Demonstration of a Low-Cost, Scalable, and Interoperable Approach to Direct Load Control

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Demonstration of a Low-Cost, Scalable, and Interoperable Approach to Direct Load Control

Final Report

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Abstract

This field demonstration of approximately 150 commercially available smart grid devices with built-in CTA-2045 interface aims to demonstrate the technical viability of an end-to-end CTA-2045 system to satisfy both utility mass-market direct load control use cases in New York State and include smart automation features that consumers would find desirable. Still in early stage of adoption, key takeaways and lessons learned during field demonstrations such as this offer opportunities to improve manufacturers' implementations of the standard.

Keywords

Demand Response, CTA-2045, Peak shaving

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Acronyms and Abbreviations

AMI	advanced metering infrastructure
ANSI	American National Standards Institute
CEA	Consumer Electronics Association
ConEd	Consolidated Edison, Inc.
CTA	Consumer Technology Association
DLC	direct load control
DR	demand response
DRMS	Demand Response Management System
EPRI	Electric Power Research Institute
EVSE	electric vehicle supply equipment
HVAC	heating ventilation and air conditioning
kWh	kilowatt hours
MW	megawatts
NYISO	New York Independent System Operator
NYPA	New York Power Authority
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
OEM	original equipment manufacturer
ORU	Orange and Rockland Utilities
PTAC	packaged terminal air conditioner
SFTP	Secure File Transfer Protocol
SGD	smart grid device
UCM	universal communications module
W	watts

Executive Summary

CTA-2045 is an open standard which defines an interface that could be used to exchange any kind of information between residential appliances and a demand response or energy management system. It was designed specifically to support demand response applications, including regular load control/curtailment, critical peak, price-based programs, and ancillary services such as up/down regulation. CTA-2045 offers functional improvement over existing DR technologies because of the data that can be transferred through bi-directional communication with appliances. Additionally, because it is an open standard, utilities can avoid undesirable vendor lock-in. Further, consumers could control their own appliances using the same physical interface and messaging protocol. Consumers may use mobile apps for home automation or energy management, even responding to hourly energy prices.

With funding from NYSERDA, Electric Power Research Institute (EPRI) managed a multi-year field demonstration project in which approximately 150 smart grid devices were deployed in New York State with help from stakeholders New York Power Authority (NYPA) and Consolidated Edison (ConEd), who recruited volunteer host sites.

The primary project objective is to demonstrate the technical viability of CTA-2045 and appliances with a CTA-245 compliant port to satisfy both utility mass-market DLC use cases in New York State and include ‘smart automation’ features that consumers would find desirable.

The primary use case for NYPA was winter peak shaving. A key motivation for NYPA’s use case is to give municipal utilities tools to improve the effective management of hydro allocations during winter peaks. Opportunities exist in NYPA territories to curtail electric resistance water heaters, which are popular because of low electricity rates in upstate NY. ConEd/Orange and Rockland Utilities (ORU) described a use case of primary interest that is centered around residential cooling during summer peaks where residential mini-splits are seen as distributed loads for bulk system relief scenarios. Key takeaways and lessons learned are as follows:

CTA-2045 offers functional improvement over remote-controlled load switches because of its bi-directional communication with appliances. Operators can see immediate feedback from connected devices to quantify the load being shed. However:

- Data being returned is device-specific (or manufacturer-specific). While some appliances report power, which is the parameter of primary interest for a DR application, other appliances may report temperature setpoint or speed in RPM. Lack of power data from the smart grid device (SGD) makes success of the DR event difficult to quantify.
- The project experienced issues regarding device compliance with CTA-2045 messaging protocol. In two cases, product updates resulted in the loss or degradation of some functionality that had performed as expected beforehand. The solution to this issue is a CTA-2045 certification process. As the standard gains in maturity and foothold, these types of issues are expected to be resolved.

The field demonstration showed that CTA-2045 can reveal details about Demand Response events that might otherwise go unnoticed. For example, the rebound (or snapback) after curtailment events can be significant, especially observed in the behavior of water heaters.

- A multi-stage staggering of the release after curtailment can reduce the magnitude of the rebound.
- A pre-curtailment load-up event could be dispatched and staggered as well. This would shift some of the peak to the onset of the event rather than the end.

One issue worth noting is the reliability of customer Wi-Fi for persistent and long-term applications such as utility DLC. During the field demonstration, an online success rate of 70% was considered acceptable and was roughly the average across participating munis. Some hardware failures did occur, but most of the offline units were attributed to loss of Wi-Fi communication.

Overall, the project demonstrated that the technical viability of the CTA-2045 standard to meet the objectives of the DLC use cases of interest to stakeholders and includes ‘smart automation’ features that consumers would find desirable.

1 Introduction

Demand response (DR) has been used effectively for decades through peak reduction programs and through emergency interruptible load programs wherein large industrial and commercial customers agree to reduce load as an emergency resource when called upon by system operators. On the residential side, certain types of loads are attractive to utilities as a demand response resource but challenging and costly to control because they are numerous and dispersed. In aggregate, demand response from residential appliances could improve the operational efficiency and reliability of the grid, reduce peak load on stressed distribution circuits, shave load during New York Independent System Operator (NYISO) system peaks, and help integrate intermittent renewables.

Utility direct load control (DLC) types of DR programs are typically initiated because of a utility's near-term megawatt curtailment objectives (i.e., non-wires alternative). Utilities benefit from aggregation of specific types of loads, common and numerous in their territory, such as central AC, pool pumps, and water heaters. The utility (or their contractors) recruit customers and equip the existing appliances with controls at the program's expense. The utility industry has turned to vendors that typically bundle proprietary retrofit hardware controls for the targeted appliance with communications and deployment services. DLC programs have historically delivered a crude consumer experience with simplistic on/off curtailments, no consumer configurability, and no feedback from the loads. Over the years, utilities have found that DLC customer recruitment and retention is laborious, the hardware controls proprietary, installation expensive, and the communications challenging to keep in service. All this makes DLC an expensive and difficult resource to scale and to maintain over the long term, which is needed to justify the program expense. Additionally, proprietary systems often include a degree of undesirable vendor lock-in that reduce competition and value.

The CTA-2045 is an open standard that defines an interface that could be used to exchange any kind of information, but it was initially designed specifically to support demand response applications, including regular load control/curtailment, critical peak, price-based programs, and ancillary services such as up/down regulation. Further, smart appliances could give consumers remote control from mobile apps and enable consumers to respond to hourly energy prices. The challenge to scale adoption of these connected devices has been one of enabling lower cost production, distribution, and deployment.

The primary project objective is to demonstrate the technical viability of CTA-2045 and appliances with a CTA-245 compliant port to satisfy both utility mass-market DLC use cases in New York State and include “smart automation” features that consumers would find desirable.

2 About the CTA-2045 Standard

A group of appliance vendors, utilities, and third-party service providers collaborated to develop a standard port to provide the latent capability for device-to-grid connectivity, resulting in the publication of the Consumer Technology Association, ANSI/CTA-2045 standard. This approach to "DR-ready" devices separates the appliance, curtailment instructions, communication module, networks, and control systems from each other, but defines a standard interface between each. This approach both lowers costs and enables flexibility so manufacturers can design a single version of their key consumer products with a universal port that would work in any utility territory. The port and standard curtailment operating modes would add negligible cost to the appliance. This way DR-ready products could be practically mass-produced with a universal port and supplied through mainstream retail and installer channels. The port could also enable "smart" functionality that might drive consumers to choose these enabled appliances and voluntarily participate in utility programs. The utility or a utility partner would supply a low-cost standards-based communication module (i.e., Wi-Fi, AMI, radio frequency, FM or cellular) to be plugged into the universal port by the consumer. The standard was published in February 2013. A brief milestone history of the standard is as follows:

- 2010–Initial collaboration among 60+ vendors and utilities to develop an open standard.
- 2013–ANSI/CEA-2045 standard was published.
- 2015–Consumer Electronics Association (CEA) changed their name to Consumer Technology Association (CTA).
- 2015–Vendors began delivering UL certified appliances.
- 2015-2016–Specifications were developed for water heaters, thermostats, EVSE, PTAC.
- 2016-2020–Field demonstrations and pilot programs.
- 2020–Washington State passed legislation that all water heaters manufactured after Jan 1, 2023 will have CTA-2045 functionality built in.
- Present–Other states are following Washington's lead.

The authors of CTA-2045 envisioned that products purchased from retailers will have built-in demand-responsive capabilities. The idea of a high-end model product that few consumers would buy does not satisfy the intent of the standard. In order to be practical for mainstream retail, the incremental upfront cost must be very low. A modular interface defers the cost of communication electronics and associated power supplies until the time of actual DR program enrollment. At present, only a small percentage of target products are ever enrolled in any energy-related program, making it a necessity to minimize or eliminate upfront costs. Therefore, the CTA-2045 intentionally does not define the technology of a communication module or how it communicates to the outside world, but only the interface between the appliance and the communication module. It defines the mechanical, electrical, and logical aspects of this interface with the vision so that:

- An appliance manufacturer would design their product with a CTA-2045 communication interface that would be compatible with any communication system, even those not yet invented (for example, 6G cellular).
- A provider of a communication system could make a module compatible both with their system and the CTA-2045 standard.
- When plugged into one another, information can be shared between the communication network and the end device.

2.1 Physical Interface

CTA-2045 defines two physical form factors: AC and DC form factor. The messaging/protocol is the same for both, but they differ mechanically and electrically. The DC form factor is a necessity for small appliances, such as thermostats and in-home displays, where only low-voltage DC exists and where miniaturization is important. The AC form factor is a necessity for communication technologies that require higher power, larger components (such as antennas), or direct AC line access for PLC power-line carrier networks. The AC form factor may also be necessary for large appliances that have longer wires and electrically noisy environments. An illustration of the physical interface is given for the water heater example in Figure 1.

Figure 1. Socket Standard for CTA-2045

2.2 Messaging Protocol

In the language of the CTA-2045 standard, end devices are referred to as Smart Grid Devices (SGDs), and communication modules are referred to as Universal Communication Modules (UCMs). CTA-2045 seeks to achieve interoperability of any end-use device, meaning that any UCM plugged into any SGD will work, at least to the level at which both are capable. This recognizes that some end-use devices will be very simplistic, supporting only an on and off state of operation with only very limited computational and communication capabilities. It recognizes that other end-use devices might be very capable, including Internet browsing capabilities, with high performance capabilities.

For any UCM/SGD combination, the simpler of the two naturally dictates the level of capability of the complete system. The CTA-2045 standard allows for variable degrees of capability, mandating only that a few basic messages are supported—sufficient to enable basic demand responsiveness.

