ELECTRIC POWER RESEARCH INSTITUTE

EPRI's Distributed Energy Resources Integration Toolkit

An Overview of EPRI Tools for Testing and Implementing Open Protocols

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

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ABSTRACT

As grid codes and utility programs are increasingly requiring end-use devices and their control systems to use open standards it is increasingly important that validation tools, simulation tools, and reference implementations are available to foster growth in the industry. Utilities need tools that can be used to evaluate these products and their capabilities to ensure they meet the requirements of RFPs, interconnection agreements, and intended use cases.

The integration of distributed energy resources and bi-directional demand response technologies into deployments with other utility control system using open communications standards are new and have few case studies. Utilities, national labs, and industry researchers are exploring and validating these new use cases through laboratory and field testing. EPRI's reference control systems and device simulators make testing of these use cases simple and enable advanced hardware and software in the loop testing. These test tools have been deployed in National Labs including Sandia and NREL and utilities including SMUD, Hydro One, TVA, Jackson EMC, EPB, Duke Energy, and Ameren.

EPRI has produced numerous tools through base programs, supplemental projects, and government projects. The types of tools include open source protocol implementations, reference control systems, device simulators, reference hardware designs, and protocol converters. The DER Integration Toolkit pulls these tools together into a repository of test tools and implementation resources for applying open communication protocols to both demand response and distributed energy resources applications. EPRI continues to maintain the tools in the toolkit and provide support to EPRI's members. The goal of the toolkit is to help support development and testability of open protocols so EPRI's support of these tools extends to vendors or other stakeholders involved in member projects. The end goal is to create a "demonstration in a box" where any component of the communication architecture can be simulated or implemented using components of the EPRI DER Integration Toolkit.

This report summarizes each of the test tools included in the 2018 EPRI DER Integration Toolkit.

Keywords
Communications
Distributed Energy Resources
Demand Response
DERMS
Smart Grid

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1
OVERVIEW

As grid codes and utility programs are increasingly requiring end-use devices and their control systems to use open standards it is increasingly important that validation tools, simulation tools, and reference implementations are available to foster growth in the industry. Utilities need tools that can be used to evaluate these products and their capabilities to ensure they meet the requirements of RFPs, interconnection agreements, and intended use cases.

Many products claim to fulfil specific communication requirements, but unless there are independent tools to evaluate these claims, it is unlikely that multiple brands or types of equipment will interoperate. Third parties have created test tools however not all protocols have test tools or established certification frameworks. Even when protocols are implemented properly there are other, non-standardized practices that can lead to barriers including custom control algorithms or other proprietary management techniques. Test tools help identify these barriers prior to deployment in the field.

The integration of distributed energy resources and bi-directional demand response technologies into deployments with other utility control system using open communication standards are new and have few case studies. Utilities, national labs, and industry researchers are exploring and validating these new use cases through laboratory and field testing. EPRI's reference control systems and device simulators make testing of these use cases simple and enable advanced hardware and software in the loop testing. These test tools have been deployed in National Labs including Sandia and NREL and utilities including SMUD, Hydro One, TVA, Jackson EMC, EPB, Duke Energy, and Ameren.

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This deliverable is compilation of test tools designed to support the development and testing of control systems including DERMS and DRAS systems and devices including solar, storage, and demand response technologies. The team will assess opportunities for expanding existing toolsets by improving exiting tools and developing new tools.

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CONTENTS OF THE TOOLKIT

The DER Integration Toolkit consists of five types of tools: open source code, reference control systems, device simulators, and reference hardware. Communication protocols vary between management of demand response and distributed energy resources so the toolkit has been divided into inverter-based technologies (Figure 2-1) and DR technologies (Figure 2-2) tools to simplify the overview.

