ELECTRIC POWER RESEARCH INSTITUTE

Overview of EPRI's Simulation Tool for Emulating Smart Water Heaters on Communication Networks

An Introduction to EPRI's Smart Water Heater Simulator

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An Introduction to EPRI’s Smart Water Heater Simulator

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EPRI Project Manager

B. Ealey

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Principal Investigators
B. Ealey
A. Desai

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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 Water Heater Simulator to validate protocol implementations in both control modules and control systems and serve as a research tool for deeper evaluation of their performance. 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 Smart Water Heater Simulator emulates a smart water heater with communications capabilities. The simulator has two-way communications and supports functionality including variable degrees 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.

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

Keywords
Device Simulator
CTA-2045
Water Heater
Demand Response
DRAS

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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 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.

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 PNNL and NREL and utilities including SMUD, HydroOne, 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" where any component of the communication architecture can be simulated or implemented using components of the EPRI DER Integration Toolkit[1].

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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: 2017. 3002009853.

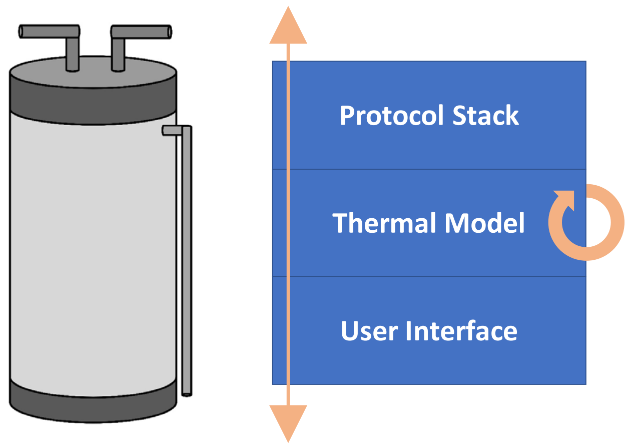


Figure 1-1
Functional Architecture of Smart Water Heater Simulator

The smart water heater 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 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 Smart Water Heater Simulator emulates a smart water heater with communications capabilities. The simulator has two-way communications and supports functionality including variable degrees 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.

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

2

WATER HEATER PARAMETERS

Upon initial startup of the Smart Water Heater Simulator, two windows are presented. One window is used to modify water heater parameter values that will be used for the specific simulation throughout until changed. Both are shown in Figure 2-1. The other window is the main window where the simulation will take place. The user will not be allowed to access the main window without setting and applying water heater parameters on the first pop up window.

