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Overview of EPRI's DER Simulation Tool for Emulating Smart Solar Inverters and Energy Storage Systems on Communication Networks

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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 more and more 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.

In 2017, EPRI created the EPRI Smart Solar Inverter Simulator to validate protocol implementations in control systems and serve as a research tool for deeper evaluation of their performance. In 2018 the tool was expanded to include energy storage systems. The new tool has been renamed the Distributed Energy Resources Simulator. 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.

The Distributed Energy Resources Simulator emulates smart solar inverters or energy storage systems with communications capabilities. 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 interface to talk to grid simulators like OpenDSS, Opal-RT systems, or others.

This report is a summary of this tool, its features, and an overview of the parameters. EPRI's Distributed Energy Resources Simulator provides the means to validate these products and serve as a research tool for deeper evaluation of their performance.

Keywords
Device Simulator
DNP3
SunSpec
Smart Inverter
DERMS

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1 SUMMARY

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.

EPRI has produced numerous tools through base programs, supplemental projects, and government projects. 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 members of the Information and Communication Technology for Distributed Energy Resources and Demand Response program (P161D). 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" or "in-the-loop" testing where any component of the communication architecture can be simulated or implemented using components of *EPRI's DER Integration Toolkit*[1].

The DER simulator provides the means to validate protocol implementations in control systems and serve as a research tool for deeper evaluation of their performance. The value of this test tool is the ability to evaluate control strategies and protocol implementations in control systems.

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

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.

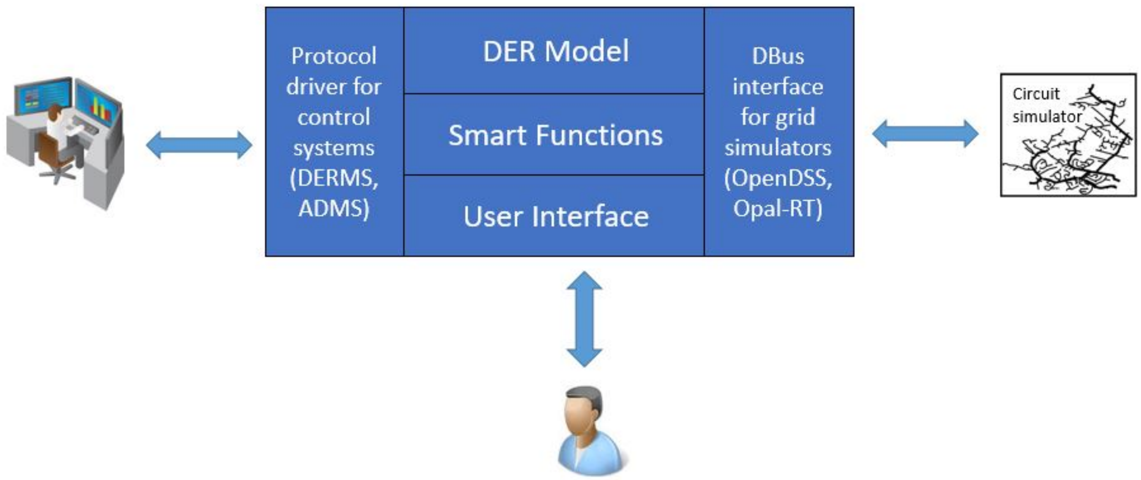


Figure 1-1
Functional Architecture of DER Simulator

The DER Simulator emulates smart solar inverter and energy storage system with communications capabilities. The simulator has models that emulate the behavior of a smart inverter or energy storage system. The simulator can perform common smart functions including connect/disconnect, adjust maximum generation level, adjust power factor, volt-var curves, frequency-watt mode, volt-watt mode and charge discharge 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[2] interface to talk to grid simulators like OpenDSS, Opal-RT systems, or others. The general architecture is shown in Figure 1-1.

This report is a summary of this tool, its features, and an overview of the parameters. EPRI's DER Simulator provides the means to validate these products and serve as a research tool for deeper evaluation of their performance.

[2] 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

DER SMART FUNCTIONS

The DER simulator is designed to emulate real world behavior of smart inverter and energy storage systems in the field. DERs are capable of adjusting their behavior to provide support to the grid through smart inverter functionality. This includes adjusting to both active and reactive power based commands from control systems or frequency/voltage measurements on the grid. There are over 20 smart functions. These are described in detail in EPRI's Common Functions for Smart Inverters – 4th Edition[3]. This DER simulator supports seven smart inverter functions. Table 2-1 provides a summary of the functions supported by the solar smart inverter simulator. EPRI has plans to expand the functionality in this tool over time. The six included in the tool were requested by utilities to meet their use cases. EPRI plans to expand the list of functionalities to include all functionality required by grid codes and others upon request.

Table 2-1
Supported Smart Inverter Functions

Function Name	Description
Connect/Disconnect	This function is used to command the device to connect or disconnect from the grid.
Adjust Maximum Generation Level Up/Down	This function is used to set the maximum generation limit of the device as a percentage of its nominal capacity.
Adjust Power Factor	This function is used to set the power factor of the smart inverter. The DER follows the IEEE sign convention in which a leading (capacitive) power factor is positive and a lagging (inductive) power factor is negative. Note that this function and the Volt-VAR functions are mutually exclusive and it is not possible for both to be active simultaneously.
Charge/Discharge *(Energy Storage only)*	This function is used to set the charging and discharging set points for the storage systems
Volt-VAR Curves	This function is used to send Volt-VAR curves to the device to produce or absorb reactive power as a function of locally-observed voltage.
Frequency-Watt Mode	This function is used to alter the active power output in response to the measured deviation from a specified nominal frequency.
Volt-Watt Mode	This function is used to filter the active power output in proportion to the measured deviation from the grid nominal voltage.