The application layer defines the functional messaging: status of the monitoring device, behavior of the managing device, or any number of other actions. At the application layer, CTA-2045 is designed to support the transparent pass-through of any relevant application layer protocol. It is in this regard that the goal of being “simple yet extensible” is addressed. Some protocols for the application layer for demand response are complex, and their security mechanisms are even more complex. For some end-use devices, this complexity is supportable, but for others, it is not. To address the more limited devices, the CTA-2045 standard defines a set of simple application layer messages that are only a few bytes in length.

“Basic” and “Intermediate” messages defined by the CTA-2045 standard are a simple set of messages that are intended to be supportable by all devices, even those with most limited capabilities. The “shed” and “end shed” basic messages are mandatory for all devices in order to achieve interoperability. The simple messages defined in the CTA-2045 standard including examples of their use are shown in Table 1.

Table 1. Basic Load Control Commands

Load Control Commands	Interpretation
Shed	Moderately reduce demand. Upon the receipt of this command the SGD could reduce demand while minimizing customer discomfort.
Critical Peak	Aggressively reduce demand. The SGD may respond to more aggressively due to the infrequency of this type of event.
Grid Emergency	Most aggressively reduce demand. Reserved for use to avoid blackouts and during restoration activities.
End Shed	End demand reduction event (run normal).
Load Up	Increase load or run now. Opposite of “shed.” Instructs SGD to use energy now, if practical without wasting energy.

3 Overview of the Field Demonstration Project

This project demonstrated the technical viability of CTA-2045 and appliances equipped with a CTA-2045 compliant port to satisfy utility mass-market Direct Load Control (DLC) use cases in New York State. This demonstration focused on appliance types that are already commercially available from the manufacturer with a CTA-2045 port. The project stakeholders include NYSERDA, Electric Power Research Institute (EPRI), and utilities NYPA, ConEd, and Orange & Rockland. Prior to this project, these stakeholders have identified several appliances of most interest, some with more mature Demand Response (DR) use-cases than others. These appliances are as follows: electric resistive hot water heaters, residential electric vehicle service equipment (EVSE) (as opposed to fleet or charge-provider equipment), packaged terminal air conditioners (PTAC), mini-split heat pumps, and variable speed pool pumps.

The major tasks of this project include:

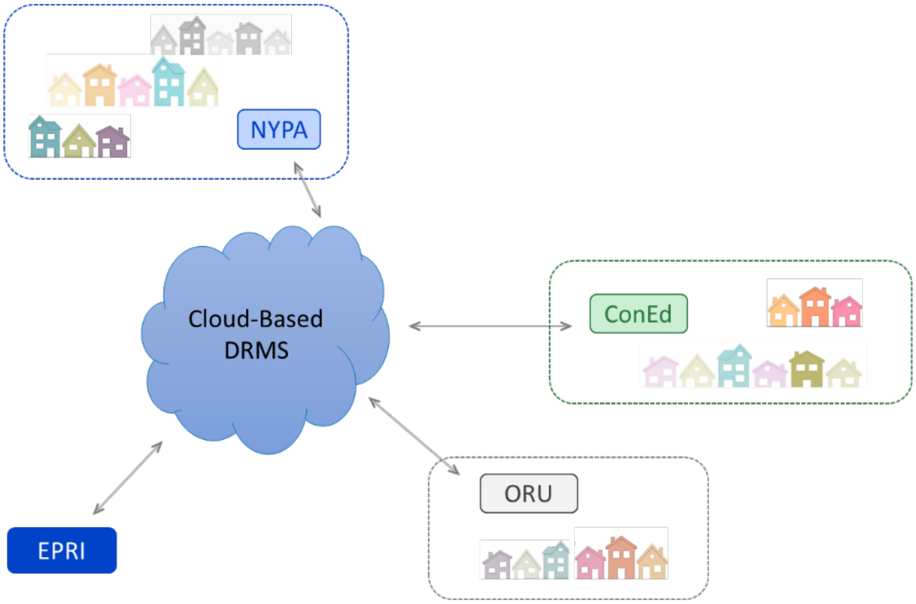
- Documentation of the utility participants' primary use cases of interest.
- Field demonstrations of the DLC use cases.
- Analysis showing the degree to which CTA-2045 supported those use cases, noting successes, gaps, lessons learned, and considerations for future deployments at scale.

Key objectives of the field demonstration project were:

- Demonstrate the viability of CTA-2045 appliances to satisfy utility use cases for direct load control.
- Accelerate the adoption of open standards and product availability.
- Provide guidance to manufacturers for developing their implementations.

NYPA, ConEd, and Orange & Rockland (ORU) identified their primary use cases and committed to an allotment of appliances to be installed at volunteer host sites. Each utility identified host sites and managed the devices in a cloud-based Demand Response Management System (DRMS) provided by SkyCentrics, a partner in the project and in the development of the CTA-2045 standard. This arrangement is depicted in Figure 2. Through a shared account, EPRI oversaw the activities and collected data but delegated control of devices to each participating utility. In this way, utilities were given the experience of using the controls and were able to provide useful feedback. EPRI provided training on the interface and periodic interim results throughout the field demonstration to maintain engagement with the utility participants and to obtain their feedback.

Figure 2. High-Level System View of the Field Demonstration



Appliance installations across all participants totaled 144 and were broken out by type as follows:

- 52 water heaters
- 50 EVSE
- 2 pool pumps
- 40 mini-split HVAC

NYPA recruited six municipal utilities who would participate in the program. These municipal utilities or munis, then recruited host sites within their territories. These municipal utilities and their number of appliance hosts are summarized in Table 2.

Table 2. NYPA's Participating Municipal Utilities and Their Number of Appliance Hosts

Utility	Appliances
Penn Yan	10 water heaters
Solvay	10 water heaters
Fairport	50 EVSE
Sherburne	10 water heaters
Jamestown	10 water heaters
Massena	10 water heaters

ConEd managed the host site recruiting on behalf of themselves and Orange & Rockland Utilities. Their appliance installations are given in Table 3.

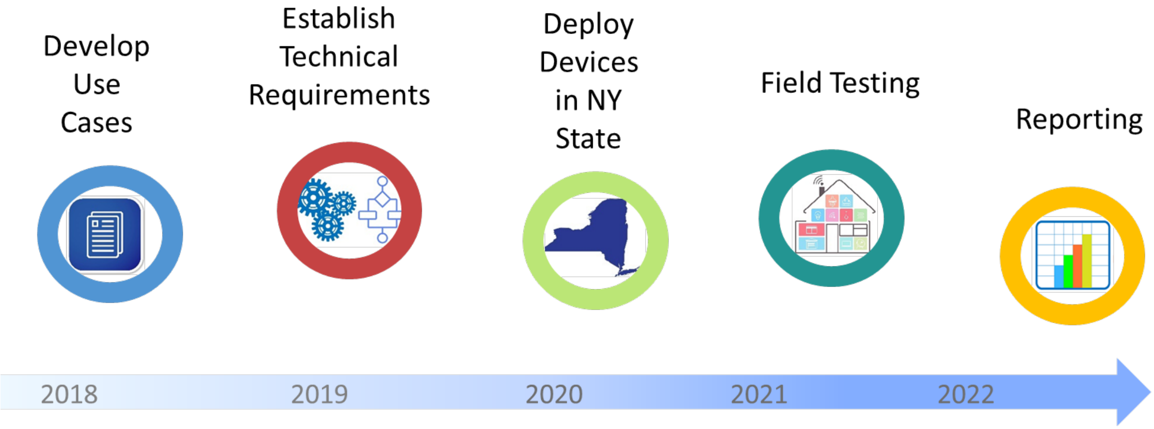
Appliances were installed by licensed installers and included new appliance warranties. Customers were given the option to register with SkyCentrics for access to their individual devices. Additionally, customers were informed how to override single DR events dispatched during the program.

Table 3. ConEdison's Number of Installed Appliances

Utility	Appliances
ConEd/ORU	40 mini-splits
ConEd/ORU	2 pool pumps
ConEd/ORU	2 water heaters

A timeline of the project is shown in Figure 3. Installations began in NYPA territory in early 2020 but were halted for approximately one year due to COVID-19, during which time, installers were prohibited from entering the homes of the volunteer hosts. When installations resumed, utilities began implementing their use cases as soon as their own devices came online even as installations continued. Nearly 1000 demand response events were executed in total. The final date of the field demonstration was Sept 30, 2022.

Figure 3. Timeline of the Demonstration Project



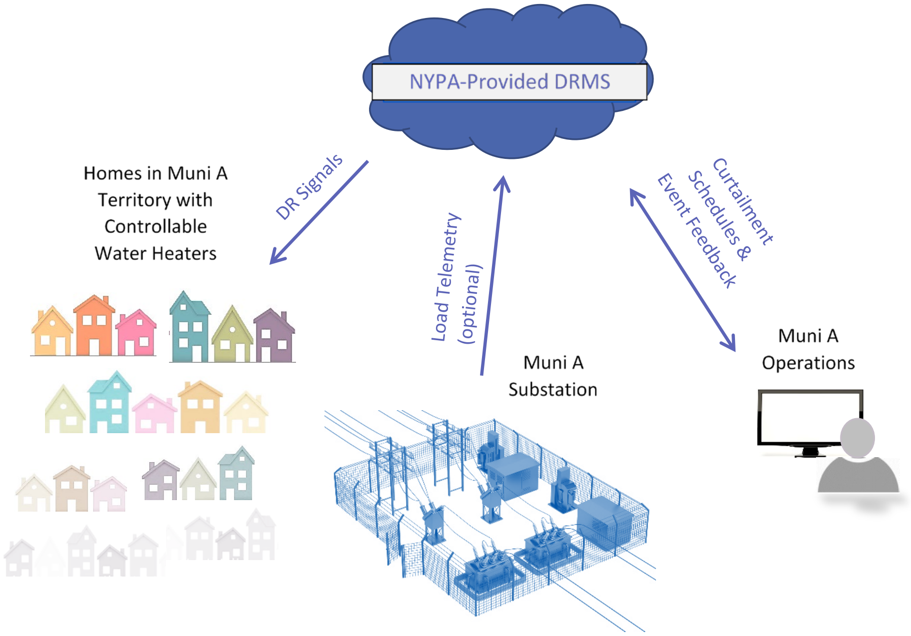
4 Use Case Development

EPRI developed a questionnaire and conducted phone interviews with participating utilities to assess the primary use cases for NYPA and ConEdison/ORU. The questionnaire was designed to help communicate the background, motivations, and details of desired use cases around direct load control. Details for each use case included issues of scale, curtailment levels, messaging, hours of operation, days of the week, seasonal variations, and so forth. Some of the responses were based on successful attributes of existing programs, while other input reflects what would be desired given the new capabilities offered by CTA-2045.