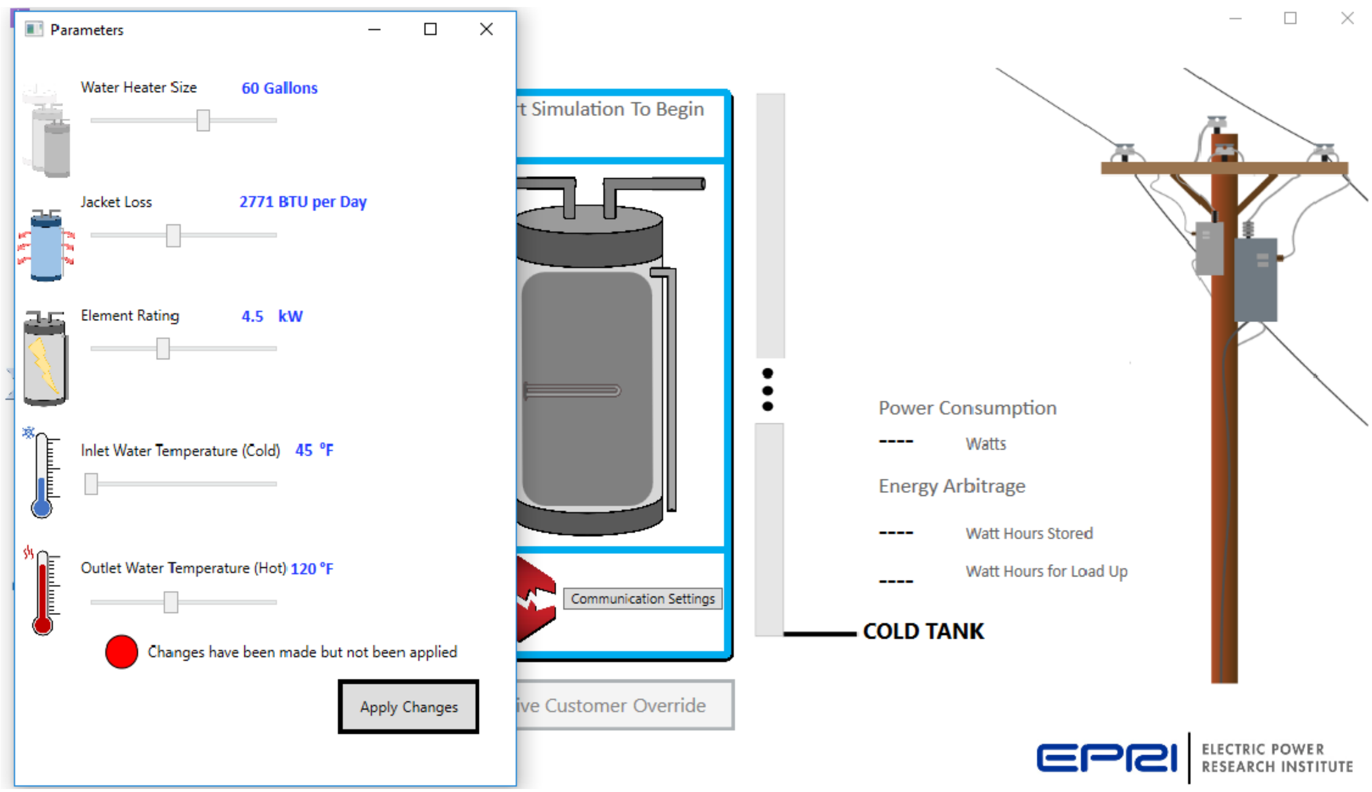


Figure 2-1
Water Heater Parameters

Setting Water Heater Parameters

- **Water Heater Size**

  To adjust the size of the water heater, drag the top most slider on the parameters window. The slider will increase/decrease in increments of 5 ranging from 30 to 80 gallons.

- **Jacket Loss**

  Jacket Loss is used to represent the amount of energy that will be lost from the tank throughout the day from typical heat transfer from the inside of the tank to the surrounding environment. To adjust the jacket loss amount, drag the second slider on the parameters window. The slider will increase/decrease in increments of 1 ranging from 1000 BTU per day to 5000 BTU per day. 2771 BTU per day is used as a default per modeling data from Lawrence Berkley National Laboratory[2].

- **Element Rating**

  The Element Rating is the kW rating on water heater. This rating determines the operating wattage of the water heater. To adjust the element rating, drag the third slider on the parameters window. The slider will increase/decrease in increments of 0.5 ranging from 1 kW to 10 kW.

- **Inlet Water Temperature**

  The inlet water temperature is the temperature of the water flowing into the water heater. To adjust the inlet water temperature, drag the fourth slider on the parameters window. The slider will increase/decrease in increments of 1 ranging from 45 °F to 60 °F.

- **Outlet Water Temperature**

  The outlet water temperature is the temperature of the water that will be flowing out of the water heater into the home. To adjust the outlet water temperature, drag the last slider on the parameters window. The slider will increase/decrease in increments of 1 ranging from 90 °F to 160 °F.

Applying Water Heater Parameters

The red circle at the bottom indicates that changes have been made, but have not been saved. Once you have adjusted your parameters, click the "Apply Changes" button and the circle will turn green indicating all parameters have been saved. If you adjust a slider position after applying changes, then the circle will turn red again.

[2] Biermayer, Peter; Lutz, Jim; *Gas Water Heater Energy Losses*. Lawrence Berkeley National Laboratory. January 2009. Accessed 6/12/2017. https://eta.lbl.gov/sites/all/files/publications/gas_water_heater_energy_losses_4826e.pdf

3
COMMUNICATION SETTINGS

A main feature of most smart appliances is to be able to remotely control them. The communication settings allow this simulator to be connected to a UCM module using the SGD module as an interface. This way, the operator of the UCM can send event commands to the water heater, query operating states, and record other numerical data. The user must have a set of test cables to connect to the computer running the simulator and either a control module or a control module simulator.

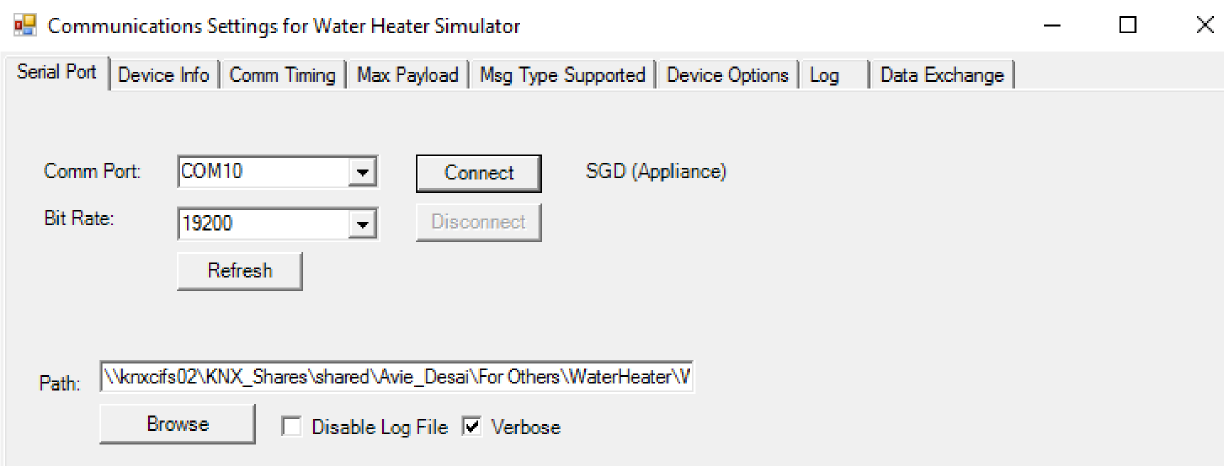


Figure 3-1
Communication Settings Window

To connect the Water Heater Simulator to the UCM, first open the communication window by clicking the "Communication Settings" button underneath the Water Heater. You should then see a new window with eight tabs (Figure 3-1).

