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Evaluation of SunSpec Modbus for Distributed Energy Resources

Results from EPRI Interoperability Testing and Market Research

3002009854

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Technical Update, December 2017

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ABSTRACT

IEEE 1547 and California Rule 21 are both requiring communication capabilities to DER including solar and storage. As utilities explore the options for connecting to DER in their service territory it is important that standards implementations are matured to reduce unexpected, potentially costly delays. Knowledge on the state of the art and processes for activating these new interfaces in existing devices can help utilities structure their programs efficiently and cost effectively. The goal of this project is to identify barriers in interoperability and associated business practices needed to successfully integrate smart inverters on the grid and utility programs.

Open standards should make devices and control systems plug and play but experience says that even with the most robust standards, this does not happen. Interoperability testing of DER provides utilities, manufacturers, and standards groups with feedback about how well standards are being implemented in products today and identify common source of conflicts. The findings are relayed to manufacturers and standards bodies so solutions are created before they are experienced in field.

This update consists of three main parts: an update on the results from 2016 testing, overview of the state of the industry and other non-technical considerations for working with smart inverters supporting SunSpec Modbus, and results from interoperability testing of a three-phase smart inverter.

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PRIMARY AUDIENCE: Utilities focusing on including 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

Open standards should make devices plug and play but experience says that even with the most robust standards, this does not happen. Interoperability testing of DER with provide feedback to utilities about how well standards are being implemented in products today and help identify the source of conflicts so feedback and be provided to the manufacturer and standards bodies.

RESEARCH OVERVIEW

The report consists of three main parts: an update on the results from 2016 testing, overview of the state of the industry and other non-technical considerations for working with smart inverters supporting SunSpec Modbus, and results from interoperability testing of a three-phase smart inverter. The results provide the audience with an overview of the state of the art including the number of products on the market, observations on the maturity of manufacturer support (sales and technical) for the protocol, and trends in practices for activating the interface in products. The interoperability testing identifies key barriers to the adoption and integration of SunSpec Modbus devices. EPRI shares these trends with manufacturers and standards organizations so they can address the barriers accordingly.

KEY FINDINGS

- The approaching update to IEEE 1547 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.
- Most smart inverter manufacturers listed by SunSpec have not yet incorporated SunSpec Modbus into their marketing nor their Tier 1 technical support staff.
- Adoption of SunSpec Modbus in smart inverter is low but expected to grow quickly following ratification of the update to IEEE 1547.
- The process to active SunSpec Modbus in smart inverters varies between manufacturers. Firmware updates are used by some manufacturers to add SunSpec Modbus capabilities to existing products. Others have SunSpec Modbus enabled out of the box.
- Multiple implementation issues were discovered in testing of the smart inverter. Issues appeared to be in the link between communications and functionality.
- The implementation of DeptRef (multiple modes nested in a single function) and generic modbus error codes continues to be an issue.

- If devices in a solar or storage plan use the modbus interface then switching to SunSpec Modbus may cause compatibility issues if multiple modbus interfaces are not supported. EPRI has observed both devices that support only SunSpec Modbus when enable and devices that support proprietary and SunSpec Modbus simultaneously.

WHY THIS MATTERS

IEEE 1547 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. Knowledge on the state of the art and processes for activating these new interfaces in existing devices can help utilities structure their programs efficiently and cost effectively. This project will identify and encourage discussion on key technical gaps but also provide insights into the state of the art of SunSpec Modbus to help utilities make informed decisions.

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

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

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PROGRAM: Information and Communication Technology for DER and DR, 161D

CONTENTS

ABSTRACT ..... **V**

EXECUTIVE SUMMARY ..... **VII**

1 **INTRODUCTION** **1-1**

2 **UPDATES ON 2016 TEST RESULTS** **2-1**

DeptRef 2-1

Proprietary Feature Unlock Key 2-2

Varied Support of Modbus Functionality 2-2

3 **STATE OF THE ART** **3-1**

Products on the Market 3-1

Navigating Conformance 3-3

Manufacturer Marketing and Technical Support 3-3

Asking the Right Questions 3-4

Certification and Firmware Versions 3-5

Activating SunSpec Modbus 3-6

4 **INTEROPERABILITY TESTING** **4-1**

Device Under Test 4-2

Test Results 4-3

Supported Models 4-5

Summary of Testing 4-10

5 **SUMMARY** **5-1**

Key Findings 5-1

LIST OF FIGURES

Figure 3-1 Breakdown of devices listed as SunSpec compliant 3-2
Figure 3-2 Breakdown of models supported by SunSpec compliant inverters 3-2
Figure 3-3 Example of firmware update. 3-5
Figure 4-1 Smart inverter installed in EPRI Knoxville Laboratory. 4-3
Figure 4-2 Model 103 – Inverter (Three-Phase) Monitoring 4-5
Figure 4-3 Model 120 – Nameplate Ratings 4-6
Figure 4-4 Model 121 – Basic Settings 4-7
Figure 4-5 Model 122 – Measurements and Extended Status Reporting 4-7
Figure 4-6 Model 123 – Immediate Controls 4-8
Figure 4-7 Model 123 – Volt-VAR Arrays 4-9
Figure 4-8 Model 127 – Frequency-Watt Control 4-10
Figure 4-9 Monitoring data through SunSpec interface 4-11
Figure 4-10 Example of error when attempting to change DeptRef 4-13
Figure 4-11 Example of error when attempting to change Volt-Watt parameters 4-14

1
INTRODUCTION

Open standards should make devices and control systems plug and play but experience says that even with the most robust standards, this does not happen. 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 and be provided to the manufacturer and standards bodies. The goal of this project is to identify barriers in interoperability and associated business practices needed to successfully integrate smart inverters on the grid and utility programs.

The report consists of three main parts: an update on the results from 2016 testing, overview of the state of the industry and other non-technical considerations for working with smart inverters supporting SunSpec Modbus, and results from interoperability testing of a three-phase smart inverter.

2
UPDATES ON 2016 TEST RESULTS

EPRI testing of smart inverters in 2016 identified a few key takeaways and potential barriers to interoperability. The following section provides an update to the status of those key takeaways that have advanced since 2016. More information about these issues and other results from the 2016 interoperability testing can be found in the 2016 interoperability test summary.[1]

DeptRef

2016 Finding: DeptRef is a parameter that allows users to change the behavior of a smart inverter function. 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.

Why it Matters: 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.

2017 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.

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 states specific modes but allows for other

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[1] *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.

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.

Proprietary Feature Unlock Key

2016 Finding: One manufacturer implemented a proprietary feature unlock key on their inverter. The key is required to unlock smart inverter capabilities on the device. The manufacturer indicated that this feature was to protect users and utilities from unintentional activation of smart grid functionality. The key lasts for 10 hours or until the inverter is powered off. The feature is not part of the SunSpec standard and required a custom approach to allow uninterrupted access to the inverter.

Why it Matters: 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 the SunSpec Modbus protocol 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.

2017 Update: Exceptions like this one run contrary to the idea of standardization and prevent interoperability because they require case-by-case customization. It is possible SunSpec or other protocols may adopt a mechanism to transmit these sort of commands but SunSpec did not appear to have near term plans to do so.