4.1 Use Case No. 1—New York Power Authority

A key motivation for NYPA's use cases is to give their municipal utilities tools to improve the effective management of hydro allocations during winter peaks. This motivation is passed to each of NYPA's more than 50 local municipal utilities who manage their own hydro allocations and pay demand penalties. One visionary concept is depicted in Figure 4 where NYPA is the aggregator for a DR program and the implementation is carried out by the municipal utilities. With NYPA as aggregator, even the small munis could participate because costs of enrollment and administration could be borne by NYPA.

Figure 4. Operational Concept Showing New York Power Authority as DR Aggregator



NYPA provided two distinct demand response use cases initially, one for water heaters and another for Packaged Terminal Air Conditioners (PTAC) at colleges and universities. However, because of a lack of host sites to carry out a PTAC demonstration, the use case was dropped, and the demonstration focused on water heater curtailment during winter peaks.

Low-cost electricity supplied by NYPA to municipal utilities has made electric water heaters a popular alternative over gas. A municipal utility's system peaks on cold winter nights impact their system capacity factor and therefore impact the use of their hydro allocations from NYPA.

Electric water heaters are examples of highly distributed loads that can be curtailed strategically with minimal impact to the consumer. A couple of NYPA's larger muni and coop customers have developed their own hot water heater direct load control (DLC) programs to realize an economic benefit by reducing demand during peaks and improving system capacity factor calculations. However, it is difficult for most muni and coops, due to their small size, to operate the many necessary facets of a DLC program.

In the proposed visionary scenario, NYPA offers a service to administer hot water heater DLC programs that assist munis and coops to proactively manage these loads to improve capacity factors. The hot water heater DLC program would be branded locally but be administered and operated by NYPA, operating on behalf of multiple municipal and coop utilities. NYPA would offer contract support, fulfillment, and consulting. In this central role, NYPA would help munis and coops realize economics of scale from:

- Centralized automation of digital interaction with the DLC end devices deployed with multiple participating muni and coop utilities. This would likely mean a single demand response automation server/platform to manage both the aggregation for DLC devices and customer interactions as through smart-home/smart-appliance Web portal or mobile device app. The platform could also be used to empower muni utility personnel with data on their loads and the demand response potential, even giving them the ability to schedule or call curtailment events.
- Central collection of real-time muni and coop substation load telemetry needed for prediction/identification of peak load events, creation, and execution of curtailment events.
- Standardizing modes of connectivity with end-use devices including Internet, cellular or power-line carriers backhauls as appropriate.
- Consolidation of other DR/DLC programmatic support activities including customer recruitment and onboarding, device fulfillment and subcontractor installation services, customer support and opt-in/opt-out interactions, device, and participate in performance reporting.
- The devices in multiple muni or coop territories, operated via a shared platform system can be aggregated for additional demand participation in the NYISO Special Case Resource program or a future dispatchable distributed energy resource participation model.

Additionally, below are some high-level estimates of what a muni's DLC hot water heater program might look like:

- Assume about 1,000 to 2,000 participating water heaters for ~1 MW of load curtailment potential per muni.
- Curtailment of water heaters would mainly occur at night or early morning during winter peaks for about four to six hours requiring heater curtailment through temperature reduction, coordinated duty cycling of the heating elements to OFF for periods of time.
- Consumers opt into the program and receive credits for participation.
- Curtailment can occur any day of week.
- Consumers receive notification via email or app notification six hours before impending events and can opt out of the current event.

4.2 Use Case No. 2—ConEd/Orange & Rockland

Consolidated Edison (ConEd) and Orange & Rockland (ORU) serve Manhattan and surrounding areas, characterized by high population density. ConEd/ORU described a use case of primary interest that is centered around residential cooling during summer peaks where residential mini-splits are seen as distributed loads for bulk system relief scenarios.

During the hot summer months in New York City and its suburbs, peak electrical demand often reaches a level that strains the bulk distribution system. As the heat of the day occurs, commuters return home, often to engage in cooking, which further increases the cooling load. The ORU territory along with Manhattan both have peaks around 2:00–6:00 p.m., where the other boroughs in ConEd territory have night peaks between 7:00 and 11:00 p.m. What is desired is a system-level relief scenario for the bulk distribution system. Local peaks exist in some regions of the grid but are more difficult to manage at the local level.

Both ConEd and ORU have implemented "Bring Your Own Thermostat" programs, wherein customers voluntarily enroll and thereby allow the utility to control their cloud-connected thermostats through vendor-specific aggregation portals. Examples are Nest and Honeywell thermostats, that have their own proprietary network. Additionally, ConEd has a Direct Load Control (DLC) program for window air conditioners that are outfitted with ThinkEco smart inline power switches. This gives ConEd the ability to simply turn off the AC units during peak times as needed through the ThinkEco cloud service. In both of these voluntary programs, customers receive financial incentive for participation.

Both ConEd and ORU are in experimental stages regarding control strategies that strike the best balance between benefit to the grid and customer retention in the programs. Because these programs are small-scale and in various stages of maturity, no single control method has yet taken a foothold in the DR space. A concern of utilities embarking on DLC programs is the lack of standardization, and therefore, the necessity to operate multiple proprietary aggregation portals. Utilities are interested in DR solutions that are portable (non-proprietary), reliable, scalable, and easy to implement.

As for existing DLC programs, utility system operators forecast the following day's peak demand 24 hours in advance. If the peak is expected to exceed 92% of the system design specification, the system operator notifies the DR team, who would then control the CTA-2045-enabled mini-split systems through the same head-end system that can address any type of appliance by any manufacturer as long as it meets the open-source CTA-2045 standard.

What is envisioned is a voluntary program where customers will receive a discount toward the purchase of a CTA-2045-enabled mini-split system. Further, customers will receive a financial benefit for allowing the utility to send shed events during the peak hours 2:00–6 p.m. or 7:00–11:00 p.m. depending on geography. Customers will receive 24-hour advanced notice of a pending curtailment event and can opt out of the event. The financial incentive, however, is tied to their participation in events.

Pre-cooling is an option that ORU currently uses in their DR program. This feature is enabled in the CTA-2045-enabled mini-splits as well.

5 Technical Requirements/Architecture

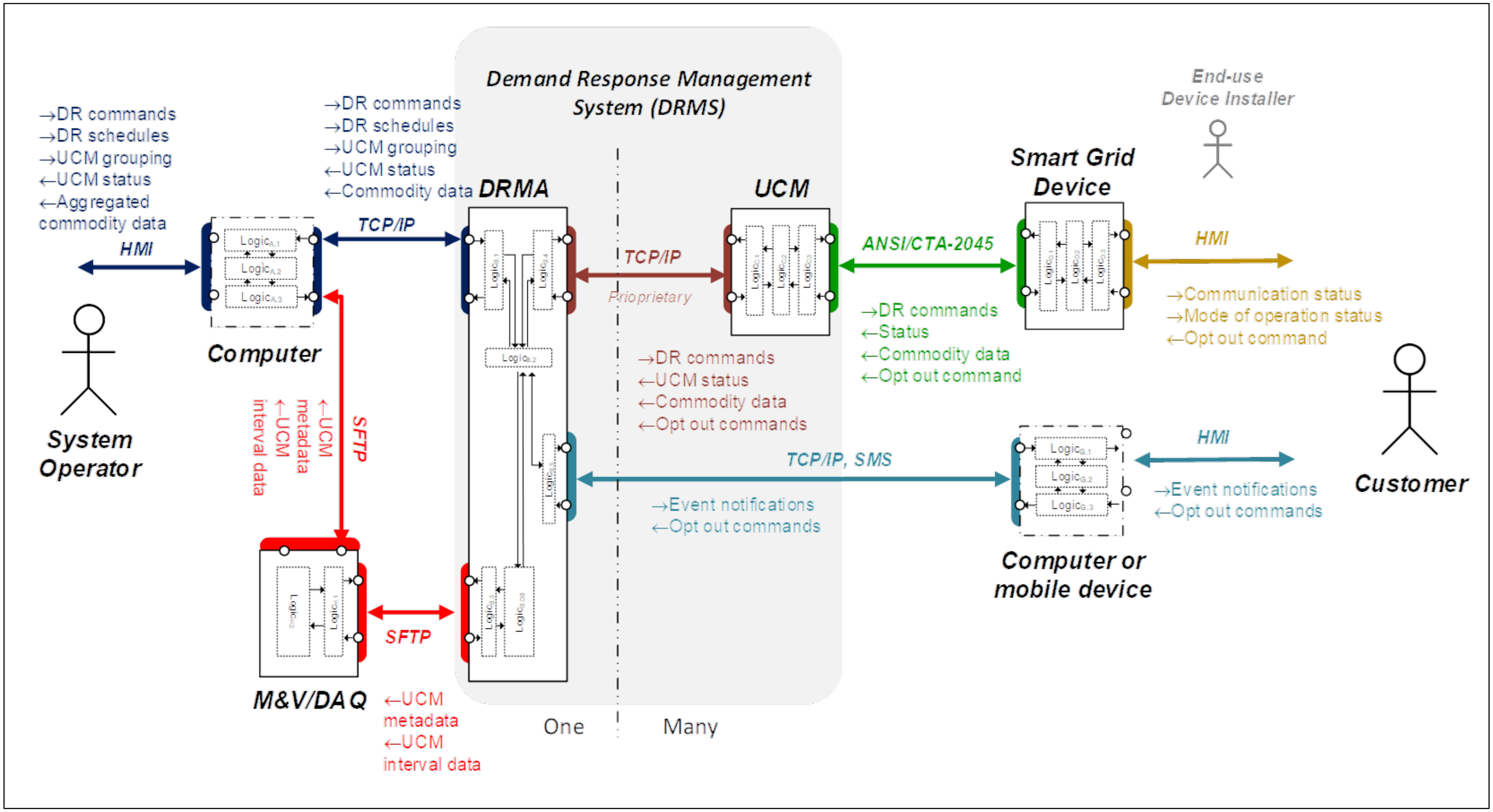
The hardware and software needed to create the end-to-end demand response system included multiple actors (appliance, module, home automation platform, utility application, etc.) and multiple applications to implement and analyze each of the use cases. In this chapter are diagrams that document the system architecture along with the minimum set of required instructions/data to be exchanged between the utility or other head-end system and the end-use device to implement each use case. The data exchange between each interface is documented along with the desired end-use device functions.

5.1 Demand Response Management System CTA-2045 Standard Configuration

The use cases identified by NYPA, ConEd/ORU share many similar operational characteristics, involving scheduled load shedding coincident with system peaks. Therefore, the architecture and information exchange are identical for each of the use cases.

