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Energy Research and Development Division

FINAL PROJECT REPORT

Certified Open Source Software to Support the Interconnection Compliance of Distributed Energy

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Certified Open Source Software to Support the Interconnection Compliance of Distributed Energy Resources is the final report for the Certified Open-Source Software to Support the Interconnection Compliance of Distributed Energy Resources project (Contract Number EPC-15-044) conducted by the Electric Power Research Institute, Inc. The information from this project contributes to and supports the objectives of the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

This project developed, certified, and demonstrated an open source communication software that is an Institute of Electrical and Electronics Engineers 2030.5 client for smart distributed energy resources, which meets the new California Rule 21 requirements. The Institute of Electrical and Electronics Engineers 2030.5 architecture is a client-server and the client component that resides in end devices such as an inverter gateway or an aggregator control system. This open source client is available to large numbers of inverter and system manufacturers for use in their products.

The project also developed a certification procedure and the associated test software allowing any system or device to be checked for compliance with the Institute of Electrical and Electronics Engineers 2030.5 communication standard — a major step toward achieving interoperability. The certification procedure creates an opportunity for independent evaluation, provides manufacturers with an unbiased assessment of their products, and provides both business and individual consumers with assurance that their purchases will work as expected.

The end products resulting from this project will help ensure that distributed energy resource equipment or systems remain compatible with value-added opportunities over their service life and allow California ratepayers to accelerate the adoption of increased grid-tied solar generation.

Keywords: interoperability, smart inverters, distributed energy resource, distribution system, rule 21

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EXECUTIVE SUMMARY

Introduction

California has set the stage for a carbon-free future by mandating 100 percent of its electricity be derived from renewable energy and zero carbon energy-based resources by 2045. Although it is expected that more than 50 percent of this energy will come from large renewable solar, wind, and hydroelectric power plants, much of it will need to come from distributed energy resources, which are owned and operated by people and businesses of California as self-generation. These distributed energy resources consist primarily of photovoltaic systems whose net energy effect on the electric grid may vary widely by day, season, and year, depending on weather and customer decisions.

Over the last several years, the Smart Inverter Working Group sponsored by the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) determined that distributed energy resources must be capable of providing grid support and accessible communication. The working group effort resulted in an update to California Rule 21 — the regulations for the interconnection of distributed energy resources by California investor-owned utilities. Phase 1 of the Smart Inverter Working Group required distributed energy resources to implement key autonomous functions, while Phase 2 addressed the communication requirements for supporting these Phase 1 functions, as well as additional Phase 3 distributed energy resources functions.

The Smart Inverter Working Group's Phase 2 communication requirements identified the need for utilities to manage the distributed energy resources dispersed throughout their jurisdictions. Such management necessarily involves monitoring and controlling these resources, in most cases indirectly through aggregators. To ensure these utilities can communicate with all distributed energy resources, the Smart Inverter Working Group Phase 2 selected a default communications protocol, Institute of Electrical and Electronics Engineers (IEEE) 2030.5, that all installations must support although other communication protocols are permitted. California Rule 21 codified these communication requirements with distributed energy resources manufacturers given a short time to implement the IEEE 2030.5 communication protocol.

Although IEEE 2030.5 is a capable and secure communications protocol, it has not been previously implemented in the distributed energy resources environment. Aggregators and distributed energy resource manufacturers find the new communication requirements complex and time-consuming and expensive to apply. This cost and complexity impede achieving the energy policy goals of California in three primary ways:

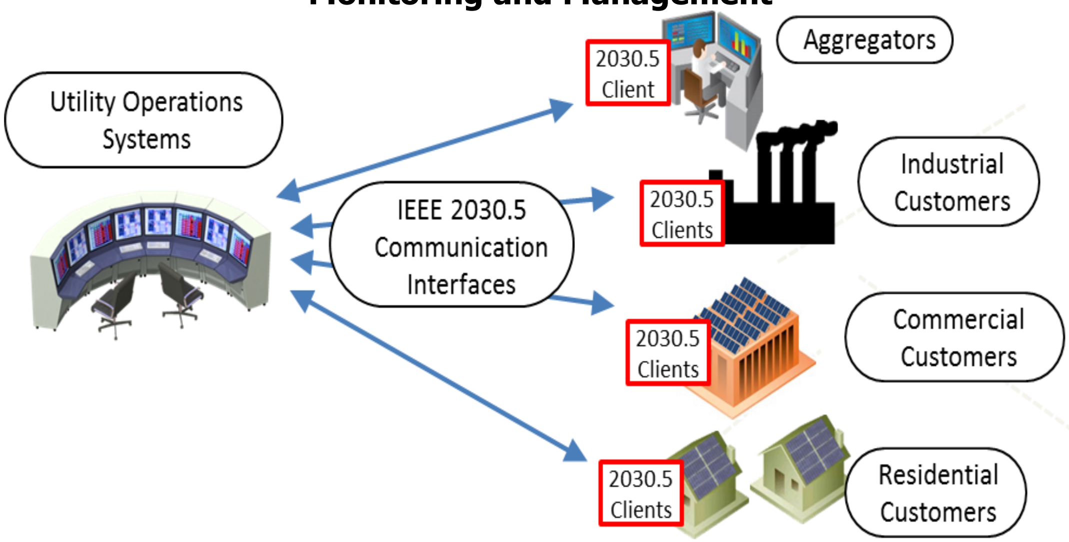
1. Communication software development, testing, and integration time for products that meet the California Rule 21 requirements is taking longer than expected, delaying the availability of products.
2. The cost of development is a significant business hurdle for distributed energy resources manufacturers and aggregators, also delaying implementation of products.
3. Interoperability across different applications of this communication protocol cannot be achieved without a testing and certification process. Lack of interoperability is costly to overcome and could prevent timely deployments.

Project Purpose

This project addressed these issues by providing two key technologies that help minimize the costs of developing communication software and accelerate the use of distributed energy resources:

1. First is to develop, certify, and demonstrate an open source communication software meeting the new Rule 21 requirements that is an IEEE 2030.5 client for smart distributed energy resources. The IEEE 2030.5 architecture is client-server and, as illustrated in Figure ES-1, it is the client component that resides in the end user devices such as an inverter's gateway or an aggregator's control system. This open source client will thus be available for implementing in their products by large numbers of inverter and system manufacturers.
2. Second is to develop a certification procedure, mandated by the CPUC, and the associated test software by which any system or device can be checked for compliance to the standard. This process would be a major step toward achieving interoperability. Independent evaluation provides manufacturers with an unbiased assessment of their products and provides both business and individual consumers with assurance that their purchases will work as expected.

Figure ES-1: Communications for Distributed Energy Resource Monitoring and Management



Source: Electric Power Research Institute

Project Process

The process followed in this project included the following steps.

- Determine the scope of this project based on California Rule 21. The process revising California Rule 21 resulted in a specific set of mandatory smart inverter functions, data monitoring, control, and communication capabilities. The project scope was based on the most current version of Rule 21 at the time of execution.
- Develop specifications for the IEEE 2030.5 client conforming to the California Smart Inverter Profile for IEEE 2030.5. There are multiple ways to use the IEEE 2030.5 protocol to support a given function. This ambiguity results in a lack of product and

system interoperability unless a specific approach or "communications profile" is chosen. Specific ways to use a communication standard are sometimes referred-to as "profiles." As agreed during the Smart Inverter Working Group Phase 2 process, the California Smart Inverter Profile was developed as a joint effort of the California investor-owned utilities to address this issue. The California Smart Inverter Profile guide, along with the IEEE 2030.5 specifications, were used to develop the functional and performance specifications for the client.

- Develop flexible open source software for the IEEE 2030.5 client in compliance with those specifications and with simple, flexible licensing. This project developed the IEEE 2030.5 client with almost unlimited licensing freedom, allowing for derivative works without requiring implementers to contribute back to the open source project.
- Develop compliance test procedures for California Rule 21 functions and IEEE 2030.5 communications. The project created Rule 21-specific test procedures that enabled conformance testing for distributed energy resources to meet Rule 21 requirements. The certification testing ensured that the open source client met both the industry standard for IEEE 2030.5 and Rule 21-specific requirements.
- Integrate and test the certified IEEE 2030.5 open source client in a commercial distributed energy resources control system. The open source client was integrated into a commercial distributed energy resources gateway and tested for a set of California Rule 21 functions. This testing validated that the distributed energy resources provider was able to successfully connect to an IEEE 2030.5 server and was able to report inverter performance and respond to control commands as required by Rule 21.

Project Results

The project achieved several results that are valuable for California distributed energy resources stakeholders.

IEEE 2030.5 Distributed Energy Resource Compliance Test Procedure

A major goal of this project was to develop a compliance test procedure by which any IEEE 2030.5 software could be verified by a software developer or commercial enterprise. This test procedure ensures that commercial use is compliant with IEEE 2030.5 functionality and options as specified in the California Smart Inverter Profile document. Availability of this test procedure addresses a major challenge for California's energy goals by enabling Rule 21-compliant products to have their communications capabilities certified, thus avoiding the costs and time delays for correcting software implementations in the field. This test procedure is based on the latest version of the California Smart Inverter Profile specification (March 2018) and the 2018 version of the approved IEEE 2030.5 standard.

Open Source IEEE 2030.5 Client

Another goal of this effort was to create and certify an open source software product that can be readily integrated by aggregators, distributed energy resources vendors, energy management system vendors, etc., for interoperable communications with utility servers based on the Rule 21 communication requirements. The project was successful in developing all the requirements of an IEEE 2030.5 client defined in the California Smart Inverter Profile and Rule 21. Moreover, for the final product to be readily useable in the marketplace, all components of the software were released with simple, flexible licensing.

Availability of open source code ensures uniform implementation, reduces the cost and complexity of bringing systems to market, streamlines the certification process, and helps ensure that products can successfully connect and participate in grid programs.

Commercial Implementation of the Software

Finally, the open source client was successfully integrated into a commercial distributed energy resources system and tested to validate the completeness and quality of the developed test procedure and the open source software. Commercial application will enable more rapid deployment of distributed energy resources that meets the Rule 21 requirements.

Technology/Knowledge Transfer

To facilitate information dissemination, The Electric Power Research Institute (EPRI) and project partner SunSpec Alliance have executed a multi-pronged outreach program to reach engineers and managers working in product development, software development, and cybersecurity for industry participants such as DER manufacturers, inverter manufacturers, aggregators, communication system providers, system integrators, utilities, regulatory agencies, and related organizations.

The key deliverables of this project are an open source software stack, an updated test harness and a set of test procedures to enable software developers and implementers to validate California Rule 21 Phase 2 compliance.

More than 20 California inverter and aggregator vendors have licensed the test tools from QualityLogic. Two leading nationally recognized test labs (including Underwriter Laboratories) are using the QualityLogic test tools to offer formal SunSpec California Rule 21 certification testing.

Four different product vendors have currently implemented the open sourced IEEE 2030.5 client. The software is integrated with their commercial gateways or facility energy management systems to provide a Rule 21 compliant interface to utility operations. Several others are currently testing the viability of incorporating the open source software in their products.

“Providing cutting edge Smart Grid features in our microinverters has always been important for Enphase, and the IEEE 2030.5 client from EPRI provides a convenient path to integrating communications and security infrastructure as well as messaging support for certification requirements,” said Raghu Belur, co-founder and chief products officer at Enphase Energy. “With our software-defined inverter platform, the Enphase team was able to quickly test the sample application and client from EPRI. The client is a good foundation for developing IEEE 2030.5 functionality, and we look forward to providing EPRI a comprehensive report documenting our experience with it.”

“EPRI’s IEEE 2030.5 open-source software client is a very valuable framework for us as we try to be one of the leaders with a vision to adapt open standards and to be at the forefront of interoperability across disparate DER management platforms and Distributed Energy Resources” said Co-Founder and CEO of the San Francisco based startup, OpenEGrid, Mr. Prabhakar Nellore. OpenEGrid is one of the first companies to incorporate the EPRI Client software in their products.

Key Lessons Learned

Some of the key lessons learned include:

- The IEEE 2030.5 specification is a complex communication standard. Test procedures developed for such standards must be targeted for maximum efficiency. The test procedures created for the IEEE 2030.5 functionality specified by the California Smart Inverter Profile requirements must be comprehensive but also able to be performed at a reasonable cost. This objective required that the tests emphasize the more critical and relevant features through all of the test cases.
- It became clear as a result of this project that an ongoing effort is necessary to maintain and improve the test procedures because experience is gained in testing and deployment of IEEE 2030.5 systems.
- There is a need for portability across different operating environments to accommodate the wide variety of implementations. Different distributed energy resources vendors prefer different operating environments to run the IEEE 2030.5 software. When developing an open source software that can be potentially leveraged by different distributed energy resources developers, it is important to address this need for portability.
- It is possible that some end devices may need to communicate with the utility server over low bandwidth networks, or over networks where data exchanges need to be minimized — like mobile networks. In such cases, it is important for the client to store the last available configuration and switch back to default configuration when required.
- In some solar installations, the gateway may be powered by the generated solar power. If so, the gateway may be powered-off each night and started-up each morning. In such a case, the gateway would have to store the default distributed energy resources configuration and fallback to defaults.
- There is a need for memory-efficient code for use on constrained devices. Toward the end of the project, the team realized that many distributed energy resources providers were interested in implementing this software locally in a gateway that was memory-constrained and using a limited power supply. For this reason, several steps were taken to ensure the software could be used by such lightweight devices. These steps included using C as the programming language of choice, limiting the scope of implementation to address only the requirements of IEEE 2030.5 and Rule 21, and developing an event-driven framework.

Benefits to California

Communications between utilities and the vast number of dispersed distributed energy resources are critical to managing the paradigm shift confronting California utilities as the State moves toward its renewable goals. The rapid and low-cost deployment of the default IEEE 2030.5 communications protocol is instrumental to achieving this visionary objective. Providing an IEEE 2030.5 open source client is a major step toward this goal.

This project has provided many key benefits to California investor-owned utility ratepayers, distributed energy resources owners, utilities, and their customers.

- Distributed energy resources owners benefit from the reduced costs that the distributed energy resources manufacturers will potentially charge to upgrade and deploy their resources to meet the new Rule 21 mandates.
- Utilities and their customers benefit from continued and improved grid safety and reliability by ensuring that distributed energy resources can respond rapidly and correctly to grid conditions and utility commands.
- Utilities benefit by having the necessary visibility into grid situations to provide incentives and manage efficient and effective distributed energy resource deployments.
- Ratepayers benefit from the reduced costs for utilities to ensure interoperable communications with the millions of distributed energy resources.
- Californians benefit from the rapid deployment of these Rule 21-capable distributed energy resources, and from the increased likelihood of California meeting its ambitious 100 percent renewable energy goal by 2045.

This project has, therefore, been an enabler and accelerator to address the California renewable energy goals; making it easier for the utilities, aggregators, and distributed energy resources manufacturers to:

- Comply with CPUC Rule 21 for smart inverter interconnection requirements.
- Dispatch distributed renewable generation uniformly regardless of manufacturer, or type of load (through aggregator or direct-dispatch).
- Take full advantage of the Smart Inverter Working Group Phase 1, 2 and 3 smart inverter functions that enable grid safety, efficiency, and reliability through timely dispatch.
- Enable improvement in renewable penetration at the lowest possible incremental cost to the utilities and their ratepayers, as well as to the distributed energy resources manufacturers.
- Increase competition within the provider base by reducing the barriers to entry, and further driving down the costs to the end customers to acquire and deploy these technologies.