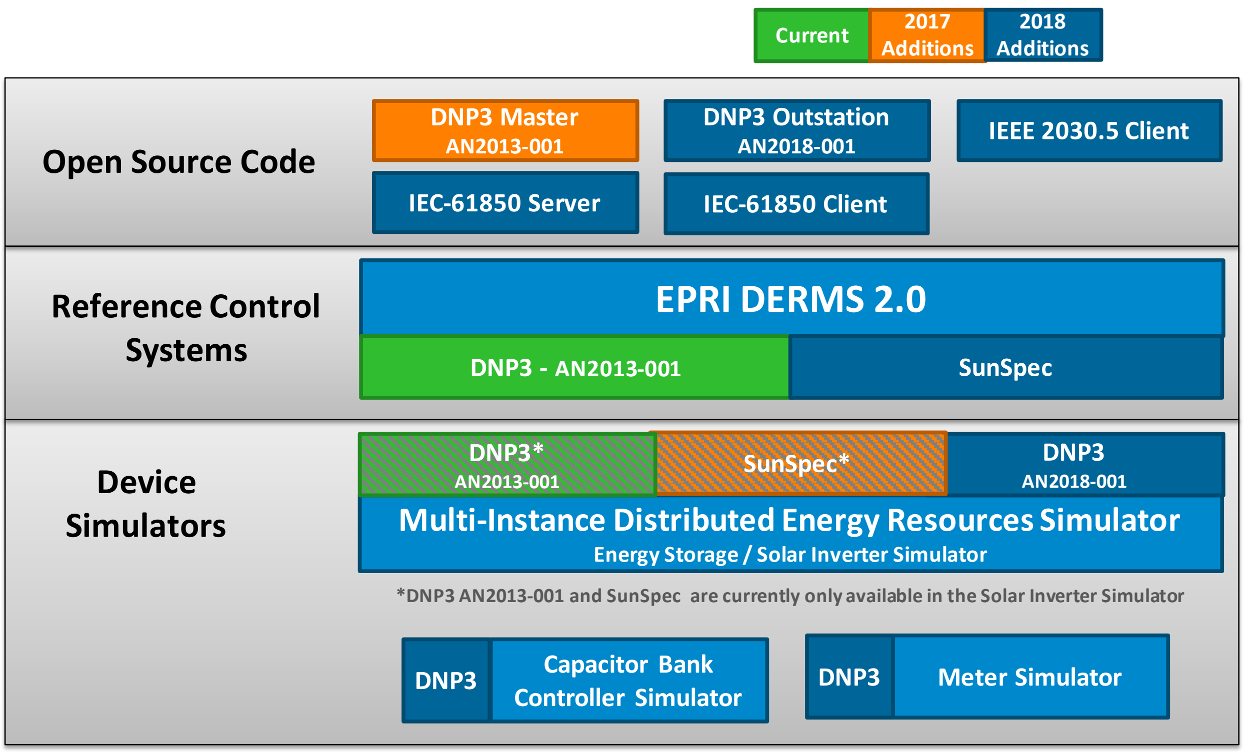

Figure 2-1
Tools available for inverter-based technologies.

EPRI is continuously maintaining, updating, and developing test tools so the contents of the toolkit are constantly changing. Some tools in the toolkit are developed through the EPRI base membership however many are developed through supplemental or government funding. The schedules of supplemental and government projects do not always follow a typical calendar year so tools developed in this project may not be formally captured below until the following year. This is also the reason not all the tools are formally published but are instead available upon request. Tools currently being revised or part of an active project don't always get published until the activity and development is finalized.

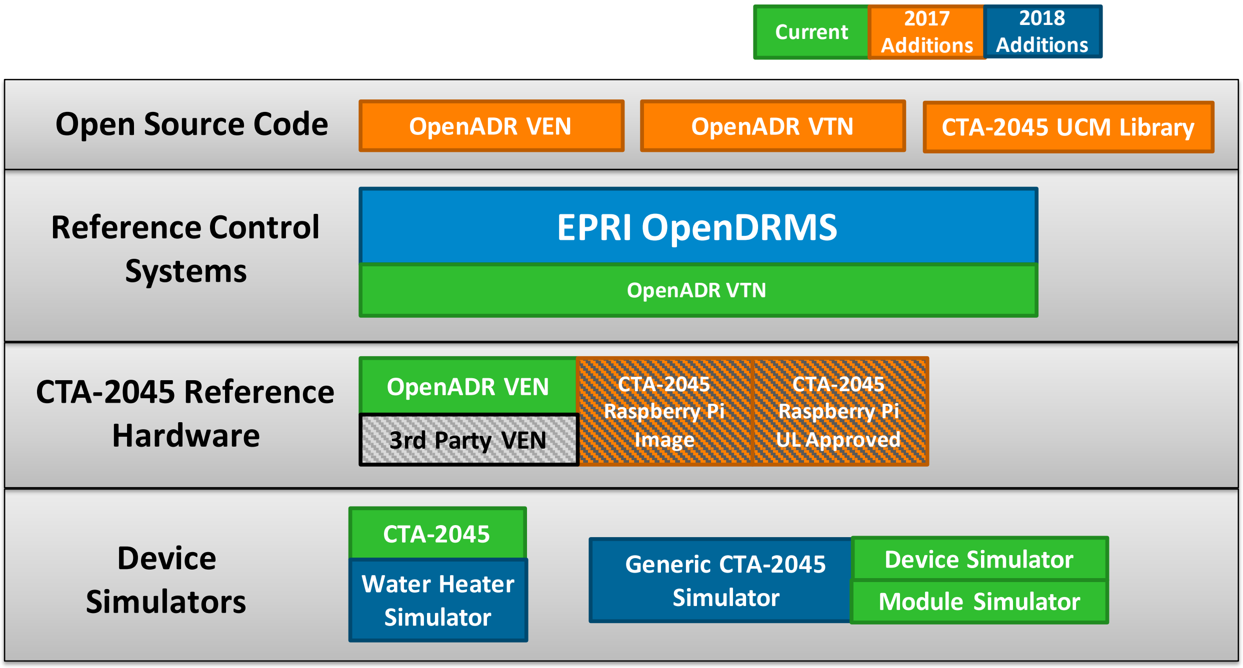

Figure 2-2
Tools available for demand response technologies.

The following captures a snapshot of the state of the toolkit in 2018.

Open Source Code

Open source code is an example implementation of protocol stacks for both devices (clients/slaves) and control systems (servers/masters). The purpose of these tools is to provide guidance to the industry for how protocol can be implemented. Software developers and manufacturers are welcome to use the code in their own products following the open source license. The goal is to provide publicly accessible code to help accelerate the addition of open protocols in devices and control systems while helping to minimize implementation errors by providing examples of how to do it.

