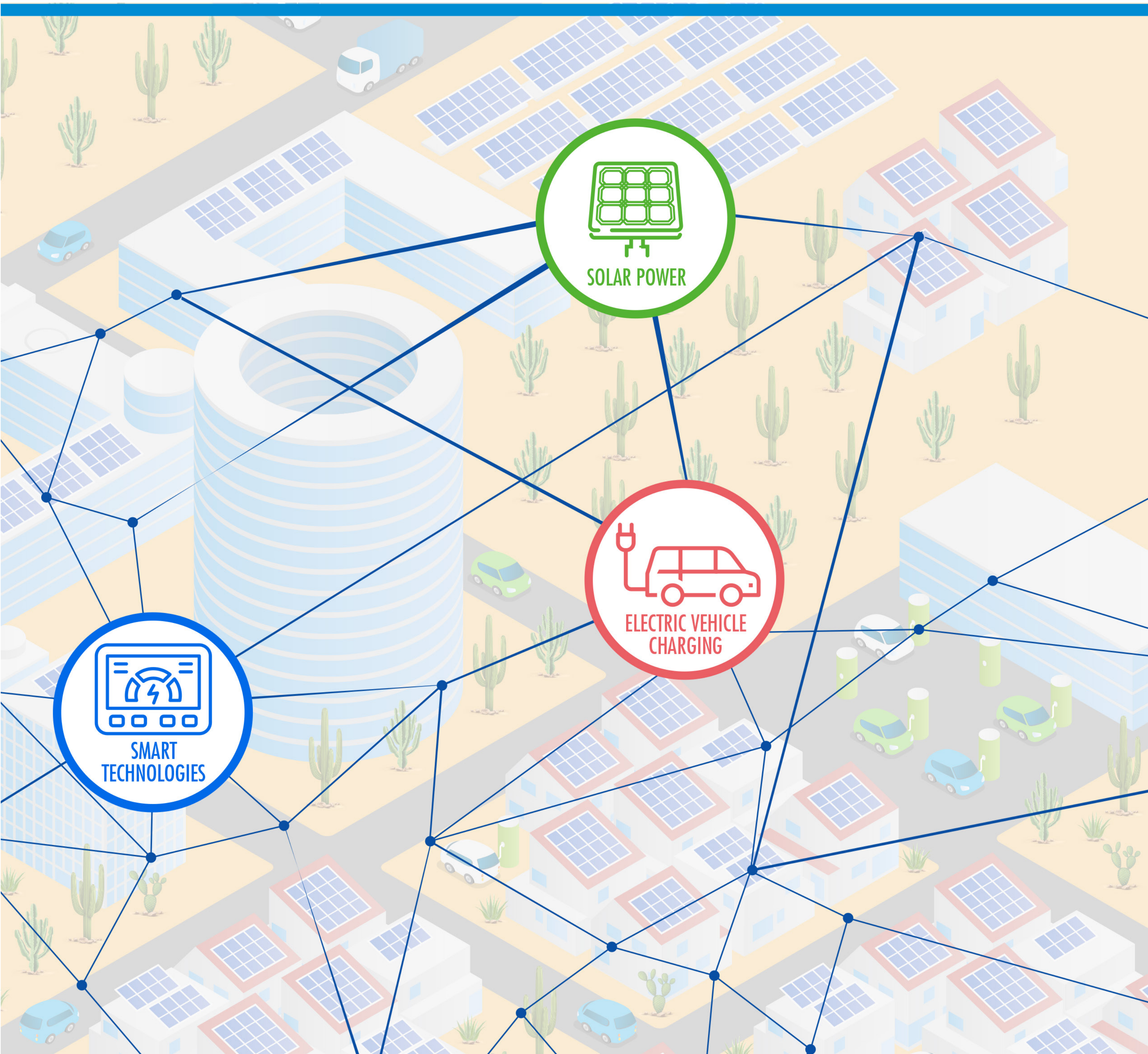
ELECTRIC POWER
RESEARCH INSTITUTE

# TUCSON ELECTRIC POWER
# PROJECT RAIN

## OCTOBER 2018 UPDATE



## EXECUTIVE SUMMARY

Tucson Electric Power (TEP) and the Electric Power Research Institute (EPRI) are examining and evaluating technologies for coordinating distributed energy resources (DER) to provide maximum benefit. For 2018 and 2019 we will, investigate:

- The state of the industry with respect to DER aggregation
- The practical capabilities of individual and aggregated DER
- Potential for customer engagement in supporting the grid
- Practical challenges of communication and coordination
- Strategies for applying DER management to TEP grid operations

Expanding on recent demonstrations of individual technologies, such as smart inverters and battery storage, Project RAIN—Resource Aggregation and Integration Network—is one of the first globally to explore how distributed generation and energy storage might be combined with flexible loads (such as electric vehicle chargers or smart thermostats) to respond optimally to dynamic system needs. Open standards and protocols (such as SunSpec Modbus and OpenADR) will be utilized in an effort to improve future system performance and reduce integration costs.

TEP and EPRI have framed research questions to guide the project, requiring a combination of laboratory and field evaluations. Several controller vendors (both established and new entrants) were engaged in laboratory testing, though the field trial features a single control system that is coordinating DER from multiple suppliers.

TEP, with staff from renewable generation, customer programs, distribution planning and operations, information technology, and cybersecurity, will enable a multidisciplinary understanding and implementation of the work.