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

3
DER MODEL

The DER Simulator contains smart inverter and energy storage system simulator depending on the mode the user selects. This section describes the model for each system.

Energy Storage

The model architecture for the energy storage system follows the structure represented in Figure 3-1. The model described focuses on the battery storage physics, not on the control modes.

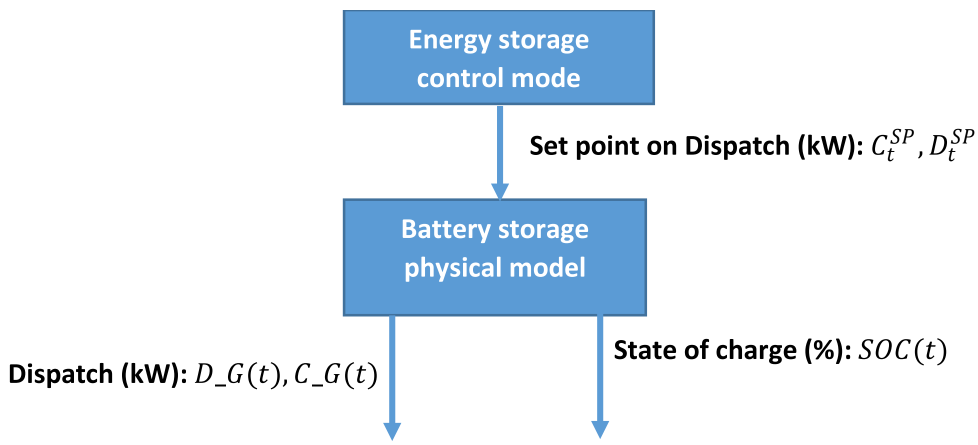


Figure 3-1
Energy Storage Model Architecture

It receives the set point of charge and discharge to be delivered, but delivers according to the energy and power capacity of the system. It outputs the actual charge and discharge depending if the capacity can provide it. It also outputs an updated state of charge. This state of charge might be used as an input for a feedback loop for some control modes, depending on the design of the mode.

Physical Model Equations

Table 3-1
Physical Model Parameters

Parameter	Units	Description
EFF_C	Percentage	Charging efficiency
EFF_D	Percentage	Discharging efficiency
EFF_RT	Percentage	Roundtrip efficiency
SOC_MAX	Percentage	Maximum state of charge
SOC_MIN	Percentage	Minimum state of charge
PCAP_C	Watts	Maximum power capacity when charging (at the grid)
PCAP_D	Watts	Maximum power capacity when discharging (at the grid)
ECAP	Watts Hour	Discharge Energy capacity of the system
SELF_D1	$hour^{-1}$	Self-Discharge Rate (SOC-dependent)
SELF_D2	Percent/hr	Self-Discharge Rate (constant)
SOC(t)	Percentage	Energy state of charge at the end of time interval *t*
Δt	Hour	Sampling period for simulation
C_G(t)	Watts	Charging power during time interval *t* (at the PCC)
D_G(t)	Watts	Discharging power during time interval *t* (at the PCC)

The time evolution of a battery storage system is modeled as a discrete-time dynamic system that presents (possibly time-varying) input and state constraints. Although this is the case for all storage systems, the structure of such model as well as the set of parameters involved in it.

The equation that represents the dynamic evolution of the SOC of the storage system is:

$$SOC(t) = SOC(t-1) + \left(\frac{EFF\_RT}{ECAP} C\_G(t) - \frac{1}{ECAP} D\_G(t) - SELF\_D1 \cdot SOC(t-1) - SELF\_D2\right) \cdot \Delta t$$

for all t. Notice that the product $EFF\_C \cdot EFF\_D$ is equivalent to the roundtrip efficiency EFF_RT .

The model includes the following mappings to guarantee that the physical constraints hold:

$$C\_G(t) = \min\left\{\left[\frac{(SOC\_MAX - SOC(t-1))}{\Delta t} + SELF\_D1 \cdot SOC(t-1) + SELF\_D2\right]\frac{ECAP}{EFF\_RT}, PCAP\_C, C_t^{SP}\right\}$$

$$D\_G(t) = \min\left\{\left[\frac{(SOC(t-1) - SOC\_MIN)}{\Delta t} - SELF\_D1 \cdot SOC(t-1) - SELF\_D2\right] ECAP, PCAP\_D, D_t^{SP}\right\}$$

Smart Inverter

Compared to energy storage, the modeling of PV solar inverter is simpler because it only depends on the nameplate rating and the available DC / irradiance. The device is modelled to behave as an ideal inverter where the DC in power from the panels is converted to AC power without any losses and that the panels are appropriately sized for the inverter (i.e. 100% DC in = 100% of nameplate watts).The device acts in VAR priority mode such that the active power is curtailed to provide the requested reactive power. The apparent power of the inverter is calculated as follows,

$$\boldsymbol{S = sqrt(P^2 + Q^2)}$$

4

DER SIMULATOR SETUP

Setup File

The setup files are used to import the devices into the simulator. The setup file defines the characteristics of each device including nameplate ratings, network settings for ADMS & DSS interfaces, and other device settings. The format of the setup file is CSV. There are two separate files, one for solar inverter and the other for energy storage. The setup files should be placed in the same folder as the executable. Incorrect format or data type in the file can throw errors while launching the application.