Varied Support of Modbus Functionality

2016 Finding: One of the inverters only allowed curves to be written one point at a time.

Why it Matters: 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.

2017 Update: 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.

3
STATE OF THE ART

In 2016 the products tested were not complete / final production units but the results still showed that these companies are moving rapidly in that direction. The SunSpec protocol is still the only non-proprietary protocol known to EPRI that is being implemented by residential scale solar inverter manufacturers. However, this is likely to change in 2018 based on EPRI discussions with smart inverter manufacturers.

Interoperability testing 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 provides a framework for utilities to require communication capabilities and identifies some key functionality of smart inverters. However, utilities will need to identify how to get these customers purchased inverters onto into their programs. This will likely include guiding customers on how to select compliant products and working with customers to activate open protocols across a wide variety of manufacturers and models of smart inverters.

Products on the Market

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.

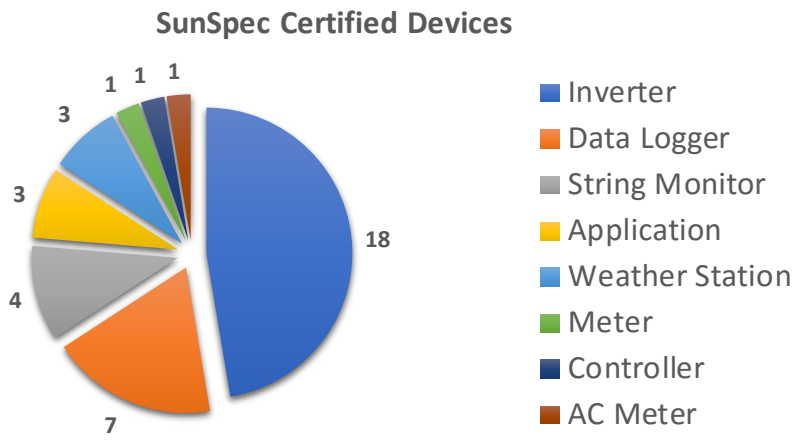


Figure 3-1
Breakdown of devices listed as SunSpec compliant

Modbus is popular with inverter manufacturers because support for the Modbus protocol is already in their current line of products. Thirty-eight DER-related product families are listed on SunSpec's website as having completed SunSpec Certification, including major manufacturers. This includes eighteen solar inverters (Figure 3-1). The number of certified inverters is likely to rise as updated IEEE 1547 requirements go into effect.

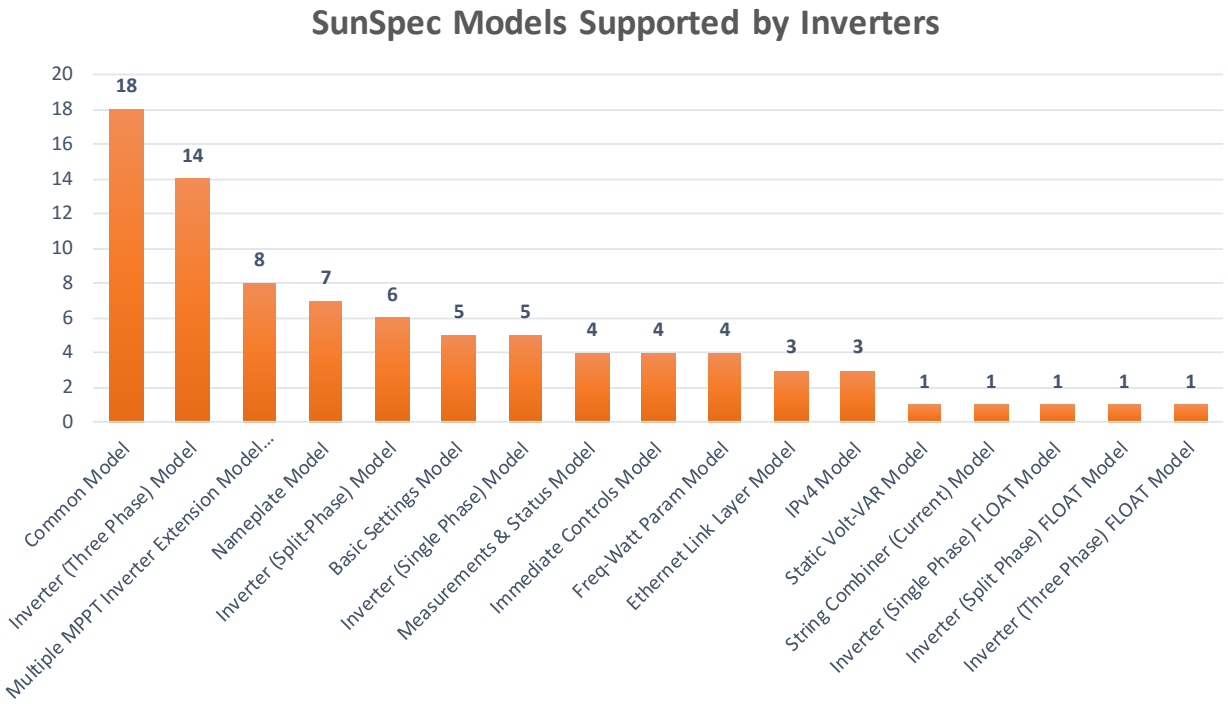


Figure 3-2
Breakdown of models supported by SunSpec compliant inverters

Out of the eighteen manufacturers the supported functionality varied. As shown in Figure 3-2, 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

SunSpec Modbus along with other protocols for controlling DER are relatively new to the industry. 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. There is a lot of variation across manufacturers for how they inform users about conformance to standard communication protocols but also how users can enable these open protocols in their products. The next section will provide an overview of common trends in manufactures and why it may matter to utilities.

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, 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 big of a deal 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 though 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 (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 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 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 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.

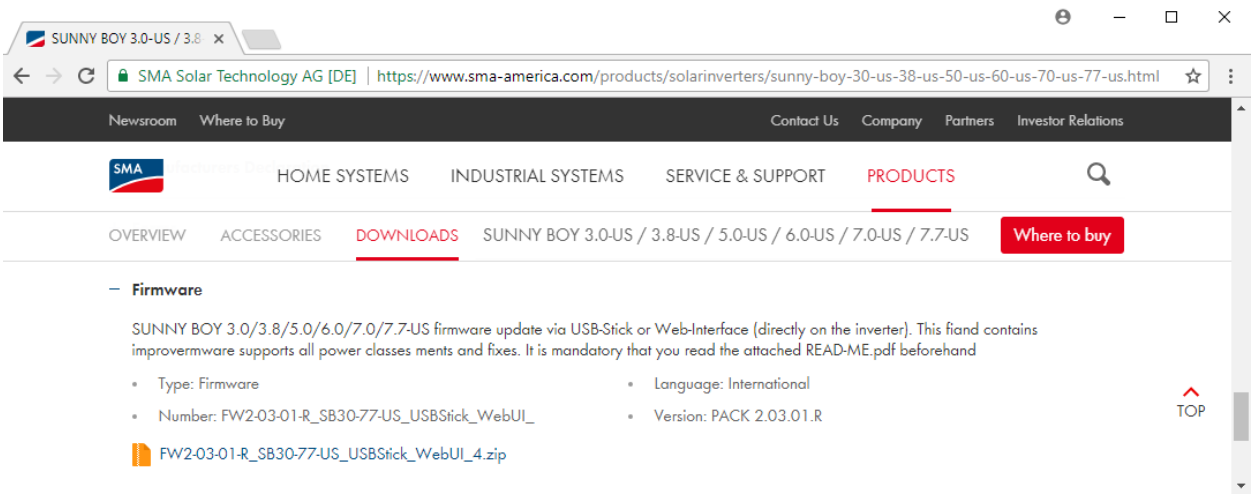


Figure 3-3
Example of firmware update.