General Benefits

- Easily integrate open protocols into the software in end devices.
- Third-party reference implementation of the protocol.
- Accelerate adoption by providing publicly accessible reference implementations.

Target Audience

- Software developers for manufacturers of end devices.
- Software developers for vendors of control systems like DERMS or DRAS.
- Researchers developing their own test environments.

DNP3 Stack for DNP Application Note AN2013-001

The DNP3 Stack implements DNP3 following DNP Application Note AN2013-001 - Advanced Photovoltaic. Generation and Storage in control systems. The audience for this tool includes developers of control systems, devices, or test tools for DNP3 enabled DER.

The DNP3 Stack is available by request.

DNP3 Outstation for DNP Application Note AN2018-001

The DNP3 Outstation stack that implements DNP Application Note AN2018-001 – DNP3 Profile for Communications with Distributed Energy Resources. The audience for this tools include developers and manufacturers of DNP3 enabled DER.

Once completed the DNP3 Outstation code will be published in EPRI's GitHub site

IEEE 2030.5 Client

The IEEE 2030.5 Client implements the latest revision to IEEE 2030.5 in distributed energy resources. The client focuses on functionality for distributed energy resources including solar and storage.

The IEEE 2030.5 Client is available on EPRI's GitHub site at https://github.com/epri-dev/IEEE-2030.5-Client.

IEC-61850 Server and Client

The IEC-61850 implements the latest draft of IEC 61850-720 for use in both server and client applications. This tool is in final stages of development and will be available on EPRI's GitHub page in early 2019.

OpenADR VEN

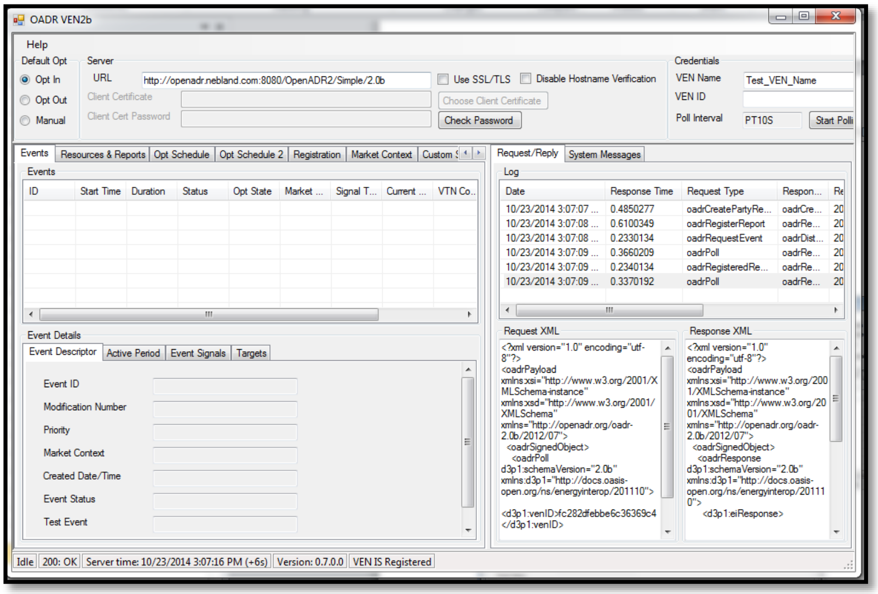

Figure 2-3
Example of OpenADR VEN user interface.

This application is an implementation of a virtual end node (VEN) as defined in the OpenADR Alliance's OpenADR 2.0 Profile B Specification (HTTP pull), updated July 1, 2013. OpenADR defines a machine-to-machine interface and includes the information model, transport and security mechanisms, and the way data is exchanged between two end points. OpenADR 2.0 defines what and how information is communicated between an electricity service provider and customers, but it does not define how either end point uses the information. This VEN application is one example of how the specification can be applied. This open source application is written in C# and includes a graphical user interface.

Developed to interact with an OpenADR 2.0 Virtual Top Node to provide users with insight into the OpenADR 2.0b specification, its information model, XML payloads, interactions with a VTN, etc.

The OpenADR VTN can be found on EPRI's GitHub site at https://github.com/epri-dev/OpenADR-Virtual-Top-Node/releases.

OpenADR VTN

The open-source OpenADR (OADR) Virtual Top Node software was developed to provide the electric power industry with an open-source research tool to demonstrate and test OpenADR 2.0 and to provide utilities with a tool to research the potential use of OpenADR 2.0 in different use cases. This server application is one example of how the OpenADR 2.0 specification can be applied. It includes a graphical user interface for setting up user accounts, assigning clients (virtual end nodes, or VENs), defining resources, selecting market contexts, and creating and scheduling demand response events. EPRI's OADR VTN was developed and tested on an Ubuntu 14.04 desktop and server. Limited testing has been done on OS X. The software has not been tested on Windows Server, though all of the software used to run the OADR VTN runs on Windows.

The OpenADR VTN can be found on EPRI's GitHub site at https://github.com/epri-dev/OpenADR-Virtual-Top-Node/releases.

CTA-2045 UCM Library

This software is a C++ library developed and released to support companies in the marketplace who are developing or planning to develop CTA-2045 communication modules. A sample program is provided to communicate to an SGD device through a serial port. The best approach is to run it with the EPRI CTA-2045 simulator and test cables.