**Major findings from the project to date include:**

- Distributed Energy Resource Management Systems (DERMS) and DER integration is still not plug-and-play. Laboratory testing and early field evaluation have shown that significant customization is necessary, even with open standards forming the basis for communication.
- DERMS today are generally targeted at only at a single type of resource (generator, storage, or controllable load). Vendors are challenged to effectively bridge to the more universal terminology and information models necessary to manage multiple technologies from a single platform.
- DERMS platforms currently focus only on the distribution of commands. Even primitive forms of optimization, such as giving a group of dissimilar devices a collective dispatch command, are still under development.
- Given the current state of technology, field testing will be phased to focus first on controller functionality testing, followed by device capability analysis, before investigating multi-technology grouping and basic optimization.

## MOTIVATION

With tremendous growth in DER such as solar photovoltaics (PV), battery storage, and responsive end-use devices comes new challenges for the electric distribution system—but also new opportunities. Cost-effective strategies for managing the realities of DER growth will likely go beyond wires-only solutions. Harnessing the capabilities of DER to provide voltage support, fault response, congestion relief, and situational awareness allows for increased hosting capacity as well as improved reliability, safety, efficiency, and affordability of the future grid.

The DERMS is a rapidly evolving technology to address the need to coordinate many different DER systems together for grid benefit. The role of the DERMS in the future power system is to:

- Translate commands among the various communication languages that DER may directly use
- Aggregate many distributed resources into a smaller set of controllable points addressable by the grid operator of the distribution management system (DMS)
- Simplify the many device-level parameters into a reduced set of instructions that are most meaningful to system operations
- Optimize the distribution of commands across the connected devices so that the requests are carried out fairly and efficiently

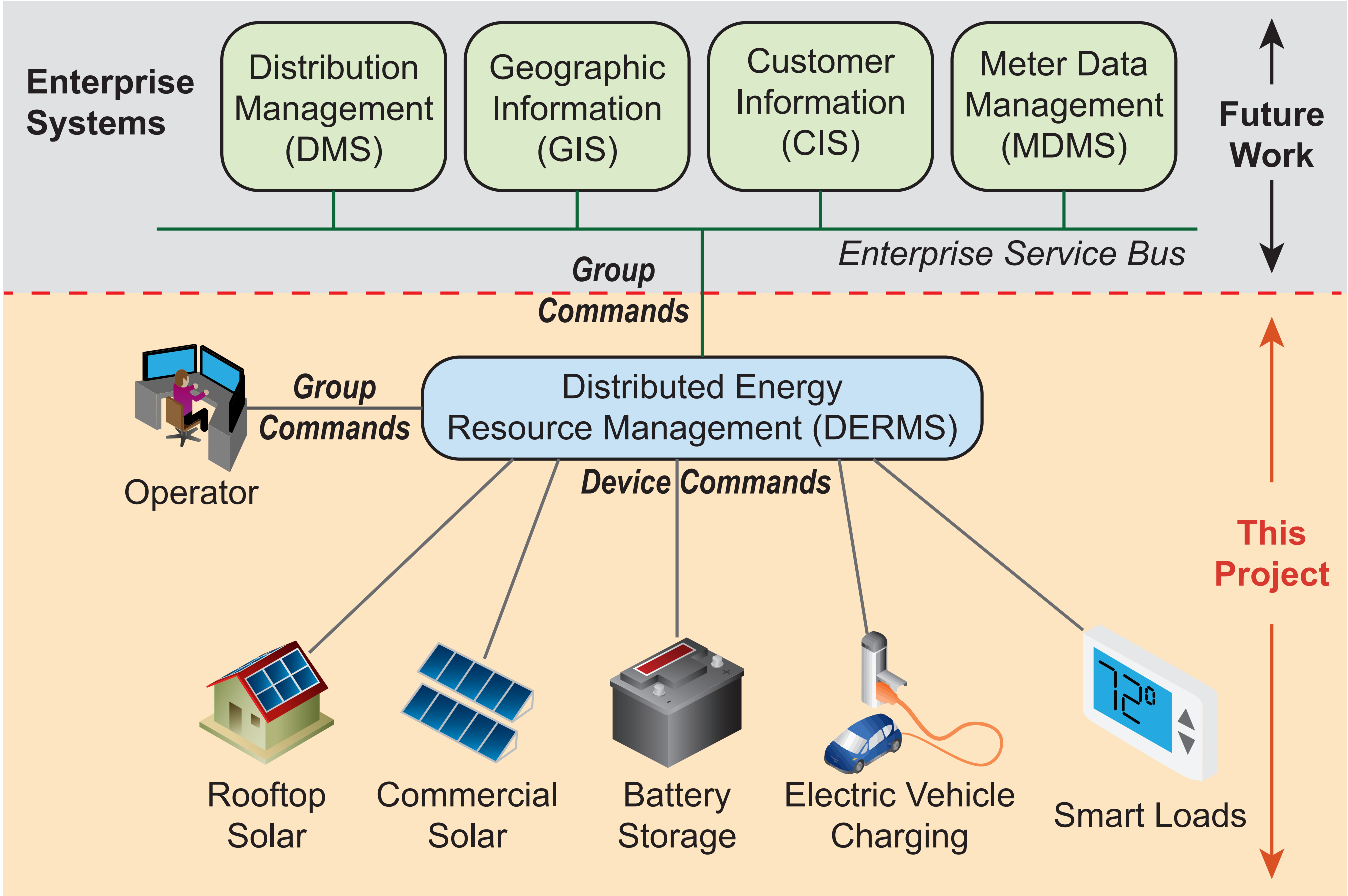


*Figure 1 – Simplified communication architecture showing the aggregation responsibilities of DERMS*

A simplified architecture diagram is shown in Figure 1. For Project RAIN, the focus will be on the downstream organization and optimization (using direct input from an operator). Future work should include connections with upstream utility enterprise systems, such as DMS or customer information systems (CIS).