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 3-3. 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 compliance testing may help with basic applications however more advanced applications

including energy storage or solar systems using functionality not defined in IEEE 1547 may create a need to navigate the process manually. 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 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.

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.

4
INTEROPERABILITY TESTING

EPRI researchers conducted a series of tests to identify any potential interoperability issues before they occur in the field. The results from this test is captured in the following section. To help the industry fix these potential barriers before they occur in the field, barriers will be communicated to manufacturers involved and appropriate stakeholder groups. This testing is not meant to certify or endorse products but instead serve a snapshot of the current state of the art. Open protocols for smart inverters are relatively new compared to control of distribution assets or demand response technologies. Though the standards are often robust there is always room for those implementing the protocol to misunderstand or encounter vague language. Formal certification processes will help to identify many of these errors and barriers. Even then interoperability is bigger than just protocol conformance. There are multiple standards and processes involved in making a device work from end-to-end (utility to end device). EPRI will use their suite of 3rd party and EPRI-made test tools to evaluate the current state of interoperability today and if gaps exist, to include them in their research roadmap. The goals of testing include the following categories.

Survey of Functionality in Device

The inverter had been certified by the SunSpec Alliance to meet the requirements of the SunSpec Specification. This includes validating the modbus protocol appears to be implemented properly, values are implemented as read only or read/write following the specification, and the device complies with other networking related requirements. The test is conducted over the internet between the SunSpec test server and the inverter that is installed at a separate, manufacturer facility. SunSpec's certification process is unable to verify the device performs the correct function.

In EPRI's testing researchers polled the inverter to understand which capabilities (control and monitoring) are supported by the inverter. Researchers will send commands the inverter and validate the inverter responds. It is considered out of scope to fully characterize the response however researchers will validate that the responses relate to the communicated request but will stop short of fully characterizing the electrical response.

Only functions supported through the SunSpec Modbus interface will be testing. Proprietary interfaces will not be used in the testing.

Understand Limitations on Values

Sometimes manufacturers put limits or requirements on specific control parameters. An example is a minimum power level. Some inverters shutdown if output power drops below a certain percent of rating. Other inverters restrict how much flexibility users have over curves like volt-var. Researchers will note any unexpected barriers they encounter.

Characterize Response Times

Smart inverters provide a variety of internal monitoring points. The communication protocols do not require these parameters be updated on a specific interval so there is potential for variation between devices. Depending on the applications utilities may need different intervals. Researchers will characterize how often registers update by comparing data from external metering to data through the SunSpec interface.

The total delay from when a measurement is taken and when it is received at the utility is a combination of multiple delays. First is delay caused by the sample interval in the device. Next is the latency between the controller and the device. An finally the delay between the site controller and the utility. Delay is therefore specific on the installation and current conditions on the communication systems. The only inverter specific delay is the one caused by sampling intervals. The total delay can never be faster than the slowest link. Researchers will characterize inverter induced delays to help utilities understand how to approach high speed applications.

Exploratory Testing for Interoperability Issues

Modern communication standards are robust however even the most thoroughly defined standard is limited by scope. Design choices outside of the communication standard itself can cause issues that may prevent devices from properly communicating with each other. Researchers will watch for these potential barriers and document them if encountered. Examples of interoperability issues identified in the past include proprietary unlock codes that must be periodically entered to unlock advanced controls. Another is conflict in access between utilities and customers when both are connected to the device simultaneously. Often manufacturer provide an interface for customers to monitor their system but it can sometimes cause unexpected issues at the utility interface.

Device Under Test

The pending update to IEEE 1547 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. 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.

The manufacturer did not mention SunSpec Modbus functionality on their website at the time of publishing this report. However, the SunSpec Alliance lists them as supporting the following models. Manufacturer technical support confirmed the model supported SunSpec Modbus. More information about each SunSpec Model and its mapping to smart inverter functionality is available through the SunSpec Modbus specifications.[2]

- Model 1 – Common Information
- Model 103 – Inverter (Three-Phase) Monitoring

[2] SunSpec Specifications & Information Models. SunSpec Alliance. Accessed November 2017. https://sunspec.org/download/

- Model 120 – Nameplate Ratings
- Model 121 – Basic Settings
- Model 122 – Measurements and Extended Status Reporting
- Model 123 – Immediate Controls
- Model 126 – Volt-VAR Arrays
- Model 127 – Frequency-Watt Control
- Model 160 – Multiple MPPT Inverter Extension Model

Test Results

EPRI installed the inverter in the EPRI Knoxville Laboratory. The inverter was updated with firmware provided by manufacturer technical support staff. The firmware was stated to add SunSpec Modbus functionality to the inverter. The inverter was connected to the local grid and a solar inverter simulator. The solar inverter simulator was slightly undersized so the full range of the solar inverter could not be tested. This was not expected to impact testing because the testing focused on the communication interface and did not include characterizing the functional characteristics of the inverter. Meters were installed on the input and output of the inverter so researchers could monitor the behavior of the inverter. A photo of the laboratory setup is shown in Figure 4-1. The inverter supports Modbus RTU and uses Modbus slave ID 1. Figure 4-1 has been digitally manipulated to obscure the make and model.



Figure 4-1
Smart inverter installed in EPRI Knoxville laboratory.

EPRI evaluated the SunSpec interface by sending commands to the inverter over the SunSpec interface and verifying that the response was appropriate. EPRI did not fully test the functionality in this project because the focus was on the communication interface not device's electrical capabilities. The findings below are from a mixture of the survey of functionality in device, understanding limitations on values, and exploratory testing for interoperability issues.

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. Next, EPRI tested each parameter and monitoring point to validate that they correctly correlated to changes in inverter behavior. There was no documentation on the SunSpec interface for this inverter so EPRI researchers relied on the SunSpec Modbus specification to navigate the different smart inverter functions and parameters.

Supported Models

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

Model 1 – Common Information

The common information model contains information about the inverter including manufacturer, model, firmware version, and serial number. The values shown through the SunSpec Modbus interface matched the expected responses. The version correlated with the firmware version provided by the manufacturer.

