623.

²³ *Common Information Model (CIM) Compliance Testing: October 2018 Summary of Results.* EPRI, Palo Alto, CA: 2018. 3002014800

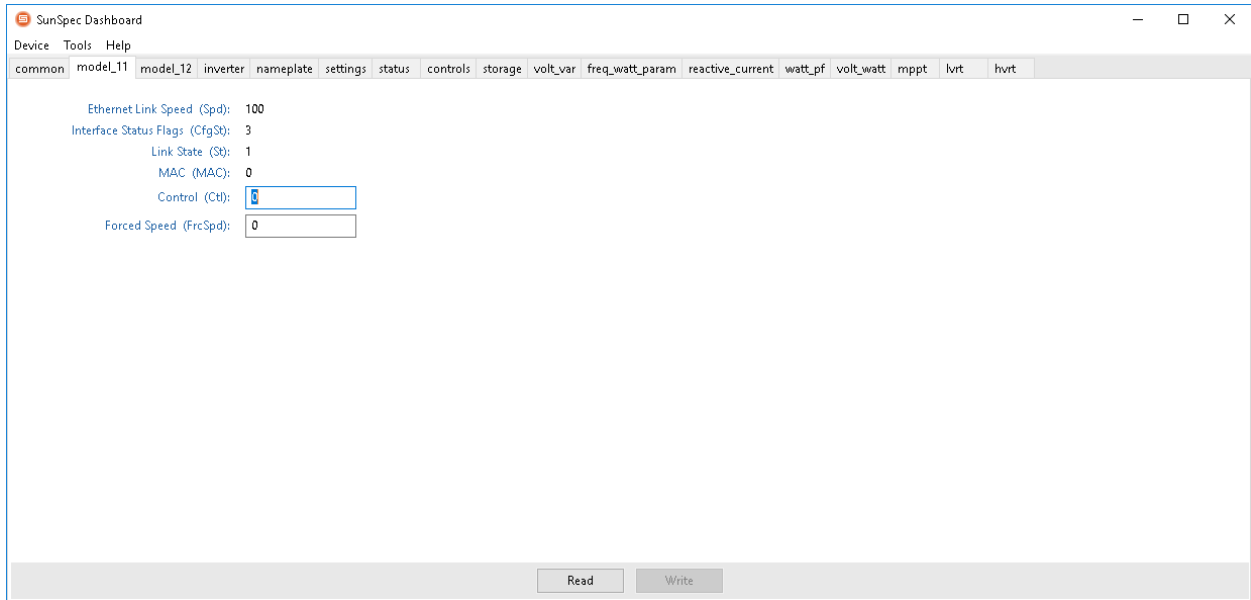
²⁴ *Common Information Model Compliance Testing for Distributed Energy Resource Group Management: October 2017 Summary of Results.* EPRI, Palo Alto, CA: 2017. 3002011233

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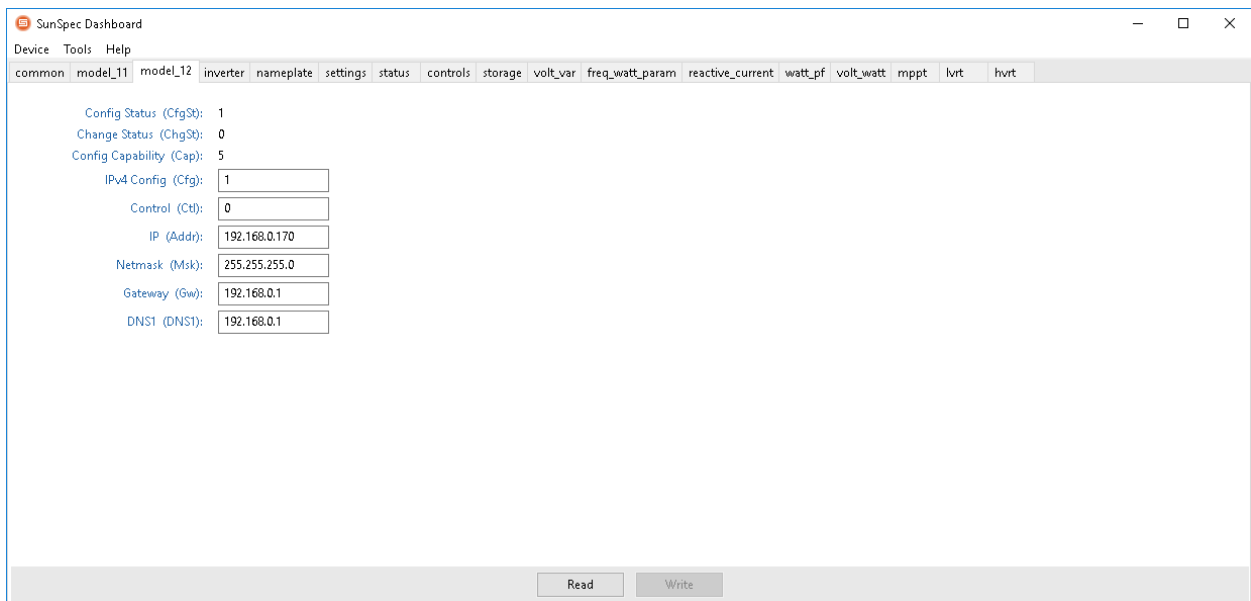
SUPPORTED MODELS

The following section provides an overview of the supported models as identified by the SunSpec Dashboard.