Many vendors claim to have created DERMS products (or products with DERMS-like functionality such as virtual power plants [VPP] or microgrid controllers); however, their products are not fully developed and their techniques are not fully proven out. Many vendors have had limited opportunities to demonstrate these products in actual distribution systems, with multiple DER vendors, and/or with disparate DER technologies. A methodical examination of these issues is needed to identify gaps and opportunities for the next round of standards as well as developing more general guidance for utilities and vendors on the expectations and capabilities of DERMS as a tool for improved integration of DER.

## EXPERIMENTAL DESIGN

TEP and EPRI staff identified nine research questions at the project outset that are intended to guide the experiment:

| ICT / Cyber Security |
|---|
| How interoperable are DERMS with downstream (DER) devices? |
| How are DERMS vendors addressing cybersecurity within their products? |
| What are the bandwidth and throughput requirements for DERMS communication under various control strategies? |
| DERMS Operations |
| How should different DER technologies be dispatched by DERMS in the field? |
| What is the impact of different approaches to grouping DER? (i.e. by technology, size, location, etc.) |
| What is the impact of communication latency, intermittency, and/or bandwidth limitations on DERMS performance? |
| Utility Operations |
| Are there advantages to centralized control over having distributed intelligence at the DER? |
| What practical approaches to DERMS implementation are most beneficial to TEP customers, operators and enterprise systems? |
| How might high-resolution data sources (such as synchrophasors) be utilized in DER and distribution system management? |

Project RAIN consists of the following five major work activities:

- **Experimental design**, including identifying and procuring DER, developing test plans, and requesting participation from DERMS vendors
- **Laboratory testing** of candidate DERMS systems for basic interoperability and cybersecurity with downstream devices
- **System integration** of a single selected DERMS with field devices through direct communication (Modbus) and business-to-business cloud communication (OpenADR)
- **Field testing** of the constructed system to investigate the accuracy of control, optimization methods, and customer impact
- **Analysis and reporting** of research findings from laboratory and field testing. Outreach to the industry is planned through public reporting, advisory councils, and presentations at various industry forums

The project schedule (Figure 2) is estimated at 18 months, running until the middle of 2019. Advisory councils are expected to be held following key milestones. Though the final reporting will be at the conclusion of the project, interim reports are also expected at key milestones.

To evaluate the DERMS in the field, a collection of controllable assets, listed below, is being installed and commissioned:

- **One 48-kWac PV array at TEP's headquarters building.** This system was already installed, but will be retrofitted with communications and power monitoring equipment.
- **Four electric vehicle chargers at TEP's garage building,** occupying pillars on existing spaces. These systems need to be procured, installed, and commissioned with associated power monitoring equipment.
- **Twelve participating TEP-owned residential solar (TORS) customers.** In addition to their installed PV arrays, each customer is receiving a programmable thermostat and either a battery energy storage device[1] or a grid-interactive water heater.
- **One demonstration site at TEP's Irvington Campus,** including a small PV array, grid-interactive water heater, and a battery energy storage device.

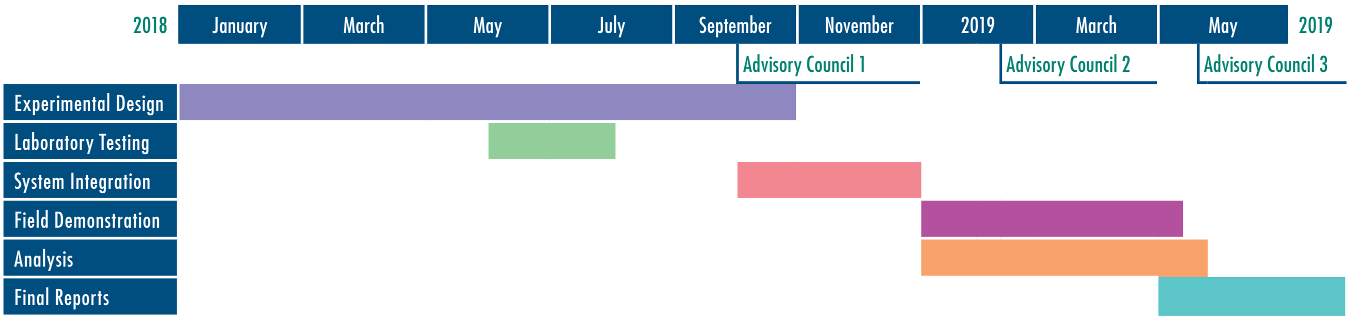


*Figure 2 – Estimated Project RAIN timeline of component tasks*

By design, multiple installations of the various device types were included to achieve significant quantities (in terms of ac power rating) in each category. This aim toward a balanced approach should help shed light on the impact of all device types and the implications of DERMS. Figure 3 shows a breakdown of DER installations by the maximum aggregate power rating (full bar) and single device power (bar segment). The color coding also indicates significant representation by each category of DER, those being demand response, energy storage, and distributed generation (PV in this case).

Control signals to individual DER requires the controller communicate over multiple protocols, namely Modbus and OpenADR as shown in Figure 4. EPRI-designed monitoring systems are also being deployed to record response for later analysis. Synchrophasor data from various points on the TEP system will be transferred to EPRI to understand the impact of high DER concentration on the power system during faults or other transient conditions.