Model 103 – Inverter (Three-Phase) Monitoring

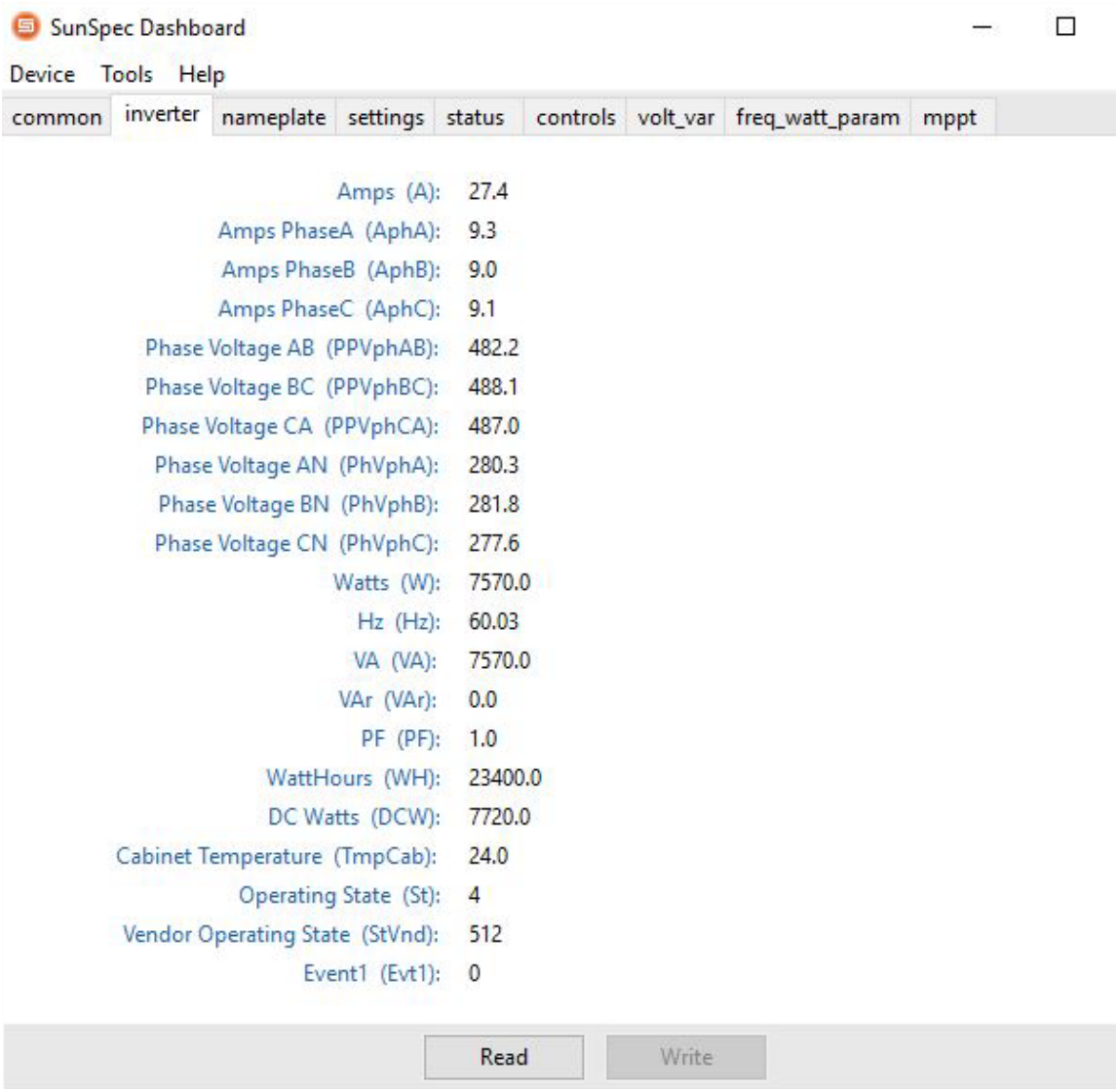


Figure 4-2
Model 103 – Inverter (Three-Phase) Monitoring

The Inverter Monitoring model contains monitoring points for both the DC input and AC output. Using external meters EPRI confirmed that the following parameters followed the expected measurement.

- AC Amps (A)
    - Total, Phase A, Phase B, Phase C.
- Phase Voltage
    - AB, C, CA, AN, BN, CN
- AC Watts
- Frequency
- Volt Amps
- VARs
- Power Factor
- DC Watts
- Cabinet Temperature

Model 120 – Nameplate Ratings

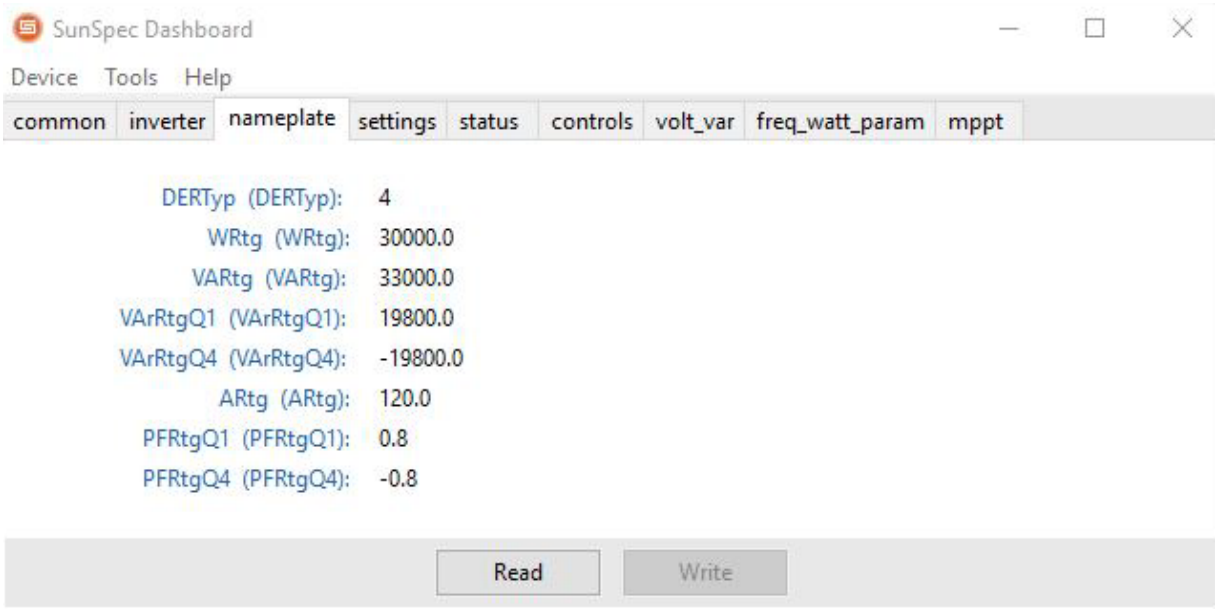


Figure 4-3
Model 120 – Nameplate Ratings

The Nameplate Ratings model includes all the design characteristics of the inverter. This includes max watts, max VARs, and power factor limits. These are read only static variables so no testing was performed. However, it was noted that the ratings match the specification sheets.