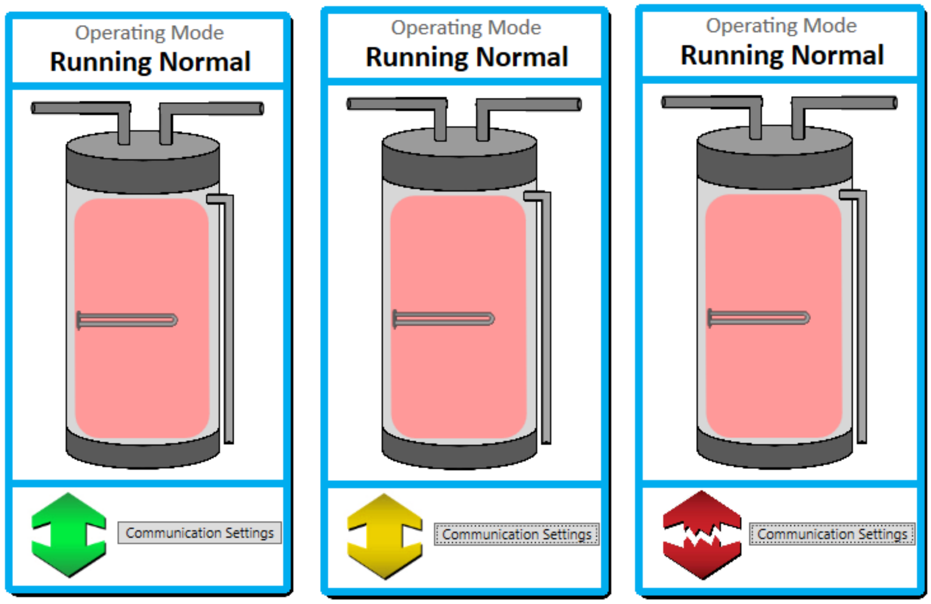
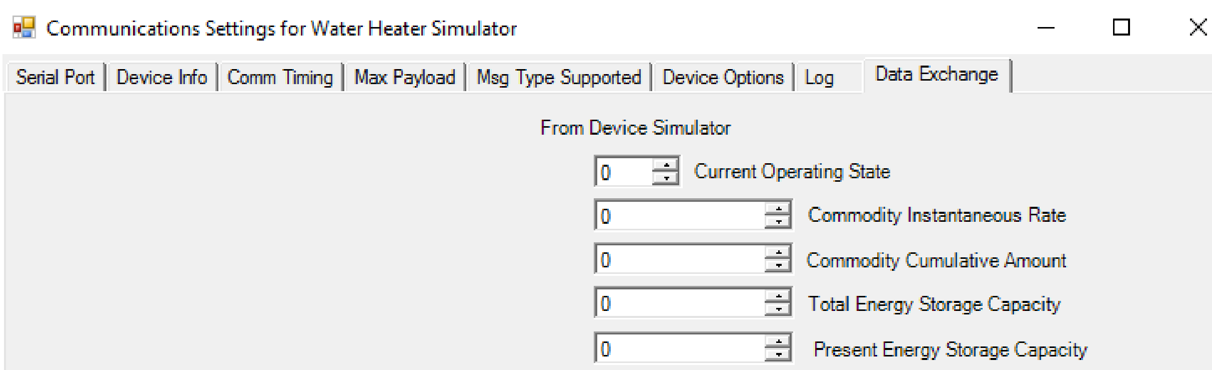


Figure 3-2
Communication Settings on Main Window (Good, Poor, and Lost Connection)

Select the appropriate comm port and bit rate you will be using and then click Connect. Once the UCM connects to the appropriate port and sends the good connection status, you will see the broken red arrow turn green. If the UCM sends a poor/unreliable connection status, then the arrow will change to yellow. And lastly, if the UCM sends a lost connection status, then the arrow will change to a broken red arrow.



On the other tabs users can adjust additional, advanced communications parameters. It also provides a view into the data exchanged between the simulator and control model. For example, on the last tab of the communication settings window, you can view the different commodity values from the simulator in real time.

4
SIMULATION WINDOW

The simulation window (Figure 4-1) is the main screen and where the simulator will show device behavior and allow the user to input simulation parameters. There are many controls on this window that will be in action throughout playback modes.