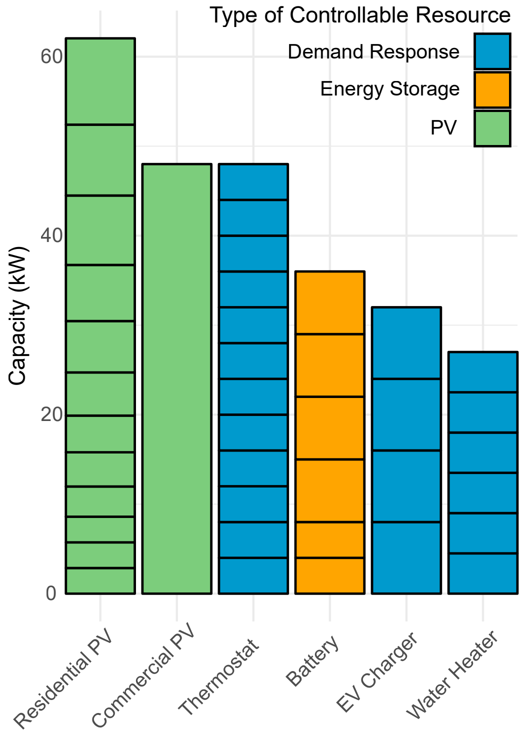


*Figure 3 – Bar chart indicating the maximum individual (device-level) and aggregate (device type level) power rating*

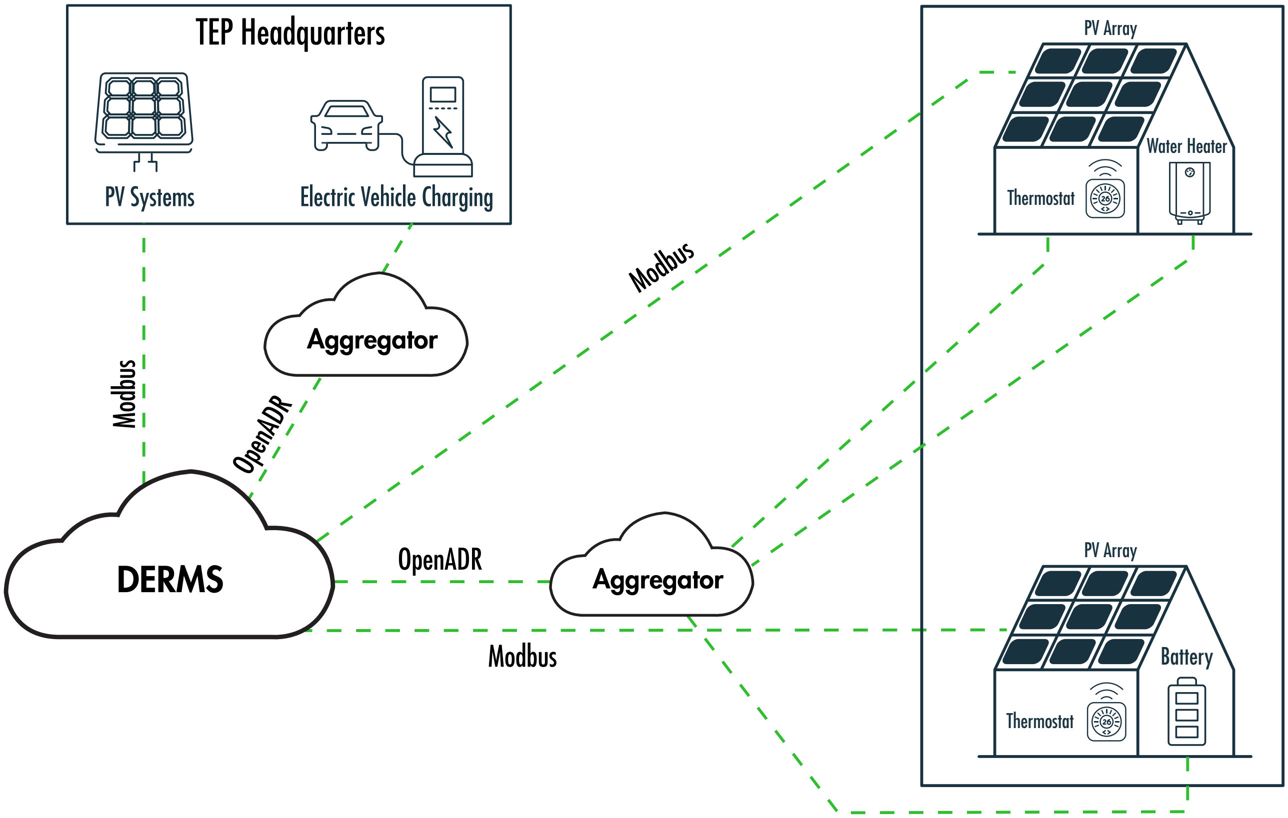


*Figure 4 – Diagram of DERMS communication with end-use devices over multiple protocols and separate power meters at each location for recording of DER operation*

---

1 The battery systems are configured so that a subpanel of customer loads (such as refrigeration and lighting) may be powered by the PV system and batteries in the event of a utility outage.