Model 121 – Basic Settings

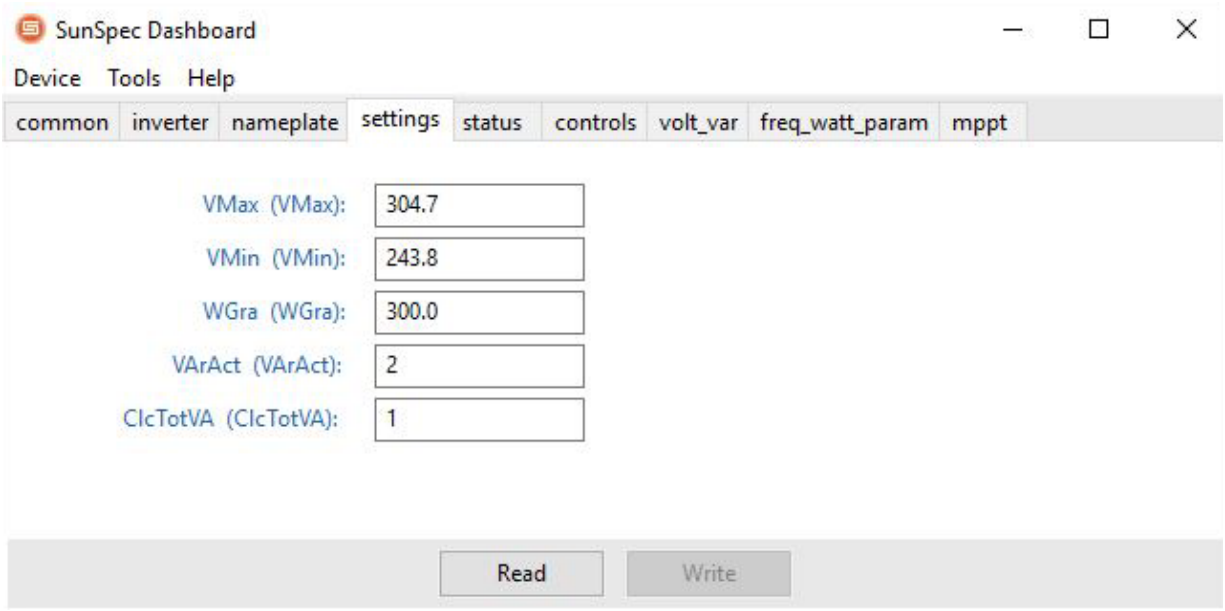


Figure 4-4
Model 121 – Basic Settings

The Basic Settings model includes all manufacturer imposed limits and some user settable parameters that impact all smart inverter functions.

Model 122 – Measurements and Extended Status Reporting

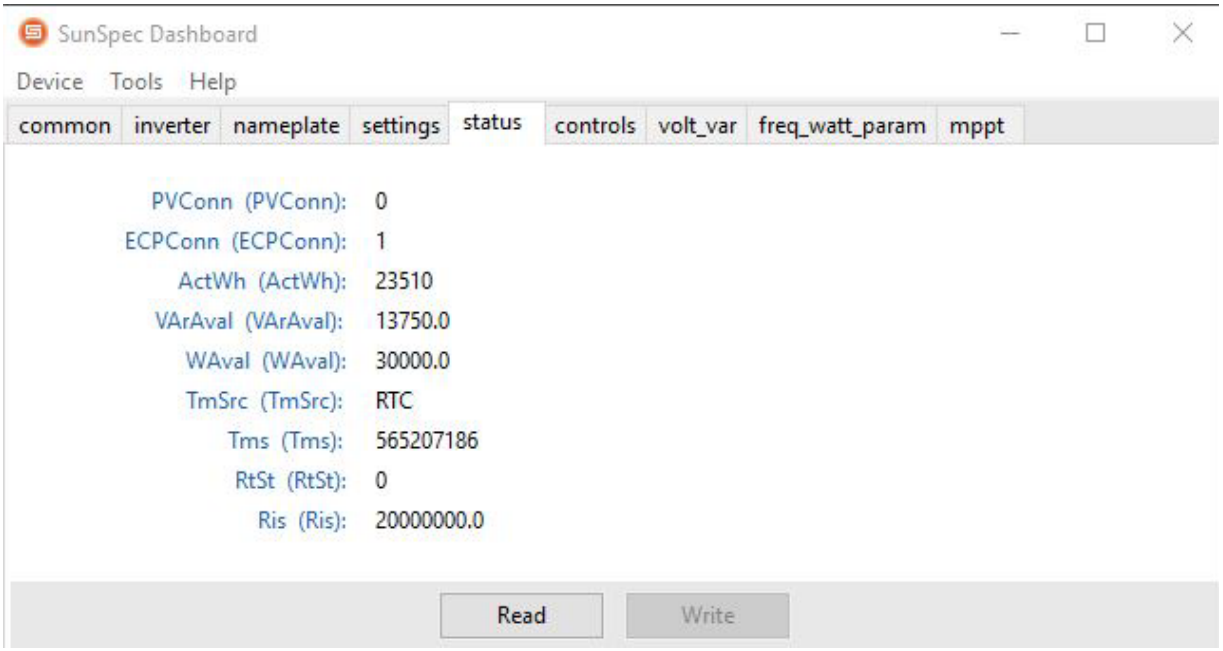


Figure 4-5
Model 122 – Measurements and Extended Status Reporting

Measurement and Extended Status Report contain additional states, monitoring points, and counters.

Model 123 – Immediate Controls

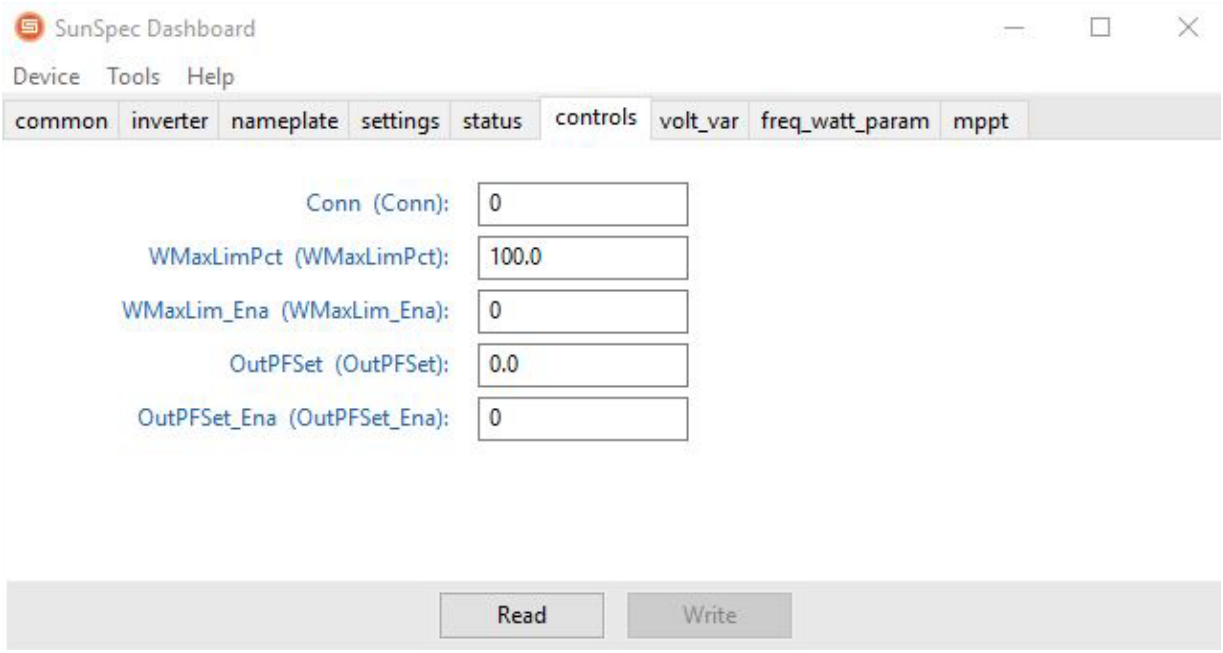


Figure 4-6
Model 123 – Immediate Controls

Immediate Controls contains parameters used to impact the current behavior of the inverter.