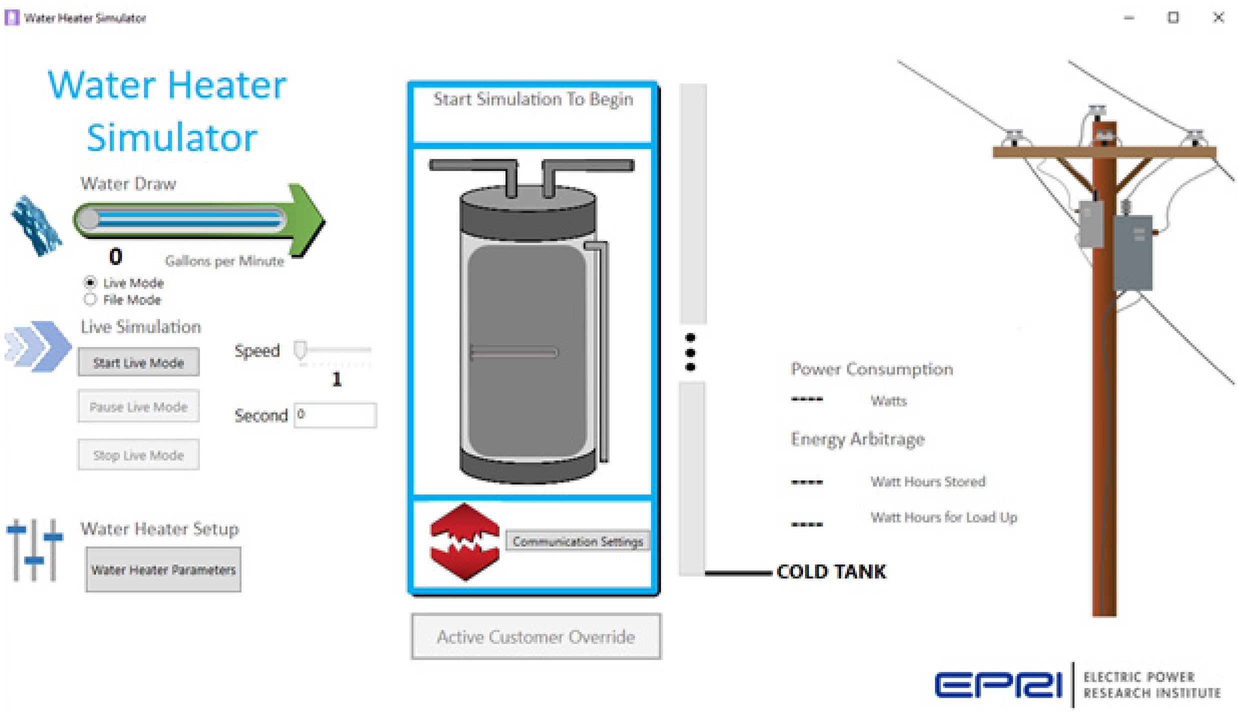


Figure 4-1
Main Window

Water Draw Selector

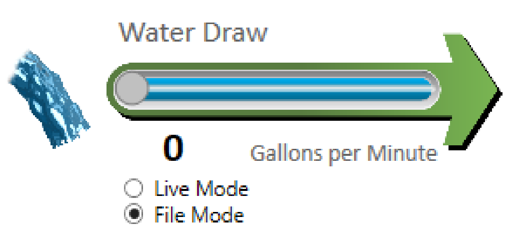


Figure 4-2
Water Draw Selector

The Water Draw Selector will allow you to choose a constant flow of water for the simulator in live mode playback or will display the water draw at the time during file mode playback. The slider is set to be disabled on default.

Electrical Measurements

The labels on the right will constantly be changing as the simulation is active to give the user some numerical output on the status of the simulation. The power consumption label will display the present output power for the water heater. Under Energy Arbitrage, the current energy content of the water heater (Watt Hours Stored) and the energy until full (Watt Hours for Load Up) are displayed. These two numbers should always total to the Empty Tank Reference, which is the point where the entire is tank is cold.