Installations are currently in progress at all locations, with some of the progress shown in the photos below:

*Figure 5 – Example grid-interactive water heater (indoor) installation*

*Figure 6 – Example battery energy storage system (indoor) installation*

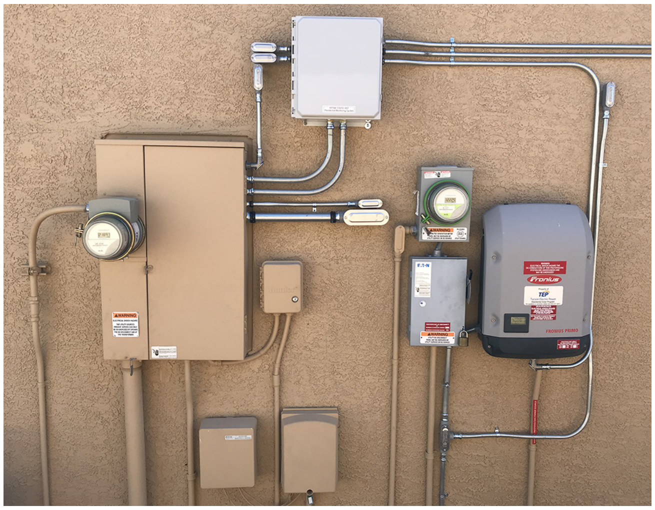


*Figure 7 – Example battery energy storage system (outdoor) installation, including power monitoring equipment (top middle of photograph)*

Some lessons learned from the experimental design process thus far include:

- Requested DER capabilities must be reflected in each protocol or aggregation method used. It is of zero value to have events (such as demand response) communicated between the utility and the aggregator, if the end devices do not support the needed functionality.
- There is always the potential for a third-party aggregator to cease providing services or to change the communication method, which could limit or interrupt utility DERMS control
- It was a relatively new application for the utility to operate a residential-scale battery on the utility-side of the meter while providing backup service to customer loads behind the meter.

## LABORATORY TESTING

### Overview

For a successful demonstration, the DERMS in Project RAIN needs to communicate with individual DER as well as aggregators. Based on the interfaces available in the installed DER and the capabilities of aggregators, SunSpec Modbus and OpenADR were requested of candidate DERMS. This is a rare combination of a low-complexity protocol (Modbus) with a verbose, XML-based protocol (OpenADR) not commonly available in vendor offerings. However, these are the most common open standards for addressing PV generation and controllable load, two of the staples of Project RAIN.

From the laboratory testing process, it was clear that the standards themselves have varying degrees of maturity. Though the standards documents may be complete, some of the interoperability and performance issues stemmed from a lack of experience in applying the standard, as well as the absence of application guides, other supporting documentation, and test tools. In fact, the laboratory testing process under Project RAIN directly led to discussions amongst the stakeholder groups surrounding behaviors that had not been expressly allowed or forbidden in the standard.

Ultimately, given the nascence of DER technology and the continued emergence of standard communication methods, agility and flexibility in implementation is a key DERMS feature to address an ever-changing collection of resources.

## Testing Process

In response to the initial Project RAIN request for proposals (RFP), prospective vendors were invited to individual 1-day interoperability tests in EPRI's Knoxville Laboratory. Interoperability of the DERMS systems were evaluated against EPRI-developed test tools for SunSpec Modbus and OpenADR, while EPRI's cyber security team discussed implementation of standards and best practices with the development teams.

Fourteen vendors were invited to respond to the RFP, and four vendors eventually participated in the testing. Vendors had the option of either bringing an instance of their software system on a local machine or connecting to a remote server.

Those that elected not to participate in the laboratory testing highlighted that they:

- Had too many other commitments and/or paid deliverables to participate in laboratory testing
- Needed further development to participate in the lab testing and the time allotted was too short
- Preferred or were limited to either proprietary or other open protocols (such as DNP3)

SunSpec Modbus testing evaluated the DERMS's SunSpec protocol implementation to identify any interoperability or performance issues (as implemented). The vendors were provided a single, simulated PV inverter at a known internet protocol (IP) and Modbus address. Each vendor was then asked to:

- Scan the available SunSpec Modbus "models" and confirm the register locations
- Read measured voltage, active power, reactive power
- Read the nameplate kW, kVA ratings from the inverter
- Limit active power to either a fixed value or a specified percentage of nameplate
- Set fixed reactive power to either a fixed value or a specified percentage of nameplate

OpenADR testing evaluated whether the DERMS could connect and register with EPRI's open source OpenADR 2.0 virtual end node (VEN), generate reports, and both poll and parse DR event signals.