Model 126 – Volt-VAR Arrays

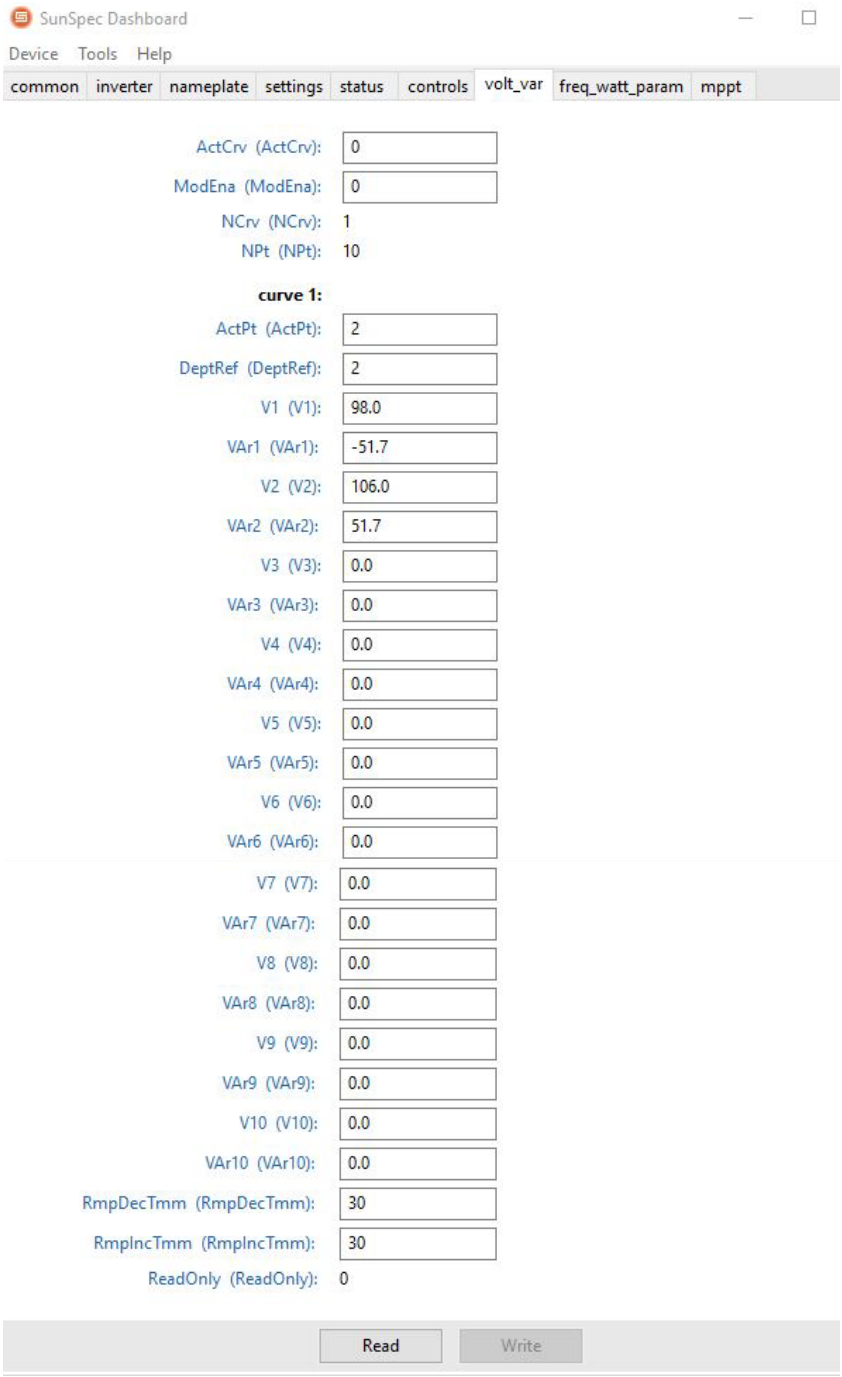


Figure 4-7
Model 123 – Volt-VAR Arrays

Volt-VAR Arrays are used to dynamically change the reactive power of the inverter to support voltage on the grid. This model contains all the parameters related to controlling this function.

Model 127 – Frequency-Watt Control

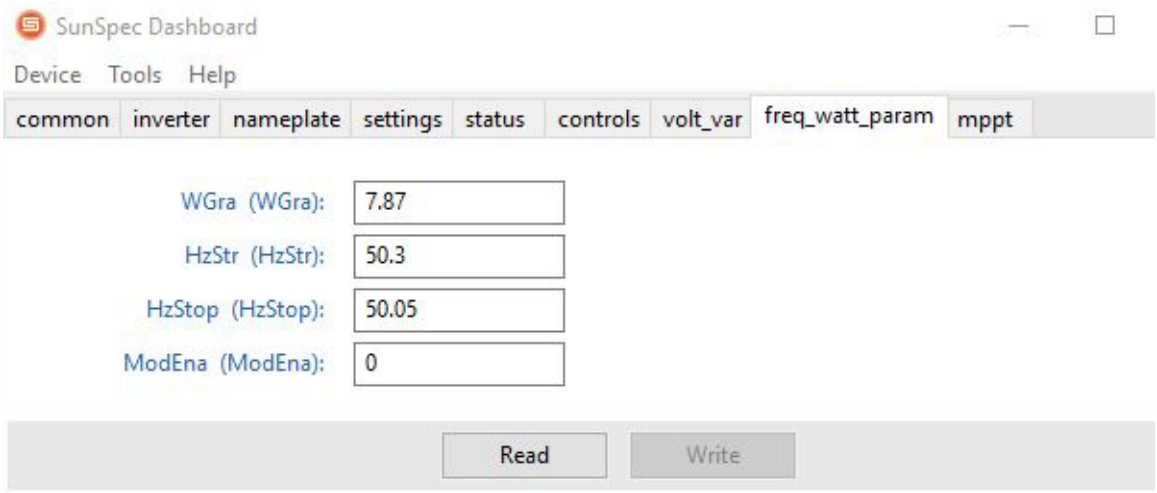


Figure 4-8
Model 127 – Frequency-Watt Control

Frequency-Watt Control is used to detect frequency deviations at the connection point of the inverter and modify output power to help support the grid. This model contains all the parameters related to this function. There are both curve based and parameter based approaches to Frequency-Watt. This model corresponds to the parameter based approach.

Summary of Testing

The following section provides an overview of the important takeaways from the testing. Most of the items below focus on potential barriers to interoperability. What is not mentioned is that many of the parameters worked as expected included monitoring data, device information, and active power control. The focus is on the potential issues and key considerations in interoperability because these are the findings that can help mature the protocol. Testing of smart inverter functions through proprietary interfaces was outside of the scope of this project so it is possible that the results would be different through another interface in the inverter.