PV Setup File Parameters

Table 4-1
PV Setup File Parameters

Parameter	Units	Description
MRID	None	Unique Master Resource Identifier
Name	None	Name of the inverter
IP Address	IPv4	Endpoint of the network adapter for the DNP3 interface
Port	None	Port at which the DNP3 Outstation will listen on
Master DNP3 Address	None	DNP3 Address of the master station
Local DNP3 Address	None	DNP3 Address of the outstation
P – Identifier	None	Variable name for the active power published to DBus server
Q – Identifier	None	Variable name for the reactive power published to DBus server
Va – Identifier	None	Variable name of the Phase A voltage to subscribe from DBus server
Vb – Identifier	None	Variable name of the Phase B voltage to subscribe from DBus server
Vc – Identifier	None	Variable name of the Phase C voltage to subscribe from DBus server
F – Identifier	None	Variable name of the Frequency to subscribe from DBus server
Inverter Rating	Watts	Nameplate rating of the inverter
Nominal Voltage	Volts	Nominal Voltage of the inverter
Phase Type	Enumeration	Type of circuit phase. Simulator supports single and three phase models
Circuit Phase	Enumeration	Phase at which the inverter is connected to

Energy Storage Setup File Parameters

Table 4-2
PV Setup File Parameters

Parameter	Units	Description
MRID	None	Unique Master Resource Identifier
Name	None	Name of the inverter
IP Address	IPv4	Endpoint of the network adapter for the DNP3 interface
Port	None	Port at which the DNP3 Outstation will listen on
Master DNP3 Address	None	DNP3 Address of the master station
Local DNP3 Address	None	DNP3 Address of the outstation
P – Identifier	None	Variable name for the active power published to DBus server
Q – Identifier	None	Variable name for the reactive power published to DBus server
Va - Identifier	None	Variable name of the Phase A voltage to subscribe from DBus server
Vb - Identifier	None	Variable name of the Phase B voltage to subscribe from DBus server
Vc - Identifier	None	Variable name of the Phase C voltage to subscribe from DBus server
f - Identifier	None	Variable name of the frequency to subscribe from DBus server
Total Energy	Watts hour	Total energy capacity of the battery system
Usable Energy	Watts hour	Usable energy capacity of the battery system
Real Power Max Discharging	Watts	Maximum available real power when the battery is discharging
Real Power Max Charging	Watts	Maximum available real power when the battery is charging
Roundtrip Efficiency	Percentage	Roundtrip efficiency of the system
Min SOC	Percentage	Minimum usable state of charge as percentage of maximum usable energy
Max SOC	Percentage	Maximum usable state of charge as percentage of maximum usable energy
Initial SOC	Percentage	Initial state of charge of the battery as a percentage of maximum usable energy
Self-Discharge ***SOC-dependent***	$hour^{-1}$	SOC dependent Self-Discharge rate of the battery
Self-Discharge - ***constant***	Percent/hr	Constant Self-Discharge rate of the battery
Reactive Power Rating	VARs	Reactive power rating of the inverter
Nominal Voltage	Volts	Nominal Voltage of the inverter
Phase Type	Enumeration	Type of circuit phase. Single or three phase
Circuit Phase	Enumeration	Phase at which the inverter is connected to

5

DER SIMULATION WINDOW

DERMS Communication

Clicking on DERMS button from the settings menu will launch the connection to the headend control system (e.g DERMS). This creates the DNP3 channels and outstations for each of the devices emulated in the simulator and listens for requests from DNP3 master stations in the headend system

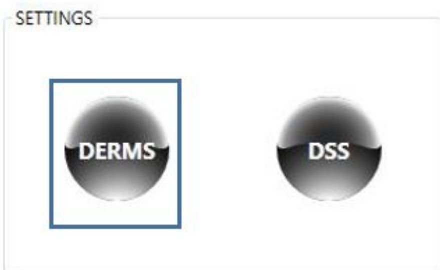


Figure 5-1
DERMS – Settings Menu

TLS Settings

TLS Settings can be enabled for the DNP3 channels by right clicking on the DERMS button and selecting "TLS Settings" from the context menu. It will launch the dialog box shown below where the user can upload certificates and keys for secure communication. Checkbox "Enable TLS" must be checked to enable TLS for the outstation. TLS settings must be enabled before clicking on ADMS button to launch secure channels. Clicking on the DERMS button without enabling the TLS will create regular TCP channels.

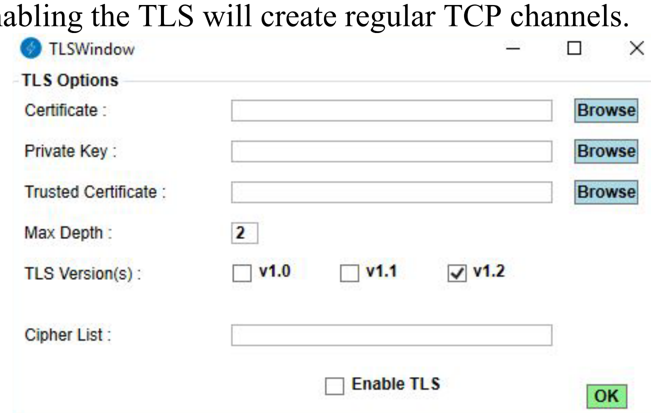


Figure 5-2
TLS Settings Dialog Box

TLS Options

Certificate – File that contains the certificate (or certificate chain) that will be presented to the remote side of the connection.

Private Key – File that contains the private key corresponding to the local certificate.

Trusted Certificate – Certificate file used to verify the peer or server. Can be CA file or a self-signed cert provided by other party.

Max Depth – Sets the maximum depth for the certificate chain verification.