EPRI estimates that it costs each distributed energy resources manufacturer approximately $1 million to $2 million and about one year of effort to bring IEEE 2030.5 communication technology on line and start installing it within the marketplace, while working with each of the third party aggregators and investor-owned utilities to ensure proper functionality. Assuming an average of $1.5 million and one year of development/integration/certification effort per stakeholder, and assuming about 20 stakeholders in the process (manufacturers, investor-owned utilities, third-party aggregators), this project has achieved California-wide cost savings to ratepayers and investor-owned utilities about $30 million (20 stakeholders times $1.5 million on average). This estimated benefit provides more than a 30:1 return on the project investment.

CHAPTER 1: Introduction

Background to IEEE 2030.5 Client Project

California has set the stage for a carbon-free future by mandating 100 percent of its electricity come from renewable energy and zero-carbon energy-based resources by 2045. Although it is expected that more than 50 percent of this energy will originate from large renewable solar, wind, and hydroelectric power plants, a significant percentage must come from DER, which are owned and operated by people and businesses of California as self-generation. These DER consist primarily of photovoltaic systems whose net energy impact on the grid may vary widely during a day, season, and year, depending upon weather and customer decisions.

Over the last few years, the Smart Inverter Working Group, sponsored by the California Public Utilities Commission (CPUC) and the Energy Commission, determined that DER must be grid-supportive and have communication capabilities that make these resources accessible. This effort resulted in the updating of California Rule 21, the regulations for the interconnection of DER by California investor-owned utilities. The Smart Inverter Working Group's Phase 1 required DER to implement key functions autonomously, while Phase 2 addressed the communication requirements for supporting these Phase 1 functions, as well as additional Phase 3 DER functions.

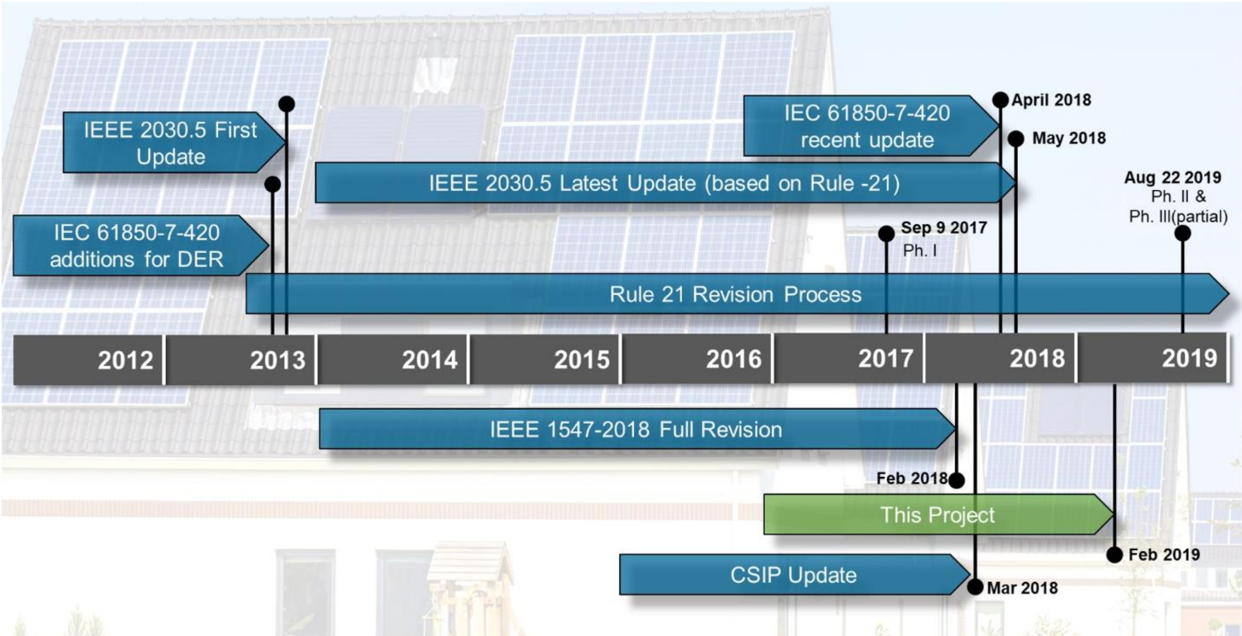
The Smart Inverter Working Group Phase 2 communication requirements identified the need for utilities to manage the DER dispersed throughout their jurisdictions. Such management necessarily involves monitoring and controlling these resources, in most cases indirectly through aggregators or through facility management systems. To ensure that these utilities can communicate with all DER, the Smart Inverter Working Group Phase 2 selected a default communications protocol, namely IEEE 2030.5, that all installations must support, although other communication protocols are additionally permitted. These communication requirements were codified in the California Rule 21, with DER manufacturers given a brief time to implement the IEEE 2030.5 communication protocol.

Although IEEE 2030.5 is a capable and secure communications protocol, it has not been previously implemented in the DER environment. Aggregators and DER manufacturers have found these new communication requirements to be complex and, therefore, time-consuming and expensive to implement. This cost and complexity is an impediment to achieving the energy policy goals of California.

IEEE 2030.5 Project Context

This project was carried out during high industry activity in the area of DER integration. The annotated timeline in Figure 1 identifies key activities related to this project.

Figure 1: Project in the Context of Related Industry Activities



Source: Electric Power Research Institute

Over the last few years it has become evident that DER can no longer just be considered as "negative load," but must become active participants in grid management. Recently, grid codes have been developed that require DER to include certain grid-supportive functionality as a prerequisite for interconnection to the grid. In California, some of these grid codes have been codified in the DER interconnection regulations, Rule 21. The Rule 21 revision process was initiated and defined by an open focus group called the Smart Inverter Working Group led by project partner, Xanthus Consulting International. The Smart Inverter Working Group's task was performed in phases, the first of which, Phase 1, defines seven autonomous functions for DER. It was approved by the state and became mandatory in September 2017. Phase 2 identifies the communication requirements, and Phase 3 defines the advanced inverter functions that will be mandatory by August 2019 (four out of the eight functions).

During the Phase 2 process, the California investor-owned utilities and the Smart Inverter Working Group members developed the CSIP that defines a more concrete set of Rule 21 communication requirements. It also identified IEEE 2030.5 as the default protocol for communication with utilities. The IEEE 2030.5 standard went through substantial revision for the DER functionality during the project to meet the functional requirements defined in Rule 21.

At the same time, the IEEE has revised IEEE 1547:2018 to address the interconnection and interoperability of DER. This revision identifies many of the same functions as Rule 21, but also identifies additional functions. It specifies that DER must be able to support at least one of three communication protocols, with IEEE 2030.5 as one of the protocols. (SunSpec Modbus, and IEEE 1815, being the other two.)

This process to develop grid codes is still on-going. Although global efforts to define common smart inverter functions began in 2008, the first communications standard to support these functions was an interim standard of International Electrotechnical Commission (IEC) 61850-90-7, which has now been incorporated into an updated edition of IEC 61850-7-420 in April

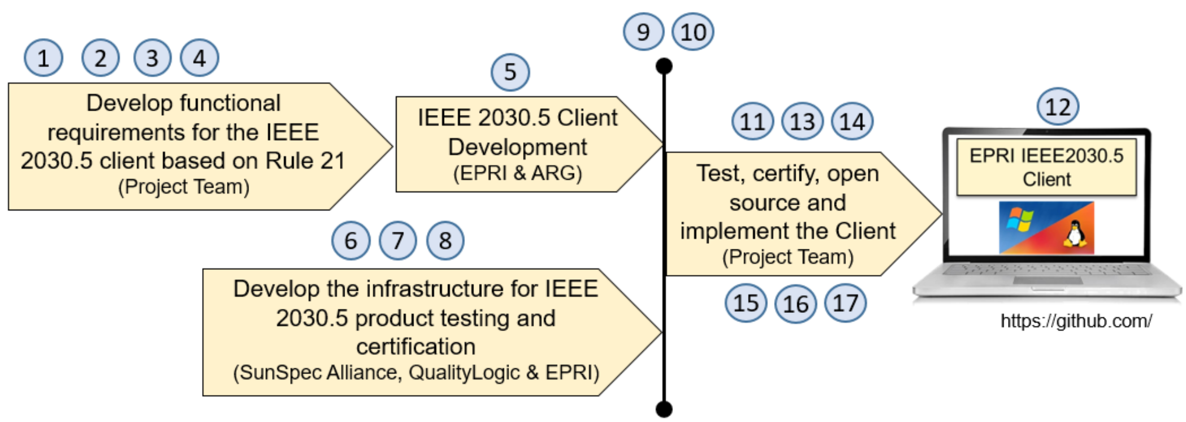
2018. This updated IEC 61850-7-420 standard provides an information model that supports all of the California Rule 21 functions and the IEEE 1547:2018 grid code functions. This information model is the source of the data objects that are mapped into several communication protocols like SunSpec Modbus, IEEE 2030.5, and IEEE 1815.

Overview of the IEEE 2030.5 Client Development Project

The EPRI undertook a project that developed, certified, and demonstrated an open source communication software of an IEEE 2030.5 client for DER that meets the Smart Inverter Working Group Phase 1 and Phase 2 Rule 21 requirements. The project also developed the IEEE 2030.5 certification test procedure, the associated test software/harness to make compliance testing available for all the California Rule 21 Phase 2 requirements.

The primary steps involved in the project are identified in Figure 2. The numbered circles indicate resulting materials and artifacts of the project listed in Table 1.

Figure 2 Project Approach



Source: Electric Power Research Institute

Development of Functional and Performance Communication Requirements

As a first step, the functional and performance requirements were developed. They must be supported by a DER communications client to meet the California Rule 21 smart inverter requirements.

The present project aimed to use the California Rule 21 revisions developed by the Smart Inverter Working Group to establish the functional scope. Rule 21 prescribes IEEE 2030.5 as the default protocol for communication between the California investor-owned utilities and DER aggregators, DER management systems, and DER themselves. The Phase 2 process of Rule 21 focused on defining the communication requirements for DER. The California investor-owned utilities, in conjunction with other Smart Inverter Working Group members, created the CSIP implementation guide following Phase 2. The guide establishes a concrete method of enabling communications between utilities and DER control systems that included inverters with integrated and external gateways, generating facility energy management systems, and aggregators. CSIP specifies that IEEE 2030.5 is required to be the default protocol for communicating with a utility server. IEEE 2030.5 standardizes communication between smart grid-enabled components. The standard uses current networking technologies to provide a secure and interoperable framework for information exchange. This functional scope of this project is based on the latest versions of the CSIP and IEEE 2030.5 specifications.

Table 1: Project Deliverables

Deliverable Number	Title	Description
1	Report on Communication Requirements to Support Rule 21	Technical Report
2	Report on Required Enhancements to IEEE 2030.5	Gap Analysis Report
3	Report on IEEE 2030.5 Client Specifications for DER	Technical Report
4	Technical Advisory Committee meeting #1 Slides	PowerPoint Slides
5	Report on Development and Availability of Open-Source IEEE 2030.5 Client Software for DER	User Manual & Developers Manual
6	Protocol Implementation Conformance Statement (PICS)	Statement of Conformance
7	Report on DER Compliance Test Procedure for IEEE 2030.5	Test Procedure
8	Compliance Test Plan	Test Plan
9	Technical Advisory Committee Meeting #2 Slides	PowerPoint Slides
10	Critical Project Review (CPR) Meeting Slides	PowerPoint Slides
11	Report on Compliance Test Results and Compliance Testing Availability	Compliance Test Results
12	Open-Source IEEE 2030.5 Client Software for DER	Software
13	Field Test Plan	Test Plan
14	Field Test Results	Test Results
15	Final Project Report	This Document
16	Final Project Presentation	PowerPoint Slides
17	Project Fact Sheet	One-page summary
18	Technology/Knowledge Transfer Report	Report

Source: Electric Power Research Institute

The CSIP documentation specifies a usage model for communicating with smart inverter systems that implement the IEEE 2030.5 standard, and imposes the following IEEE 2030.5 functional qualifications:

- Identifies the required IEEE 2030.5 functional subset that must be supported
- Where applicable, specifies the required functionality option that must be used to promote interoperability
- Identifies capacity constraints, which might differ from the default values (but are still allowed by the specification) specified in IEEE 2030.5

IEEE 2030.5 Open Source Software

As a next step, the development of the IEEE 2030.5 client—that can be readily deployed by aggregators, DER vendors, energy management system vendors, and others—started using the IEEE 2030.5 specification. Like many communication protocols used in the area of DER, IEEE 2030.5 uses a client/server architecture. For interoperable IEEE 2030.5 servers and clients, the IEEE 2030.5 standard specifies a RESTful[1] web service architecture with HTTPS protocol as a required baseline.

CSIP Client-Server Framework

The CSIP specification describes the interaction between a utility server and a DER system in two ways as illustrated in Figure 3.

1. Direct DER communications, including generating facility energy management system
2. Aggregator-mediated communications

Accordingly, the test functional scope of the project addresses the following functional profiles:

- Direct DER Client
- DER aggregator client

Direct DER client includes the basic IEEE 2030.5 communications modules and the DER functionality required for clients. The DER aggregator client additionally includes some functionality required for aggregator-mediated communications.

Infrastructure for IEEE 2030.5 Certification and Testing

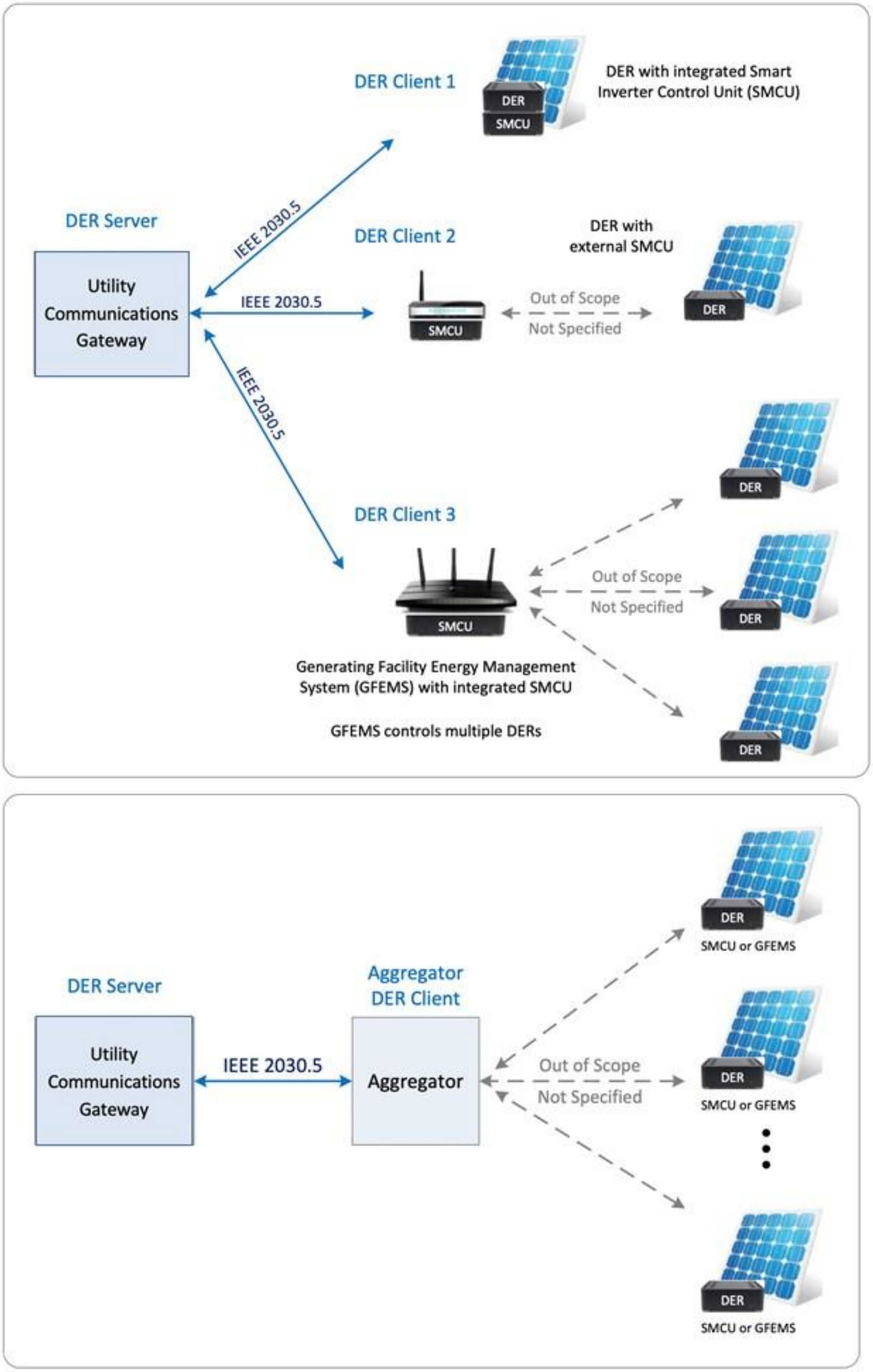
Certification procedures and test software are necessary for any successful communication standard. Regardless of how extensive descriptions may be in a written standard, small differences at the bit and byte level result from independent implementations and these differences are all it takes to prevent successful communication connectivity. Certification processes and software provide an exact framework that ensures that products implement the standard in the same way, and therefore work together as intended.