Energy Storage Indicator

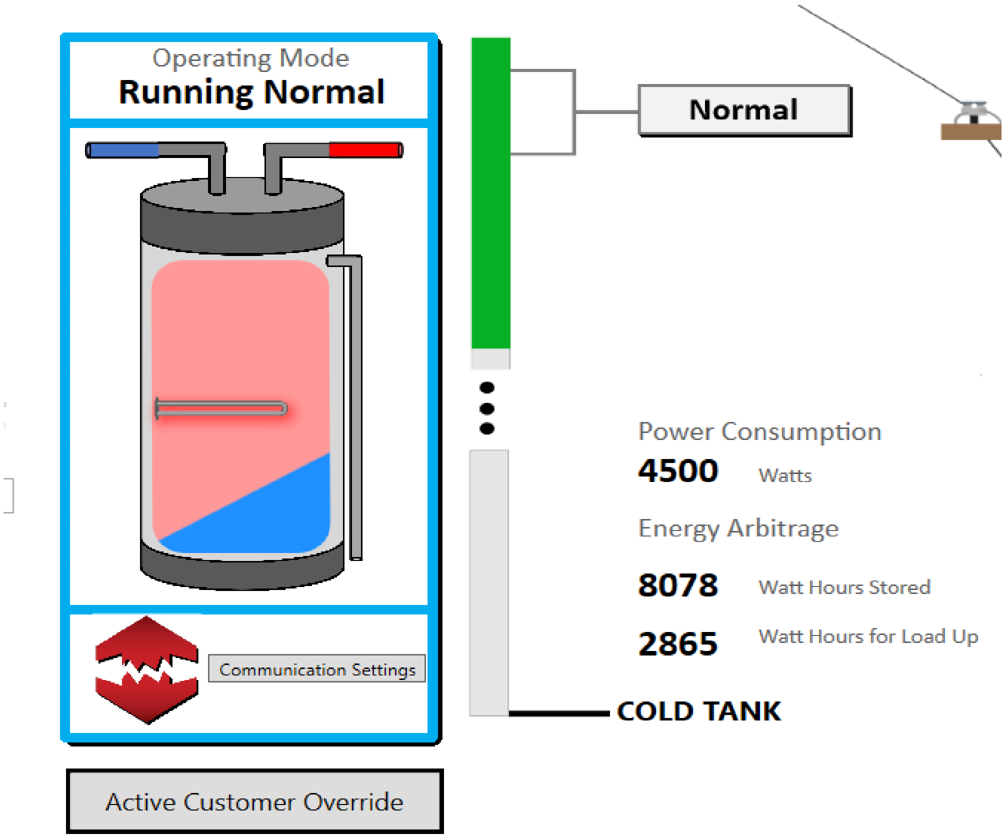


Figure 4-3
Energy Storage Indicator

The Energy Storage Indicator represents the amount of heat energy that has either been delivered or lost through the jacket. As the energy in the tank drops the green bar extends from the top. Once the entire tank is cold, the green bar will reach the bottom. The range is large so the top and bottom portion of the indicator have different scales. The three dots indicate this jump.

On the left of the bar the current operating mode is shown. The attached bracket shows the upper and lower limits of the operating mode. If the energy content hits the bottom of the bracket the water heater will turn on. Once the energy content hits the top bracket it will turn off again. The bracket will update as operating modes change. There is no bracket for grid emergency because the water heater will stay off regardless of energy content.

File Mode and Live Mode

There are two main modes of playback, live mode and file mode. Live mode requires the user to manually operate the sliders to change operation. File mode uses a csv to automate slider operation.

The user selects which mode they would like to use based on the radio buttons. The radio buttons are mutually exclusive meaning that both cannot be selected at the same time. The controls for each mode are different so when the radio button is changed the respective modes will be displayed.

File Mode

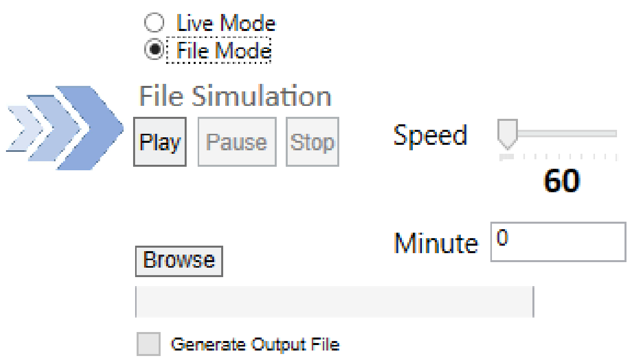


Figure 4-4
File Mode Settings

In File Mode, the simulator will automate the sliders based on the data in the file.

The user has the option to play, pause, or completely stop the simulation.

Users select the file by clicking on the "Browse" button. There are requirements for the input file. Not following the requirements will cause the simulator to error. The requirements for the file is a CSV type file with two columns containing the Time Stamp and Water Draw in gallons.

In file mode, the user can select to create a log file of the simulation including communications received and water heater behavior. By checking the "Generate Output File" checkbox, the simulator will generate an output file with information about the simulation including operating modes, cold water delivered in gallons, power consumption etc. An example of the output file is show below in Figure 4-5.

Time Stamp	Water Heater Power (W)	Flow Rate (Gal/Min)	Element Energy In (BTU)	Water Energy In (BTU)	Water Energy Out (BTU)	Watt-Hours for Load-Up	Watt-Hours Stored	Operating Mode	Event Type	Cold Water Delivered (Gallons)
12:01 AM	0	1	0	374.85	999.6	183.6155715	10759.93443	Running Normal	Normal	0
12:02 AM	0	1	0	374.85	999.6	367.2311431	10576.31886	Running Normal	Normal	0
12:03 AM	0	1	0	374.85	999.6	550.8467146	10392.70329	Running Normal	Normal	0
12:04 AM	0	1	0	374.85	999.6	734.4622861	10209.08771	Running Normal	Normal	0
12:05 AM	0	1	0	374.85	999.6	918.0778576	10025.47214	Running Normal	Normal	0
12:06 AM	4500	1	0	374.85	999.6	1101.693429	9841.856571	Running Normal	Normal	0
12:07 AM	4500	1	255.9105	374.85	999.6	1210.327224	9733.222776	Running Normal	Normal	0
12:08 AM	4500	1	255.9105	374.85	999.6	1318.961019	9624.588981	Running Normal	Normal	0
12:09 AM	4500	1	255.9105	374.85	999.6	1427.594814	9515.955186	Running Normal	Normal	0
12:10 AM	4500	1	255.9105	374.85	999.6	1536.228609	9407.321391	Running Normal	Normal	0
12:11 AM	4500	1	255.9105	374.85	999.6	1644.862404	9298.687596	Running Normal	Normal	0
12:12 AM	4500	1	255.9105	374.85	999.6	1753.496199	9190.053801	Running Normal	Normal	0
12:13 AM	4500	1	255.9105	374.85	999.6	1862.129994	9081.420006	Running Normal	Normal	0
12:14 AM	4500	1	255.9105	374.85	999.6	1970.763789	8972.786211	Running Normal	Normal	0
12:15 AM	4500	1	255.9105	374.85	999.6	2079.397584	8864.152416	Running Normal	Normal	0
12:16 AM	4500	1	255.9105	374.85	999.6	2188.031379	8755.518621	Running Normal	Normal	0
12:17 AM	4500	1	255.9105	374.85	999.6	2296.665174	8646.884826	Running Normal	Normal	0
12:18 AM	4500	1	255.9105	374.85	999.6	2405.298969	8538.251031	Running Normal	Normal	0
12:19 AM	4500	1	255.9105	374.85	999.6	2513.932765	8429.617235	Running Normal	Normal	0
12:20 AM	4500	1	255.9105	374.85	999.6	2622.56656	8320.98344	Running Normal	Normal	0
12:21 AM	4500	1	255.9105	374.85	999.6	2731.200355	8212.349645	Running Normal	Normal	0
12:22 AM	4500	1	255.9105	374.85	999.6	2839.83415	8103.71585	Running Normal	Normal	0
12:23 AM	4500	1	255.9105	374.85	999.6	2948.467945	7995.082055	Running Normal	Normal	0
12:24 AM	4500	1	255.9105	374.85	999.6	3057.10174	7886.44826	Running Normal	Normal	0
12:25 AM	4500	1	255.9105	374.85	999.6	3165.735535	7777.814465	Running Normal	Normal	0
12:26 AM	4500	1	255.9105	374.85	999.6	3274.36933	7669.18067	Running Normal	Normal	0
12:27 AM	4500	1	255.9105	374.85	999.6	3383.003125	7560.546875	Running Normal	Normal	0
12:28 AM	4500	1	255.9105	374.85	999.6	3491.63692	7451.91308	Running Normal	Normal	0
12:29 AM	4500	1	255.9105	374.85	999.6	3600.270715	7343.279285	Running Normal	Normal	0