The Demand Response Management System (DRMS) CTA-2045 configuration diagram is shown in Figure 5. The functional block diagram shows all human and machine actors that exchange information in order to implement the use cases. Beginning with the utility system operator, DR commands and queries will be interfaced through a local computer, which is connected to a cloud-based DRMS (provided by SkyCentrics). Interactions with the DRMS are made through a proprietary interface transferred over the Internet. The cloud-based portal communicates with many UCMs, which are individually assigned to customers. UCMS communicate with customer-hosted smart-grid devices through a physical CTA-2045 interface. Note that the way that the diagram groups the DRMS, it highlights the logical relationship rather than the physical relationship between DRMS and UCM. The customer can register for access to the cloud portal and can then opt in to receive event notifications. The customer may also override single events through the interface on the appliance (required in the CTA-2045 standard) or through the cloud portal.

Figure 5. DRMS CTA-2045 Configuration



The DRMS automatically sent 1-minute-interval historical data every 24 hours through Secure File Transfer Protocol (SFTP) to EPRI's database. In Figure 5, the system operator is shown to have access to this data because this would be a typical configuration, however, for the demonstration project, only EPRI had access to the historical data.

5.2 Demand Response Management System Account Structure

EPRI set up a DRMS account through vendor SkyCentrics. A single account was shared, where each participating utility had login credentials to manage their own devices. EPRI could also see into the account to assist with scheduling as requested and to analyze device responses to DR events. Additionally, customers hosting devices could optionally sign up for an account with SkyCentrics at no cost and use a freely available mobile app to view and control their own appliances in the cloud.

5.3 Metadata and Data Exchange

Each UCM has associated unique identifying metadata and supplies data at intervals specified by the DRMS. Interval data is polled from the DRMS to receive information which may include operational state, opt-out status, temperature setpoint (if applicable), instantaneous power, and so forth as defined in Table 4. Note that Table 4 is not a comprehensive list but gives an example of the data being exchanged. This data was logged at one-minute intervals and reported every 24 hours intervals through SFTP to a database managed by EPRI during this demonstration but would normally be managed by the utility for historical record.

Table 4. Example Device Data Definitions

Data Description	Definition
Timestamp	Date and time corresponding to the data recorded.
UCM On-line	For use to gain insight into network reliability.
SGD Not Communicating	Set if the SGD is unresponsive to any message after five minutes.
Basic Curtailment Command Opcode 1	Report Opcode 1 of the last command that was sent and acknowledged by SGD.
Basic Curtailment Command Opcode 2	Report Opcode 2 of the command recorded in "Basic Curtailment Command Opcode 2" data field.
Grid Service Active	Set to 1 when any of the Basic Curtailment Command is active.
Customer Override	Report status of customer override
Operational State	Report the result of operational state query in text.
Set Setpoint Units	When the Set Setpoint command is issued, report the unit of measure.
Set Setpoint 1	When the Set Setpoint command is issued, report the value for set point 1 that was set.
Set Setpoint 2	When the Set Setpoint command is issued, report the value for set point 2 that was set.
Get Setpoint Units	After the SGD is queried for its Setpoint, report the unit of measure.
Get Setpoint 1	After the SGD is queried for its setpoint, report the value offset point 1.
Get Setpoint 2	After the SGD is queried for its setpoint, report the value offset point 2.

6 Lab Testing of Smart Grid Devices

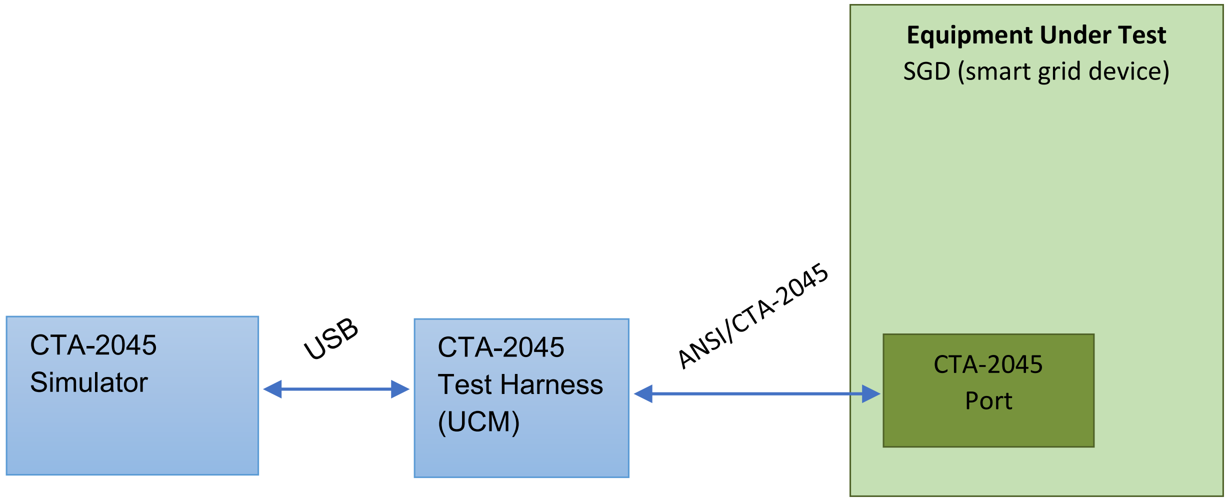
The purpose of these tests was to evaluate the SGD manufacturers' implementations of CTA-2045 so that the team would be aware of any compatibility issues. EPRI completed a laboratory evaluation of one of each of the SGD types that are part of the demonstration project. Tests were performed against a set of functional specifications written collaboratively by EPRI and approximately 12 electric utilities. A list of the relevant documents is shown in Table 5.

Table 5. Functional Requirement Documents for Smart Grid Devices

Smart Grid Device	Document Title	EPRI Document ID
EVSE	Demand Response-Ready Electric Vehicle Service Equipment Specification: Preliminary Requirements for CTA-2045 Field Demonstration.	3002002712
Water Heater	Demand Response-Ready Domestic Water Heater Specification: Preliminary Requirements for CTA-2045 Field Demonstration.	3002002710
Mini-Split and PTAC	Demand Response-Ready Programmable Packaged Terminal Air Conditioner Specification: Preliminary Requirements for CTA-2045 Field Demonstration.	3002006951
Pool Pump	Demand Response-Ready Variable-Speed Pool Pump Specification: Preliminary Requirements for CTA-2045 Field Demonstration.	3002008320

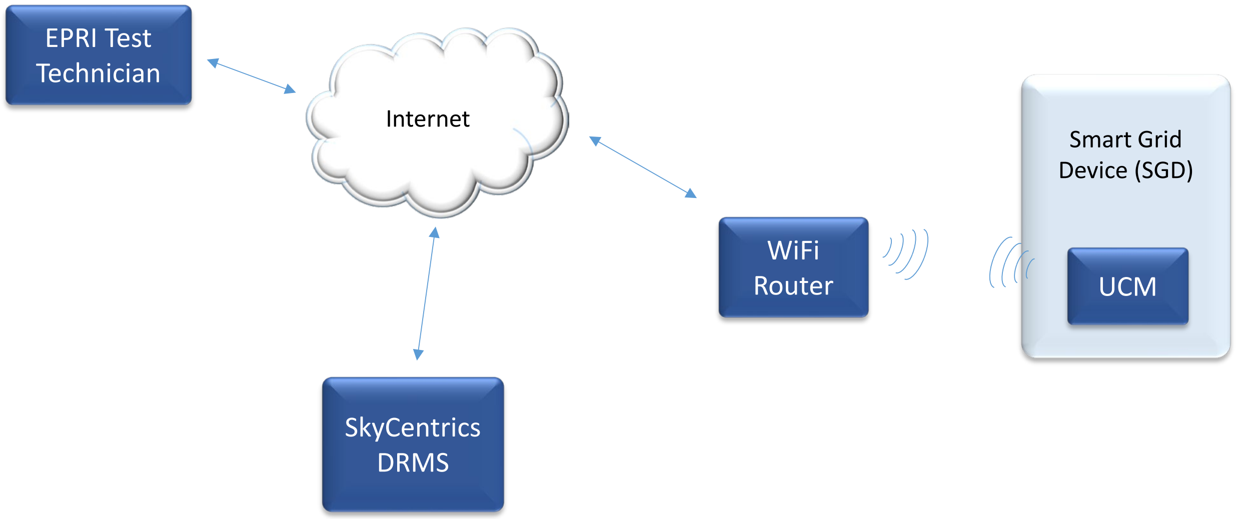
These functional specifications are defined by appliance type because of the operational differences among appliances. For example, thermostats have different functional objectives than pool pumps and therefore have different behaviors and responses. Despite the differences, all must conform to a common messaging protocol defined in CTA-2045. EPRI evaluated the functional requirements on each smart grid device using a CTA-2045 simulator which was configured to act in the role of DRMS. Messaging between the simulator and the SGD under test was reported for compliance against the standard. A generic test setup is shown in Figure 6. Summaries of the test results are given in the following sections.

Figure 6. Basic Test Setup for Functional Specification Tests



In addition to the verification of functional requirements, each SGD was paired with a wireless universal communications module and a cloud-based demand response management system DRMS by SkyCentrics. Each SGD was subjected to the suite of Basic CTA-2045 commands as defined in the standard. The setup is shown in Figure 7.

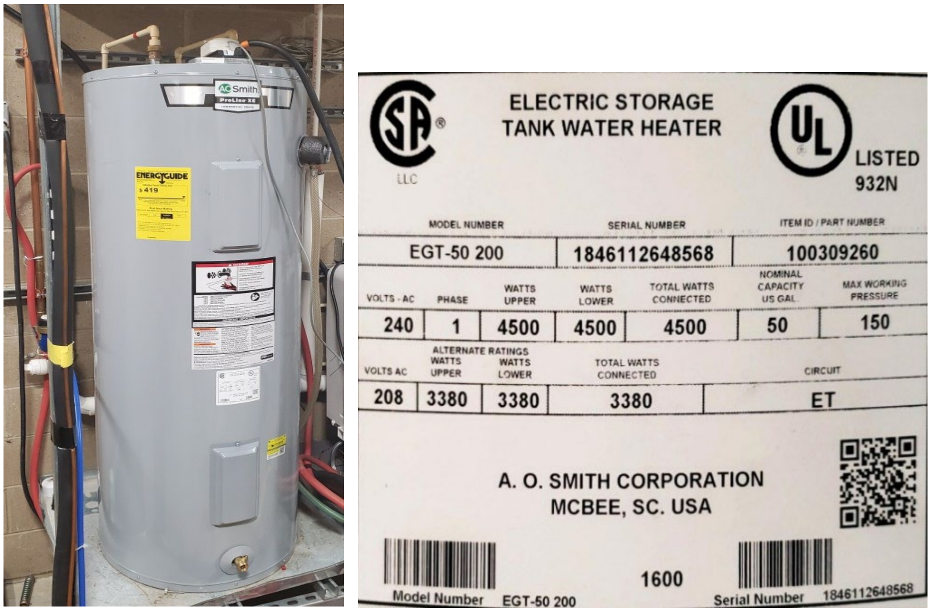
Figure 7. Test Setup for End-to-End Compatibility Tests



6.1 Lab Test Results for Electric Resistive Water Heater

EPRI tested AOSmith model EGT-50 (50-gallon residential water heater) with Gen 2 port adapter. The water heater was connected to power and water sources. An electronic valve was connected at the output in order to provide a controlled load for the water heater. The unit under test is pictured in Figure 8. Responses are summarized in Figure 9 followed by brief explanations of some of the more consequential outcomes.