The project developed specific Rule 21 test procedures that enable conformance testing of DER and the associated control systems, such as DER Management systems, DER aggregation platforms, DER gateways, and others. The CSIP guide and the IEEE 2030.5 standard were primarily used to develop the IEEE 2030.5 client conformance test plan and certification program.

To perform certification testing on the IEEE 2030.5 client, a test tool that can replicate the functions of an IEEE 2030.5 server is required. An over-riding goal of this project was to make test tools available to the vendor community, test labs, and California utilities to accelerate development and interoperability of the IEEE 2030.5 Rule 21 CSIP-compliant implementations. A commercial test tool vendor and project partner, QualityLogic, committed to do so as part of this project. QualityLogic has made these California Rule 21 CSIP test tools available to the community of vendors, utilities, and test labs that are serving the California DER market.

[1] In the web services world, REpresentational State Transfer (REST) is a key design idiom that embraces a stateless client-server.

Figure 3: IEEE 2030.5 Client/Server Architecture for (1) Direct DER Communications to IEEE 2030.5 DER Clients, and (2) Aggregator Mediated Communications



Source: Common Smart Inverter Profile IEEE 2030.5 Implementation Guide for Smart Inverters – version 2.1

IEEE 2030.5 Client Testing, Certification, and Publishing

Once the IEEE 2030.5 client software was developed and the certification infrastructure was established, certification testing was conducted. This testing ensured that the software met the industry standard for IEEE 2030.5 and the California Rule 21-specific requirements. For the final product to be readily useable in the marketplace, all components need simple and flexible licensing. This project provided the final code with almost unlimited licensing freedom, allowing for derivative works without requiring manufacturers to contribute back to the open source project.

IEEE 2030.5 Client Commercial Implementation Demonstration

The software client was implemented in a commercial DER gateway by project partner Enphase and was tested to validate the completeness and quality of the developed test procedure and the open source software.

CHAPTER 2: Open-Source IEEE 2030.5 Client Software

Purpose

A major goal of this project was to create an open-source client that can be readily deployed by aggregators, DER vendors, energy management system vendors, and others. Availability of open source code ensures uniform implementation and reduces the internal development costs for integrating with utilities. The first activity of the project was the development of the open source IEEE 2030.5 client software. This took place sequentially starting with (a) the development of software requirements, and then (b) the technical specifications, and finally the (c) client software.

Open Source IEEE 2030.5 Client Software Requirements

This section describes the set of functional and performance requirements that must be supported by the open source client to meet California Rule 21 requirements. This set of requirements was developed after an extensive review of the following documents:

- The *IEEE 2030.5 Implementation Guide for Smart Inverters – version 2.0*, known as CSIP[2],
- *Recommendations for Utility Communications with Distributed Energy Resources (DER) Systems with Smart Inverte*rs - The Smart Inverter Working Group Phase 2 communication requirements which focus on the information exchanges between the utility and the DER. The Phase 2 communication requirements have been accepted by the CPUC and are in the process of being added to Rule 21
- The IEEE 2030.5, 2018 – IEEE Standard for Smart Energy Profile Application Protocol[3]

Client Requirements

Both the aggregator and DER clients developed in this project meet all mandatory requirements set forth in IEEE 2030.5 standard and CSIP. The client requirements to meet Rule 21 can be broadly classified as:

- Communication Requirements
- DER Group Management Requirements
- DER Control Events
- DER Status Information

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[2] The *IEEE 2030.5 Implementation Guide for Smart Inverters – version 2.0*, known as the Common Smart Inverter Profile (CSIP), available here, https://sunspec.org/wp-content/uploads/2018/03/CSIPImplementationGuidev2.003-02-2018-1.pdf

[3] IEEE 2030.5, 2018 – IEEE Standard for Smart Energy Profile Application Protocol, available here, https://standards.ieee.org/standard/2030_5-2018.html

- IEEE 2030.5 Resource Requirements
- Cybersecurity requirements

Communication Requirements

Polling by Distributed Energy Resource Clients

For interactions between clients and servers, "polling" and "publish/subscribe" are two methods typically available and can be used by the DER entities to access information from the utility server.

The most common and simpler way to retrieve data from the utility server is by polling, which is applicable primarily to direct DER client type. The polling times for different functions is required to be configurable in the DER client. In direct DER communication scenarios, the client system is required to initiate communications with the utility according to pre-defined polling and posting intervals to ensure the DER has up to date settings and the utility understands the operational state of the DER. Unless specified in each utility's interconnection handbook or programs/contracts, default polling and posting rates are required to be followed as specified in the CSIP.

Publish/Subscribe by Distributed Energy Resource Clients

The second method to establish communications is by using subscriptions and notifications (publish/subscribe) where the utility server notifies the DER client whenever a change occurs for the specific resources on the server the client is subscribed to. This can help aggregators reduce the large amount of data exchanged if using the polling method.

Distributed Energy Resource Group Management Requirements

The data exchange between the utility and an aggregator may involve hundreds or thousands of DER located throughout the utility's grid. Therefore, the concept of grouping was developed in the CSIP document to help manage these interactions.

DER operated by an aggregator are assigned to different groups based on their location in the distribution grid (for example, substation, feeder, feeder segment) by the utility, and the group assignments are communicated to the aggregator. CSIP specifies that DER can be assigned to a minimum of one group and a maximum of 15 groups. Beyond grouping based on location of the DER in the power system, DER can also be grouped based on other criteria like DER type, DER owner, program enrollment, type of customer (such as, commercial, residential, or others). Another concept in DER group management is that a DER can be part of multiple groups when providing grid support at multiple levels in the power system. DER group membership can also change due to a number of factors like power system conditions, feeder reconfiguration, and segmentation.

Both the aggregator client and direct DER client are required to support IEEE 2030.5-based grouping and the full lifecycle management of group relationships as specified in the CSIP. The aggregator client is required to act as a conduit for sending new controls or specific commands from the utility server to targeted groups of DER. The utility server has the responsibility for assigning, reassigning, and maintaining the DER membership in specific groups, and providing this information to the aggregator client. Section 6 of the CSIP document explains the step-by-step process involved in configuring the utility server with resources required for utility communication with both direct DER and aggregator clients.

Distributed Energy Resource Control Events

Table 2 provides a summary of the DER control functions required by Rule 21 in Phases 1 and 3 and indicates which of the functions are implemented in the open source client. The direct DER client is required to poll for DER control functions every 10 minutes. When subscribed for DER control functions, the direct DER client is required to transfer DER control to the DER within 10 minutes of receiving the control command from the server. The aggregator client is then required to transfer DER control command to the DER within 10 minutes of receiving the control command from the utility server.

Other performance-related specifications of the client follow the requirements identified in the CSIP and the IEEE 2030.5 standard. However, the anti-islanding function is not required to be implemented at this time because it does not (necessarily) involve communications with the utility, and therefore, is out of scope of the DER client.

Table 2: Distributed Energy Resource Control Functions Recommended by the Smart Inverter Working Group in California Rule 21

SIWG* (Phase) and Sl. No.	Function Name	Description	Client Support
Phase 1: 1	Anti-islanding Protection	The DER ceases to energize the grid if the voltage and/or frequency exceed the ride-through values	
Phase 1: 2	Low/High Voltage Ride-through	The DER follows the utility-specified voltage ride-through parameters to avoid tripping off unnecessarily. The function would block tripping within the fault ride-through zones. Although normally enabled by default, this ride-through mode may be updated, enabled, or disabled.	✓
Phase 1: 3	Low/High Frequency Ride-through	The DER follows the utility-specified frequency ride-through parameters to avoid tripping off unnecessarily. The function would block tripping within the fault ride-through zones. Although normally enabled by default, this ride-through mode may be updated, enabled, or disabled.	✓
Phase 1: 4	Volt-Var Function	The DER is provided with voltage-var curves that define the vars for voltage levels. When the volt-var mode is enabled, the DER receives the voltage measurements from a meter (or other source) at the referenced Electric Connection Point (ECP). The DER responds by supplying or absorbing vars according to the specified volt-var curve to maintain the desired voltage level.	✓

SIWG* (Phase) and Sl. No.	Function Name	Description	Client Support
Phase 1: 5	Fixed Power Factor	The DER power factor is set to the specified power factor. A leading power factor is positive and a lagging power factor is negative, as defined by the IEEE or IEC sign conventions.	✓
Phase 1: 6	Ramp Rates	In addition to the default ramp rate, the DER may support multiple ramp rates that reflect different conditions.	✓
Phase 1: 7	Soft-Start	Use ramp rate and/or random time within window when reconnecting	✓
Phase 3: 1	DER Cease to Energize and Return to Service Command	"Cease to energize" is a different function from disconnect/connect. The definition is "cessation of active power delivery under steady-state and transient conditions and limitation of reactive power exchange." "Return to service" is defined as "enter service following recovery from a trip."	✓
Phase 3: 2	Limit Maximum Active Power Mode	The production and/or consumption of the DER is limited at the referenced ECP, indicated as percent of the maximum active power capability. Separate parameters are provided for production or consumption limits to permit these to be different.	✓
Phase 3: 3	Set Active Power Mode	The DER is set to a percentage of maximum charge or discharge rate at the referenced ECP. A positive value indicates discharge, negative means charge.	✓
Phase 3: 4	Frequency-Watt Mode	The DER is provided with frequency-watt curves that define the changes in its watt output based on frequencies around the nominal frequency during abnormal events. When the frequency-watt mode is enabled, the DER monitors the frequency and adjusts its production or consumption rate to follow the specified emergency frequency-watt curve parameters.	✓

SIWG* (Phase) and Sl. No.	Function Name	Description	Client Support
Phase 3: 5	Volt-Watt Mode	The DER is provided with voltage-watt curves that define the changes in its watt output based on voltage deviations from nominal, as a means for countering those voltage deviations. When the volt-watt mode is enabled, the DER receives the voltage measurement from a meter (or other source) at the referenced ECP. The DER adjusts its production or consumption rate to follow the specified volt-watt curve parameters.	✓
Phase 3: 6	Dynamic Reactive Current Support	The DER provides dynamic reactive current support in response to voltage spikes and sags, similar to acting as inertia against rapid changes. This mode may be focused on emergency situations or may be used during normal operations. When the dynamic reactive current support mode is enabled, the DER monitors the voltage at the referenced ECP and responds based on the parameters.	
Phase 3: 7	Scheduling	The DER follows the schedule consisting of a time offset (specified as a number of seconds) from the start of the schedule and is associated with the following functions: • Power factor • Volt/VAR • Volt/Watt	✓
Phase 3: 8	Monitoring	The DER provides status, measurements, alarms, logs, and other data as authorized and requested by users. Examples include connect status, updated capacities, real and reactive power output/consumption, state of charge, voltage, and other measurements. In addition, the DER (or a proxy of the DER) provides key forecast information.	✓

*** Smart Inverter Working Group**

Source: Electric Power Research Institute

Distributed Energy Resource Monitored Information

The required DER status information as identified by CSIP includes monitored data with data qualifiers, nameplate ratings, DER current settings, operational modes and operational state.

Monitored Status and Analog Data

The client is required to report the analog data in Table 3 and may include the data qualifiers in Table 4. Posting of this monitoring information is required to be every 5 minutes for both the Direct DER Client and Aggregator Client.

Table 3: List of Monitoring Data

Monitoring Data
Real (active) power
Reactive power
Frequency
Voltage per phase

Source: Electric Power Research Institute

Table 4: List of Data Qualifiers

Data Qualifiers
Instantaneous (latest)
Maximum over the interval
Average over the interval (the last posting)
Minimum over the interval

Source: Electric Power Research Institute

Nameplate Ratings and Adjusted Settings Information

The DER client is required to report the nameplate ratings and adjusted settings in Table 5. Nameplate ratings and adjusted settings should be reported once at start-up and the adjusted settings is required to be reported whenever there is a change in a value.

Table 5: List of Nameplate Ratings and Adjusted Settings

Nameplate Ratings and Adjusted Settings
Maximum rate of energy transfer received
Maximum rate of energy transfer delivered
Maximum apparent power
Maximum reactive power delivered
Maximum reactive power received
Maximum active power
Minimum power factor displacement

Operational status information

Source: Electric Power Research Institute

The DER Client is required to report the operational status information of each DER as specified in Table 6. The frequency of reporting will be specified in each utility's interconnection handbook or contracts/programs.

Table 6: List of Operational Status Information

Operation Status Information
Operational state
Connection status
Alarm status
Operational energy storage capacity

Source: Electric Power Research Institute

Alarms

The DER Client is required to report the DER alarms as specified in Table 7. For each alarm, there is a corresponding "return to normal" message. All alarms and their "return to normal" messages are required to include a date-time stamp along with the alarm type. The frequency of reporting of alarms is specified in each utility's interconnection handbook or contracts/programs.

Table 7: List of Alarms

Alarms
Over current
Over voltage
Under voltage
Over frequency
Under frequency
Voltage imbalance
Current imbalance
Local emergency
Remote emergency
Low input power
Phase rotation

Source: Electric Power Research Institute

IEEE 2030.5 Resource Requirements

In IEEE 2030.5, a resource is a piece of information that a server exposes. These resources are used to represent aspects of a physical asset such as a smart inverter, attributes relating to the control of those assets (such as the Volt-Var curve), and general constructs for organizing those assets. IEEE 2030.5 resources are defined in the IEEE 2030.5 extensible markup language –based schema, and access methods are defined in the web application description language. IEEE 2030.5 provides a rich set of resources to support a variety of use cases. This guide only requires the subset needed to meet the required grid DER support functionality for Rule 21. The aggregator client and DER client are required to support all CSIP-required IEEE 2030.5 function sets and resources shown in Table 8.

Table 8: List of Required IEEE 2030.5 Resources/Function Sets

Resources	Aggregator Client	Direct DER Client
Time	MUST	MUST
Device capability	MUST	MUST
End device	MUST	MUST
Function set assignment	MUST	MUST
DER	MUST	MUST
Response	MUST	MUST
Meter/mirror meter	MUST	MUST
Log event	MUST	MUST
Subscription/notification	MUST	MAY
Security	MUST	MUST

Source: Electric Power Research Institute

Cyber Security Requirements

Cyber security is required to be implemented for all interactions between the DER and the utility. Some of the cyber security requirements of the client include, but are not limited to:

1. All communications between the server and client are required to use HTTP over transport layer security (TLS) (also known as HTTPS).
2. All interactions between the DER client and the server are required to include authentication not only at the transport level but also at the application level, using certificates.
3. All interactions between the DER client and other entities are required to include access control at the transport level and are also required to include role-based access control (RBAC) for access to DER client data. In particular, the client must be prevented from accessing (read, write, control) data that they are not authorized to access.
4. Each DER that gets registered with a client is required to be uniquely identified by a globally unique identification (GUID).
5. Transport security is required to use TLS version 1.2 or higher.
6. The default cipher suite is required to be TLS_ECDHE_ECDSA_WITH _AES_128_CCM_8 for key exchange and encryption algorithms, although other cipher suites are permitted.