Figure 4-5
Output File

The speed of the simulation can be changed. It will run by default at 60x (One second real life is one minute in the simulation). The user has the option to slow down or speed up the simulation by dragging the slider to the right of the "Speed" label. If the user drags the slider to 1, then the simulation will run at 1x a minute (1 min = 1 min). The slider ranges from 1 to 1000 in increments of predetermined ticks.

Live Mode

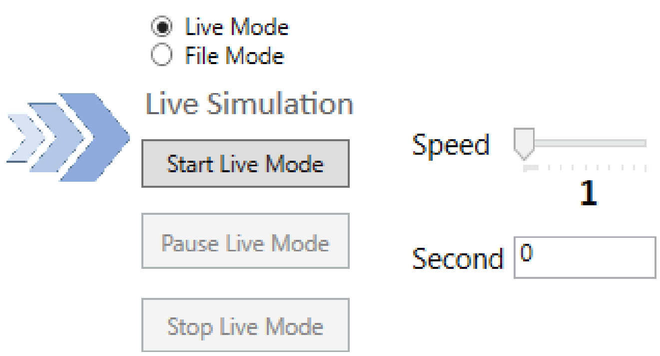


Figure 4-6
Live Mode Settings

In Live Mode, the user can adjust the settings and water draw manually. The simulation will run until the user stops the simulation. Similar to file mode, there is a start, pause, and stop live mode. Note that the water draw selector will only be enabled when "Start Live Mode" is clicked. When live mode is stopped, the water draw selector will be disabled. The simulation in live mode is by default set to run in real time (one sec = one sec). The user has the option to speed up the simulation by dragging the slider to the right of the "Speed" label. The slider ranges from 1x to 1000x speed.

Operating Modes

The simulator supports multiple modes and monitoring points. It can receive shed, critical peak, grid emergency, and load up commands. Shed is a general curtailment command. Critical peak is a more aggressive curtailment command. Grid emergency will cause the water heater to turn off if it was on. Load up will cause the water heater to turn on if possible. The current operating mode will display above the water heater graphic. It will also be displayed on the energy storage indicator along with a bracket showing the upper and lower bounds of operating for that mode. Some examples of how different modes are displayed is shown in Figure 4-7.

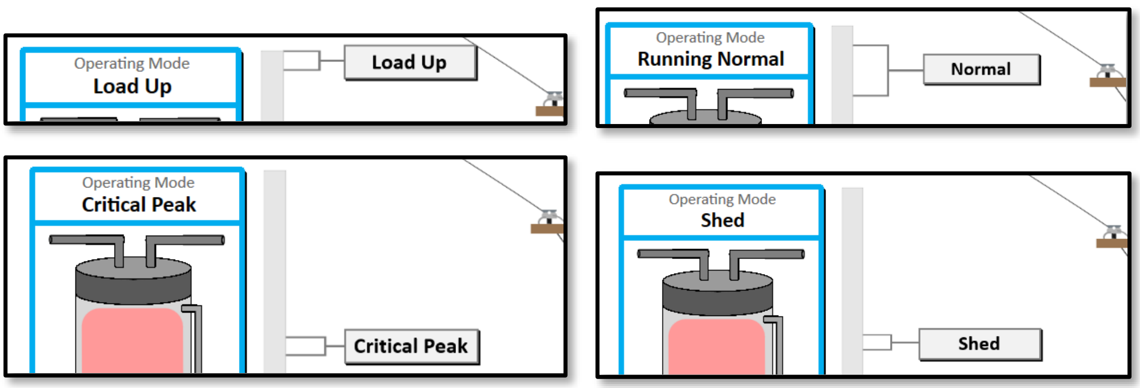


Figure 4-7
Examples of different operating modes in action.