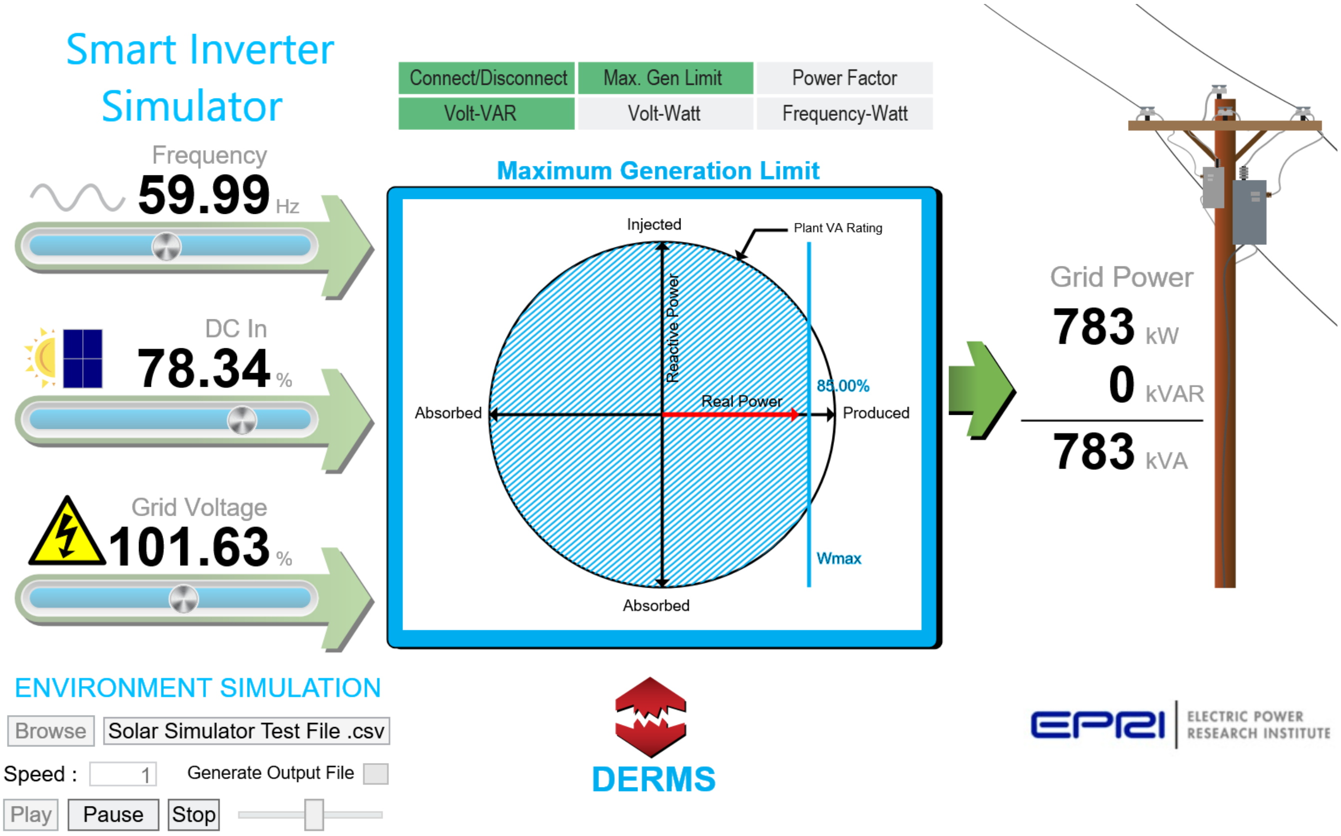
OpenADR operations included:

- Respond to a registration query from VEN
- Receive registration information from VEN
- Send a control signal of the "SIMPLE" signal type (having a value of 0, 1, 2, or 3)
- Register for and receive reports from the VEN

Vendors were encouraged to "pre-test" their systems using available test tools. EPRI's OpenADR VEN is publicly available, however, several vendors were not able to pre-test the Modbus interface (though tools are available through membership in the SunSpec Alliance).

An interview was conducted with each of the DERMS vendors to discuss the cyber security posture of their system. Topics covered included:

- Basic cyber security functionality and features
- Standards compliance (including NIST SP800-53)
- System architecture
- Security of development environments
- Maturity of internal cyber security procedures



Frequency 59.99 Hz

DC In 78.34 %

Grid Voltage 101.63 %

Grid Power
783 kW
0 kVAR
783 kVA

Solar Simulator Test File .csv

Speed : 1

*Figure 8 – Screenshot from EPRI's Smart Inverter Simulator (used for SunSpec Modbus testing)*

## IMPLEMENTATION ISSUES

The following issues were identified during the testing process with one or more vendors. These issues may prevent interoperability, and make it difficult to seamlessly interface with individual devices or aggregators in the field without custom configuration for each DER:

- **Scanning SunSpec Registers** – Implementation of SunSpec Modbus requires the DERMS to "scan" a new device to determine its capabilities as well as the location of key data points for monitoring and control (this is to allow manufacturers flexibility to accommodate legacy systems and testing tools that may overlap with SunSpec Modbus point addresses). Multiple DERMS tested had not implemented the search function, and instead had to be given the register locations in advance – risking a need for continuous work by software developers and/or DERMS operators.
- **Modifying OpenADR Parameters** – In order to complete the registration of a new device or aggregator, the parameters of the exchange (such as device names, polling rates, and event signals) between it and the DERMS may have to be negotiated. In a couple of examples, the OpenADR implementation in the DERMS could not be adjusted (either automatically or by the operator) causing it to fail pairing with certain devices.

## PERFORMANCE AND USABILITY LIMITATIONS

Even though they did not register as true "interoperability" issues, there were several items that came up during the evaluation, either in the communication path or the operator interface. These issues would either make system integration more complex, less flexible, or more difficult to interact with (for the operator).

Probably the largest and most impactful challenge for all of the DERMS vendors was to find a way to unify terminology and information models at the device level. Depending on the origin of the product (from either generation control or demand response), the nomenclature was often retained when referring to the other set of products. For instance, a controllable load model with controls for absorbing energy might get applied to a PV generator that has only a function to limit generation. The challenge for any potential DERMS solution will be to juggle multiple information models at the device level as well as map each to the group level successfully.

Some of the tested products did not offer separate actions for updating a parameter (such as a power limit) and enabling the command. Having a separate (or two-step) process for this action provides a level of protection against an entry error, as well as a guard against a communication failure causing an erroneous action from the DER. In the Modbus testing, some vendors opted to keep a "persistent" connection to the device even when commands were not being sent, preventing other devices from connecting (even for monitoring). At least one vendor's system was designed in a way that if a large number of DER were unresponsive, it caused the Modbus interface to lock up. Given that customer Wi-Fi is a common choice for devices connection and may not always be reliable, it is reasonable to suspect that such shortcomings could occur in the field.