7. Certificates are required to be compliant with the X.509 v3 standard or later.
8. Certificate fingerprints are required to use long form device identifier (LFDI) and short form device identifier (SFDI) for device identification.

Open Source IEEE 2030.5 Client Technical Specifications

This section provides an overview of the IEEE 2030.5 client technical specification. The specification includes the implementation details of the functional and performance requirements of the client.

Product Features

The IEEE 2030.5 client is an open source framework that can be readily deployed by aggregators, DER vendors, energy management system vendors, and others. It is designed to communicate with IEEE 2030.5-compliant servers with the necessary DER resources. The open source IEEE 2030.5 client consists of a C library and application framework for creating IEEE 2030.5 compliant applications. The framework is lightweight, portable, and fast (based on state machines and asynchronous events). Some of its unique features include:

- Portable networking layer (UDP, TCP, IPv6/IPv4)
- Support for the Linux platform
- TLS 1.2 currently supported through the OpenSSL library
- DNS-SD client for IEEE 2030.5 service discovery
- HTTP 1.1 client/server
- XML/EXI schema based parser/serializer
- IEEE 2030.5 client API
- IEEE 2030.5 client examples (DER function set)
- Small modular source code

Operating Environment

The open source client was developed and tested in a Linux operating system. This client can also be ported to other operating environments like Windows, Mac OS X, etc. The guidelines to port the client to different operating systems are provided in the IEEE 2030.5 client user's manual.

Design and Implementation Constraints

Language

The language of choice for this project is C due to it universality. Many popular operating systems are C based and C is widely used for systems programming, especially embedded systems. The choice of C enables the development of applications on a variety of devices from conventional desktop personal computers, to constrained embedded devices, and currently popular mobile platforms.

Platform and Dependencies

The target platform is Linux. Besides the C standard library, the only other dependency is OpenSSL. To build the framework and run applications the following are required:

- Compiler (GCC) version 4.6 or greater
- OpenSSL version 1.1.0 or greater
- GNU Bash or compatible shell
- Linux 2.6 or greater

Extensible Markup Language and EXI Schema-based Parsing

The application payloads in IEEE 2030.5 messages are XML documents encoded either in XML or EXI formats with the form of these documents being described by an XML schema. Because the payload data is described by a schema, the parsing and validation of data can be automated. The approach taken by this framework is to generate a C data type for each type described by the schema and also a table that describes the attributes and elements for each possible document. This table can be used with a generic parser that can parse any schema defined XML document, with the result of parsing as an object in system memory with a native C type. Parsing in this way means that the values contained in the attributes and elements of XML documents can be used directly in C expressions and can be passed to and returned from C functions.

Event Driven

The client framework is event driven by design. This means the client applications are only responding to events such as network events, timer events, and others. If there are no events, the application remains idle in a wait state, giving control back to the operating system until the next event occurs. The framework makes extensive use of state machines and non-blocking IO operations so that the Client applications can pause and resume anywhere in the context of establishing connections, negotiating TLS sessions, and parsing incoming data. This design allows the client application to be responsive as well as minimize the resources used.

On the Linux platform the framework uses the epoll interface which provides the least latency in receiving events on system-defined file descriptors. Other systems have similar event-based polling mechanisms, such as IO completion ports on the Windows platform. The event-based framework should be portable to other systems that are not currently supported.by TLS.

IEEE 2030.5 requires the use of TLS for secure communication using the TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 cipher suite. Of the existing TLS libraries, OpenSSL was identified as a C-based library supporting the required cipher suite with license terms that are compatible with the goals of this project, providing an open source client that can be used for any purpose. OpenSSL is a mature library with numerous additions to address the security of the implementation, it is also widely used in major open source projects providing additional confidence for its use. The client uses OpenSSL to provide secure communication with an IEEE 2030.5 server. The choice of OpenSSL, however, should not limit the use of other libraries that provide the same functionality. WolfSSL is another library that can be used with the framework, although its use is outside the scope of this project.

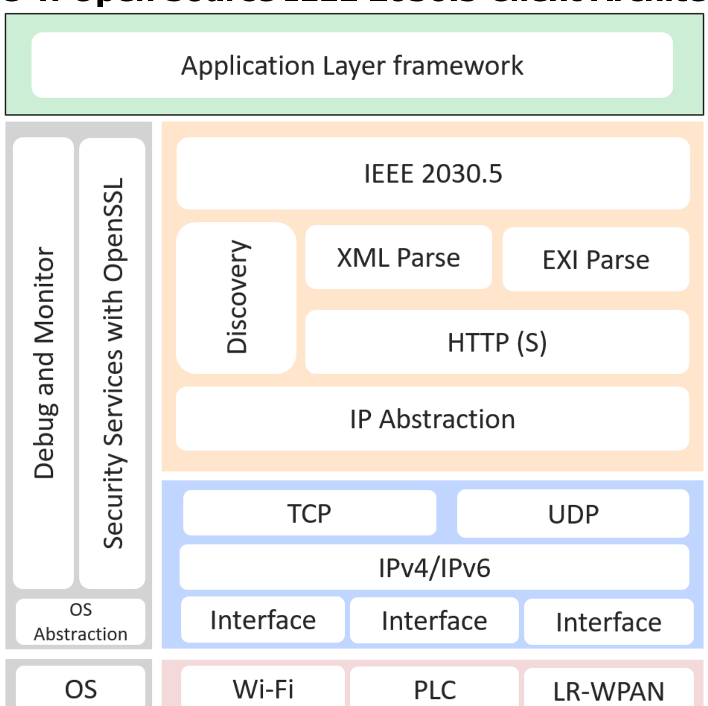
Open Source IEEE 2030.5 Client Software

The EPRI worked with project partner Automation Research Group to develop the IEEE 2030.5 Client Software. Once the specification for the software was finalized by the project team, the Automation Research Group started developing the components of the software. The objective of this task was to develop a complete open source framework for an IEEE 2030.5 DER client that meets the requirements of Rule 21 and the IEEE 2030.5 standard. The DER client is the downstream component that could reside on a DER gateway, facility energy management systems or an aggregator's control system in the cloud. As the development process began, a major challenge faced by the project team was the non-availability of an IEEE 2030.5 server (upstream component) to test the capabilities of the client during development. Since California Rule 21 requirements were new, there were no commercial implementations of IEEE 2030.5 servers at that time with the capability to meet Rule-21 requirements. To address this issue, the project team built a prototype IEEE 2030.5 server to test the developed features of the client.

When the development process approached completion, project partner, QulaityLogic released an update to the IEEE 2030.5 test tools with necessary enhancements to meet Rule 21. EPRI and QualityLogic then performed engineering verification tests using the QualityLogic IEEE 2030.5 Ad Hoc Tester, which emulated the behavior of a California Rule 21/CSIP DER head end server. Several issues were identified, reported, and fixed by the project team on the open source software client, and the QualityLogic test tool during this process. By doing so, the EPRI client implementation improved its 2030.5 conformance and reduced risks during the actual certification testing phase.

For reference, a client architecture of the developed open source IEEE 2030.5 client software is shown in Figure 4.

Figure 4: Open Source IEEE 2030.5 Client Architecture



Source: Electric Power Research Institute

The client software is built on a representational state transfer architecture that is used widely to deploy Web services over HTTP. A representational state transfer architecture is based on a client-server model in which servers contain and perform operations on resources. Servers expose resource representations to clients, and clients make requests to access representations of resources on the servers such as read, write, create, and delete. The common resources developed for the open source client are listed in Table 8. The result is an XML protocol developed on a representational state transfer architecture using HTTP for transport. Moreover, the software client is developed with the capability to decode IEEE 2030.5 application payloads that are XML documents encoded either in XML or EXI formats. In local area network environments, IEEE 2030.5 software client uses multicast domain name system (xmDNS)/DNS-SD to perform internet protocol address discovery as well as resource discovery. However, xmDNS does not work over the internet, so another mechanism called DNS/DNS-SD was developed.

Moreover, since IEEE 2030.5 is agnostic to the physical networking layer, the client software enables communication between devices (servers and clients) on heterogeneous physical layers (such as, Wi-Fi, HomePlug, low-rate wireless personal area networks, Ethernet, or others). providing utilities with a range of technologies for DER integration – Broadband, Cellular, AMI, PLC, and others.

Another feature of the client software is the operating system abstraction layer that enables porting to other operating environments beyond Linux OS, like Windows and Mac OS X.

The complete implementation details of the client are reported in the API documentation[4] and the *IEEE 2030.5 Client User's Manual*[5] which explains in detail EPRI client's architecture and features. This source code was built on an Ubuntu Linux v14.04 desktop system using the bundled gcc compiler v4.8.4 and openSSL v1.1.0g library. The tested and certified source code for the open source IEEE 2030.5 client can be downloaded from EPRI's GitHub repository[6].

[4] Open Source IEEE 2030.5 Client API documentation, available here, https://github.com/epri-dev/IEEE-2030.5-Client/releases

[5] *IEEE 2030.5 Client User's Manual*, available here, https://github.com/epri-dev/IEEE-2030.5-Client/releases

[6] Open Source IEEE 2030.5 Client, available here, https://github.com/epri-dev/IEEE-2030.5-Client/releases/tag/v0.2.11

CHAPTER 3: Common Smart Inverter Profile Compliance for IEEE 2030.5

Purpose

A major goal of the project is to make available to the vendor community, test labs, and California utilities, test procedures to verify that software implementations of the IEEE 2030.5 clients are compliant with IEEE 2030.5 functionality and options as specified in the common smart inverter profile (CSIP) document and specific test tools that can accelerate the development and interoperability of the IEEE 2030.5 California Rule 21 CSIP-compliant implementations.

This chapter provides an overview of the developed test procedure, the test tools, and how they were applied to test the developed IEEE 2030.5 client software for compliance.

Common Smart Inverter Profile Compliance Test Procedures for IEEE 2030.5

The scope of this section is to provide an overview of the *SunSpec California Rule 21/CSIP IEEE Conformance Test Procedure*. The detailed list of test cases and the steps to conduct each test case are covered in the publicly released *SunSpec California Rule 21/CSIP IEEE Conformance Test Procedure*[7].

Common Smart Inverter Profile Test Procedure Development and Maintenance Procedure

Project partner, SunSpec Alliance developed the *SunSpec California Rule 21/CSIP IEEE Test Procedure* for the interfaces described in Table 9. Development was performed in the typical manner that all SunSpec standards are developed, under the guidelines specified in the SunSpec member agreement and with participation from SunSpec members, the three California investor-owned utilities, and the public.

Document review and comment gathering was also performed in the standard manner, with a well-publicized comment period, a system to gather and track comments, and an open invitation to the general public to provide commentary.

Version 1.0 of the *SunSpec California Rule 21/CSIP IEEE Conformance Test Procedure* was published on May 22, 2018 on SunSpec.org and is offered for free download and use. SunSpec provides a facility on SunSpec.org for the general public to provide feedback, comments, and reports of suspected defects on these procedures. The comment period prior to publication generated approximately 160 comments that were reviewed and cataloged.

[7] *SunSpec CA Rule 21/CSIP IEEE Conformance Test Procedure*, available here, https://sunspec.org/wp-content/uploads/2018/05/SunSpecCSIPConformanceTestProceduresV1.0.pdf.

Table 9: IEEE 2030.5 Testing Scope

Category	Description	IEEE 2030.5 Sections
BASE	Base functionality used by multiple function sets.	8,B.1.2, B.1.5, B.1.6
BILL	Billing function set	10.6, B.1.18
CFG	Configuration function set	9.6, B.1.12
DER	Distributed energy resources function set	10.9, B.1.21
DI	Device information function set	9.2, B.1.8
DNS	Discovery	7
DRLC	Demand response and load control function set	10.2, B.1.14
EVENT	Event rules	10.1.3, B.1.22
FILE	File Download function set	9.7, B.1.13
FLOW	Flow reservation function set	10.8, B.1.20
GEN	General networking	4, 9, 11
LOG	Log Event function set	9.5, B.1.11
METER	Metering function set	10.3, B.1.15
MSG	Messaging function set	10.5, B.1.17
MULTI	Multi-Server	10.1.5
MUP	Metering mirror function set	10.10, B.1.15.1
NSTAT	Network status	9.4, B.1.10
POWER	Power status function set	9.3, B.1.9
PPAY	Prepayment function set	10.7, B.1.19
PRICE	Pricing function set	10.4, B.1.16
RAND	Randomization	10.1.4
SEC	Security	6
TIME	Time function set	9.1, B.1.7

Source: Electric Power Research Institute

SunSpec also has an interoperability testing and certification program supported by eight global testing labs (including six nationally recognized testing labs) that use these test procedures.

IEEE 2030.5 Testing Scope

The CSIP documentation specifies a usage model for communicating with smart inverter systems that implement the IEEE 2030.5 standard, and imposes the following IEEE 2030.5 functional qualifications: (1) identifies the required IEEE 2030.5 functional subset that must be supported; (2) specifies the required functionality option that must be used to promote interoperability, where applicable; and (3) identifies capacity constraints that might differ from the default values specified in IEEE 2030.5.

This test procedure is based on CSIP 2.1 and the IEEE 2030.5:2018 specification. The tests in this document cover IEEE 2030.5 functionality, as addressed in the CSIP requirements. The IEEE 2030.5 requirements in this specification are derived directly from the functionality specified as mandatory in the IEEE 2030.5 specification.

IEEE 2030.5 functional areas are categorized, and each requirement is assigned an identification, consisting of the function category prefix and a unique, sequential number. For example, requirement ID DER.001 identifies requirement number one of the distributed energy resources (DER) function set.

IEEE 2030.5 Compliance Test Tools

As a commercial test tool vendor, and project partner, QualityLogic committed to provide these specific test tools as part of the project and has already made the California Rule 21 CSIP test tools available to the worldwide community that is serving the California DER market. The scope of this section is to provide an overview of their IEEE 2030.5 DER test tools. The developed test harness was also used to test the open source IEEE 2030.5 client.

IEEE 2030.5 DER Test Tools

The test tool suite for IEEE 2030.5 DER applications developed by QualityLogic include both development (ad hoc testers) and conformance test tools (functional test suite, or FTS) for both IEEE 2030.5 Servers and Clients.

Ad Hoc Testers

Ad Hoc Testers are actual conformant implementations of IEEE 2030.5 Client and Server, and they provide real-world IEEE 2030.5 event simulations and thorough analysis of IEEE 2030.5 messages. IEEE 2030.5 Ad Hoc Testers allow developers to set up complex scenarios for IEEE 2030.5 clients and servers and ensure interoperability using the most recent IEEE 2030.5 Standard.

The two testers, IEEE 2030.5 Client Ad Hoc Tester and the IEEE 2030.5 Server Ad Hoc Tester, each supports all the commonly implemented elements in the Protocol Specification. The tools provide users with the ability to simulate reference implementations of IEEE 2030.5 compliant products and conduct interoperability testing. The Ad Hoc testers are valuable for exploring use case scenarios with real devices or simulating devices or head-end servers that would be communicated with real-world installations.