The OpenADR VTN can be found on EPRI's GitHub site at https://github.com/epri-dev/CTA-2045-UCM-CPP-Library.

Reference Control Systems

Reference control systems are fully functional control systems for DER and DR. They are not designed to be commercial systems but instead research systems to allow for lab testing, validation of protocol implementations in end-devices, or testing/sandboxing use cases. EPRI members have deployed reference control systems in their demonstration projects. The implementations have also been shared with utility project members (vendors or manufacturers) to help support testing of new devices.

General Benefits

- Saves time and cost in field deployments through upfront ability to assess interfaces without procuring commercial systems.
- Validation of protocol implementations of end-use devices or other downstream control systems.
- Sandbox for studying effective control algorithms and mapping of group-level commands to individual-level commands.
- Unbiased, vendor-neutral implementations of communication standards.

Target Audience

- Researchers interested in conducting demonstration projects without having to acquire a commercial DERMS or ADMS system.
- Researchers interested in validating communication protocols in end-devices or downstream control systems.
- Utility project partners in need of a tool for validating their protocol implementations.

EPRI OpenDERMS 2.0

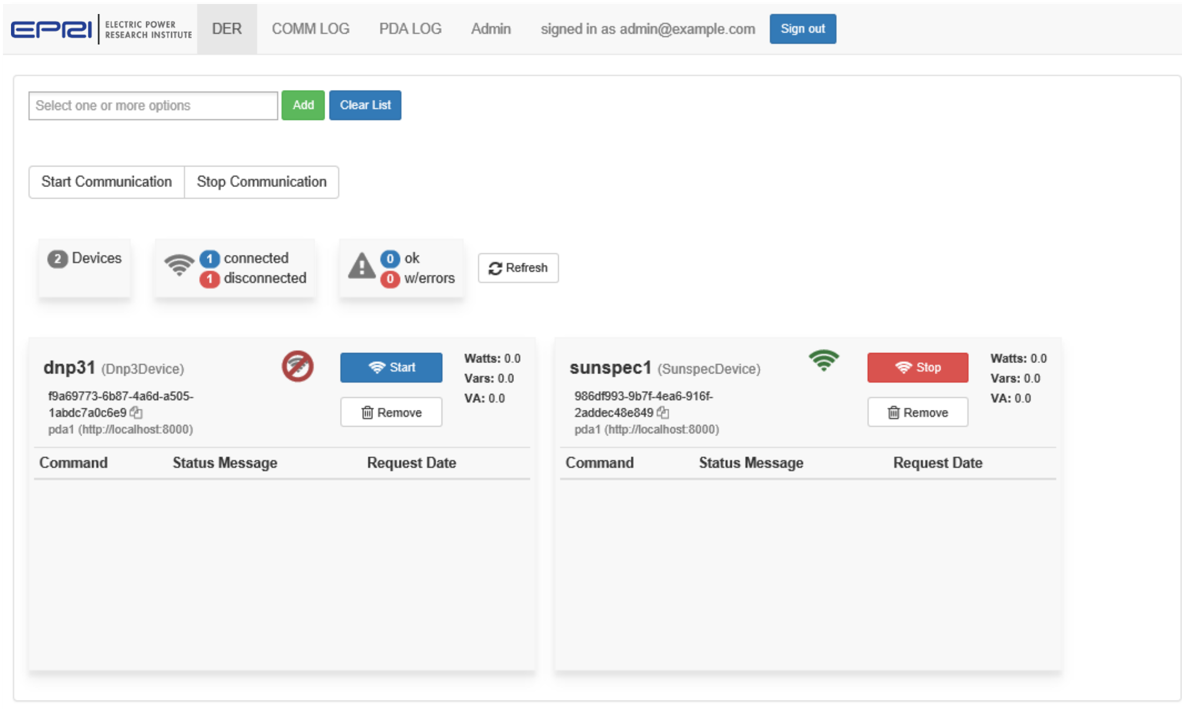

Figure 2-4
Example of EPRI OpenDERMS user interface

EPRI's OpenDERMS 2.0 is a reference implementation of a distributed energy resource management system. It consists of tools for management of smart inverters and an interface to connect to other enterprise systems and receive aggregation requests.

The DERMS tool allows the connection of many DER, organization into logical groups and the monitoring and management by group or individual levels. This tool supports all the IEC standard functions for smart inverters, including volt-var control, power limiting, power factor, etc. These tools are useful for performing lab evaluations, to back-up RFP requirements and to speed and simplify field integration. These tools can also be directly referenced in RFPs and extended to partner companies to aid their engineering and development processes. In this way, compatibility is guaranteed upfront.

Currently OpenDERMS 2.0 supports DNP3 and SunSpec Modbus for downstream solar and storage devices. The largest improvement over OpenDERMS 1.0 is the addition of an API to easily add new downstream protocols. OpenDERMS 2.0 is a web application that runs on any operating system.

EPRI's OpenDERMS 2.0 is available by request.