Initial Connection

Initial setup of the communication interface was straightforward. The manufacturer did not provide firmware on their website but their technical support was able to provide the new firmware quickly once they had information about the model and current firmware version. Once the new firmware was loaded, an Android device was connected to the USB port on the inverter. Using the manufacturer's phone application, the communications options could be modified and the SunSpec Modbus interface enabled. The SunSpec Dashboard was then able to connect to the device using the recommended SunSpec modbus parameters.

Takeaway: Initial setup of the communication interface was straightforward.

Sample Interval

EPRI was unable to test the different operating states and event flags because of limitations of the test setup. Many of the states required complex lab setups to emulate real world failures including blown fuses, over temperature, and memory failures so they were not tested.

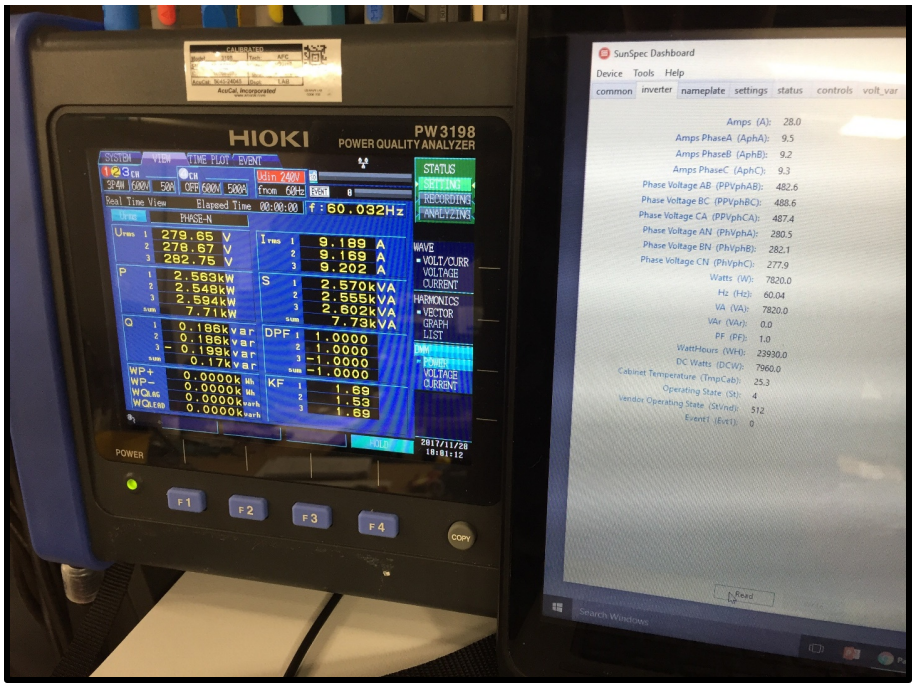


Figure 4-9
Monitoring data through SunSpec interface

EPRI evaluated the update time on the SunSpec Modbus registers and found the update interval was about 1 second. This is the rate that the inverter appeared to be updating the information in each register. This was tested by causing the output power to ramp over a long period of time by setting a small ramp rate (WGra). The inverter was then set to change the output causing steady changes in the power. Researchers rapidly polled the monitoring registers through the SunSpec Modbus interface and monitored how often the registers were updated. This setup is shown in Figure 4-9.

Communications delay over the Modbus RTU interface was negligible as is typical with these interfaces. This is the amount of time it takes for a message to be sent from the polling device (computer in this case) to the slave (inverter) and the response to be received at the polling device.

Takeaway: The sample rate is likely fast enough for many grid services.

Ramp Rate (WGra)

There was some odd behavior on the basic settings parameters specifically WGra. WGra appeared to function properly. When different ramp rates were written to WGra the inverter appeared to change its rate of change for active power. However, there were a couple issues. First, it did not seem to accept zero a valid entry. It did not return an error but instead always changed it to 300 a few seconds after writing zero. In SunSpec Modbus zero is translated as “as fast as you can” so setting a ramp rate to zero tells the inverter that when a smart inverter function changes the output power of the device it should to change active power as fast as it can. Also, 300 is an invalid value because the unit is percent of WMax per second. Second, the inverter would change the value entered to another value often adding two to the value a few seconds after writing. For example, when 100 was written to the register and read a few seconds

later the inverter would return 102. Additionally, even though the max should theoretically be 100 the inverter would allow any value to be entered however any value over 3000 was rounded down to 3000 by the inverter a few seconds later. EPRI's researchers were not able to tell why this was happening in testing but it was odd behavior for this parameter.

Takeaway: This is not the expected implementation of this parameter so this implementation will cause interoperability issues. Control systems will be unable to properly control this system because their intended settings will not be properly implemented by the device. EPRI will relay this information to the manufacturer.

Connect / Disconnect

The connect/disconnect parameter (Conn – Model 123) appeared to initialize to zero which correlates with disconnected. The inverter was connected at the time so this was an invalid value. However, setting the parameter to 1 then setting the Conn parameter to 0 causes the inverter to trip and continues to report accurately after that. The inverter performs a full restart process when disconnect is sent to the inverter. It monitors the connection for a period of time before connecting.

Takeaway: Initializing to an incorrect value could be an issue because it could cause control systems to incorrectly poll the state of the inverter. However, the issue would be corrected as soon as connect command was sent to the inverter. It is still an incorrect implementation so EPRI will relay this information to the manufacturer.

This inverter performed a full trip as opposed to cease to energize we often see in inverters. This is not an issue but a general issue (not specific to this inverter) is the variation in how connect/disconnect is implemented. Some trip (galvanic isolation + full reconnection process) and some cease to energize (set output power to zero). The reason this matter is that galvanic isolation is often related to safety where cease to energize is still technically tied to the grid. Also, returning from case to energize is instant where returning from trip requires a reconnection process of a few minutes. There is ongoing discussion to standardize this approach or at least embrace the differences to highlight that they are two different approach.

Power Factor Control

SunSpec Modbus supports direct power factor control where users can set the output of the inverter to a power factor. This inverter supported the parameters to control power factor but the parameters had no impact on the performance of the device. The inverter continued to operate at unity power factor regardless of the power factor setpoint.

Takeaway: Unimplemented features should return the max value of their datatype to tell upstream devices that they do not support this functionality. The manufacturer should either return this value or implement this feature.

Data Logger

The manufacturer sells a standalone datalogger that collects and aggregates data from multiple strings of inverters through Modbus RTU connections. It has a web interface to allow for remote monitoring over the internet. EPRI noticed that turning on SunSpec Modbus in the inverter broke the communication link to the data logger. Manufacturer support confirmed there is no support for SunSpec to the data logger.

Takeaway: This is a minor issue but it highlights the possible unintended consequences of changing communications interfaces at a plant. This product supports SunSpec Modbus but turning it on may cause a failure in other systems. For example, if a customer was using the datalogger for their own purpose and the utility required them to activate the SunSpec interface then the customer's logger would not work.