Figure 8. Water Heater under Test



ELECTRIC STORAGE
TANK WATER HEATER

LISTED
932N

MODEL NUMBER	SERIAL NUMBER	ITEM ID / PART NUMBER
EGT-50 200	1846112648568	100309260

VOLTS - AC	PHASE	WATTS UPPER	WATTS LOWER	TOTAL WATTS CONNECTED	NOMINAL CAPACITY US GAL	MAX WORKING PRESSURE
240	1	4500	4500	4500	50	150

ALTERNATE RATINGS

VOLTS AC	WATTS UPPER	WATTS LOWER	TOTAL WATTS CONNECTED	CIRCUIT
208	3380	3380	3380	ET

A. O. SMITH CORPORATION
MCBEE, SC. USA

Model Number EGT-50 200

1600

Serial Number 1846112648568

Figure 9. Summary of Lab Test Results for AOSmith Water Heater

Mechanical, Electrical Comm. and Safety Requirements		
ME1	Size and Type	✓
ME2	Daily Contactor Switching	NA
ME3	Total Contactor Switching	NA
ME4	AC Form Factor	✓
ME5	Space Allocation for AC Form Factor	✓
ME6	UL 174 and Equivalent CSA	✓

User Interface Characteristics		
UI1	Successful Communication	✓
UI2	Curtailment in Effect	✓
UI3	Customer Event Override	✗
UI4	Two User-adjustable Temperature Set Points *(Optional)*	NA

Control Requirements		
C1	DR Event Timeout	✓
C2	Recovery after Power Cycle	✓
C3	Application ACK	✓
C4	Application NAK	✓
C5	Heartbeat	✓
C6	Return to Normal Operation	✓
C7	Shed Command	✓
C8	Critical Peak Event	✓
C9	Grid Emergency	✓
C10	Present Relative Price *(Optional)*	NA
C11	Autonomous Cycling and Terminate Cycling	✓
C12	Load Up	✓

Link-Layer Requirements		
LL1	Link ACK	✓
LL2	Link NAK	✓
LL3	Query & Response: Maximum Payload Length	64 bytes
LL4	Message Type Supported Query & Response	✓

Monitoring Requirements		
M1	Maximum Data Refresh Time	✓
M2	Customer Override	✗
M3	Operational State Query & Response	!
M4	Query & Response: Info Request	!
M5	Get/Set Commodity Read Request and Reply	✓

Key for Worksheet	
✓	The unit passed the test with no issues.
!	Unusual finding or non-ideal behavior occurring outside of the expected performance envelope; consult with the test report for more information.
✗	The unit had failed the test; see comments for more details.
NA	Not Available.

Requirements UI3 and M2 test for compliance with the customer override feature. These are the only important compliance exceptions reported for the water heater. The reason for the exceptions has to do with AO Smith choosing to mainstream a low-cost version of their CTA-2045 water heater. Formerly, the CTA-2045 option was only available in their higher-end models with user controls on a front panel. In the low-cost EGT-50 model, there is no interface and thus no means for the user to override events. According to the CTA-2045 specification, a physical means for customer override on the appliance is required. For field demonstration purposes, a user can still override events through the SkyCentrics portal, if the customers choose to create an account. An unexpected result occurred when the water heater was sent a Load-up event. The expected operational states are Running Heightened Grid or Idle Heightened. However, the operational state reported by the water heater was Heightened Grid or Idle Grid, when the Load-up event occurred.

For an end-to-end system verification, a set of curtailment events was scheduled in the DRMS, and the response was observed in the same DRMS portal. First, a baseline is shown in Figure 10, where the timed valve was set to dump water every fifteen minutes. This kept the tank heaters operating regularly over a 12-hour observation period. The brown trace represents instantaneous watts, showing a cycling pattern as the heaters switch on and off. A curtailment schedule is shown in Table 6 and the water heater's corresponding response is graphed in Figure 11. The SGD performed as expected, except that for the load-up event, which terminated after 46 minutes in a 119-minute event.

Figure 10. Example of Normal Operation

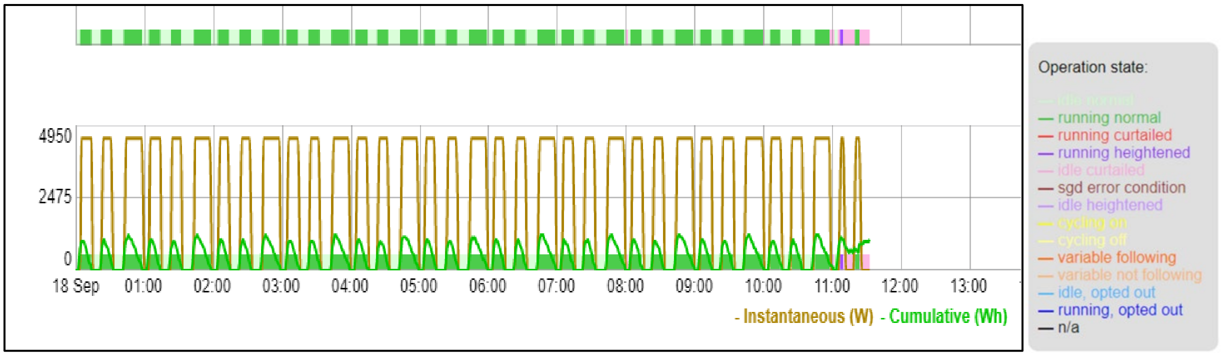


Table 6. Curtailment Schedule for Electric Resistive Water Heater

Event Number	Time	Duration (Minutes)	Event Type
1	20:00	119	Shed
2	23:00	119	Grid Emergency
3	3:00	120	Critical Peak Event
4	6:00	119	Load UP

Figure 11. Water Heater Response to Scheduled Events

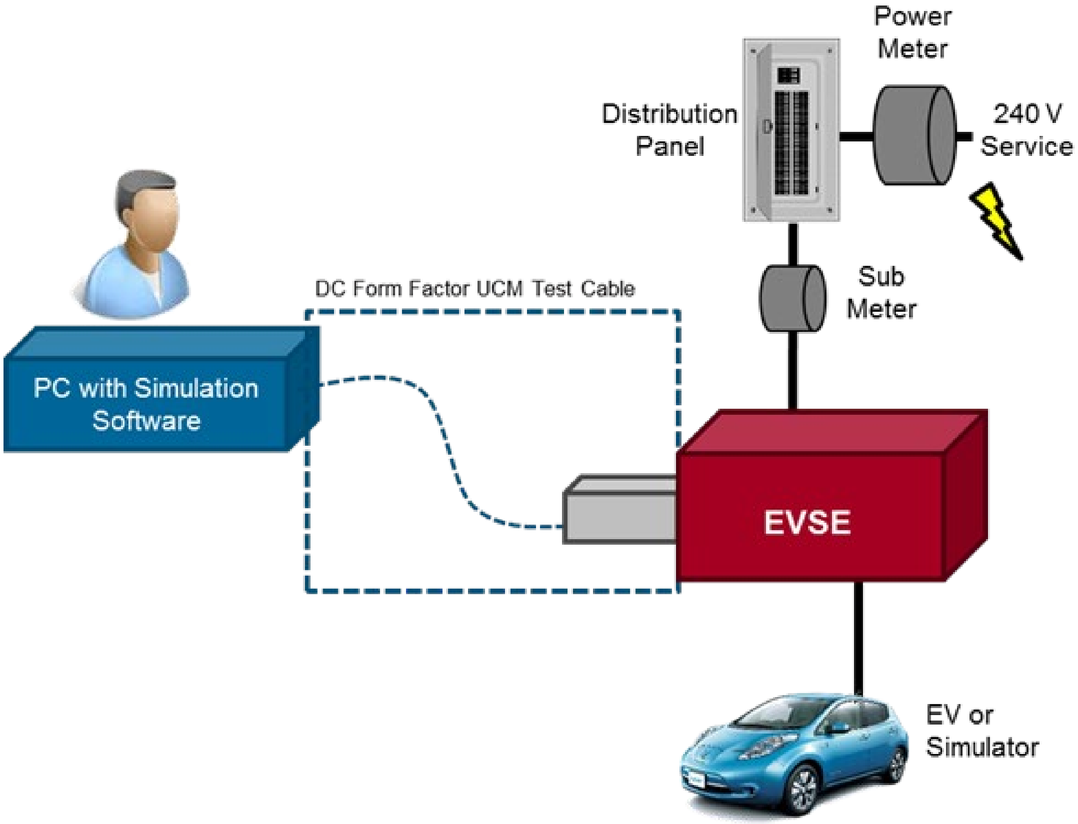
6.2 Lab Test Results for Electric Vehicle Supply Equipment

The test setup for EVSE included a 240 Volts Alternating Current (VAC) supply for the equipment under test as shown in and an electric vehicle simulator in place of an actual electric vehicle (Figure 13). A block diagram of the setup is shown in Figure 14.