EPRI OpenDRMS

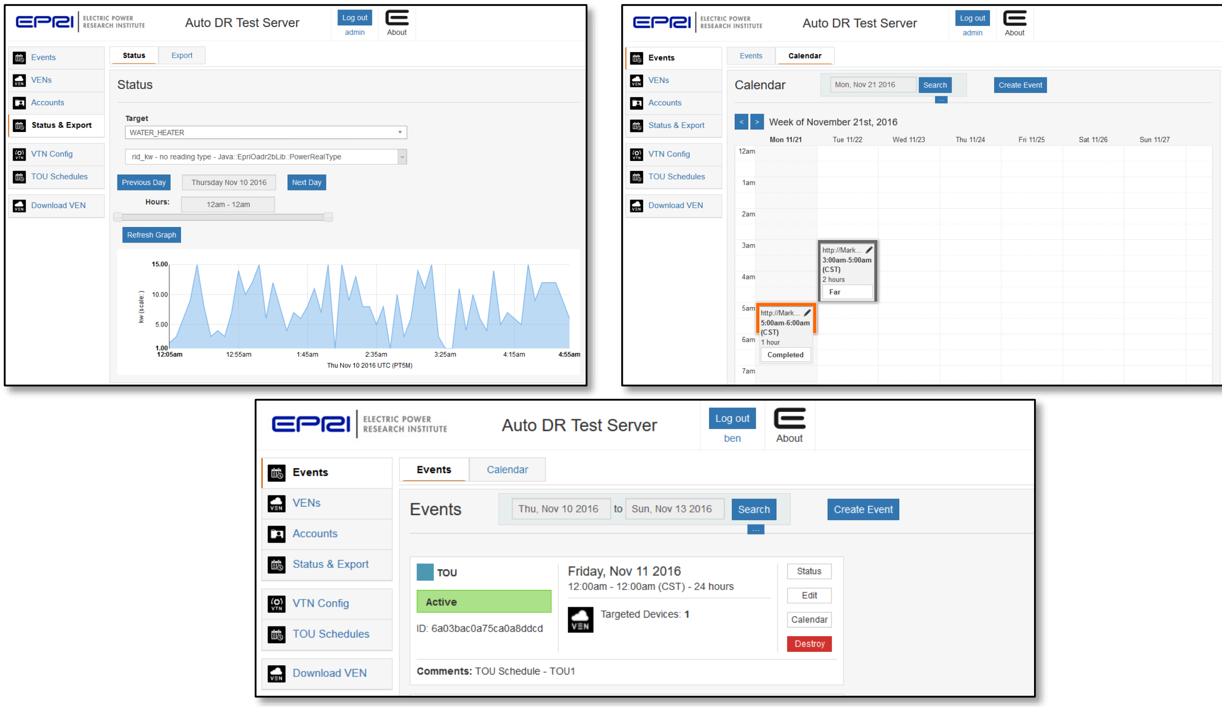

Figure 2-5
Example of EPRI OpenDRMS user interface

EPRI's OpenDRMS is an OpenADR 2.0b-compliant server (certified in October 2014) capable of controlling demand response resources and smart inverters. It consists of scheduling tools, data collection and real-time viewing, and data management capabilities. EPRI's OpenDRMS is hosted on a cloud server and is accessed using a web browser and can connect to OpenADR capable devices.

Access to EPRI's OpenDRMS is available by request.

Device Simulators

The value of this test tool is the ability to validate protocol implementations in control systems. When this tool is paired with other device simulators and distribution system modeling software users can perform targeted testing of hardware and software assets through hardware and software in the loop testing. For example, users can perform easily repeatable testing of the custom control algorithms in DERMS systems by using a mixture of device simulators to emulate device behavior and system modeling software to emulate distribution system behavior.

General Benefits

- Validate protocol implementations in control systems.
- Assist in performing targeted testing of hardware and software assets through hardware and software in the loop testing.

- Capabilities to perform repeatable device behaviors for algorithm or control scheme testing.

Target Audience

- Researchers interested in validating communication protocols in control systems.
- Utility project partners in need of a tool for validating their protocol implementations.
- Researchers interested in testing control algorithms for end-use devices.

Distributed Energy Resources Simulator – DNP3 and SunSpec

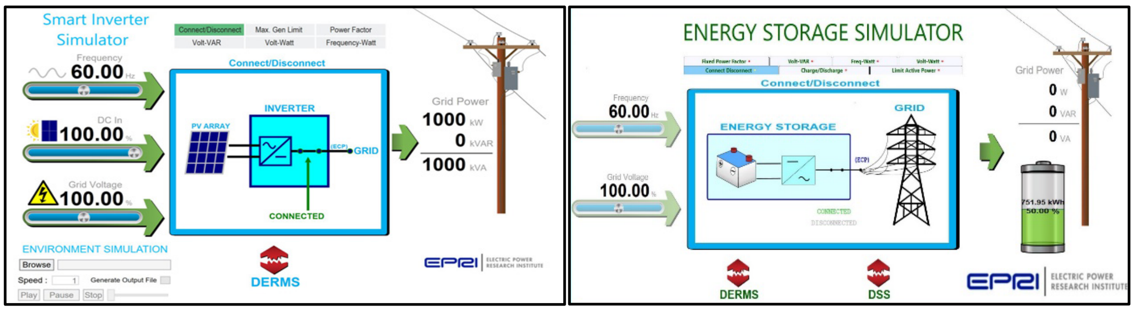

Figure 2-6
User Interface - Solar Inverter Simulator (left) and Energy Storage Simulator (right)

The DER Simulator emulates hundreds of smart solar inverters and energy storage systems with communications capabilities. The simulator has models that emulate the behavior of a smart inverter or energy storage system. The simulator can perform smart functions including connect/disconnect, adjust maximum generation level, charge-discharge, adjust power factor, volt-var curves, frequency-watt mode, and volt-watt mode. As of the end of 2018, the simulator supports both DNP3 and SunSpec Modbus. The DNP3 variant has been updated to emulate multiple devices and also has a DBus[1] interface to talk to grid simulators like OpenDSS, Opal-RT systems, or others.