During the interview process, EPRI's cyber security team commented on some of the participants clearly factoring cyber security elements into the design of the product, rather than adding a security layer after the fact. More established and/or diversified companies had the ability to draw from experience from other product lines. In general, the results of the interview were positive, though the evaluation stopped short of vulnerability scanning, fuzzing, or more in-depth security evaluations.

## TEST PLAN

### Function Testing

In demonstration projects of emerging technologies, test plans are often delayed or put on hold when the planned tests uncover unexpected issues in hardware or software. During these interruptions, tests of more basic functionality were performed before returning to regularly scheduled testing. Allocating time for these types of tests in advance may inform what capabilities are fully available in practice (as opposed to theory), lead to fewer interruptions during the remainder of testing, and culminate in more definitive test results. In order to be the most productive, these commissioning-like tests are diverse and may include the following objectives:

- Confirm the presence of active communication with each device
- Verify correct responses to commands, both manual and scheduled
- Verify responses of groupings, especially when composed on non-homogeneous device types
- Operate DERMS devices under as many different modes as possible
- Test all possible transitions between different modes
- Observe responses to out-of-bounds limits/extremes for various devices (e.g., when comfort limits are violated)
- Confirm reasonable behavior in response to a selection of a few, sample, event tests
- Repeat any tests where incorrect or unexpected behavior was observed and potential fixes were implemented

## EVENT TESTING USING HOMOGENIZED CONTROL SIGNALS

The core piece of testing is expected to be a structured period of event testing. During this time, presumed "typical" events will be scheduled and analyzed to help quantify the capabilities of various devices individually and collectively, characterize typical device behavior, and generally inform how DER and DG assets can and should be controlled to obtain desired results. Event testing plans consist of three parameters being varied as the independent variable. These include the following:

1. The duration of the event and any load-up or preparation time
2. The timing of the event - from centered on the peak to slightly preemptive or delayed
3. The magnitude of the call (e.g., Shed vs. Critical Shed) as well as the combination of shed-type events with preparatory load-up periods

On the road to more advanced group-level management, the first step is to create a common set of commands that all devices can understand. Laboratory tests of DERMS vendor solutions revealed a lack of maturity merging demand-response-type devices with DER (or vice versa). Since controls were typically designed for one and adapted to the other, a standardized set of commands across all devices is not available at the device-level. The proposed solution for testing purposes implements OpenADR SIMPLE signal commands that consist of four discrete event 'levels' and will map to predefined actions for each device type. Table 1 outlines the proposed meaning of each signal for each device type. Definitions are expected to be adjustable as needed. While simplistic in nature, the OpenADR SIMPLE signal structure should allow for consistent testing of device capabilities within the present capabilities of control devices and will both help inform and prepare for more advanced control strategies.

Toward the end of testing, which should be during late Spring and early Summer, a selection of these structured tests will be repeated. Doing so will allow for comparisons with identical tests previously run in winter months. The difference in impact between baseline and test days during these different seasons should help identify changes in device capability, behavior, and relative effect on load shape resulting from external factors such as temperature and loading conditions.

## MANUAL GROUPING TESTS

At full maturity, DERMS may be capable of automatically managing resources to provide a fixed amount of real power dispatch or manipulate DER's power usage to conform to utility-requested profiles. An example of what controllable loads, PV, and a battery can do is shown in Figure 9.[2] In this simulated example, a controller shifts load, charges/discharges a battery, and potentially curtails generation to stay almost entirely between a fixed export limitation and a variable import limitation made of discrete levels.

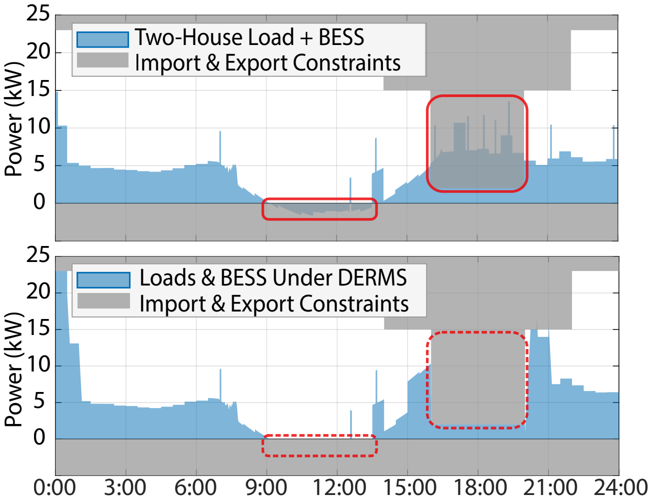


*Figure 9 – Simulated behavior of a two-residence power profile both with devices acting autonomously (top) and under DERMS control (bottom)*

*Table 1 – Proposed mapping of device responses to OpenADR SIMPLE signal command levels*

| DEVICE | 'LOAD-UP' ('0') | 'SHED' ('1') | 'CRITICAL SHED' ('2') | 'GRID EMERGENCY' ('3') |
|---|---|---|---|---|
| **WATER HEATER** | Heat water to max temp. | Avoid heating, maintain lower water tempature | Avoid heating, maintain minimum water tempature | Turn off WH for length of event |
| **HVAC** | Lower setpoint 6°F (Load-up)† | Relax setpoint 3°F | Relax setpoint 6°F | Turn off HVAC for length of event |
| **EV CHARGER** | Charge normally | Limit charge rate to 60% | Limit charge rate to 30% | Stop charging (0%) |
| **PV** | Curtail PV to 0 kW, 60% VAR absorption‡ | 100% kW, 30% VAR injection‡ | 100% kW, 60% VAR injection‡ | 100% kW, 100% VAR injection‡ |
| **BATTERY** | Charge at 60% rated power | Discharge at 30% rated power | Discharge at 60% rated power | Discharge at 100% rated power |

† Assumes a cooling mode; in the event of cooler ambient temperatures, setpoint would be raised
‡ Percentages are of max reactive power capability (typically 50% of kVA rating)

---

[2] For more information on this modeled controller and its application in field testing, see EPRI's research on the development of a DERMS as part of the DOE SHINES project.