Cipher List – Sets the algorithm for the cipher suite that is used to encrypt the messages to be exchanged.

DSS Communication

DSS Communication allows the DER simulator to interface with other components in a co-simulation framework via DBus server for studying and evaluating the impact of a control system such as DERMS on a circuit. The devices modelled in the DER simulator replaces the behavior of the DER devices modelled in the circuit simulation. During simulation the devices receive the grid conditions – typically the nodal voltage and frequency values – from the circuit simulator and the output of the devices – typically the active and reactive power values – are fed back into the nodes where the devices are connected in the circuit.

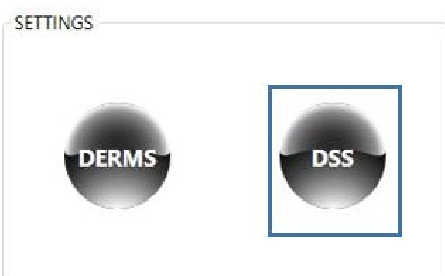


Figure 5-3
DSS – Settings Menu

Clicking on DSS button, Figure 5-3, will launch the DBus settings dialog box shown in Figure 5-4.

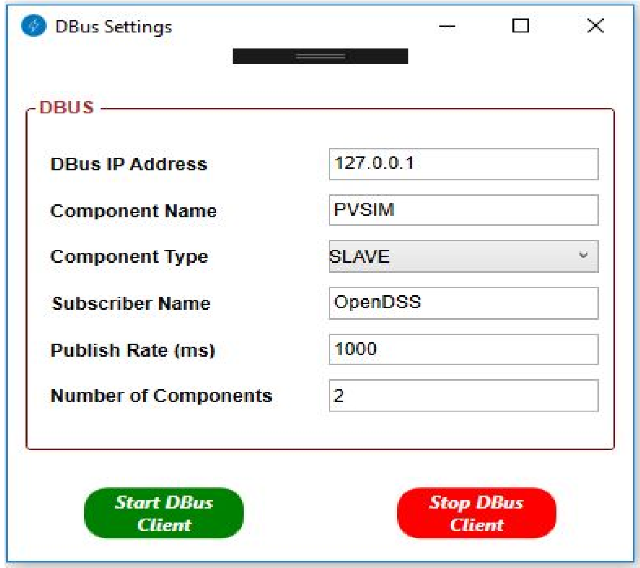


Figure 5-4
DBus Settings Dialog Box

DBus Settings

DBus IP Address – This field allows the user to enter the IP address for the TCP connection in the DBus interface to DSS. The default IP address is localhost, i.e 127.0.0.1

Component Name – This field allows the user to enter the component name for the selected component to register with the DBus. This name will be used by other components in the co-simulation framework connected to DBus server to identify the solar smart inverter and energy storage components. The default component names are PV-SIM and ES-SIM for solar and energy storage respectively.

Component Type – DBus server allows components to register as a master, slave, multiple master or a supervisor. DBus server expects at least one of the connected components in the co-simulation framework to act as a master component. The master component is required to control the progress of the simulation and to enable the execution of slave components. The master component regularly checks the synchronism flags in DBus for making decisions on the next steps of the simulation. This field allows the user to select the role of the selected component in the co-simulation framework. Following are the available options

1) **Master** - The component is a Master component and is unique (no other components can register as Master).
2) **Slave** - The component is a slave component.
3) **Multiple Master** – The component is a Master but allows other components to register as Master as well.
4) **Supervisor** - The component is a supervisor, this is used for monitoring and controlling DBus from a resident GUI.

Currently, DER Simulator has support only to act as a master or slave component in the co-simulation framework.

Subscriber Component Name – This field allows the user to enter the component name of the circuit simulator to which the components will subscribe for the measurement values and power simulation status. The default value is OpenDSS.

Publish Rate – This field allows the user to set the time step for the simulation. This option is enabled only when the selected component type is Master. The default value is 1000 milliseconds.

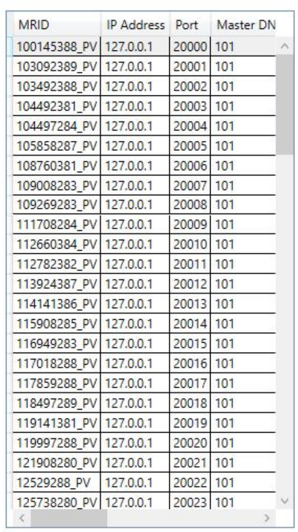
Number of Components – This field allows the user to set the number of components that will be registered in the co-simulation. This information is required by the component to set the appropriate flag registers in the DBus to drive the simulation. This option is enabled only when the component type is Master. The default value is 2.

Start DBus Client – Clicking on “Start DBus client” will make the connection to DBus server. Starting the DBus client will register the component and its variables. It will also continuously poll for the subscriber until the subscriber component is found in DBus server and once the subscriber is discovered, the component will subscribe to its variables.

Stop DBus Client – Clicking on “Stop DBus Client” disconnects the connection to DBus server

Device Directory

DER Simulator is capable of emulating multiple devices. The device directory lists all the devices emulated in the simulator in a table structure and lets users navigate between the devices. The simulation pane on the right side shows the simulation data of the device selected in the directory. The device directory also lists the basic characteristics of the device in the table such as MRID, DNP3 network data, nameplate ratings, etc. The devices that are connected to the control system (e.g DERMS) are highlighted in green. By default, the first device in the directory is selected in the list.