Figure 12. Electric Vehicle Supply Equipment Under Test

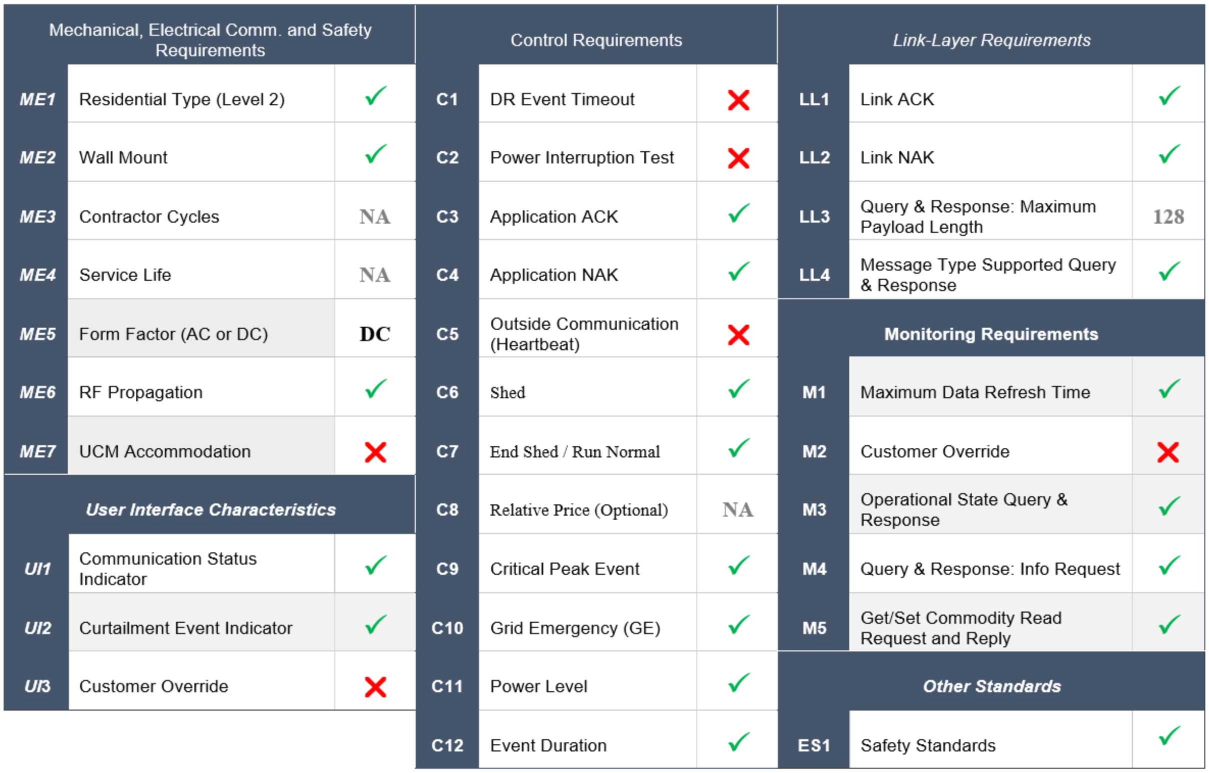
Figure 13. Electric Vehicle Simulator

Figure 14. Block Diagram for Electric Vehicle Supply Equipment Tests



Responses are summarized in Figure 15 followed by brief explanations of some of the more consequential outcomes.

Figure 15. Summary of Lab Test results for Siemens Electric Vehicle Supply Equipment



Mechanical, Electrical Comm. and Safety Requirements		
ME1	Residential Type (Level 2)	✓
ME2	Wall Mount	✓
ME3	Contractor Cycles	NA
ME4	Service Life	NA
ME5	Form Factor (AC or DC)	DC
ME6	RF Propagation	✓
ME7	UCM Accommodation	✗

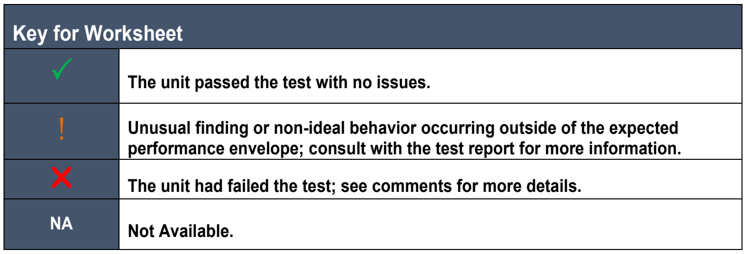
User Interface Characteristics		
UI1	Communication Status Indicator	✓
UI2	Curtailment Event Indicator	✓
UI3	Customer Override	✗

Control Requirements		
C1	DR Event Timeout	✗
C2	Power Interruption Test	✗
C3	Application ACK	✓
C4	Application NAK	✓
C5	Outside Communication (Heartbeat)	✗
C6	Shed	✓
C7	End Shed / Run Normal	✓
C8	Relative Price (Optional)	NA
C9	Critical Peak Event	✓
C10	Grid Emergency (GE)	✓
C11	Power Level	✓
C12	Event Duration	✓

Link-Layer Requirements		
LL1	Link ACK	✓
LL2	Link NAK	✓
LL3	Query & Response: Maximum Payload Length	128
LL4	Message Type Supported Query & Response	✓

Monitoring Requirements		
M1	Maximum Data Refresh Time	✓
M2	Customer Override	✗
M3	Operational State Query & Response	✓
M4	Query & Response: Info Request	✓
M5	Get/Set Commodity Read Request and Reply	✓

Other Standards		
ES1	Safety Standards	✓



Key for Worksheet	
✓	The unit passed the test with no issues.
!	Unusual finding or non-ideal behavior occurring outside of the expected performance envelope; consult with the test report for more information.
✗	The unit had failed the test; see comments for more details.
NA	Not Available.

For requirements UI3 and M2 regarding the customer's ability to generate an event override from the front panel of the SGD, the EVSE fails the customer override as the Siemens EVSE lost its override functionality with a firmware update to the latest version at the time of testing, which was 3.0. The EVSE requires a specific way to initiate communications using the CTA-2045 simulator, first request max payload must be requested. After max payload is requested and accepted, the EVSE can accept other start-up requirements. However, when changing the state of the EVSE from "standby" to "charge" or from "charge" to "standby," the EVSE loses all communication acknowledgments by sending timeout NAK until several minutes after the state has changed. This is unique, as other SGDs don't have the issue. It takes many attempts to reconnect the communication, but once the user is able to reestablish the Max Payload request and acknowledges it, the EVSE communications are stable.

During the end-to-end system compatibility test, the EVSE would appear to cycle intermittently as if it had been reset. EPRI contacted both Siemens and SkyCentrics to troubleshoot the issue. The team determined that a recent board revision on the EVSE coupled with a firmware update had introduced the error that did not exist in previous versions. An example response is shown in Figure 16 where a power (brown trace) appears to cycle on and off. However, instrumentation connected to the EVSE input during the same test shows that the cycling did not occur (see Figure 17).

Figure 16. Power Data Reported by Siemens EVSE to the DRMS Portal during a Curtailment Event

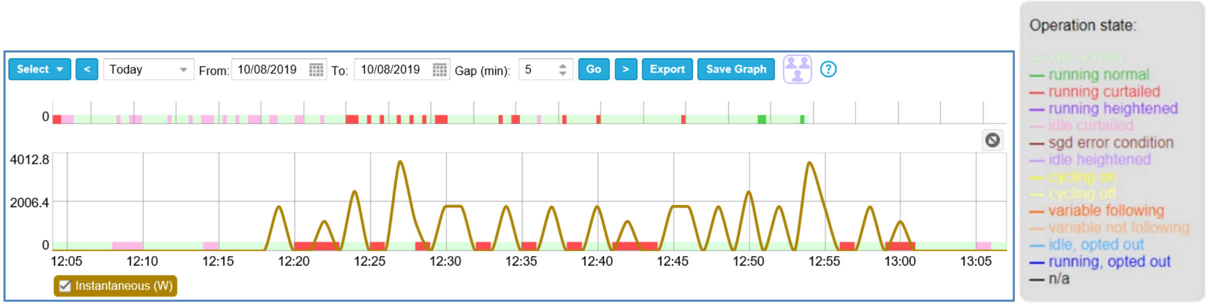


Figure 17. Power Data from Instrumentation

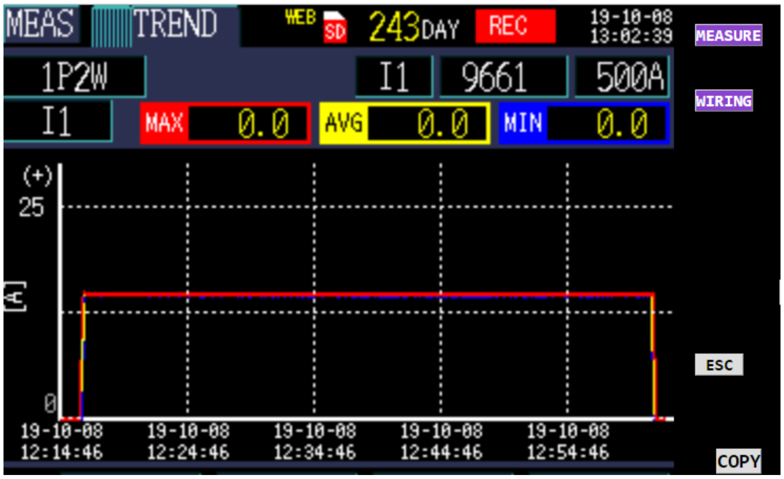
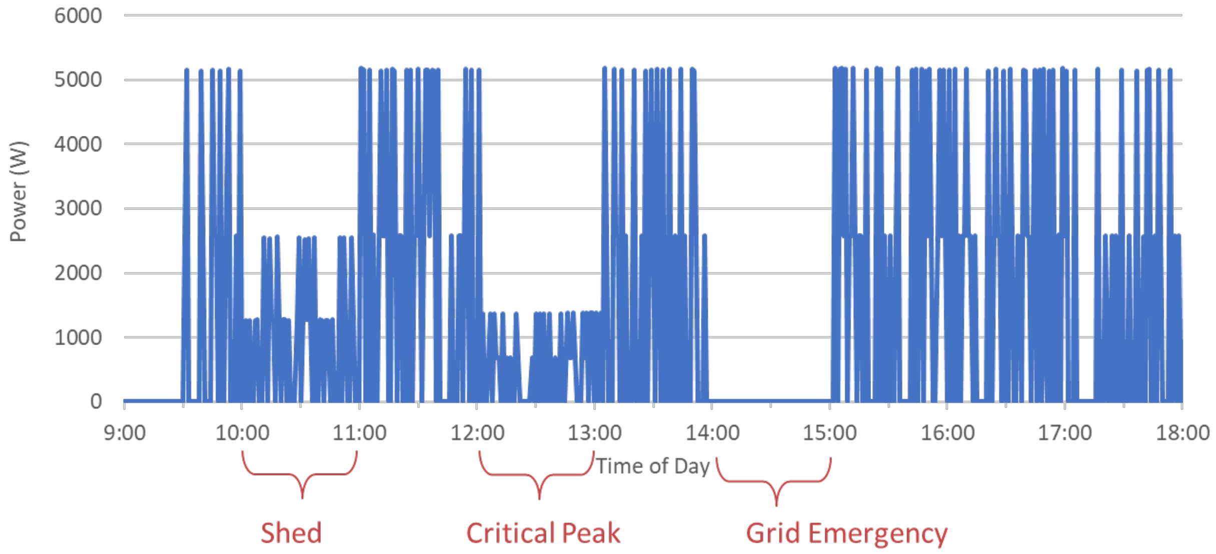


Figure 18 shows a sequence of eight Shed events of varying duration. The schedule was set up to occur for two Siemens EVSEs. One EVSE was connected to an EV simulator while the other was idle. Note that the two EVSEs did not respond to every event and they each responded differently to the events. The green indicators are expected to be solid over time but appear to be intermittent. Similarly, during curtailment, the expectation is a solid pink, meaning idle curtailed (parking lot EVSE) or red, meaning running curtailed (the EVSE with simulator). These reporting errors are the result of a messaging incompatibility between the Siemens and the SkyCentrics system. Although both manufacturers attempted to troubleshoot and understand the issue, neither was able to commit the resources to resolve it.