The simulators are available by request. More information on the Solar Inverter Simulator can be found in *Overview of EPRI's DER Simulation Tool for Emulating Smart Solar Inverters and Energy Storage Systems on Communication Networks* [2].

[1] DBus is an interface to facilitate the communication between Co-Simulation components running in separate threads, enabling these components to deliver data in an asynchronous/synchronous interaction depending on the simulation needs.

[2] *Overview of EPRI's DER Simulation Tool for Emulating Smart Solar Inverters and Energy Storage Systems on Communication Networks: An Overview of EPRI's Distributed Energy Resource Simulator.* EPRI, Palo Alto, CA: 2018. 3002013622.

Generic CTA-2045 Simulator

This application is a software tool designed to aid technology providers in the development and testing of end-use devices and communication modules with an ANSI/CEA-2045 interface. It is available from https://github.com/epri-dev/CTA-2045-Desktop-Simulator. It provides a standardized, ANSI/CTA-2045 tool to aid in the development and testing of technologies, supports the role of either an end-use device or communication module, supports both AC and DC form factor per the CEA-2045 standard, and supports a select set of data link and application-layer messages (basic and intermediate demand response).

Smart Water Heater Simulator – CTA-2045

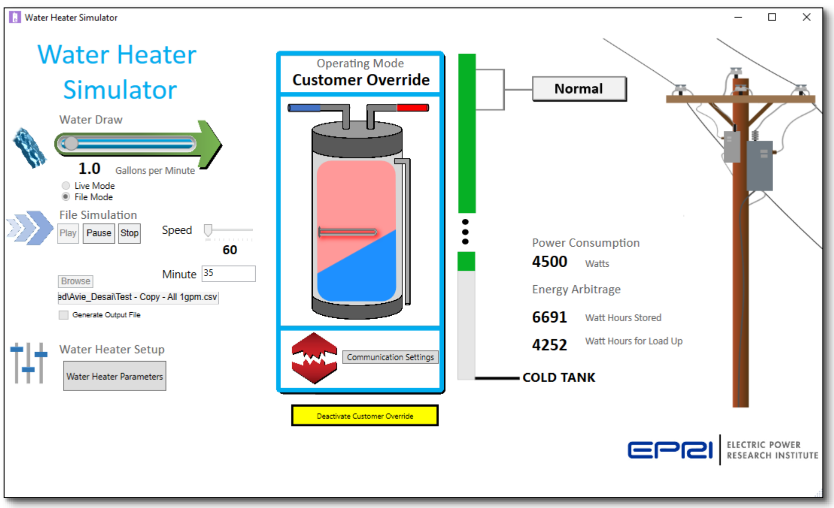

Figure 2-7
Smart Water Heater Simulator user interface

The Smart Water Heater Simulator emulates a smart water heater with communications capabilities. The simulator has two-way communications and supports functionality including multiple levels of load reduction (shed, critical peak, grid emergency), increase load, customer override, device operational state, and monitoring data including present energy capacity of the device. The simulator currently supports CTA-2045.

The Smart Water Heater Simulator is available by request. More information on the Smart Water Heater Simulator can be found in *Overview of EPRI's Simulation Tool for Emulating Smart Water Heaters on Communication Networks* [3].

[3] *Overview of EPRI's Simulation Tool for Emulating Smart Water Heaters on Communication Networks: Overview of EPRI's Simulation Tool for Emulating Smart Water Heaters on Communication Networks.* EPRI, Palo Alto, CA: 2017. 3002009852.

Distribution Automation Device Simulator

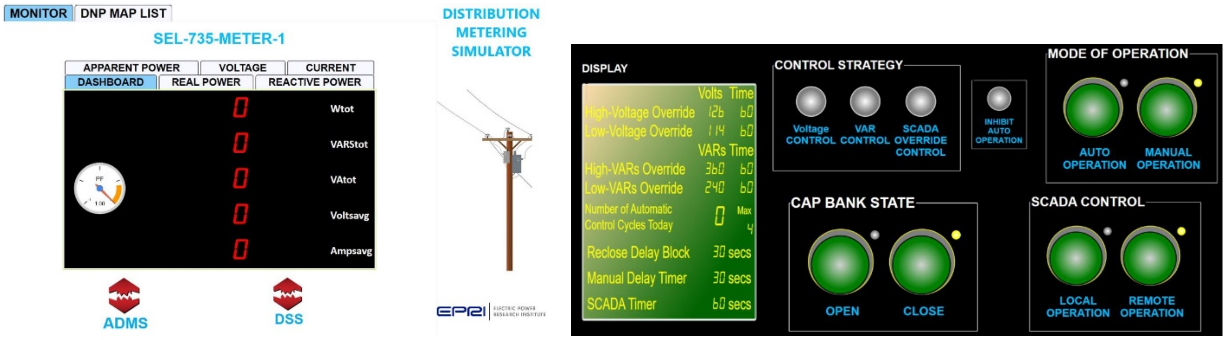

Figure 2-8
SCADA Smart Meter simulator interface (left), Cap-bank Controller simulator interface (right)