Functional Test Suites

The IEEE 2030.5 Functional Test Suites (FTS) are a quick, convenient way to test IEEE 2030.5 device functional conformance against a formal industry certification test specification. The Functional Test Suites implement the Server tests and Client tests covering the core Function Sets and optional Function Sets specified by a specific test specification. The test suites are designed to be both pre-certification tests for vendors and for certification testing by Nationally Recognized Test Labs or other approved test labs. Currently, QualityLogic functional test suite versions have complete implementations of the conformance tests defined by the

SunSpec California Rule 21/CSIP Conformance Test Procedure developed as part of this project.

The QualityLogic tools are the first test tools to implement the *SunSpec California Rule 21/CSIP Conformance Test Procedure*. The SunSpec tests cover communications basics (seven tests); core functions such as group management and metering (22 tests); Basic function tests such as inverter control tests (24 tests); utility aggregator tests such as aggregator commissioning and event tests (16 tests); and error handling and maintenance tests (eight tests). The new QualityLogic IEEE 2030.5 Functional Test Suite V3 includes both client and server testers to validate conformance to California Rule 21 CSIP. The user interface allows testers to select one or more of the tests to be run, see the results in real-time, understand any conformance issues, and drill down into the detailed IEEE 2030.5 message exchanges.

Project Application of the Test Tools

The QualityLogic test tools are demonstrated and used within the project as follows:

1. EPRI used the ad hoc server to simulate a utility IEEE 2030.5 communications server as a way to test interoperability between the open source client and a compliant IEEE 2030.5 server that meets CSIP requirements.
2. Project partner, Enphase, used the QualityLogic ad hoc server for the same purpose. The server test tool provided an effective way to test and demonstrate integration of the Open Source Client into their gateway.
3. Project partner, QualityLogic also used its recently released IEEE 2030.5 DER functional test suite client tester to validate compliance of the open source client based on the *SunSpec California Rule 21/CSIP Conformance Test Procedure*. The test results are summarized in the next chapter.

The first nationally recognized test lab to publicly announce certification test services for CSIP requirements are Underwriter Laboratories, using the QualityLogic test tools. Subsequently, two of the SunSpec-approved test labs have decided to use the test tools and three other approved labs (of a total of seven approved labs) are seriously considering using the test tools. This means that a vendor can choose from among multiple test labs and be assured of consistent certification testing. If the vendor is also using the QualityLogic test tools, the certification test process is significantly reduced in time, complexity, and costs.

With the availability of the test tools to vendors, combined with the SunSpec certification framework, a complete program for developing, testing, and certifying interoperable Rule 21-compliant products using IEEE 2030.5 is currently available.

Open Source IEEE 2030.5 Client Compliance Test

Project Partner, QualityLogic, performed certification testing on the open source IEEE 2030.5 client using the QualityLogic IEEE 2030.5 test harness. The testing was performed based on the approved *SunSpec California Rule 21/CSIP Conformance Test Procedure*. The test results confirm compliance of the client software to meet California Rule 21 and CSIP requirements.

EPRI provided one sample of the client to be tested in C source code format through the GitHub repository. This section contains the results for the EPRI IEEE 2030.5 DER open source client. Testing was conducted to determine the software’s ability to comply with the requirements and its ability to communicate with IEEE 2030.5 servers as required by the

SunSpec California Rule 21/CSIP Test Procedures document. SunSpec Alliance certified the EPRI IEEE 2030.5 DER open source client by approving this certification test report.

Test Report Information

Tables 10-12 provide information about the vendor offering a software for compliance to Rule 21, the certification test program supplier and the test lab, and the certification test alliance.

Table 10: Product Vendor

Company	EPRI
City	Palo Alto
Address	3420 Hillview Ave.
Postal code	94304
Country	USA
Telephone	+1-650-855-2000
Contact person	Ajit Renjit
e-mail	arenjit@epri.com

Source: Electric Power Research Institute

Table 11: Certification Test Program Supplier and Test Lab

Company	QUALITYLOGIC
City	Simi Valley
Address	2245 First St. #103
Postal code	93065
Country	USA
Telephone	+1-805-531-9030
URL	www.qualitylogic.com
Test Harness Version	Version 3.1

Source: Electric Power Research Institute

Table 12: Certification Test Alliance

Company	SUNSPEC ALLIANCE
City	San Jose
Address	4040 Moorpark Ave Suite#110
Postal code	95117
Country	USA
Telephone	+1-408-217-9110
URL	www.sunspec.org
Contact Person	Tom Tansy

Source: Electric Power Research Institute

Test Summary

The certification test was conducted using the QualityLogic IEEE 2030.5 test harness V3.1, which implements the test cases that are described in the *SunSpec California Rule 21/CSIP Test Procedures* document. All of the relevant tests applicable, or that could be conducted by the test date for the EPRI IEEE 2030.5 DER open source client, version 1.0, were completed.

EPRI provided QualityLogic with the full source code of the EPRI IEEE 2030.5 DER open source client version 1.0 along with documentation that explained the EPRI client's architecture, API, and features. This source code was built on an Ubuntu Linux v14.04 desktop system using the bundled gcc compiler v4.8.4 and openSSL v1.1.0g library. Furthermore, during development of this EPRI client, EPRI and QualityLogic also performed engineering verification tests using the QualityLogic IEEE 2030.5 Ad Hoc Tester V3.1, which emulated the behavior of a California Rule 21/CSIP DER head end system. By doing so, the EPRI client implementation improved its 2030.5 conformance and reduced risks during the actual certification testing phase.

Device(s) Under Test Identification

Key technical information about the IEEE 2030.5 software client subjected to compliance testing by EPRI is shown in Table 13

Table 13: General Information of Device Under Test

Product Type	California Rule 21/CSIP DER Client
Product Name	EPRI IEEE 2030.5 DER open source client
Product Version	Version 1.0
IP Version	IPv6/IPV4
Interface	Ethernet / Wi-Fi (platform dependent)
Encoding	XML/EXI

Source: Electric Power Research Institute

Test Configuration

Test Scope

The tests in Table 14 were performed based on EPRI's Protocol Implementation Conformance Statement. The information provided in Table 15 as part of the protocol implementation conformance statement (PICS) are defined in the California Rule 21/SunSpec CSIP compliance test procedure.

Table 14: Category of Tests Conducted

SunSpec Tests	Description	Mandatory	EPRI
COMM	Communication fundamentals	M	Yes
CORE	Core function set	M	Yes*
BASIC	Basic DER functions	M	Yes
UTIL	Utility server aggregator model	N/A	N/A
AGG	Aggregator operation	M	Yes*
ERR	Error handling	M	Yes*
MAINT	Maintenance of model	M	Yes*

EPRI IEEE 2030.5 DER open source client did not support the subscription feature when the client was offered for testing and certification in June 2018. Therefore, the tests were executed using the polling method instead of subscription and all the tests that require subscription were not included in the certification tests.

Source: Electric Power Research Institute

Table 15: Protocol Implementation Conformance Statement

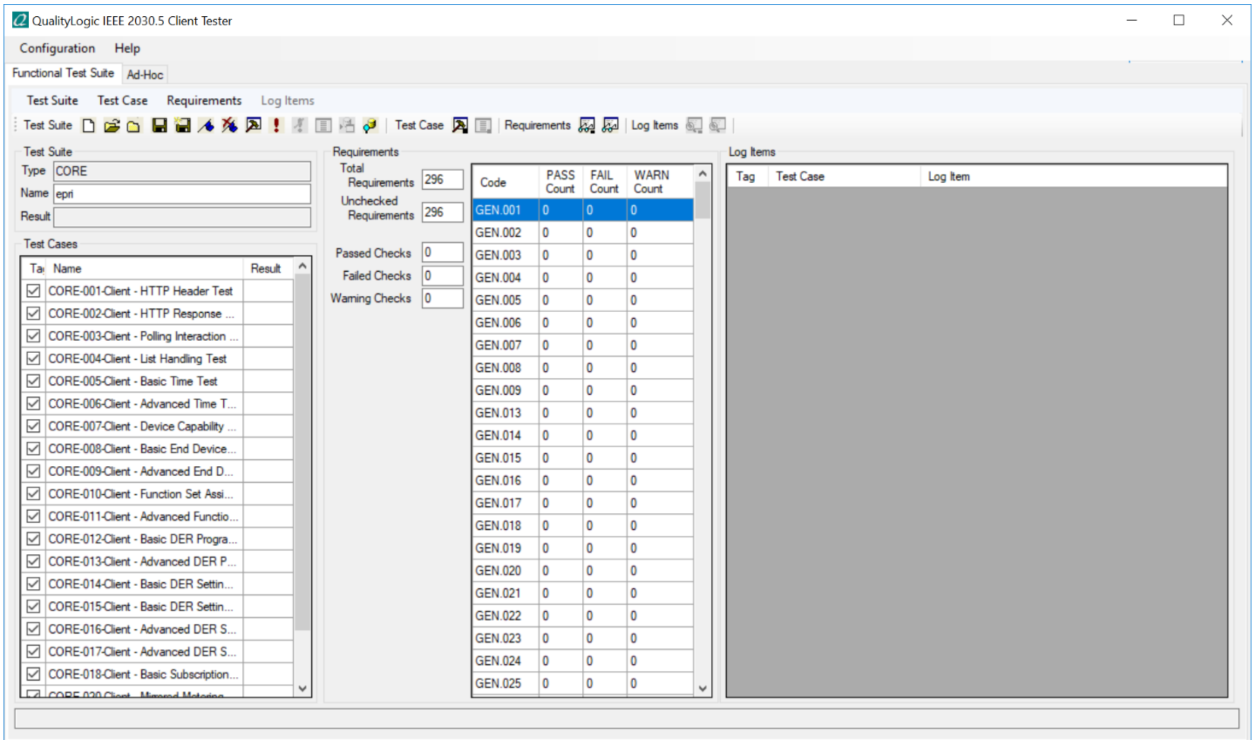
2030.5 Features	Description	Mandatory	EPRI
BASE (DCAP)	Device capability	M	Yes
DER	Distributed energy function set	M	Yes
DNS	Discovery	M	Yes
BASE (EDEV)	EndDevice	M	Yes
EVENT	Event rules	M	Yes
BASE (FSA)	Function set assignments	M	Yes
GEN	General networking	M	Yes
LOG	Log event function set	M	Yes
METER	Metering function set	M	Yes
MUP	Metering mirror function set	M	Yes
RAND	Randomization	M	Yes
BASE (Response)	Response	M	Yes
SEC	Security	M	Yes
BASE (Subscription)	Subscription	M	No
TIME	Time function set	M	Yes

Source: Electric Power Research Institute

Test Harness

QualityLogic IEEE 2030.5 test harness V3.1 implements the test cases described in the *SunSpec California Rule 21/CSIP IEEE Test Procedure* v1.0, dated May 22, 2018. The tests were performed by QualityLogic staff using the test harness in an automated fashion. The testing included detailed requirements analysis and test verification. The test harness itself runs on a native Windows PC using the available IPv6/IPV4 connections through TLS or non-TLS ports. Version 3.1 dated May 2018 was used to perform the EPRI certification testing.

Figure 5: QualityLogic IEEE 2030.5 Test Harness for SunSpec California Rule 21/CSIP Tests



Source: Electric Power Research Institute

Test Results

Summary Convention

Table 16 defines the convention used for results of tests.

Table 16: "Result" Convention Used in This Summary

Result Items	Description
PASS	All test cases that have been executed have passed.
FAIL	At least one test case has failed.
WARN	At least one test case generated a WARN result, while all others have passed.
VOID	At least one test case generated a VOID result, while all others have passed.
WAIVED	Not supported by vendor or test harness yet.

Source: Electric Power Research Institute

Summary of Test Results

Table 17 summarizes the test results. Based on the test procedure.

Table 17: Summary of Test Results

Test Code	Description	Results	Comment
COMM	Communication fundamentals	PASS	
CORE	Core function set	PASS*	Except for subscription tests
BASIC	Basic DER functions	PASS*	Except for subscription tests
UTIL	Utility server aggregator model	N/A	
AGG	Aggregator operation	PASS*	Except for subscription tests
ERR	Error handling	PASS*	Except for subscription tests
MAINT	Maintenance of model	PASS*	Except for subscription tests

Please see the detailed test results section for detailed test report including any tests that were waived or not successful.

Source: Electric Power Research Institute

Detailed Test Results

Tables 18 through 23 present the detailed test results:

Table 18: COMM (Communication Fundamentals)

Test Item	Description	Results	Comments
COMM-001	Basic discovery (xmdns/dns-sd)	PASS	
COMM-002	Basic discovery (out of band)	PASS	
COMM-003	Basic security	PASS	
COMM-004	Advanced security	PASS	
COMM-005	Basic authorization	PASS	
COMM-006	Basic registration	PASS	

Source: Electric Power Research Institute

Table 19: CORE (Core Function Set)

Test Item	Description	Results	Comments
CORE-001	HTTP header	PASS	
CORE-002	HTTP response	PASS	This test is primarily a server test.
CORE-003	Polling interaction test	PASS	
CORE-004	List handling test	PASS	
CORE-005	Basic time test	PASS	
CORE-006	Advanced time test	PASS	
CORE-007	Device capability test	PASS	
CORE-008	Basic end device test	PASS	
CORE-009	Advanced end device test	PASS	
CORE-010	Function set assignment test	PASS	
CORE-011	Advanced function set assignment test	PASS	
CORE-012	Basic DER program/control test	PASS	
CORE-013	Adv DER program/control test	PASS	
CORE-014	Basic DER settings test (Power Gen)	PASS	
CORE-015	Basic DER settings Test (Storage)	PASS	
CORE-016	Advanced DER setting test (Power Gen)	PASS	
CORE-017	Advanced DER setting test (Storage)	PASS	
CORE-018	Basic subscription test	WAIVED	Subscription not supported by EPRI client
CORE-019	Advanced subscription test	WAIVED	Subscription not supported by EPRI client
CORE-020	Mirrored metering tests	PASS	
CORE-021	Randomized events tests	PASS	
CORE-022	Responses test	PASS	

Source: Electric Power Research Institute

Table 20: BASIC (Basic DER Functionality)

Test Item	Description	Results	Comments
BASIC-001	DER identification test	PASS	
BASIC-002	Basic group management test	PASS	
BASIC-003	Advanced group management test	WAIVED	Test case not supported yet by test harness.
BASIC-004	Basic inverter control test (LHVRT)	PASS	
BASIC-005	Basic inverter control test (LHFRT)	PASS	
BASIC-006	Basic inverter control test (dynamic VoltVAR power)	PASS	
BASIC-007	Basic inverter control test (ramp rates)	PASS	
BASIC-008	Basic inverter control test (fixed power factor)	PASS	
BASIC-009	Basic inverter control test (connect/disconnect)	PASS	
BASIC-010	Basic inverter control test (limit maximum active power mode)	PASS	
BASIC-011	Basic inverter control test (volt-watt)	PASS	
BASIC-012	Basic inverter control test (frequency-watt)	PASS	
BASIC-013	Basic inverter control test (set active power mode – in % of maximum power)	PASS	
BASIC-014	Basic inverter control test (set active power mode – in watts)	PASS	
BASIC-015	Advanced inverter control	PASS	
BASIC-016	Event – 2 DERP, 2 DDERC, 0 DERC	PASS	
BASIC-017	Event test - 1 DERP, 0 DDERC, 1 DERC	PASS	
BASIC-018	Event Test - 1 DERP, 1 DDERC, 1 DERC	PASS	
BASIC-019	Event - 1 DERP, 1 DDERC, 2 non-overlapping similar DERC	PASS	
BASIC-020	Event - 2 DERP, 2 DDERC, 2 non-overlapping similar DERC	PASS	
BASIC-021	Event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - system DERC followed by	PASS	