MRID	IP Address	Port	Master DN
100145388_PV	127.0.0.1	20000	101
103092389_PV	127.0.0.1	20001	101
103492388_PV	127.0.0.1	20002	101
104492381_PV	127.0.0.1	20003	101
104497284_PV	127.0.0.1	20004	101
105858287_PV	127.0.0.1	20005	101
108760381_PV	127.0.0.1	20006	101
109008283_PV	127.0.0.1	20007	101
109269283_PV	127.0.0.1	20008	101
111708284_PV	127.0.0.1	20009	101
112660384_PV	127.0.0.1	20010	101
112782382_PV	127.0.0.1	20011	101
113924387_PV	127.0.0.1	20012	101
114141386_PV	127.0.0.1	20013	101
115908285_PV	127.0.0.1	20014	101
116949283_PV	127.0.0.1	20015	101
117018288_PV	127.0.0.1	20016	101
117859288_PV	127.0.0.1	20017	101
118497289_PV	127.0.0.1	20018	101
119141381_PV	127.0.0.1	20019	101
119997288_PV	127.0.0.1	20020	101
121908280_PV	127.0.0.1	20021	101
12529288_PV	127.0.0.1	20022	101
125738280_PV	127.0.0.1	20023	101

Figure 5-5
Device Directory

Simulation Pane

This section describes the GUI elements that are common in both solar and energy storage simulation panes.

Environment Sliders

The environment sliders on the left section of the simulation window allows users to adjust frequency, irradiance (solar-only), and grid voltage of the device. The environment sliders will be disabled by default when emulating multiple devices and will be enabled when the simulator emulates only one device. Additionally, the sliders are disabled during the simulation when the simulator is running in File mode or Circuit mode. The environment sliders are shown in Figure 5-6.

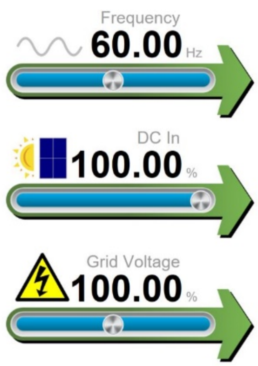


Figure 5-6
Environment Sliders in Solar Inverter Simulator

Frequency Slider

This slider can be used to adjust the grid frequency to the inverter. The range of the slider is 59.70 Hz to 60.30 Hz with a resolution of 0.01 Hz. The slider is set at 60.00 Hz by default at the initial startup of the application.

Irradiance Slider (Solar-only)

This slider is available only in the solar inverter component. This slider can be used to adjust the percentage of input power to the inverter. The simulator assumes panels are well matched to the inverter so 100% irradiance will allow the inverter to produce 100% output power. The range of the slider is 0 to 100% with a resolution of 0.01%. The slider is set at 100% by default at the initial startup of the application.

Grid Voltage Slider

This slider can be used to adjust the percentage of the grid voltage to the inverter as compared to the nominal voltage. The range of the slider is 85 to 115% with a resolution of 0.01%. The grid voltage is expressed in percentage of nominal voltage that is set in the settings window initially. The slider is set at 100% by default at the initial startup of the application.

Modes of Operation

There are three modes of operation to help the user simulate multiple scenarios; live mode and File Mode, and Circuit mode. The following section provides details for applying each mode.

Live Mode – Users manually adjust the environment slides to control the simulation. See the Environment Sliders section for the descriptions of each slider.

File Mode – File Mode allows users to replay field data or pre-configured test files. This mode makes repeatable tests simple.

Circuit Mode – In circuit simulation mode, the simulator is driven by the measurement values from the circuit simulator.

Functions Header Tab

The functions header tab is in the top-center of the simulation window. It allows users to identify which smart functions are enabled. Clicking on them bring up a function-specific diagram or graph showing the function's behavior. The active functions are highlighted by a yellow LED indicator in the header. The function header tab is shown in Figure 5-7.

Figure 5-7
Functions Header Tab

Functions Display Frame

The function display frame shows graphs/graphics of the selected inverter function. If the function is not enabled by the headend (e.g. DERMS), the selected function frame shows a message indicating the function is not active. Figure 5-7 shows the inactive frame of Volt-VAR function on the left and an active Volt-VAR frame on the right.

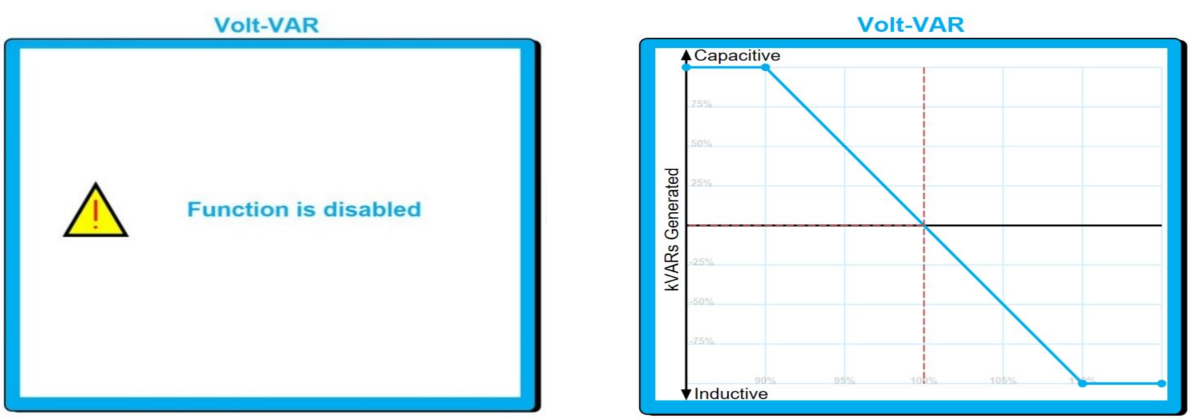


Figure 5-7
Function Frame, Disabled on Left and Enabled on Right

Device Output Power

The active power, reactive power, and the apparent power from the devices are displayed on the right section of the simulation window. The output powers are re-calculated during each time step of the simulation. The simulation time step is set to 1-second by default. Figure 5-8 shows an example of the output powers in the simulator.