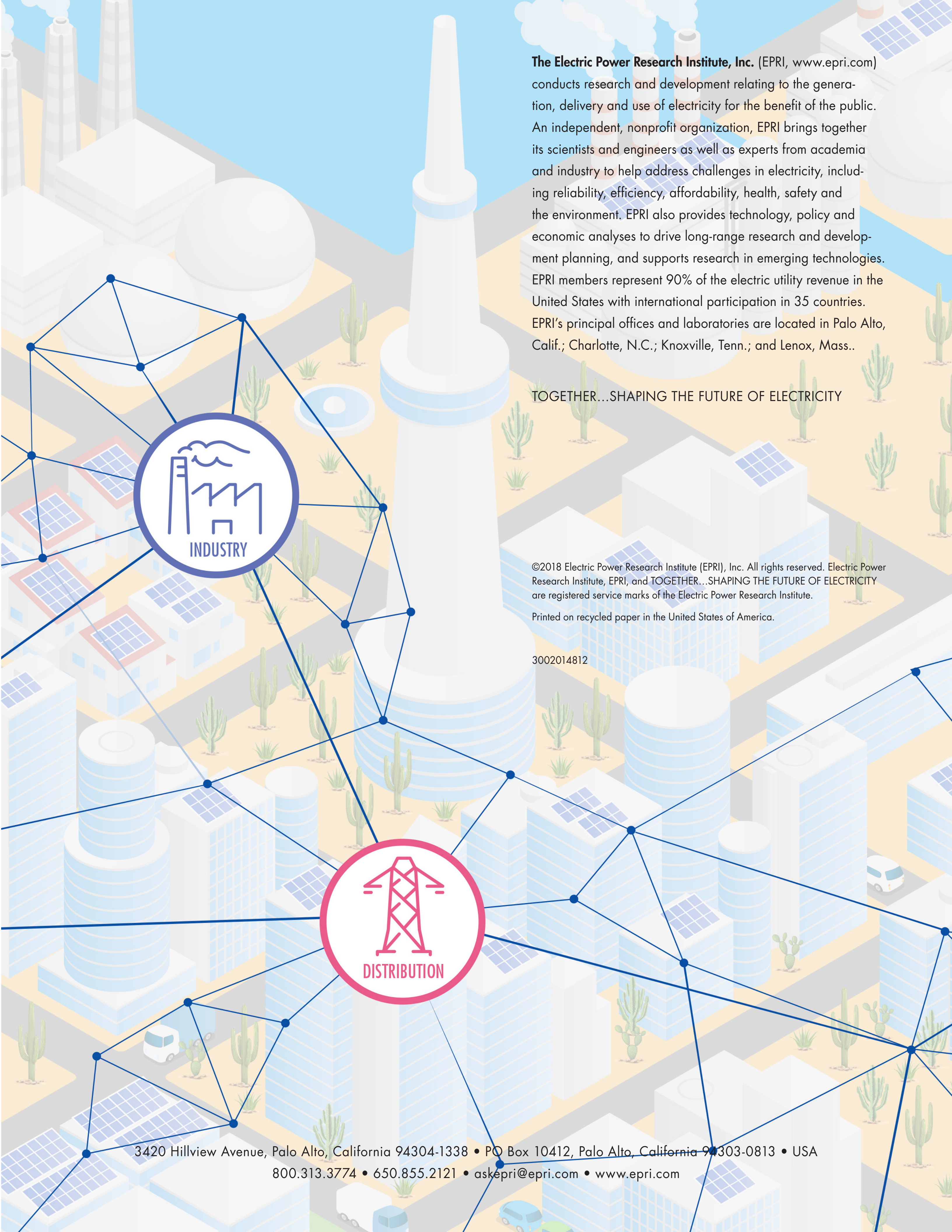
As a possible second step toward this advanced capability stage (beyond the first step of just being able to control devices), manual creation and scheduling of groupings is planned. These groups may be defined by typical power and energy capabilities, location, device type (e.g., demand response), or other groupings designed to achieve certain goals. The actual makeup of these groupings is expected to be informed by the capabilities and behavior observed in event testing. If successful, the desired capabilities of a mature DERMS solution may be approximated by manual grouping and scheduling of certain devices.

If the necessary controls and software integration can be completed in time, iterative controller strategies may be tested as well. Such algorithms would request an action from certain devices, observe the response, and continuously send updated commands to maintain the desired effect.

## NEXT STEPS

As Project RAIN continues into the demonstration phase, upcoming work includes:

- Completing the installation of the DER, communications, and power monitoring equipment
- Initializing and verifying basic connectivity between the DERMS, aggregators, and devices
- Executing the test plan from the DERMS
- Analyzing and reporting on field results.



**The Electric Power Research Institute, Inc.** (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass..

TOGETHER...SHAPING THE FUTURE OF ELECTRICITY

Printed on recycled paper in the United States of America.

3002014812

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