Test Item	Description	Results	Comments
	service point DERC before start of system DERC		
BASIC-022	Event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - service point DERC followed by system DERC	PASS	
BASIC-023	Event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - system DERC followed by service point DERC after start of system event	PASS	
BASIC-024	Event - 2 DERP, 2 DDERC, 2 overlapping independent DERC - system DERC followed by service point DERC before start of system DERC	PASS	
BASIC-025	Event - 2 DERP, 2 DDERC, 2 overlapping independent DERC - service point DERC followed by system DERC	PASS	
BASIC-026	Event - 2 DERP, 2 DDERC, 2 overlapping independent DERC - system DERC followed by service point DERC after start of system event	PASS	
BASIC-027	Alarms	PASS	
BASIC-028	Inverter status	PASS	
BASIC-029	Inverter meter reading	PASS	

Source: Electric Power Research Institute

Table 21: AGG (Aggregator Operation)

Test Item	Description	Results	Comments
AGG-001	Aggregator operation subscription	WAIVED	Subscription not supported by EPRI client at the time of QualityLogic testing
AGG-002	Aggregator Event - 2 DERP, 2 DDERC, 0 DERC	PASS	
AGG-003	Aggregator Event - 1 DERP, 0 DDERC, 1 DERC	PASS	
AGG-004	Aggregator Event - 1 DERP, 1 DDERC, 1 DERC	PASS	
AGG-005	Aggregator event - 1 DERP, 1 DDERC, 2 non-overlapping similar DERC	PASS	
AGG-006	Aggregator event - 2 DERP, 2 DDERC, 2 non-overlapping similar DERC	PASS	
AGG-007	Aggregator event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - system DERC followed by transformer DERC before start of system DERC	PASS	
AGG-008	Aggregator event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - transformer DERC followed by system DERC	PASS	
AGG-009	Aggregator event - 2 DERP, 2 DDERC, 2 overlapping similar DERC - transformer DERC followed by system DERC after start of system event	PASS	
AGG-010	Aggregator event - 2 DERP, 2 DDERC, 2 Overlapping independent DERC - system DERC followed by transformer DERC before start of system DERC	PASS	
AGG-011	Aggregator Event - 2 DERP, 2 DDERC, 2 overlapping independent DERC - transformer DERC followed by system DERC	PASS	
AGG-012	Aggregator event - 2 DERP, 2 DDERC, 2 overlapping independent DERC - transformer DERC followed by system DERC after start of system event	PASS	

Source: Electric Power Research Institute

Table 22: ERR (Error Handling)

Test Item	Description	Results	Comments
ERR-001	Error scenario 1	PASS	
ERR-002	Error scenario 2	WAIVED	Subscription not supported by EPRI client

Source: Electric Power Research Institute

Table 23: MAINT (Maintenance of Model)

Test Item	Description	Results	Comments
MAINT-001	Inverter maintenance (out-of-band)	PASS	
MAINT-002	Inverter maintenance (in-band)	PASS	
MAINT-003	Group maintenance	PASS	
MAINT-004	Maintenance of controls	WAIVED	Test case not supported yet by test harness (will be tested at a future date).
MAINT-005	Maintenance of programs	WAIVED	Test case not supported yet by test harness (will be tested at a future date).
MAINT-006	Maintenance of subscriptions	WAIVED	Subscription not supported by EPRI client

Source: Electric Power Research Institute

Discussion of Test Results

1. The EPRI IEEE 2030.5 DER open source client Version 1.0 obtained compliant results for 69 SunSpec California Rule 21/CSIP tests that were tested. Eight tests were waived.
2. Subscription/notification was not implemented in the software. Therefore, the tests were executed using polling method instead of subscription and all the tests that require subscription were not included in the certification tests.

3. Some of the test cases were applicable only to IEEE 2030.5 servers (e.g., CORE-002 in Source: Electric Power Research Institute
4. Table 19. These test cases are excluded.
5. Both the SunSpec California Rule 21/CSIP IEEE 2030.5 test procedure and the certification testing conducted by QualityLogic in this project contributed to improvements of California Rule 21 certification program.
6. Tests conducted by EPRI and Automation Research Group during the development phase and by QualityLogic during certification phase identified issues that were instrumental in correcting the SunSpec California Rule 21/CSIP IEEE 2030.5 test procedures and the QualityLogic IEEE 2030.5 test harness.
7. Similarly, during certification testing, the QualityLogic IEEE 2030.5 test harness identified bugs and incompleteness with the open source client software, which were updated before final certification.
8. Since the project involved testing the IEEE 2030.5 client software using standard certification test procedures and approved test harness, it enabled improving the quality of the software.
9. Some test cases were not tested because the test harness was not being fully developed to test all the features of a Rule 21 compliant test software at the time of testing. QualityLogic's latest test harness has the necessary enhancements to test all the requirements for Rule 21.

CHAPTER 4: Enphase Implementation of the Open-Source Client

Purpose

The final project task was to integrate the Open Source Client with a commercial DER gateway and validate the completeness of the developed software in meeting the SunSpec Rule 21/CSIP IEEE Conformance Test Procedure[8] requirements. This process ensures that the software can be freely downloaded by any company and incorporated into their own designs to provide certifiable, interoperable products faster and more economically.

Scope

This chapter summarizes the field test plan and the test results conducted by Enphase. Project partner Enphase integrated the open source software into the commercial DER gateway, Envoy, and tested its compliance to Rule 21 Phase 2 requirements. The Envoy gateway is used by Enphase in their residential and commercial applications to communicate with smart inverters.

Testing Scope

To demonstrate the capability of Enphase gateway to meet the project requirements, a set of tests were identified to validate the following,

1. Capability of the gateway to receive and execute commands from an upstream entity, IEEE 2030.5 utility server thereby meeting the requirements set forth by Rule 21 Ph 2.
2. Capability of the gateway and the inverter to functionally execute the received command from the IEEE 2030.5 utility server.

Accordingly, the project team arrived at two categories of test cases.

Category 1 – Conformance to Rule 21/SunSpec CSIP test cases

The purpose of this category of conformance tests is to test communication between an IEEE 2030.5 server and a DER gateway based on the SunSpec Rule 21/CSIP IEEE Conformance Test Procedure. This ensures compliance to the IEEE 2030.5 standard and CSIP requirements. 23 different test cases were hand-picked from the list of SunSpec CSIP conformance test cases. The test cases were diverse enough to validate different functions specified by CSIP. Several issues were reported by Enphase during the integration and validation process that were jointly debugged by EPRI, QualityLogic, and Enphase. Many fixes were done by all the parties to resolve these issues.

[8] SunSpec CA Rule 21/CSIP IEEE Conformance Test Procedure, available here, https://sunspec.org/test-criteria-california-rule-21-communication/

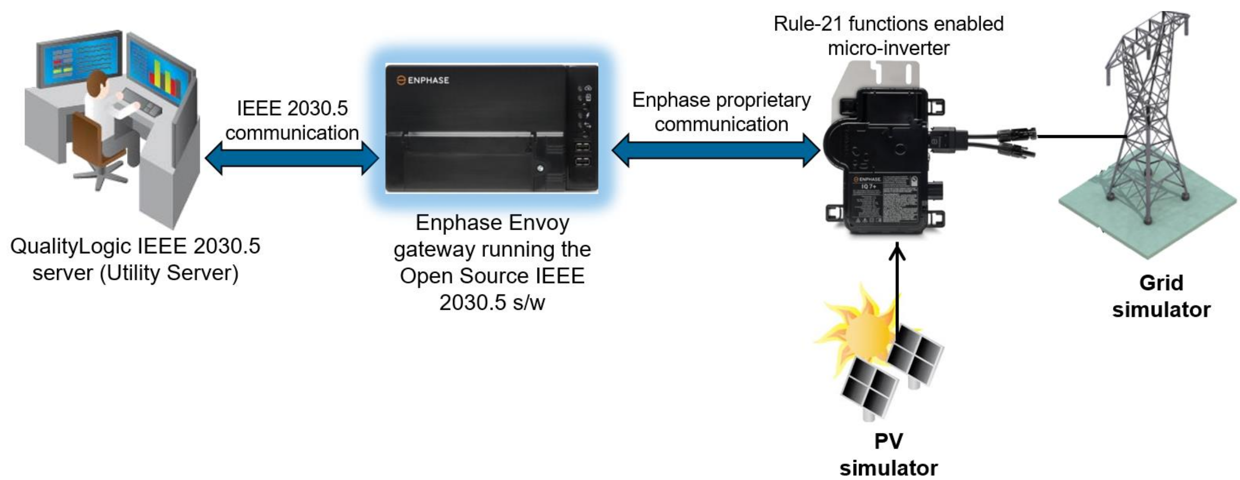
Category 2 – End-to-End Communication and Functional Testing

The second category of tests evaluated the capability of the end-to-end setup for compliance to Rule 21. In addition to the list of communication tests specified under Category 1, these test cases ensured the Enphase gateway successfully received and translated an IEEE 2030.5 utility signal to correct commands that were functionally executed by the inverter.

Test Setup

A prototype of a direct DER communication between a utility DER headend server and individual DER was deployed at Enphase's lab facility in Petaluma. An overview of the communication architecture is illustrated in Figure 6. For this demonstration, the utility DER headend server was provided by QualityLogic. The server can send control signals conforming to Common Smart Inverter Profile for California Rule 21 and IEEE 2030.5 protocol standard. EPRI's open source IEEE 2030.5 DER client was integrated in the Enphase gateway. The gateway translates the received IEEE 2030.5 messages from the server to individual photovoltaic (PV) micro inverter control signals. Details on other test components are provided in the following sections.

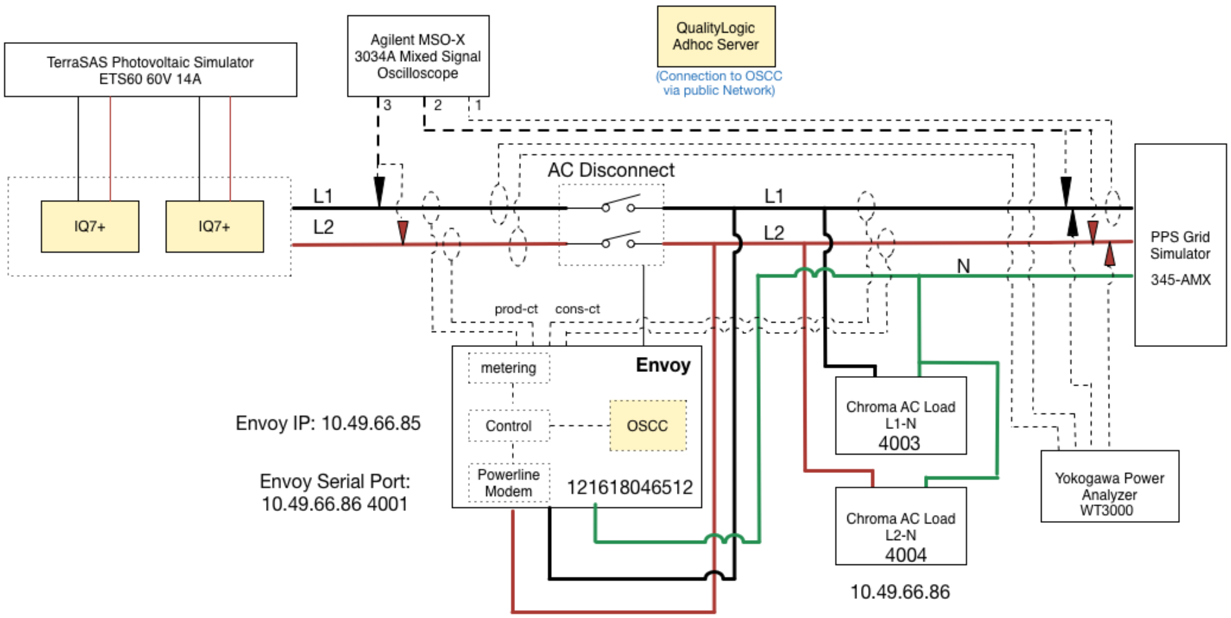
Figure 6: Laboratory Test Setup



Source: Electric Power Research Institute

The electrical configuration of the testbed setup is illustrated in Figure 7. The TerraSAS PV simulators provide the DC input to the inverters emulating the behavior of real-world PV modules. The inverters are then connected to a grid simulator that provides 120V line to neutral two-phase electrical power supply. The voltage and current signals from the grid and the inverter terminals are monitored by the Envoy gateway. The gateway also relays control signals to the inverter received from the upstream IEEE 2030.5 server. Furthermore, oscilloscopes and power analyzers are also used in the test bed to measure and display grid conditions and the inverter output for different test cases.

Figure 7: Electrical Line Diagram of the Test Bed



Source: Electric Power Research Institute

Test Equipment Specifications

PV Simulator

A PV simulator is used to emulate the characteristics of the actual solar irradiance and the DC output from the PV panel. In the lab testing setup, Enphase used a TerraSAS ETS60X14C model from Elgar. Some of the key aspects of this model are that it can track high resolution I-V curves, emulate various irradiance profiles and can also track the maximum power point. Further specification of the simulator is given below in Table 24. The DC output of the simulator is connected to the microinverter.

Table 24: PV Simulator Specifications

Specification	Description
Manufacturer	Elgar
Model	TerraSAS ETS60X14C
AC Power Supply	100-240 Vac
Max. Output	840W
Max. Output Voltage (DC)	60 V
Short Circuit Current (DC)	14 A
Interface	TerraSAS Software
Tracking Speed	250 Hz
Accuracy	< 0.35 Vpp, < 60 mApp
Sampling Resolution	200 kS/s

Source: Electric Power Research Institute

Inverter Under Test

The Enphase IQ7+ microinverters were used in this demonstration. They are smart inverters that can meet all the requirements of the California grid code Rule 21 Phase 1 and some of the Phase III functions. As illustrated in

Figure 7, the PV Simulators provide DC input to the inverter, and the AC output of the inverter is interfaced with the Grid Simulator. Table 25 provides some of the key parameters of the inverter.

Table 25: Inverter Specifications

Specification	Description
Manufacturer	Enphase
Model	IQ 7+ Microinverter
Phases	1
Max. DC Voltage Input	60 V
Max. DC Power Input	440 W
Peak AC Power Output	295 kW @ 120 V
Max. Current Output	2.4 A @ 120V

Source: Electric Power Research Institute

AC Grid Simulator

The AC output of the inverter, which is part of the DER System under test, is connected to the AC grid simulator that provides the ability to simulate various grid conditions such as overvoltage, undervoltage, and grid frequency greater/lesser than 60 Hertz to test the inverter operation. Table 26 provides key specifications of the AC grid simulator

Table 26: AC Grid Simulator Specifications

Specification	Description
Manufacturer	Pacific power
Model	345 AMX
Capacity	4.5 kVA
AC Power Supply	120 V (LN)
Output Voltage V_{rms} Max (1ph/2ph)	135/270 (LN/LL)
Output Current Ranges A_{rms} (1ph/2ph)	36/12

Source: Electric Power Research Institute

Category 1 – SunSpec Rule 21/CSIP Conformance Test Results

During Phase I testing, Enphase successfully integrated EPRI's open source IEEE 2030.5 software in their Envoy gateway and conducted conformance testing to validate the client performance to meet Rule 21 Phase 2 requirements. The testing criteria was defined by SunSpec through the approved SunSpec CSIP test procedure. It should be noted that this set of test cases under category 1 does not include integrating the gateway with the inverters and testing them functionally for Rule 21 compliance. Table 27 summarizes the test cases performed by Enphase and the test results. Readers are recommended to review the details of each test case in the publicly released SunSpec California Rule 21/CSIP IEEE Conformance Test Procedure[9].