It is expected that as the industry matures these issues will sort themselves out.

Volt-Var Curve

The volt-var curve did not work as specified in the SunSpec Specification.

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. The inverter supported DeptRef however changing it from anything but two returned exception 3 ("Illegal Data Value") modbus error (Figure 4-10).

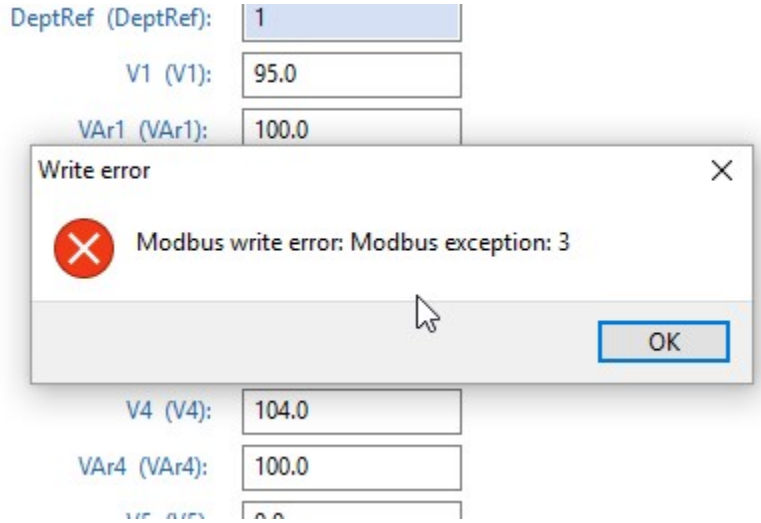


Figure 4-10
Example of error when attempting to change DeptRef

SunSpec Modbus uses ModEna in each model to enable or disable the corresponding function. Setting ModEna to 0 did not disable the curve. The only way EPRI's researchers could find to disable the curve was to set ActCrv – the index for the currently active curve – to zero.

The inverter ignored any changes to volt-var curves unless ModEna was changed. ModEna is a binary input. Changing from 1 to 0 or 0 to 1 would cause the new curve to become active. This is an incorrect implementation. As previously mentioned, ModEna is intended to enable or disable the function.

Takeaway: Volt-Var has been implemented improperly and would not work with another SunSpec device. EPRI will relay this information to the manufacturer.

Frequency-Watt Function

The frequency-watt function did not allow for new values to be set. Writing to any of these values returned an exception 3 (“Illegal Data Value”) modbus error.

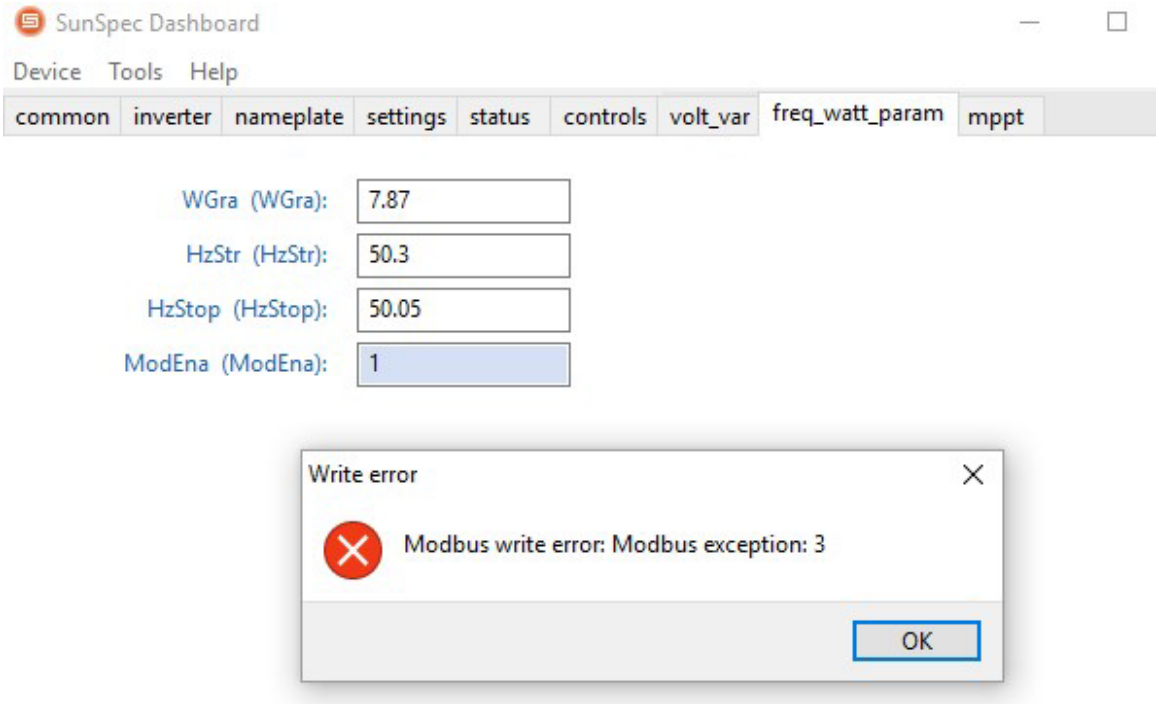


Figure 4-11
Example of error when attempting to change Volt-Watt parameters

Takeaway: The function appeared fixed because no new values were accepted by the inverter however the registered were set to read/write.

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 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 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.

The implementations of SunSpec Modbus in solar inverters has not matured. EPRI's testing of inverters indicates that manufacturers continue to misunderstand the purpose of each parameter. It should be noted that these products are some of the first to market so some barriers are expected. EPRI plans to communicate these key misunderstandings to the industry and standards group to help develop more robust certification processes and identify key gaps in the understanding of these protocols.

Key Findings

- The approaching update to IEEE 1547 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.
- Most smart inverter manufacturers listed by SunSpec have not yet worked SunSpec Modbus into their marketing nor their Tier 1 technical support staff.
- Adoption of SunSpec Modbus in smart inverter is low but expected to grow quickly following ratification of the update to IEEE 1547.
- The process to active SunSpec Modbus in smart inverters varies between manufacturers. Firmware updates are used by some manufacturers to add SunSpec Modbus capabilities to existing products. Others have SunSpec Modbus enabled out of the box.
- Multiple implementation issues were discovered in testing. The issues were matching communications parameters with the correct device behavior.
- The implementation of DeptRef (multiple modes nested in a single function) continues to be a potential barrier.
- The sample rate of the SunSpec Modbus registers in the smart inverter test appeared to update once a second.
- If devices in a solar or storage plan use the modbus interface then switching to SunSpec Modbus may cause compatibility issues if multiple modbus interfaces are not supported. EPRI has observed both devices that support SunSpec Modbus exclusively when enabled and devices that support proprietary and SunSpec Modbus simultaneously.

The industry will continue to mature as demand increases for open communications standards in smart inverters. Currently open communications standard in smart inverters are new so processes outside the communication standard including marketing, technical support, and setup are not fully developed. As this capability matures across manufacturers and the industry learns from experiences in the field this process will continue to be refined and streamlined. Until then utilities may want to consider the current state to help drive decision making to streamline the inclusion of these systems in their programs and distribution system.

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