Figure 18. EVSE Responses to a Sequence of Scheduled Events

Figure 19. EVSE Indication of Power during Curtailment Events



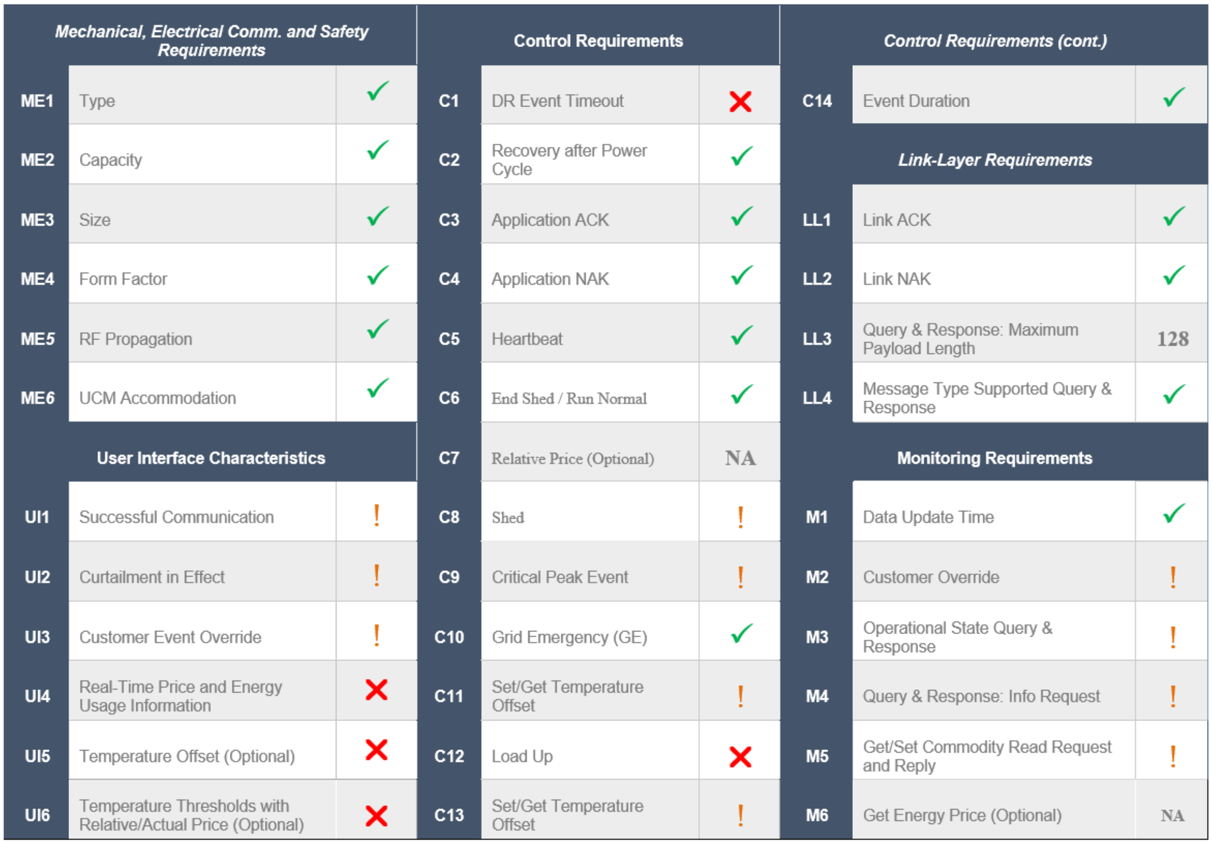
Nominal power: 5.2kW
Power during shed: 2.5kW (~50%)
Power during critical peak: 1.4kW (~25%)
Power during grid emergency 0 kW (0%)

Figure 19 again shows that the power data communicated from the EVSE to the SkyCentrics system contains extraneous zeros, making the power appear to cycle on and off. Despite this non-ideal result, the team decided to move forward with the deployment because the curtailment events were still discernible in the data if the duration of the observation is at least one hour.

6.3 Lab Test Results for Mini-Split HVAC System

The two-piece mini-split system was mounted on a portable rack and was tested indoors as a system. Loading the system or installing it in a thermal chamber was not necessary, as the evaluation criteria are related to messaging and response rather than heating or cooling performance. Responses are summarized in Figure 20 followed by brief explanations of some of the more consequential outcomes.

Figure 20. Lab Test Results for the Mini-Split HVAC System



Mechanical, Electrical Comm. and Safety Requirements			Control Requirements			Control Requirements (cont.)		
ME1	Type	✓	C1	DR Event Timeout	✗	C14	Event Duration	✓
ME2	Capacity	✓	C2	Recovery after Power Cycle	✓	Link-Layer Requirements		
ME3	Size	✓	C3	Application ACK	✓	LL1	Link ACK	✓
ME4	Form Factor	✓	C4	Application NAK	✓	LL2	Link NAK	✓
ME5	RF Propagation	✓	C5	Heartbeat	✓	LL3	Query & Response: Maximum Payload Length	128
ME6	UCM Accommodation	✓	C6	End Shed / Run Normal	✓	LL4	Message Type Supported Query & Response	✓
User Interface Characteristics			C7	Relative Price (Optional)	NA	Monitoring Requirements		
UI1	Successful Communication	!	C8	Shed	!	M1	Data Update Time	✓
UI2	Curtailment in Effect	!	C9	Critical Peak Event	!	M2	Customer Override	!
UI3	Customer Event Override	!	C10	Grid Emergency (GE)	✓	M3	Operational State Query & Response	!
UI4	Real-Time Price and Energy Usage Information	✗	C11	Set/Get Temperature Offset	!	M4	Query & Response: Info Request	!
UI5	Temperature Offset (Optional)	✗	C12	Load Up	✗	M5	Get/Set Commodity Read Request and Reply	!
UI6	Temperature Thresholds with Relative/Actual Price (Optional)	✗	C13	Set/Get Temperature Offset	!	M6	Get Energy Price (Optional)	NA

Key for Worksheet	
✓	The unit passed the test with no issues.
!	Unusual finding or non-ideal behavior occurring outside of the expected performance envelope; consult with the test report for more information.
✗	The unit had failed the test; see comments for more details.
NA	Not Available.

REQ.C13–Set/Get Setpoint: The CTA-2045 simulator successfully manipulates setpoint and it pulls the correct setpoint from the SGD. However, the user interface of the remote control shows no sign of change when the setpoint is manipulated. This can make the user unaware of any curtailment or change in their system. The user may think the device isn't working properly or defective.

REQ.M5–Get/Set Commodity: The commodity of the SGD data pulled showed only a value of 0 for each of the following categories, Electricity Consumed, Total Energy Storage, and Present Energy Storage.

For an end-to-end system verification, a set of curtailment events was scheduled in the DRMS and the response observed in the DRMS portal. The curtailment schedule is shown in Table 7 and the response is graphed in Figure 21. The response shows three graphs that are reported in the SkyCentrics portal. The top graph is for power, measured in watts. There is no data in this graph because the mini-split does not report power. Mitsubishi is an early implementer of CTA-2045 but did so without hardware design changes to their off-the-shelf product. Reporting the device power consumption would require additional hardware, which may be a future consideration. The bottom graph in Figure 21 shows the temperature setpoints (heating and cooling setpoints are maintained separately) responding to the curtailment events by shifting +/- 2 degrees Fahrenheit.

Table 7. Curtailment Schedule for Electric Vehicle Supply Equipment

Event	Start	End
Shed	12:00 pm	2:00 pm
Critical Peak	3:00 pm	4:00 pm
Load Up	6:00 pm	8:00 pm
Grid Emergency	9:00 pm	11:00 pm

Figure 21. Mitsubishi Mini-Split Response to Scheduled Events

The key takeaway is that the mini-split does not report power. Instead, like other thermostat-controlled CTA-2045 devices, it reports temperature setpoints. The effect on the current field demonstration is that the data analysis for the mini-splits was different than that of the water heater and EVSE, both of which report power in watts.

6.4 Lab Test Results for Variable Speed Pool Pump

The pool pump was connected to a 240V AC source, a small water tank, and a closed plumbing loop for circulation. The test setup is shown in Figure 22. The unit under test is the IntelliConnect pool pump controller, the open gray box at the top of the photo. The pump itself is one of several that are compatible with this controller. Pentair provided this new version of their controller to EPRI for evaluation in May 2022. The controller had been newly approved by UL. Previous versions of Pentair's IntelliConnect had already been evaluated and were known to comply with the CTA-2045 messaging protocol. The lab test results are summarized in Figure 23 and the impactful results are described in the following paragraphs.