Distribution Automation Device (DAD) simulator emulates the characteristics of smart grid devices in the distribution grid. As of 2018, DAD simulator emulates a cap-bank controller and a metering device with communication capabilities. The cap-bank controller simulator can be setup to manage a cap-bank's switch automatically based on preconfigured season settings or from a remote SCADA system. Metering simulator emulates a smart SCADA meter that are used for monitoring three phase systems and provide the telemetry to headend control system (e.g ADMS/DERMS). DAD Simulator has a DBus interface to talk to grid simulators like OpenDSS, Opal-RT systems or others

The Distribution Automation Device simulator is available by request.

Reference Hardware

Reference hardware designs are collaborative produced hardware designs that allow for testing of specific use cases, proofs of concepts to show functionality, or prototypes to allow demonstration projects while manufacturers mature their designs.

General Benefits

- UL approved control module hardware to allow for safe field testing of end use devices.
- Provide a reference design for manufacturers to follow.

Target Audience

- Researchers conducting field demonstration projects.

CTA-2045 Reference Hardware

Figure 2-9
Example CTA-2045 modules.

The CTA-2045 reference hardware implements a CTA-2045 module that supports CTA-2045 between the module and the device (water heater, pool pump, etc) and OpenADR back to the utility headend using cellular connection. The reference hardware includes a UL approved hardware design, CTA-2045 raspberry Pi image, and an OpenADR VEN. Third parties can modify the design to replace the OpenADR VEN with their protocol of choice.

More information about the CTA-2045 Reference Hardware is available by request.

3
NEXT STEPS

The industry continues to improve current communications standards to meet modern use cases for The industry continues to improve current communications standards to meet modern use cases for solar, energy storage, and demand response systems. As the industry evolves EPRI plans to adapt the DER Integration Toolkit, including the Distributed Energy Resources Simulator, to meet the needs of the industry.

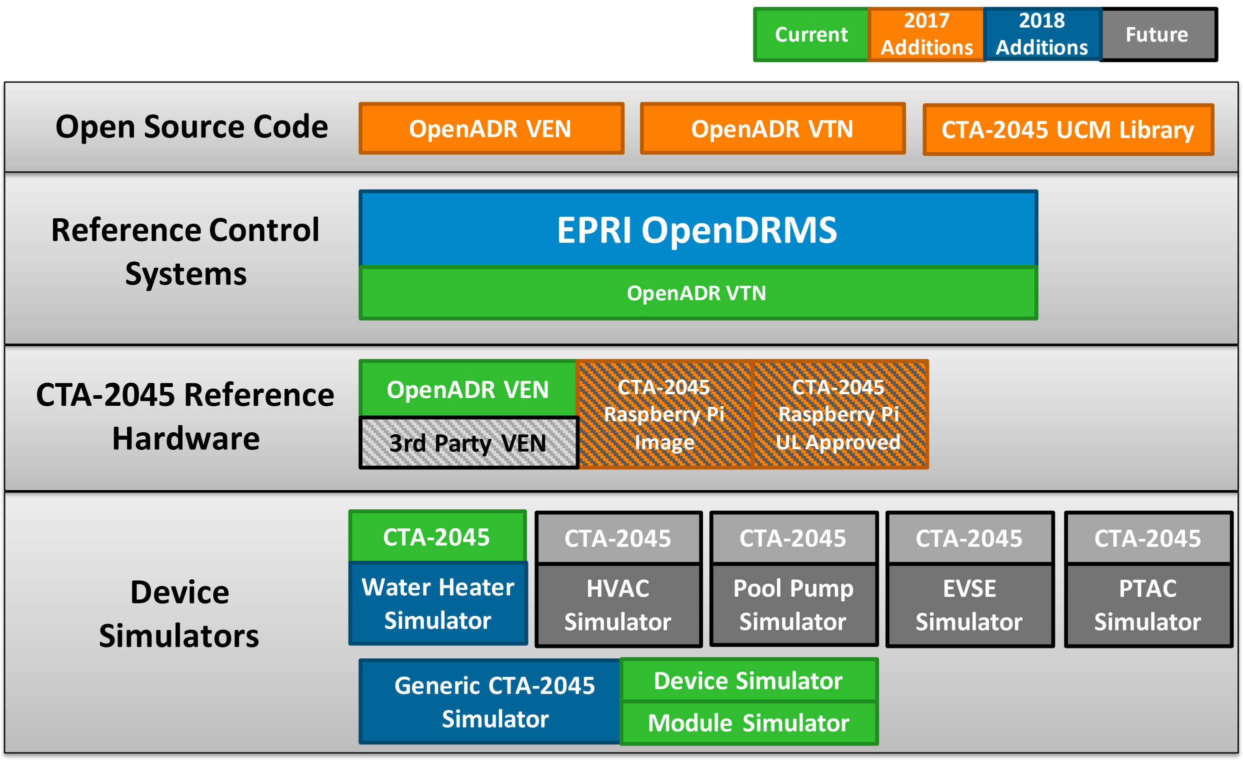

Figure 6-1
Upcoming tools for demand response technologies.