Model 11 – Ethernet Link Layer



Model 12 – IPv4



Model 122 – Measurement Status

The screenshot shows the SunSpec Dashboard interface for Model 122. The 'nameplate' tab is selected, displaying a list of measurement parameters and their values. The interface includes a menu bar with 'Device', 'Tools', and 'Help', and a navigation bar with tabs for 'common', 'model_11', 'model_12', 'inverter', 'nameplate', 'settings', 'status', 'controls', 'storage', 'volt_var', 'freq_watt_param', 'reactive_current', 'watt_pf', 'volt_watt', 'mppt', 'lvt', and 'hvt'. At the bottom, there are 'Read' and 'Write' buttons.

Amps (A):	12.4
Amps PhaseA (AphA):	12.4
Amps PhaseB (AphB):	12.4
Amps PhaseC (AphC):	3276.8
Phase Voltage AB (PPVphAB):	255.3
Phase Voltage AN (PhVphA):	127.6
Phase Voltage BN (PhVphB):	127.7
Watts (W):	3160.0
Hz (Hz):	60.01
VA (VA):	3160.0
VAR (VA):	30.0
PF (PF):	1.0
WattHours (WH):	861770.0
Cabinet Temperature (TmpCab):	24
Operating State (St):	4
Event1 (Evt1):	0

Model 120 – Nameplate Ratings

The screenshot shows the SunSpec Dashboard interface for Model 120. The 'nameplate' tab is selected, displaying a list of nameplate ratings and their values. The interface includes a menu bar with 'Device', 'Tools', and 'Help', and a navigation bar with tabs for 'common', 'model_11', 'model_12', 'inverter', 'nameplate', 'settings', 'status', 'controls', 'storage', 'volt_var', 'freq_watt_param', 'reactive_current', 'watt_pf', 'volt_watt', 'mppt', 'lvt', and 'hvt'. At the bottom, there are 'Read' and 'Write' buttons.

DERTyp (DERTyp):	4
WRtg (WRtg):	6000.0
VARtg (VARtg):	6000.0
VARtgQ1 (VARtgQ1):	3000.0
VARtgQ4 (VARtgQ4):	3000.0
ARtg (ARtg):	25
PFRtgQ1 (PFRtgQ1):	0.8
PFRtgQ4 (PFRtgQ4):	0.8

Model 121 – Basic Settings

The screenshot shows the SunSpec Dashboard interface for Model 121. The 'settings' tab is active, displaying a list of configuration parameters with input fields. The values are as follows:

Parameter	Value
WMax (WMax):	6050.0
VRef (VRef):	120
VRefOfs (VRefOfs):	0
VAMax (VAMax):	6050.0
WGra (WGra):	20
MaxRmpRte (MaxRmpRte):	10000
ECPNomHz (ECPNomHz):	60

At the bottom of the settings area, there are two buttons: 'Read' and 'Write'.

Model 122 – Measurements and Extended Status Reporting

The screenshot shows the SunSpec Dashboard interface for Model 122. The 'status' tab is active, displaying measurement and status data:

PVConn (PVConn):	5
ECPCConn (ECPCConn):	1
ActWh (ActWh):	861628
Ris (Ris):	3000000.0

At the bottom of the status area, there are two buttons: 'Read' and 'Write'.

Model 123 – Immediate Controls

The screenshot shows the SunSpec Dashboard interface for Model 123. The top navigation bar includes 'Device', 'Tools', and 'Help'. Below this is a menu with tabs for 'common', 'model_11', 'model_12', 'inverter', 'nameplate', 'settings', 'status', 'controls', 'storage', 'volt_var', 'freq_watt_param', 'reactive_current', 'watt_pf', 'volt_watt', 'mppt', 'lVRT', and 'hVRT'. The 'controls' tab is active. The main content area displays five control parameters, each with a label and a text input field:

- Conn (Conn): 1
- WMaxLim_Ena (WMaxLim_Ena): 0
- OutPFSet_Ena (OutPFSet_Ena): 0
- VArPct_Mod (VArPct_Mod): 1
- VArPct_Ena (VArPct_Ena): 0

At the bottom of the page, there are two buttons: 'Read' and 'Write'.

Model 124 – Storage

The screenshot shows the SunSpec Dashboard interface for Model 124. The top navigation bar includes 'Device', 'Tools', and 'Help'. Below this is a menu with tabs for 'common', 'model_11', 'model_12', 'inverter', 'nameplate', 'settings', 'status', 'controls', 'storage', 'volt_var', 'freq_watt_param', 'reactive_current', 'watt_pf', 'volt_watt', 'mppt', 'lVRT', and 'hVRT'. The 'storage' tab is active. The main content area displays one control parameter with a label and a text input field:

- StorCtl_Mod (StorCtl_Mod): 0

At the bottom of the page, there are two buttons: 'Read' and 'Write'.