Table 27: Results of SunSpec Rule 21/CSIP Conformance Tests Conducted on the Enphase Gateway

SunSpec CSIP Test Case	Description	Results	Comments
CORE-003	Polling Interaction Test	PASS	
CORE-005	Basic Time Test	PASS	
CORE-008	Basic End Device Test	PASS	
CORE-009	Advanced End Device Test	PASS	
CORE-010	Function Set Assignment Test	PASS	
CORE-011	Advanced Function Set Assignment Test	PASS	
CORE-012	Basic DER Program/Control Test	PASS	
CORE-013	Adv DER Program/Control Test	PASS	
CORE-014	Basic DER Settings Test (Power Gen)	PASS	
CORE-016	Adv DER Setting Test (Power Gen)	PASS	
CORE-020	Mirrored Metering Tests	PASS	
CORE-021	Randomized Events Tests	PASS	
BASIC-002	Basic Group Management Test	PASS	
BASIC-015	Advanced Inverter Control	Conditionally Verified	Tried with only 10 DER Controls (events) instead of 24
BASIC-016	Event – 2 DERP, 2 DDERC, 0 DERC	PASS	
BASIC-018	Event Test - 1 DERP, 1 DDERC, 1 DERC	PASS	

[9] SunSpec California Rule 21/CSIP IEEE Conformance Test Procedure, available here, https://sunspec.org/wp-content/uploads/2018/05/SunSpecCSIPConformanceTestProceduresV1.0.pdf

SunSpec CSIP Test Case	Description	Results	Comments
BASIC-019	Event - 1 DERP, 1 DDERC, 2 Non-overlapping Similar DERC	PASS	
BASIC-020	Event - 2 DERP, 2 DDERC, 2 Non-overlapping Similar DERC	PASS	
BASIC-021	Event - 2 DERP, 2 DDERC, 2 Overlapping Similar DERC - System DERC followed by Service Point DERC before Start of System DERC	PASS	
BASIC-022	Event - 2 DERP, 2 DDERC, 2 Overlapping Similar DERC - Service Point DERC followed by System DERC	PASS	
BASIC-024	Event - 2 DERP, 2 DDERC, 2 Overlapping Independent DERC - System DERC followed by Service Point DERC before Start of System DERC	PASS	
BASIC-025	Event - 2 DERP, 2 DDERC, 2 Overlapping Independent DERC - Service Point DERC followed by System DERC	PASS	
BASIC-029	Inverter Meter Reading	PASS	

Source: Electric Power Research Institute

Category 2 – End-to-End Test Results

In the second phase of testing, the Envoy gateway was connected to the commercial Enphase inverters and the end-to-end test bed was setup as illustrated in

Figure 7. A select list of Rule 21 functions was then tested and validated for compliance. The next section summarizes some of these test cases performed by Enphase.

The following DER Controls were tested using the test setup.

1. High Frequency Ride-through (HFRT)
2. Low Voltage Ride-through (LVRT)
3. Fixed Power Factor
4. Limit Maximum Watts

The purpose of this test was to verify that the gateway successfully received the DER control signal from a 2030.5 server and translated it into control signals that can be functionally executed by the inverter. A DER control is an IEEE 2030.5 event that has a start time, duration, and a control value. Prior to a control event, the control is either "off" or operating under a default control value. At the start time of the event, the control is enabled at a certain set point value for the specified duration. Once the duration has expired, the control reverts to "off" or its default control value. For the purpose of this test, the DER Control event shown in Table 28 was configured in the QualityLogic server.

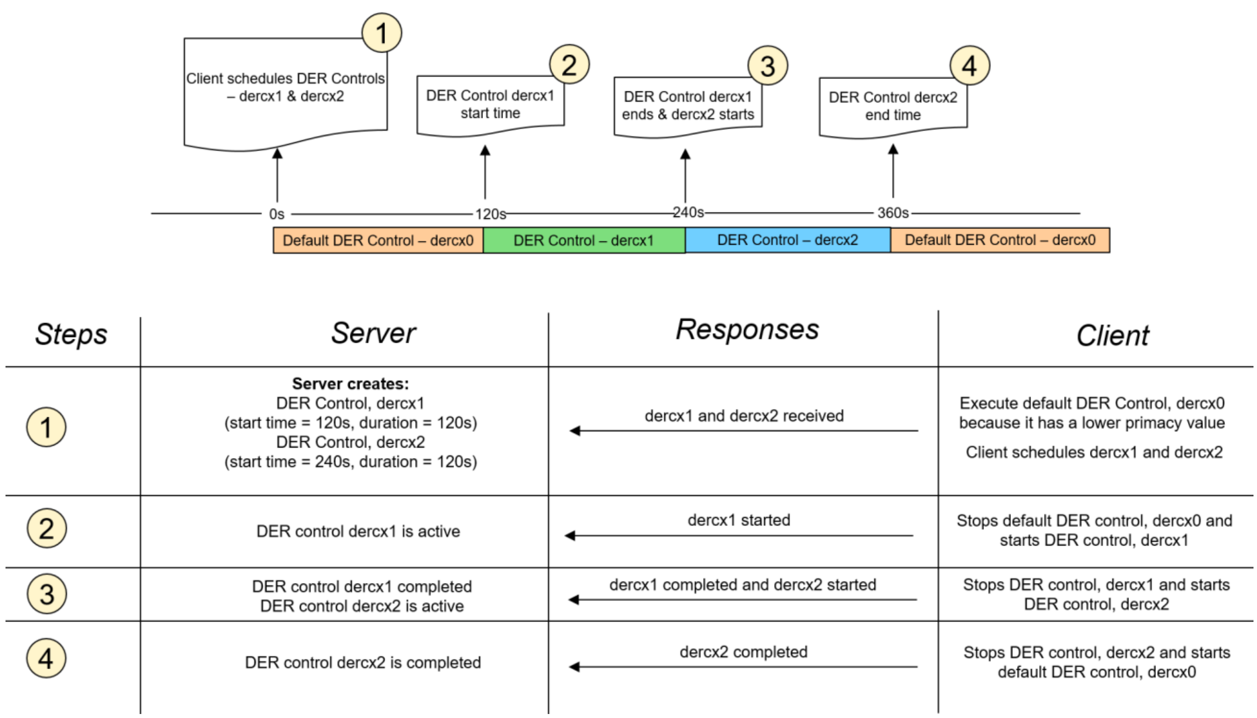
Table 28: DER Control Event Schedule

Type of DER Control	Event Schedule
Default DER Control (dercx0): 1. HFRT Settings for Rule 21 2. LVRT Setting for Rule 21 3. Fixed Power Factor = 1 4. Limit Maximum Watts = 100%	N/A
DER Control (dercx1): Fixed Power Factor = 0.95	Start Time = 120s Duration = 120s
DER Control (dercx2): Limit Maximum Watts = 50%	Start Time = 240s Duration = 120s

Source: Electric Power Research Institute

When the Client establishes communication with the Server, it receives the configured DER control event in Table 28 (presented in Chapter 5) and schedules the event. The ensuing sequence of events is illustrated in Figure 8.

Figure 8 Sequence of DER Control Events and Server Client Interaction

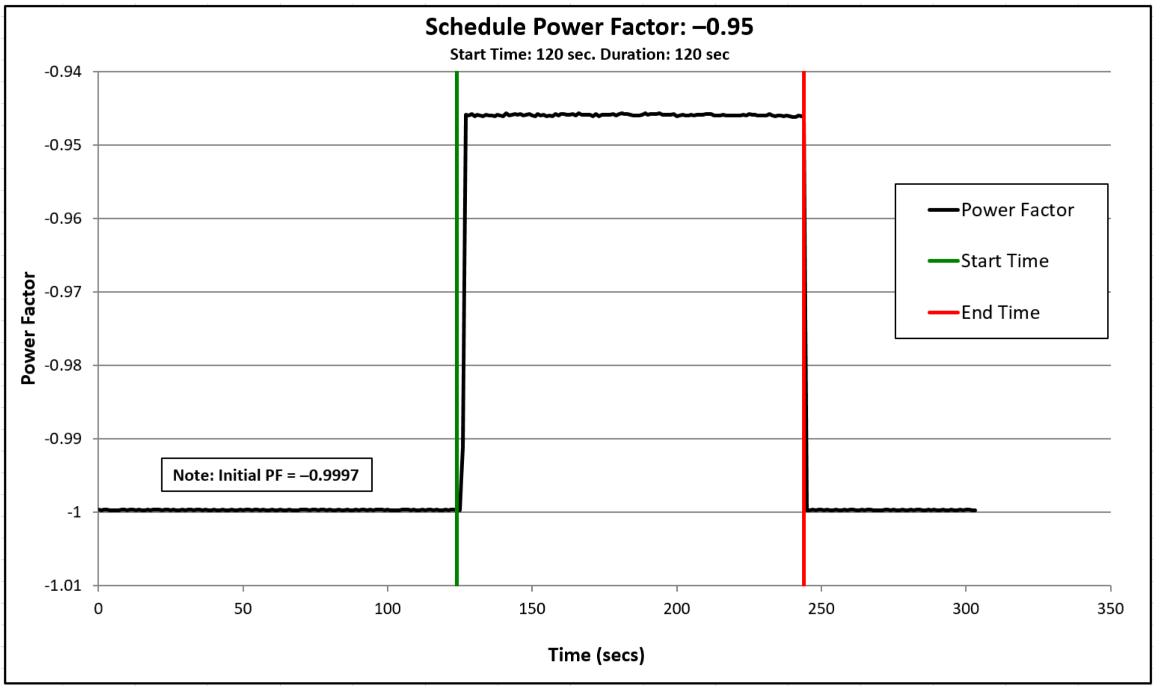


Source: Electric Power Research Institute

According to the event schedule, the default DER control, dercx0 is executed for the initial 120 seconds. During this phase, the active power from the inverters are uncurtailed and exported to the grid at unity power factor. The default DER control executes the HFRT and LVRT settings as per Rule 21 Phase 1. Since the grid conditions are steady and the inverter output frequency and voltage are close to the nominal value, the inverters do not execute the ride-through function.

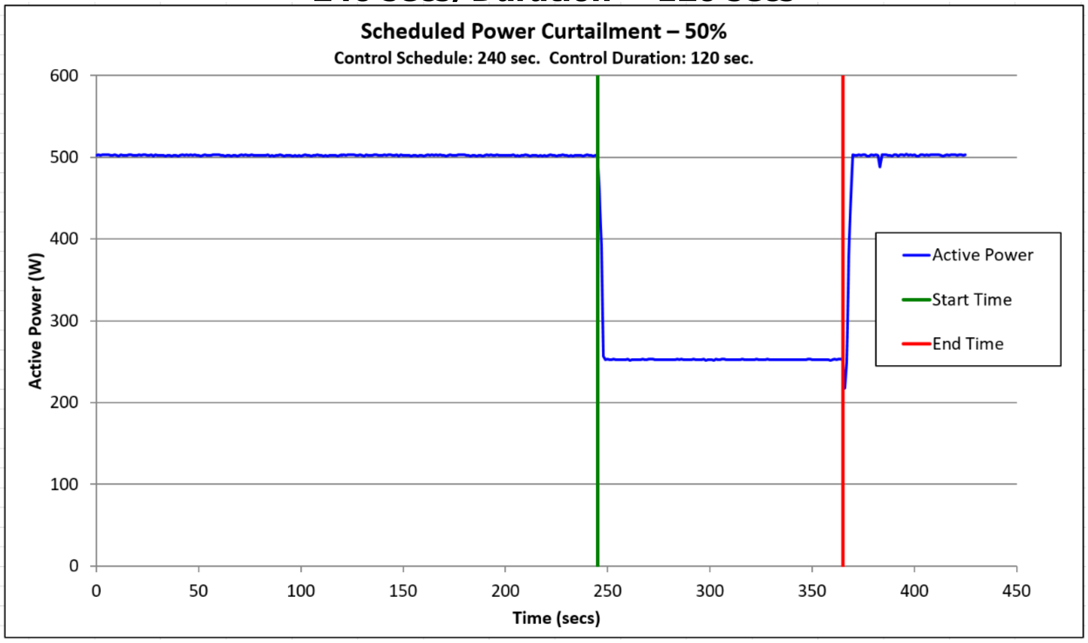
After 120 seconds, the next DER control dercx1 gets executed as scheduled. This causes the inverter to change its power factor from unity to 0.95.

Figure 9: Schedule DER Control, dercx1, Power Factor = 0.95, Start time = 120 secs, Duration = 120 secs



Source: Electric Power Research Institute

Figure 10: Schedule DER Control, dercx2, Active Power Limit = 50%, Start time = 240 secs, Duration = 120 secs



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Source: Electric Power Research Institute

After 240 seconds, the next DER control event dercx2 gets executed. At the same time, the previous control event dercx1 completes which is illustrated by the change in power factor to unity. At the end of 360 seconds, the change in real power to its uncurtailed maximum value marks the completion of the DER control event dercx2.

Key Takeaways from the Testing Conducted at Enphase

The project team successfully integrated the certified open source client into a commercial DER gateway and tested a set of California Rule 21 use cases.

1. The client software in Enphase gateway successfully supported most of the functions in an interoperable way but had certain issues with others which were debugged and fixed later.
2. This testing validated that the DER operator was thereby able to successfully connect to a utility head end server and execute control commands based on the IEEE 2030.5 standard and CSIP. This testing exercised both data reporting and control use cases from California Rule 21.
3. Subscription/Notification feature was not tested in the Enphase gateway since it was not implemented in the certified version of the client software. It was later implemented and tested separately by Enphase.
4. As part of the Enphase testing, project partner conducted both communication and functional testing of Rule 21, ensuring end-to-end compliance between utility operations and end devices.
5. Several issues were reported by Enphase during the integration and validation process that were jointly debugged by EPRI, QualityLogic, and Enphase. Some of the identified issues were instrumental in updating the SunSpec California Rule 21/CSIP IEEE 2030.5 test procedures and the QualityLogic IEEE 2030.5 test harness.

Lessons Learned

There is a need for portability across different operating environments to accommodate the wide variety of implementations. Different DER vendors prefer different operating environments to run the IEEE 2030.5 software. When developing an open source software that can be potentially leveraged by different DER developers, it is important to address this need for portability.

It is possible that some end devices may need to communicate with the utility server over low bandwidth networks or over networks where data exchanges need to be minimized, like mobile networks. In such cases, it is important for the client to store the last available configuration and switch back to default configuration when required.

In some solar installations, the gateway may be powered by the generated solar power. If so, the gateway may be powered off each night and started up each morning. In such a case, the gateway would have to store the default DER configuration and fallback to defaults.

Towards the end of the project, the team realized that many DER providers were interested in implementing this software locally in a gateway that was memory-constrained with a limited power supply. For this reason, several steps were taken to ensure that the software could be used by such lightweight devices. These steps included using C as the programming language of choice, limiting the scope of implementation to address only the requirements of IEEE 2030.5 and Rule 21, and developing an event driven framework.

CHAPTER 5: Technology Transfer

Scope

This chapter summarizes the technology transfer activities conducted by the project team to make the knowledge gained, experimental results, and lessons learned available to the public and key decision makers.

Target Audience

To facilitate information dissemination, EPRI and project partner SunSpec Alliance have executed a multi-pronged outreach program to reach engineers and managers working in product development, software development, and cybersecurity for industry participants such as Distributed Energy Resource manufacturers, inverter manufacturers, aggregators, communication system providers, system integrators, utilities, regulatory agencies, and related organizations.

Core Deliverables

The core deliverables of this project are an open source software stack and the set of test procedures to enable software developers and implementers to validate California Rule 21 Phase 2 compliance.

The open source code can be accessed directly by anyone for free at https://github.com/epri-dev/IEEE-2030.5-Client. Access to the source code repository is provided from www.epri.com and www.sunspec.org.