The simulator also supports customer override. Demand response devices often have a method for a customer to opt-out of demand response event. In CTA-2045 this is called Customer Override.

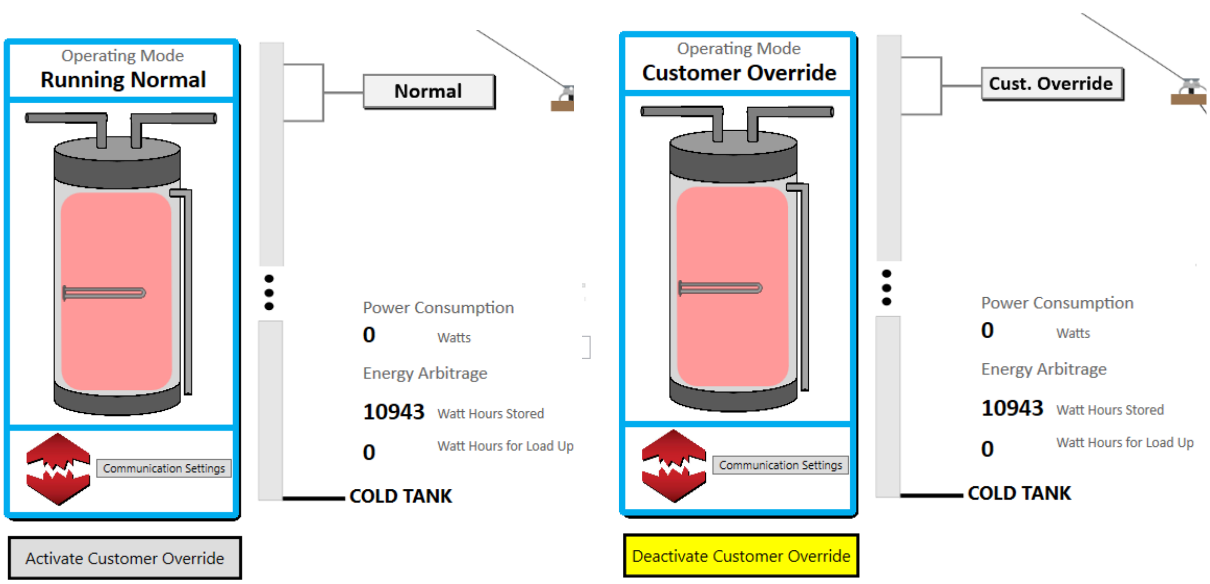


Figure 4-8
Customer Override

The customer override feature is activated through the simulator main window. Clicking on the button will turn it on and off. When Customer Override is activated, the button becomes yellow (Figure 4-8). In this mode, the water heater is set to run identical to normal mode until the mode is disabled. It will override any other grid command it has received. The water heater will not respond to any command that is sent, but will save the most recent operating mode command sent and will change to that mode when customer override is deactivated.

5
ONGOING DEVELOPMENT

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 Smart Water Heater Simulator, to meet the needs of the industry.

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.