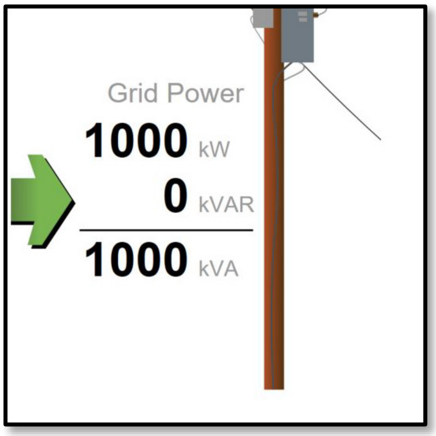


Figure 5-8
Device Output Power in the Solar Inverter Simulator

DERMS and DSS Connection

The simulator provides users with an indicator for whether the connection to the DERMS (or other control system) and DBus server are active.

Figure 5-9
DERMS and DSS Connection Arrow

The broken red arrow indicates that a connection has not been established. The blue arrow indicates the TCP connection has been established and can be managed by the DERMS or be driven by the DSS respectively. Figure 5-9 shows an inactive TCP connection to DERMS (left) and an active TCP connection to DBus server (right).

Solar Simulation Pane

This section describes the GUI elements that are specific to solar smart inverter simulation pane

Tripped and Ramping Indicators

The LED indicators in the bottom left section of the simulation pane are used to indicate the state of the device when it is tripped or ramping.

Tripped State

The device will trip when the device is generating less than 5% of its nameplate rating. This is illustrated by a stable red light in the TRIPPED LED indicator.

Ramping State

When the device is restoring from the tripped state, the device will restore the active power with a ramp rate within an adjustable range between 0 and 1000s with a default time of 300 s. There is a delay of 15 seconds before the device starts ramping to ensure continuous DC supply that is sufficient to generate more than 5% of the nameplate capacity. This transition or delay is illustrated by the flashing red light in the TRIPPED LED indicator. Once the device starts ramping, the RAMPING LED indicator starts flashing in green to indicate the ramping status. The number below the RAMPING LED indicator indicates the active power limit in terms of percentage when the device is ramping.

Figure 5-10
Tripped and Ramping LED indicators

Environment Simulation

The Environment simulation settings are shown in Figure 5-11. Environment simulation allows users to drive the environment variables of the devices from a CSV file. It can also be used to import a solar irradiance profile for the inverters in circuit mode. During environment simulation, the environment sliders will be disabled and re-enabled automatically after the simulation has stopped. The simulation by default runs at real time as determined by the Time Stamp value in the file. So, if the file has one second intervals then the simulator will update the sliders each second. If the file has one minute intervals the simulator will update the sliders every sixty seconds.

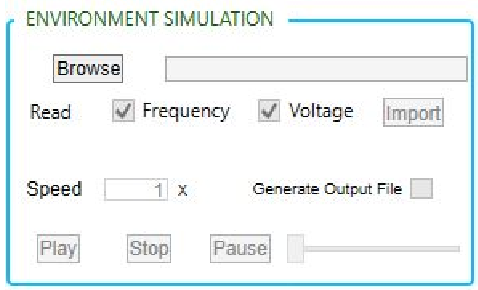


Figure 5-11
Environment Simulation Settings

The simulator has options to select the variables that the user would like to import. The user can uncheck the Frequency and Voltage checkboxes to ignore importing frequency and voltage profiles respectively. The irradiance profile will be imported regardless of these settings.

The simulator also has speed control to accelerate playback of the file. The user can accelerate the simulation speed by modifying the value in the textbox to the right of the "speed" label. For example, if the user enters a value of 10 as the speed factor, the simulation occurs 10x faster than the time stamp frequency.

In addition to speed controls the user also has the option to play, pause, resume, completely stop the simulation, or even seek a specific place in the playback file. The file navigation slider to the right of "stop" button allows user to navigate through the file. The far left is the beginning of the simulator and the far right is the end of simulation.