The test procedures can be accessed directly by anyone for free at https://sunspec.org/test-criteria-california-rule-21-communication/. A Protocol Implementation Conformance Statement (PICS) and IEEE 2030.5 Compliance Test Plan is also made available from www.SunSpec.org.

Outreach

The knowledge gained from the project is made available to inverter and Distributed Energy Resource manufacturers, aggregators, end users, utilities, regulatory agencies, and other members of the public using EPRI and SunSpec Alliance distribution channels including web sites, newsletters, educational events, and promotional events.

Results of Primary Outreach Activities

A composite view of the 2017/2018 results for all outreach and promotional activities is provided in Table 29. The 2018 results are current as of October 20, 2018.

Table 29: Results of the Outreach Activities Conducted During This Project

Audiences Reached	2017	2018
SunSpec – unique website visitors	8,209	18,552
SunSpec – all mailing lists	8,038	9,915
SunSpec – newsletter subscribers	1,083	1,680
SunSpec – web event registrants	1,226	486
SunSpec – member company employees	734	773
SunSpec – Cybersecurity work group members	114	181
SunSpec – Inverter work group members	80	86
Email Campaigns Referencing IEEE 2030.5 client		
Campaigns targeting Inverter and Cybersecurity experts		
Total campaigns	21	8
Messages sent	73,995	27,834
Number of opens	13,207	5,392
Number of clicks	1,556	691
Other campaigns targeting Distributed Energy market participants		
Total campaigns	56	41
Messages sent	196,070	208,141
Number of opens	34,617	37,515
Number of clicks	3,222	2,799
Web Events Referencing IEEE 2030.5 client		
EPRI’s Information and Communication Technologies Program Webcasts for Utilities		
Start of Year Webcast: CEC 15-044 Project update		31
Mid-Year Webcast: CEC 15-044 Project update		10
DER Toolkit Webcast: IEEE 2030.5 Client is one of the three protocol implementations in the toolkit		61
Dedicated IEEE 2030.5 Webcasts	35	50
Web events targeting Inverter and Cybersecurity experts		
Total web events	5	0
Total web event registrants	463	0
Other web events targeting Distributed Energy market participants		
Total web events	3	5
Total web event registrants	476	283
EPRI/SunSpec Live Events, Conferences and Activities Featuring IEEE 2030.5 client		
Project update in EPRI’s U.S. advisory meeting to Information and Communication Technologies Program members	45	55

Audiences Reached	2017	2018
Project update in EPRI's U.S. advisory meeting to Energy Storage Program members		45
Project updates in EPRI's European advisory meeting		70
Energy Storage Integration Council (ESIC), Boston		12
IEEE 2030.5 Conformity Assessment Roundtable		16
SolarPlaza Asset Management North America 2017	150+	
SunSpec 2017 annual member meeting	89	
Intersolar North America 2017 Finance Summit	130+	
SolarPlaza Asset Management North America 2018 (multiple presentations)		300+
SunSpec Executive Summit on California Rule 21 in SF		64
Intersolar North America 2018 workshop on California Rule 21		68
Gridvolution @ Solar Power International 2018		100+
SunSpec 2018 annual member meeting		87
SunSpec online engineering at UC San Diego, fall term: Secure Communication Networking for DER		17
SunSpec IEEE 2030.5 test procedure downloads		528
Whitepapers/Technical Reports/Conference Publications		
EPRI's DER Integration Toolkit: An Overview of EPRI Tools for Testing and Implementing Open Protocols. EPRI, Palo Alto, California: 2017. 3002009853 QualityLogic published the whitepaper "Scaling DER Communications in California: protocol certification requirements"		
Linkedin Posts		
EPRI representatives shared an update on the availability of the open source IEEE 2030.5 s/w		> 1000 viewers
Press Releases Solar Power World broke news on the availability of this software, https://www.solarpowerworldonline.com/2019/02/epri-releases-open-source-communication-software-for-DER/		
GreenTech Media also published an article about the availability of the open source software, https://www.greentechmedia.com/squared/dispatches-from-the-grid-edge/tying-together-the-technology-standards-behind-der-grid-integration		
Trainings QualityLogic continues to transfer technical knowledge through its training courses on California Rule 21, IEEE 2030.5/DER and CSIP technologies. To date, QualityLogic has trained over 100 engineers and managers from over a dozen companies in two-day workshops. Participants include utility, aggregator and vendor technical staff.		

Audiences Reached	2017	2018
QualityLogic is a key instructor for the UCSD Extension Course on California Rule 21, IEEE 2030.5 and CSIP (offered from Fall 2018) QualityLogic continues training nationally recognized test labs in testing California Rule 21, IEEE 2030.5/DER and CSIP based Inverters, Aggregators and other DER Systems		

Source: Electric Power Research Institute

Policy Impact

SunSpec Alliance personnel have been regular attendees of the CPUC Smart Inverter Working Group since its inception. In support of this project and others, SunSpec has presented at the Smart Inverter Working Group on multiple occasions to provide clarity on the role of aggregators, end device compliance criteria for California Rule 21 Phases 2 and 3, cybersecurity considerations, and the impact of IEEE 1547-2018 on the California Rule 21 implementation schedule. SunSpec personnel have also testified at CEC hearings on the topics of battery storage impacts and implications for the CEC-approved equipment list. All of these issues are directly and fundamentally impacted by the deliverables of this program.

In addition, all project artifacts (specifications, documents, and software) will be disseminated to non-profit organizations involved in state-level policy development in order to foster dialog regarding how open communication standards are positively impacting the grid. Minimally, project artifacts will be disseminated to Technet, Silicon Valley Leadership Group, Clean Coalition, and the Interstate Renewable Energy Council.

Vendor Implementations and Feedback

Over 20 California inverter and aggregator vendors have licensed the test tools from QualityLogic. Two leading nationally recognized test lab (including Underwriter Laboratories) are using the QualityLogic test tools to offer formal SunSpec California Rule 21 certification testing.

Four different product vendors have currently implemented the open sourced IEEE 2030.5 client. The software is integrated with their commercial gateways or facility energy management systems to provide a Rule 21 compliant interface to utility operations. Several others are currently testing viability of incorporating the open source software in their products.

“Providing cutting edge Smart Grid features in our microinverters has always been important for Enphase, and the IEEE 2030.5 client from EPRI provides a convenient path to integrating communications and security infrastructure as well as messaging support for certification requirements,” said Raghu Belur, co-founder and chief products officer at Enphase Energy. “With our software-defined inverter platform, the Enphase team was able to quickly test the sample application and client from EPRI. The client is a good foundation for developing IEEE 2030.5 functionality, and we look forward to providing EPRI a comprehensive report documenting our experience with it.”

“EPRI’s IEEE 2030.5 open-source software client is a very valuable framework for us as we try to be one of the leaders with a vision to adapt open standards and to be at the forefront of interoperability across disparate DER management platforms and Distributed Energy

Resources" said Co-Founder and CEO of the San Francisco based startup, OpenEGrid, Mr. Prabhakar Nellore. OpenEGrid is one of the first companies to incorporate the EPRI Client software in their products.

CHAPTER 6: Conclusions

Benefits to Ratepayers

Communications between utilities and the vast number of dispersed DER is critical to managing the paradigm shift confronting Californian utilities as California moves toward its renewable goals. The rapid and low-cost deployment of the default IEEE 2030.5 communications protocol is instrumental to achieving this visionary objective. Providing an IEEE 2030.5 open source client is a major step toward this goal.

This project has provided many key benefits to California investor-owned utility ratepayers, DER owners, utilities, and their customers:

1. DER owners benefitted from the reduced costs that the DER manufacturers will potentially charge to upgrade and deploy their DER to meet the new Rule 21 mandates.
2. Utilities and their customers are benefitted from continued and improved grid safety and reliability by ensuring the DER can respond rapidly and correctly to grid conditions and utility commands.
3. Utilities are benefitted by having the necessary visibility into grid situations to plan for incentivizing and managing efficient and effective DER deployments.
4. Ratepayers are benefitted from the reduced costs for utilities to ensure interoperable communications with the millions of DER.
5. Californian society is benefitted from the rapid deployment of these Rule 21-capable DER, and by the increase in the likelihood of California meeting the ambitious 100 percent renewable energy goal by 2045.
6. This project has therefore been an enabler and accelerator to address the State of California renewable energy goals. It is making it easier for the utilities, aggregators, and DER manufacturers to:
    - Comply with CPUC Rule 21 for smart inverter interconnection requirements.
    - Dispatch distributed renewable generation uniformly regardless of manufacturer, or type of load (through aggregator or direct-dispatch).
    - Take full advantage of the Smart Inverter Working Group Phase 1, 2, and 3 smart inverter functions that enable grid safety, efficiency, and reliability through timely dispatch.
    - Enable improvement in renewable penetration at the lowest possible incremental cost to the utilities and their ratepayers, as well as to the DER manufacturers.
    - Increase competition within DER provider base through reducing the barriers to entry, further driving down the costs to the end customers to acquire and deploy these technologies.

EPRI estimates that it costs each DER manufacturer and investor-owned utility approximately $1M-$2M of development, test and integration/certification time and resources and about one year of effort to bring IEEE 2030.5 communication technology on line and start deploying it within the marketplace, while working with each of the third party aggregators and investor-owned utilities to ensure their proper functionality. Assuming an average of $1.5M and one year of development/integration/certification effort per stakeholder, and assuming about 20 stakeholders in the process (DER manufacturers, investor-owned utilities, third-party aggregators), this project has achieved California-wide cost savings to ratepayers and investor-owned utilities of about $30M (20 stakeholders times $1.5M average). The deployment timeframe could also be decreased by at least one year. This estimated benefit alone provides more than 30:1 return on the project investment.

Key Lessons Learned

- Critical and Relevant Features in the Test Procedure: The IEEE 2030.5 specification is a complex communication standard. Test procedures developed for such standards must be targeted for maximum efficiency. The test procedures created for the IEEE 2030.5 functionality specified by the CSIP requirements must be comprehensive but also able to be performed at a reasonable cost. This objective required that the tests emphasize the more critical and relevant features through all of the test cases.
- Need for Continuous Maintenance of Test procedures: It became clear as a result of this project that an ongoing effort is needed to maintain and improve the test procedures as experience is gained in testing and deployment of IEEE 2030.5 systems.
- Software Portability Enables Commercial Adoption: There is a need for portability across different operating environments to accommodate the wide variety of implementations. Different DER vendors prefer different operating environments to run the IEEE 2030.5 software. When developing an open source software that can be potentially leveraged by different DER developers, it is important to address this need for portability.
- Default Switch-back Modes: It is possible that some end devices may need to communicate with the utility server over low bandwidth networks or over networks where data exchanges need to be minimized, like mobile networks. In such cases, it is important for the client to store the last available configuration and switch back to default configuration when required. In some solar installations, the gateway may be powered by the generated solar power. If so, the gateway may be powered off each night and started up each morning. In such a case, the gateway would have to store the default DER configuration and fallback to defaults.
- Need for Memory-efficient Code in Constrained Devices: Towards the end of the project, the team realized that many DER providers were interested in implementing this software locally in a gateway that was memory-constrained with a limited power supply. For this reason, several steps were taken to ensure that the software could be used by such lightweight devices. These steps included using C as the programming language of choice, limiting the scope of implementation to address only the requirements of IEEE 2030.5 and Rule 21, and developing an event driven framework.
- Complete Project Scope Improves Quality of Deliverables: An important takeaway from this project is its completeness in technical scope. The scope included the necessary components – test procedure, test harness, a reference software, testing, certification and commercial implementation – that fully complemented the development of each deliverable and improved the quality of end products. As an example, tests conducted by EPRI and Automation Research Group during the development phase and by

QualityLogic during certification phase contributed to enhancements to the SunSpec California Rule 21/CSIP IEEE 2030.5 test procedures and the QualityLogic IEEE 2030.5 test harness.

Product Readiness

SunSpec California Rule 21/CSIP IEEE 2030.5 Test Procedure

Project partner, SunSpec Alliance has an ongoing process to maintain and improve the test procedures as experience is gained in testing and deployment of IEEE 2030.5 systems and when gaps are identified. SunSpec provides a facility on SunSpec.org for the general public to provide feedback, comments, and reports of suspected defects on these procedures. The comment period prior to publication generated approximately 160 comments that have been reviewed and cataloged.

Additionally, SunSpec has established an interoperability testing and certification program that includes governance, test procedures, software, and the test facility certification procedures. Through this process, SunSpec Alliance has developed product certification and associated governing policies and procedures for product manufacturers. The program also defines the requirements to qualify an Authorized Testing Laboratory (ATL), and the process for performing certification testing for test laboratories.

Open Source IEEE 2030.5 Client

Four different product vendors have currently implemented the open sourced IEEE 2030.5 client. The software is integrated with their commercial gateways or facility energy management systems to provide a Rule 21 compliant interface to utility operations. Several others are currently testing viability of incorporating the open source software in their products.

EPRI is currently working on developing an IEEE 2030.5 to Modbus converter for DER through a separate effort. The converter will be tested, certified and open sourced to enable commercial adoption.

Scope for Future Work

- Reference IEEE 2030.5 Server: An open source IEEE 2030.5 client enables uniform implementation across multiple DER technologies and products enabling interoperability in communication with utility servers. Similarly, there is a need for uniform server implementation across utilities that can enable EndDevices from DER owners to interoperate across different utility server instances
- Need for DER Group Management beyond CSIP: CSIP defines a specific profile for managing DER in groups. This profile defines a one-to-one relationship between utility operations and DER resulting in DER aggregators and other intermediary control systems being used as passive routers and not products with intelligence. As DER penetration increases, several factors challenge the permanence of this architecture including, 1) latency in DER communications with intermediary passive routers and gateways, (2) communication network bandwidth limits, (3) reliability challenges due to the loss of communications or DER not responding, (4) computational complexity, overhead and accuracy required when estimating grid states, (5) failure of the

centralized control application, and (6) data volume and processing bottlenecks, etc. With technological advancements in DERMS, intelligent DER management can be performed at a wide range of levels, by different entities and can vary broadly in scale. Future group management definitions should consider intelligence and control capabilities in aggregator’s and other downstream control systems thereby pushing DER management to lower control layers.

GLOSSARY AND LIST OF ACROYNMS

Term	Definition
Area EPS	Area Electric Power System
API	Application Programming Interface
CPUC	California Public Utility Commission
CSIP	Common Smart Inverter Profile
DER	Distributed Energy Resource
DNS	Domain Name Servers
DNS-SD	Domain Name Servers – Service Discovery
FSA	Function Set Assignments
ECP	Electric Connection Point
EMS	Energy Management System
EPIC (Electric Program Investment Charge)	The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
EPS	Electric Power System
EXI	Efficient XML Interchange Format
GCC	Compiler Collection
GNU Bash	Bash is the shell, or command language interpreter, that will appear in the GNU operating system
GNU	GNU is a recursive acronym for "GNU's Not Unix!"
GFEMS	Generating Facility Energy Management System
HD	Hard Drive
HTTP	Hyper Text Transfer Protocol
IEC	International Electrotechnical Commission
OpenSSL	Robust, commercial-grade, and full-featured toolkit for the Transport Layer Security (TLS) and Secure Sockets Layer (SSL) protocols
IEEE	Institute of Electrical and Electronic Engineers
LFDI	Long Form Device Identifier

Term	Definition
RESTful	Representational state transfer (REST) or RESTful provides interoperability between computer systems on the Internet
SFDI	Short Form Device Identifier
SMCU	Smart Inverter Control Unit
URI	Uniform Resource Identifier
UTC	Coordinated Universal Time
UTF-8	A character encoding capable of encoding all 1,112,064 valid code points in Unicode using one to four 8-bit bytes.
XML	Extensible Markup Language
XmDNS	An extensible DNS management scheme that uses XML to store data