Model 126 – Volt-VAR Arrays

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lVRT hVRT

ActCrv (ActCrv):

ModEna (ModEna):

NCrv (NCrv):

NPt (NPt):

curve 1:

ActPt (ActPt):

DeptRef (DeptRef):

V1 (V1):

VA1 (VA1):

V2 (V2):

VA2 (VA2):

V3 (V3):

VA3 (VA3):

V4 (V4):

VA4 (VA4):

V5 (V5):

VA5 (VA5):

V6 (V6):

VA6 (VA6):

V7 (V7):

VA7 (VA7):

V8 (V8):

VA8 (VA8):

None (RmpTms):

RmpDecTmm (RmpDecTmm):

RmplncTmm (RmplncTmm):

ReadOnly (ReadOnly):

Read Write

Model 127 – Frequency-Watt Control

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lVRT hVRT

WGra (WGra):

HzStr (HzStr):

HzStop (HzStop):

HysEna (HysEna):

ModEna (ModEna):

HzStopWGra (HzStopWGra):

Read Write

Model 128 - Dynamic Reactive Current

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lVRT hVRT

ModEna (ModEna):

FlTms (FlTms):

DbVMin (DbVMin):

BlkZnV (BlkZnV):

HysBlkZnV (HysBlkZnV):

BlkZnTms (BlkZnTms):

Read Write

Model 131 - Watt – PF

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lVRT hVRT

ActCrv (ActCrv):

ModEna (ModEna):

NCrv (NCrv):

NPt (NPt):

curve 1:

ActPt (ActPt):

W1 (W1):

PF1 (PF1):

W2 (W2):

PF2 (PF2):

W3 (W3):

PF3 (PF3):

W4 (W4):

PF4 (PF4):

W5 (W5):

PF5 (PF5):

W6 (W6):

PF6 (PF6):

W7 (W7):

PF7 (PF7):

W8 (W8):

PF8 (PF8):

RmpPT1Tms (RmpPT1Tms):

RmpDecTmm (RmpDecTmm):

RmplncTmm (RmplncTmm):

ReadOnly (ReadOnly):

Read Write

Mode 132 - Volt/Watt

SunSpec Dashboard

Device Tools Help

common mode_L11 mode_L12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt hvrt hvrt

ActCrv (ActCrv):

ModEna (ModEna):

NCrv (NCrv):

NPt (NPt):

curve 1:

ActPt (ActPt):

DeptRef (DeptRef):

V1 (V1):

W1 (W1):

V2 (V2):

W2 (W2):

V3 (V3):

W3 (W3):

V4 (V4):

W4 (W4):

V5 (V5):

W5 (W5):

V6 (V6):

W6 (W6):

V7 (V7):

W7 (W7):

V8 (V8):

W8 (W8):

RmpPtTms (RmpPtTms):

RmpDecTmm (RmpDecTmm):

RmplncTmm (RmplncTmm):

ReadOnly (ReadOnly):

Model 160 – MPPT

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lvrt hVRT

Global Events (Evt): 0
Number of Modules (N): 6

module 1:
Input ID (ID): 1
DC Current (DCA): 3.6
DC Voltage (DCV): 443
DC Power (DCW): 1600.0
Module Events (DCEvt): 0

module 2:
Input ID (ID): 2
DC Current (DCA): 3.6
DC Voltage (DCV): 443
DC Power (DCW): 1600.0
Module Events (DCEvt): 0

module 3:
Input ID (ID): 3
DC Current (DCA): 0.0
DC Voltage (DCV): 0
DC Power (DCW): 0.0
Module Events (DCEvt): 0

module 4:
Input ID (ID): 4

module 5:
Input ID (ID): 5

module 6:
Input ID (ID): 6

Read Write

Model 137 – LVRT

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt lvrt hVRT

ActCrv (ActCrv): 1
ModEna (ModEna): 1
NCrv (NCrv): 1
NPt (NPt): 3

curve 1:
ActPt (ActPt): 3
Tms1 (Tms1): 21.0
V1 (V1): 105.6
Tms2 (Tms2): 2.0
V2 (V2): 60.0
Tms3 (Tms3): 60.0
V3 (V3): 45.0
ReadOnly (ReadOnly): 0

Read Write

Model 138 - HVRT

SunSpec Dashboard

Device Tools Help

common model_11 model_12 inverter nameplate settings status controls storage volt_var freq_watt_param reactive_current watt_pf volt_watt mppt hvrt hvrt

ActCrv (ActCrv):

ModEna (ModEna):

NCrv (NCrv): 1

NPt (NPt): 3

curve 1:

ActPt (ActPt):

Tms1 (Tms1):

V1 (V1):

Tms2 (Tms2):

V2 (V2):

Tms3 (Tms3):

V3 (V3):

ReadOnly (ReadOnly): 0



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