File Format

		1	1	1	1	2	2	2	2	3	3	3	3
TimeUTC	Frequency (Hz)	DC In (W/m^2)	Phase A Voltage (V)	Phase B Voltage (V)	Phase C Voltage (V)	DC In (W/m^	Phase A Vc	Phase B V	Phase C V	DC In (W/	Phase A V	Phase B V	Phase C V
7/1/2016 4:00	60.007	2	478.1967532	478.8594249	478.5961415	1.69826374	484.37499	486.4477	483.7119	2.054294	475.9291	477.6252	474.7593
7/1/2016 4:00	60.005	2	478.2090909	478.7865815	478.4437299	1.69826374	484.33011	486.5185	483.6962	2.054294	475.8637	477.6647	474.6849
7/1/2016 4:00	60.002	2	478.2	478.8996805	478.4186495	1.69826374	484.29183	486.5056	483.7204	2.054294	475.8591	477.7514	474.6284
7/1/2016 4:00	60.002	2	478.137013	478.8984026	478.4681672	1.69826374	484.208	486.627	483.727	2.054294	475.8967	477.6513	474.5886
7/1/2016 4:00	60	2	477.9538961	478.9463259	478.4784566	1.69826374	484.2014	486.4932	483.5969	2.054294	475.8928	477.6526	474.647
7/1/2016 4:00	60	2	478.1487013	478.9801917	478.5427653	1.69826374	484.21262	486.5627	483.6714	2.054294	475.7989	477.5174	474.5072
7/1/2016 4:00	60.001	2	478.0551948	478.9853035	478.4392283	1.69826374	484.24893	486.5984	483.6976	2.054294	475.8332	477.6481	474.6079
7/1/2016 4:00	60.002	2	478.1461039	479.0523962	478.4327974	1.69826374	484.28061	486.5874	483.6727	2.054294	475.7412	477.4193	474.6124
7/1/2016 4:00	60.001	2	478.0974026	478.9916933	478.5254019	1.69826374	484.27467	486.4081	483.7074	2.054294	475.7302	477.6411	474.5405
7/1/2016 4:00	60.002	2	478.1149351	478.9776358	478.5209003	1.69826374	484.25751	486.4101	483.727	2.054294	475.7555	477.5786	474.5816
7/1/2016 4:00	60.004	2	478.1064935	479.0370607	478.6598071	1.69826374	484.27863	486.3399	483.7361	2.054294	475.8203	477.6685	474.5347
7/1/2016 4:00	60.005	2	478.1922078	478.9182109	478.6128617	1.69826374	484.2212	486.5627	483.6871	2.054294	475.7205	477.636	474.7028
7/1/2016 4:00	60.005	2	478.224026	478.9271565	478.5884244	1.69826374	484.11428	486.6075	483.7067	2.054294	475.7568	477.6851	474.7221
7/1/2016 4:00	60.007	2	478.237013	478.9495208	478.6237942	1.69826374	484.24695	486.4809	483.7113	2.054294	475.749	477.5627	474.4366
7/1/2016 4:00	60.006	2	478.1558442	479.0779553	478.4700965	1.69826374	484.25091	486.462	483.6956	2.054294	475.8591	477.4155	474.7554
7/1/2016 4:00	60.006	2	478.2285714	478.9405751	478.7723473	1.69826374	484.29579	486.4497	483.7139	2.054294	475.7425	477.5926	474.638
7/1/2016 4:00	60.006	2	478.2948052	478.9271565	478.7768489	1.69826374	484.31031	486.4984	483.6995	2.054294	475.6318	477.4403	474.4815
7/1/2016 4:00	60.007	2	478.3298701	479.0607029	478.6790997	1.69826374	484.26345	486.4731	483.6217	2.054294	475.7231	477.5589	474.6072
7/1/2016 4:00	60.007	2	478.3233766	479.0734824	478.6758842	1.69826374	484.2113	486.4419	483.6649	2.054294	475.7076	477.6322	474.6425
7/1/2016 4:00	60.007	2	478.324026	479.0306709	478.7131833	1.69826374	484.30437	486.4211	483.6786	2.054294	475.7879	477.6099	474.5258
7/1/2016 4:00	60.007	2	478.3798701	478.9738019	478.5942122	1.69826374	484.25223	486.5101	483.7682	2.054294	475.7536	477.5665	474.4783
7/1/2016 4:00	60.007	2	478.4194805	479.028754	478.3266881	1.69826374	484.04168	486.3919	483.5132	2.054294	475.8352	477.5021	474.4526
7/1/2016 4:00	60.007	2	478.3272727	478.9961661	478.6250804	1.69826374	484.142	486.4887	483.5962	2.054294	475.8837	477.5735	474.5027

Figure 5-12
Environment Simulation File Format

In File Mode operation users can import an appropriate file and can drive the environment variables from the data written in the file. File Mode operation requires a .CSV type file. The file should have Time stamp and frequency (Hz) in hertz in the first two columns that will remain common for all the devices emulated in the simulator. It is then followed by the following four columns repeated for the number of devices emulated in the simulator: DC input (watts/m^2 or percent of maximum, it is normalized by the simulator), Phase A grid voltage (V), Phase B grid voltage (V) and Phase C grid voltage (V). Figure 5-12 shows an example CSV file format with simulation data of 1-second intervals for three devices. The DC in and the grid voltage values will be converted to equivalent percentage by the simulator. Importing a file with incorrect file format or type will throw an error message to the user.

Energy Storage Simulation Pane

This section describes the GUI elements that are specific to energy storage simulation pane

State of Charge (SOC)

The State of Charge (SOC) for each device will be displayed on the right side of the simulation pane on top of the outputs power. The battery level will indicate the SOC of the selected device. The SOC is represented as both percentage and also in terms of energy. The battery will flash in red when the system is not able to meet the desired power target.

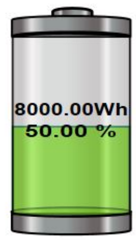


Figure 5-13
State of Charge Indicator

6
ONGOING DEVELOPMENT

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.