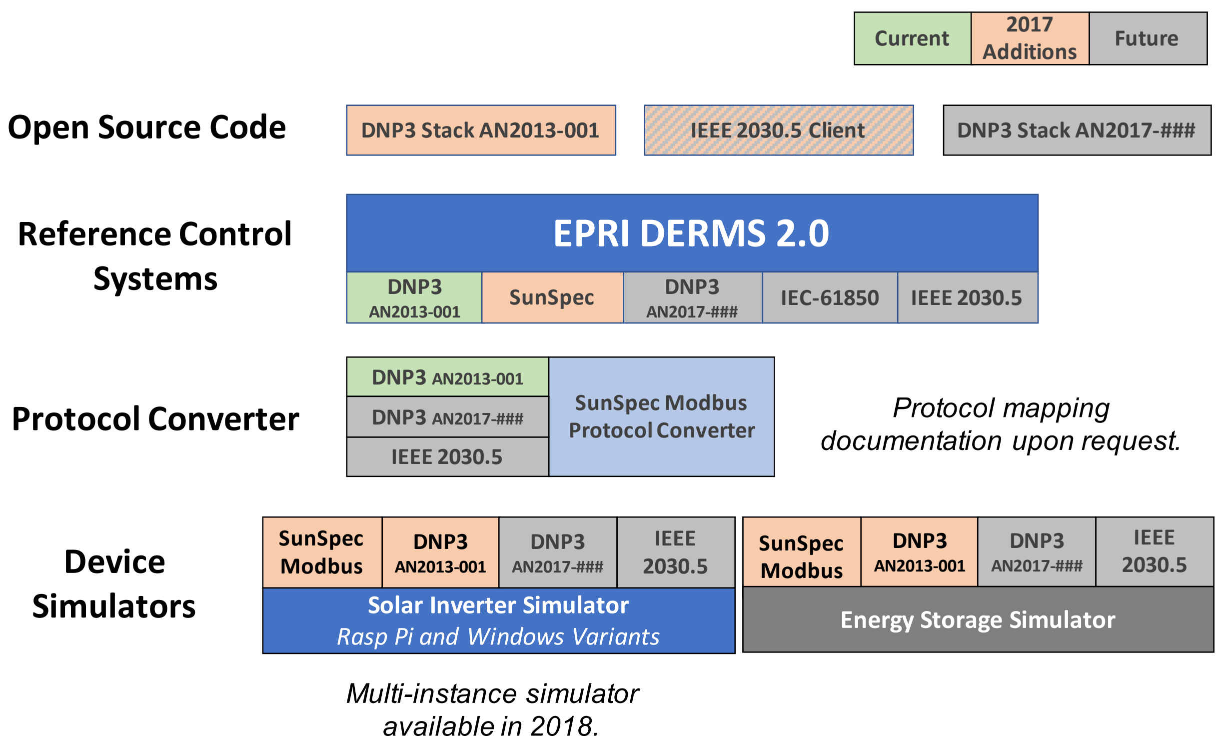


Figure 5-1
Upcoming tools for distributed energy resource technologies.

EPRI is leading a CEC funded project focused on updating the current DNP3 application note to meet grid code requirements (Rule 21 and IEEE 1547) and energy storage use cases. Once the update is complete EPRI will be creating an open source protocol stack to support the new application note (AN2017-###, final name to be determined). EPRI plans to update the EPRI Solar Inverter Simulator to include this new application note once the open source code is published on GitHub.

EPRI is working with NREL and Sandia National laboratories in ADMS test bed projects funded by DOE focused on voltage regulation, protection and other challenges associated with high penetration of PV Systems into the distribution grid. As part of this project, EPRI will convert the single inverter model to a multi-inverter model simulator. EPRI will update the simulator with additional smart inverter functions. EPRI also plans to have an additional interface to exchange data with distribution system models (e.g. OpenDSS).

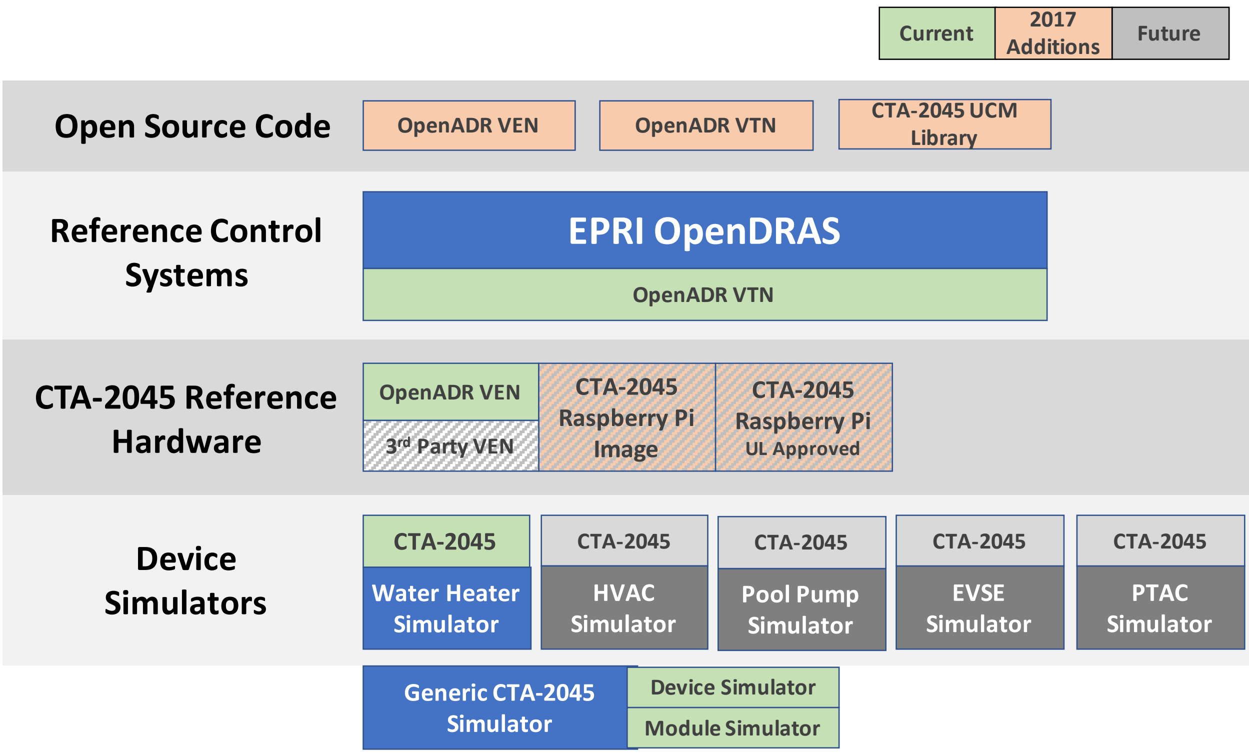


Figure 5-2
Upcoming tools for demand response technologies.

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 workplan for each tool. Severe bugs are addressed immediately.

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 the EPRI’s DER Integration Toolkit can be found in the toolkit summary report[1].

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