In the immediate term EPRI plans to continue to expand the device simulators to support additional device types including energy storage, heating and cooling systems, pool pumps, electric vehicles, and commercial room air conditioners. EPRI is also looking to expand protocol support across the entire toolkit to include all relevant communications protocols. The reference control systems and device simulators have been intentionally designed to scale well to include new protocols as needs arise. EPRI is funded through base research programs, supplemental projects with utilities, and government funded activities to expand the tools in the DER toolkit.

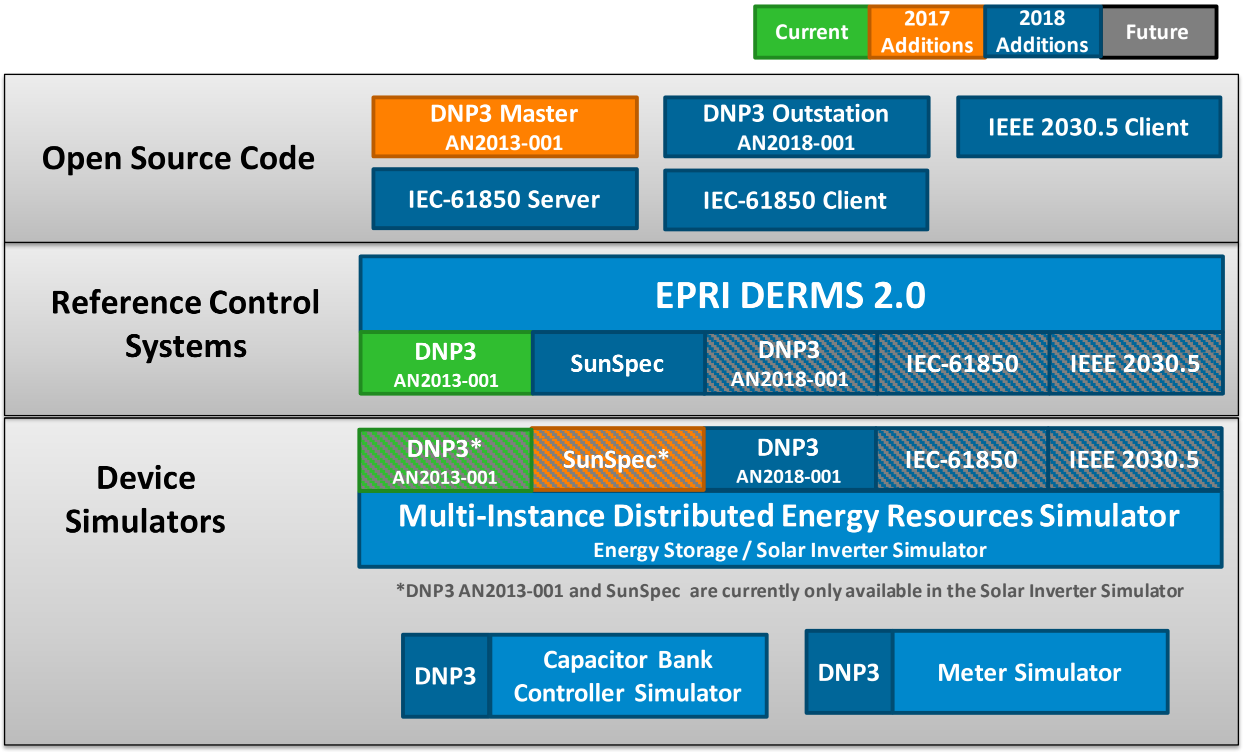

Figure 6-2
Upcoming tools for inverter-based technologies.

In addition to adding new tools EPRI is constantly receiving feedback from users of the toolkit including feature requests and bugs. This feedback is reviewed and included in the work plan for each tool. Severe bugs are addressed immediately.

EPRI is working with Sandia National Laboratory in designing a distributed monitoring system that can patrol a wide range of cyber-attack vectors, detect various attack methods, predict adversary movements, and implement controls that mitigate damage to DER devices. As part of this project, EPRI will update the DER Smart functions to latest IEEE 1547 functions. EPRI will also upgrade the DNP3 outstation to implement AN2018-001 standard and will add Transport Layer Security (TLS) to the Modbus protocol driver. EPRI is also working with EDF Energy on integrating IEC 61850 drivers to OpenDERMS and the device simulators in the next year.

Another development work planned for 2019 is an IEEE 2030.5 to SunSpec Modbus translator. To meet the recent requirements of Rule – 21 and IEEE 1547, there is much interest among DER vendors to develop an IEEE 2030.5 to Modbus translator. EPRI will extend the capability of the currently available, open source IEEE 2030.5 client, to a translator that can communicate with SunSpec Modbus compliant devices. As part of this project, a specification that documents the mapping between the two communication protocols will also be developed.

EPRI is committed to the development of test tools to ease the entry of open protocols into the market and plans to continue to develop, maintain, and support these tools for members. The end goal is to create a "demonstration in a box" where any component of the communication architecture can be validated, tested, or implemented using components of the DER Integration Toolkit.

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