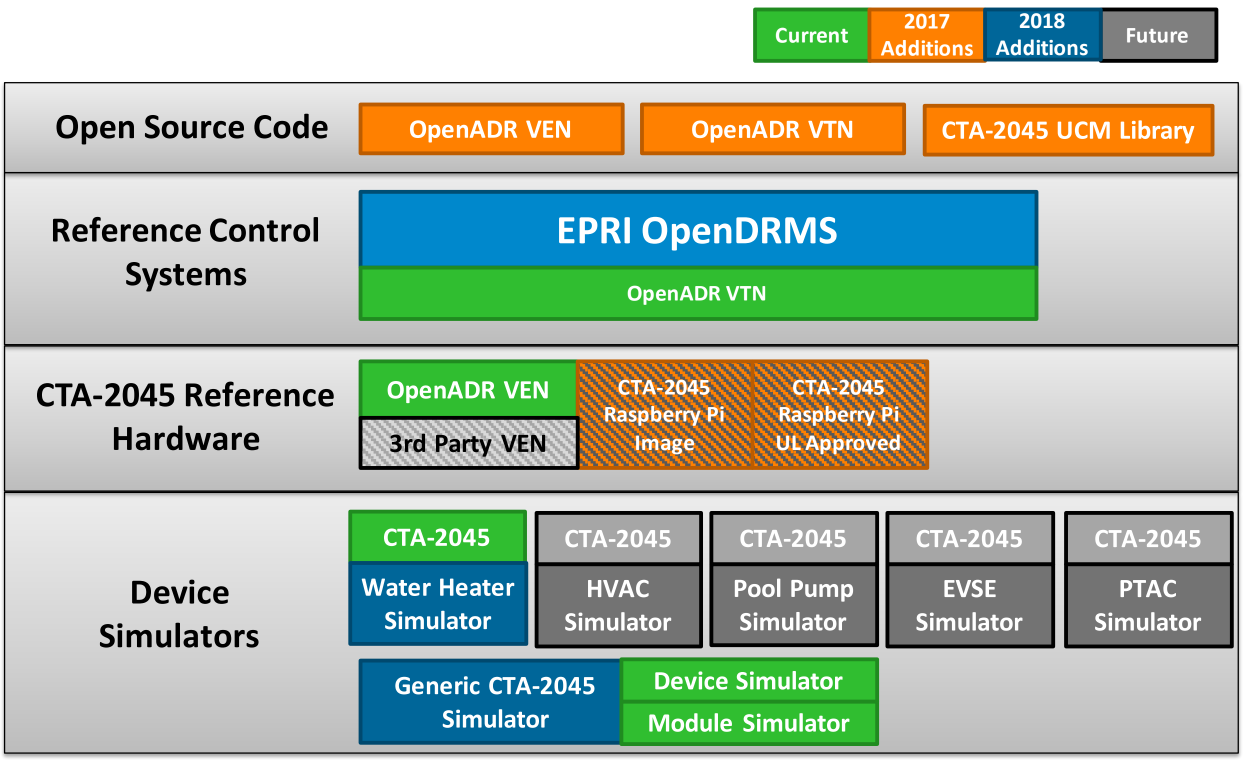


Figure 6-1
Upcoming tools for demand response technologies.

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.

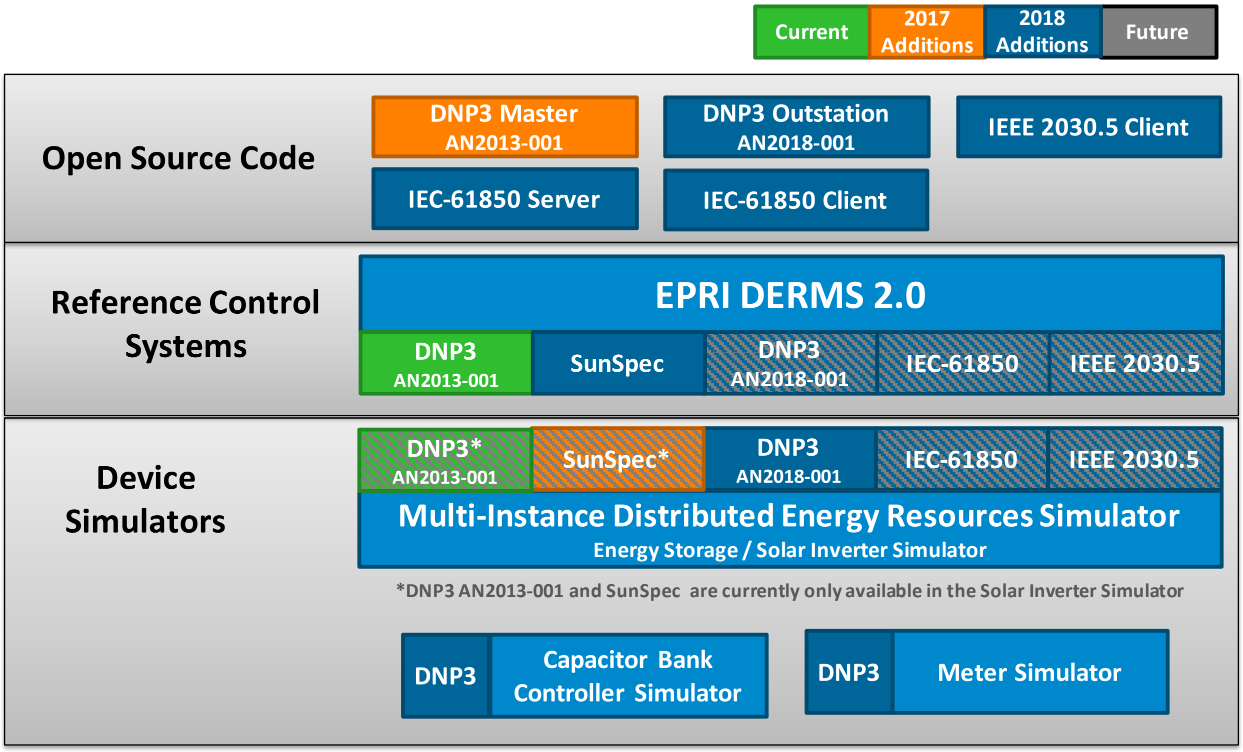


Figure 6-2
Upcoming tools for inverter-based technologies.

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. More information on other tools in EPRI's DER Integration Toolkit can be found in the toolkit summary report[1].

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