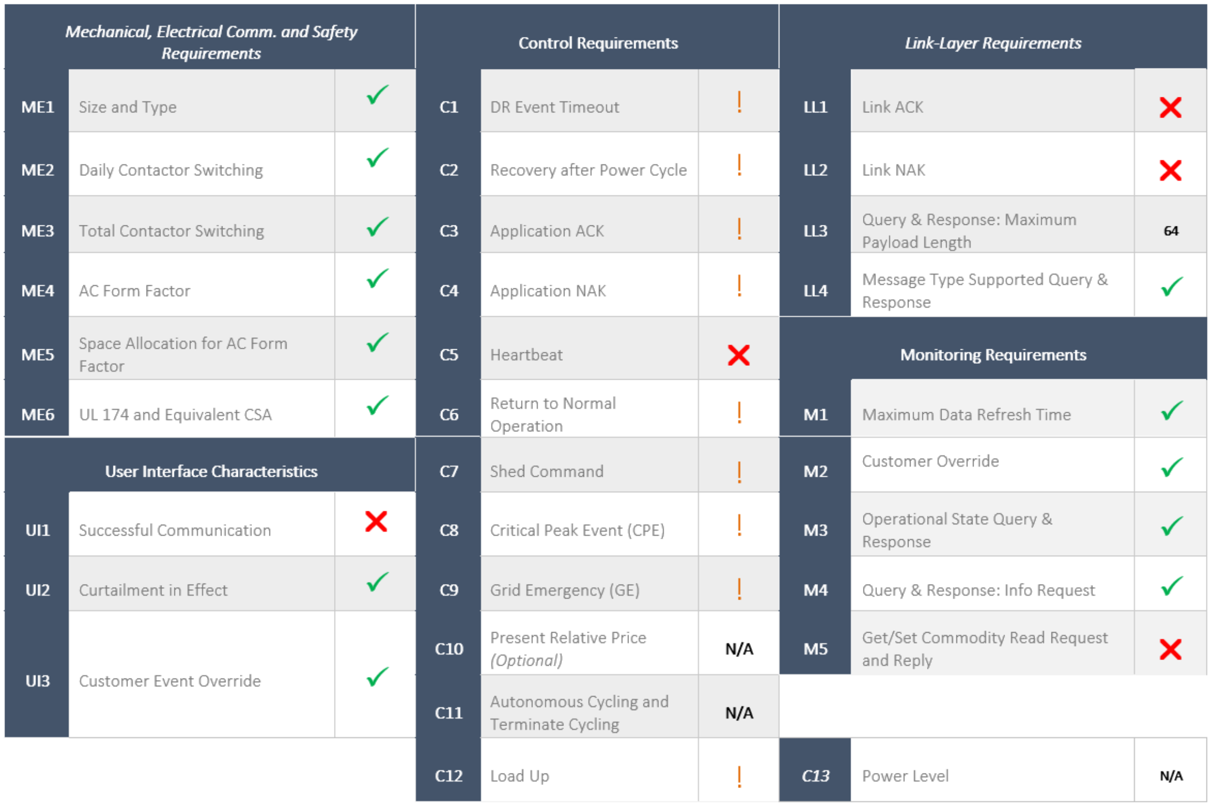
Figure 22. Lab Test Setup for Pool Pump Controller

The pool pump controller received shed commands and responded by reducing the pump's speed as expected. Most issues occurred related to the acknowledgement of commands. The capability mapping showed that the pool pump should support commodity, cycling, and power-level functions. However, the pool pump would not acknowledge these requests. The pool pump didn't acknowledge various signals of the heartbeat, nor did it return to normal operation after a period of 15 minutes when the heartbeat was no longer present.

If speed was set lower than 1100 RPM when a curtailment command was received, the pool pump used the last known speed setpoint to satisfy the event. This is not the expected behavior. For example, if the pool pump was initially operating at 2000 RPM then changed to 1000 RPM, a shed event will cause the speed to change from 1000 to 2000 RPM. This behavior occurs for operation lower than the threshold of 1100 RPM.

A critical peak event turns off the pool pump rather than reducing RPM. To recover, the user must manually restart the pool pump/schedule. The operational state of the pool pump shows the pump is in Idle Normal during the critical peak.

Figure 23. Lab Test Results for Pool Pump Controller



Mechanical, Electrical Comm. and Safety Requirements		
ME1	Size and Type	✓
ME2	Daily Contactor Switching	✓
ME3	Total Contactor Switching	✓
ME4	AC Form Factor	✓
ME5	Space Allocation for AC Form Factor	✓
ME6	UL 174 and Equivalent CSA	✓

User Interface Characteristics		
UI1	Successful Communication	✗
UI2	Curtailment in Effect	✓
UI3	Customer Event Override	✓

Control Requirements		
C1	DR Event Timeout	!
C2	Recovery after Power Cycle	!
C3	Application ACK	!
C4	Application NAK	!
C5	Heartbeat	✗
C6	Return to Normal Operation	!
C7	Shed Command	!
C8	Critical Peak Event (CPE)	!
C9	Grid Emergency (GE)	!
C10	Present Relative Price *(Optional)*	N/A
C11	Autonomous Cycling and Terminate Cycling	N/A
C12	Load Up	!

Link-Layer Requirements		
LL1	Link ACK	✗
LL2	Link NAK	✗
LL3	Query & Response: Maximum Payload Length	64
LL4	Message Type Supported Query & Response	✓

Monitoring Requirements		
M1	Maximum Data Refresh Time	✓
M2	Customer Override	✓
M3	Operational State Query & Response	✓
M4	Query & Response: Info Request	✓
M5	Get/Set Commodity Read Request and Reply	✗
C13	Power Level	N/A

Key for Worksheet	
✓	**The unit passed the test with no issues.**
!	**Unusual finding or non-ideal behavior occurring outside of the expected performance envelope; consult with the test report for more information.**
✗	**The unit had failed the test; see comments for more details.**
NA	**Not Available.**

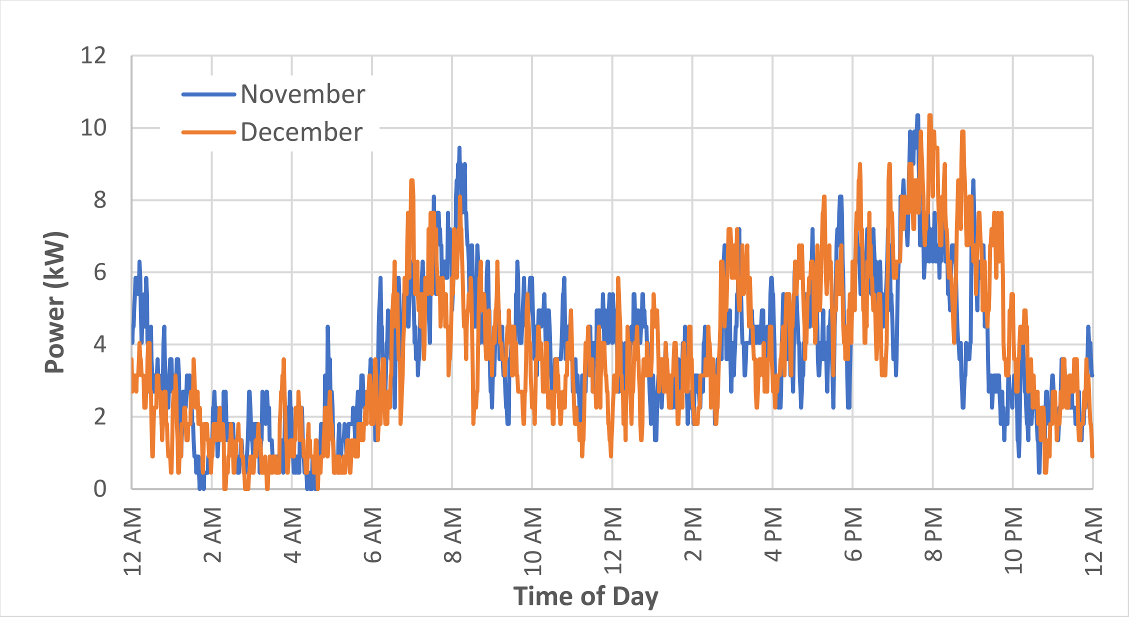
7 Field Test Results

The field demonstration occurred over approximately two years (including a delay caused by COVID-19) and included hundreds of demand response events. This chapter highlights only the test results that contributed to key takeaways or lessons learned. Appliance type had more to do with learnings than any other factor, so the discussion in this chapter is organized by appliance type, beginning with water heaters.

7.1 Water Heaters

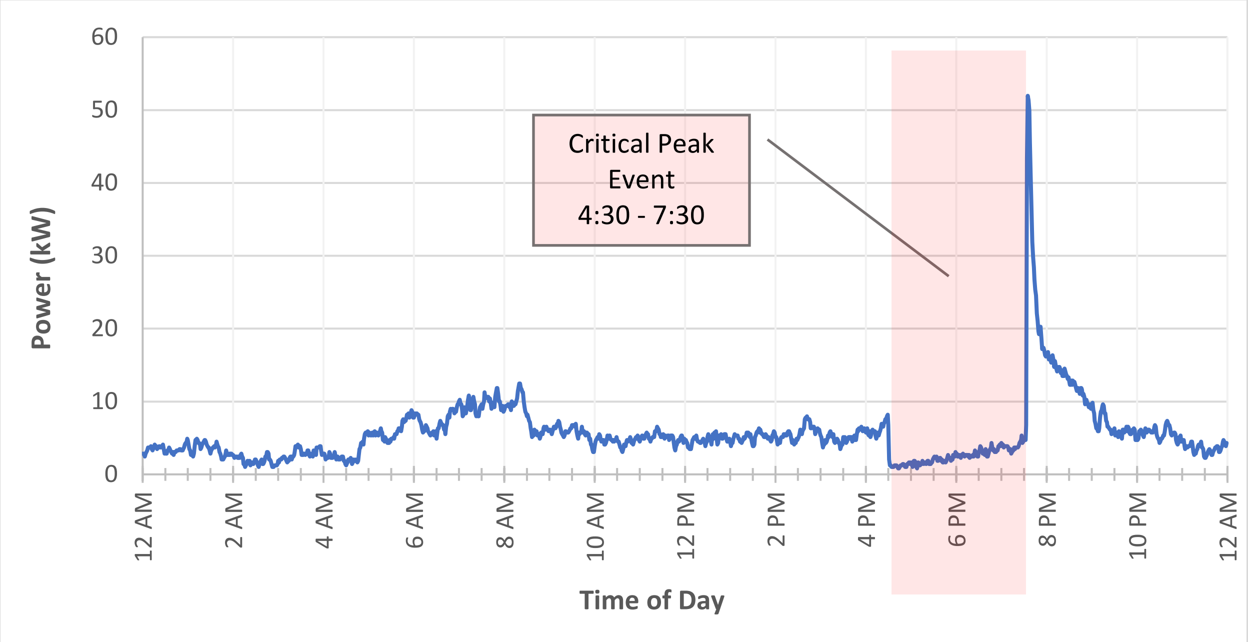
Recall that water heaters were dispersed among five municipal utilities in NYPA territory. Each muni installed 10 water heaters and controlled its water heaters independently of the other munis. An exception were the cases of Penn Yan and Solvay, which were combined, with 20 water heaters controlled in one group. Figure 24 shows the baseline response for water heaters in NYPA's Penn Yan and Solvay territories during weekdays in November and December 2021. In this graph, 15 of 20 water heaters were reporting. The data is averaged over 10 weekdays in November (the blue trace) and 10 weekdays in December (the orange trace). The result shows a morning peak power draw between 7:00 and 8:30 a.m. and another peak in the evening between 6:30 and 9:00 p.m. Because these usage peaks coincide with system peaks during the winter, there is alignment with NYPA's use case for winter peak shaving.

Figure 24. Baseline Response for Water Heaters November and December 2021



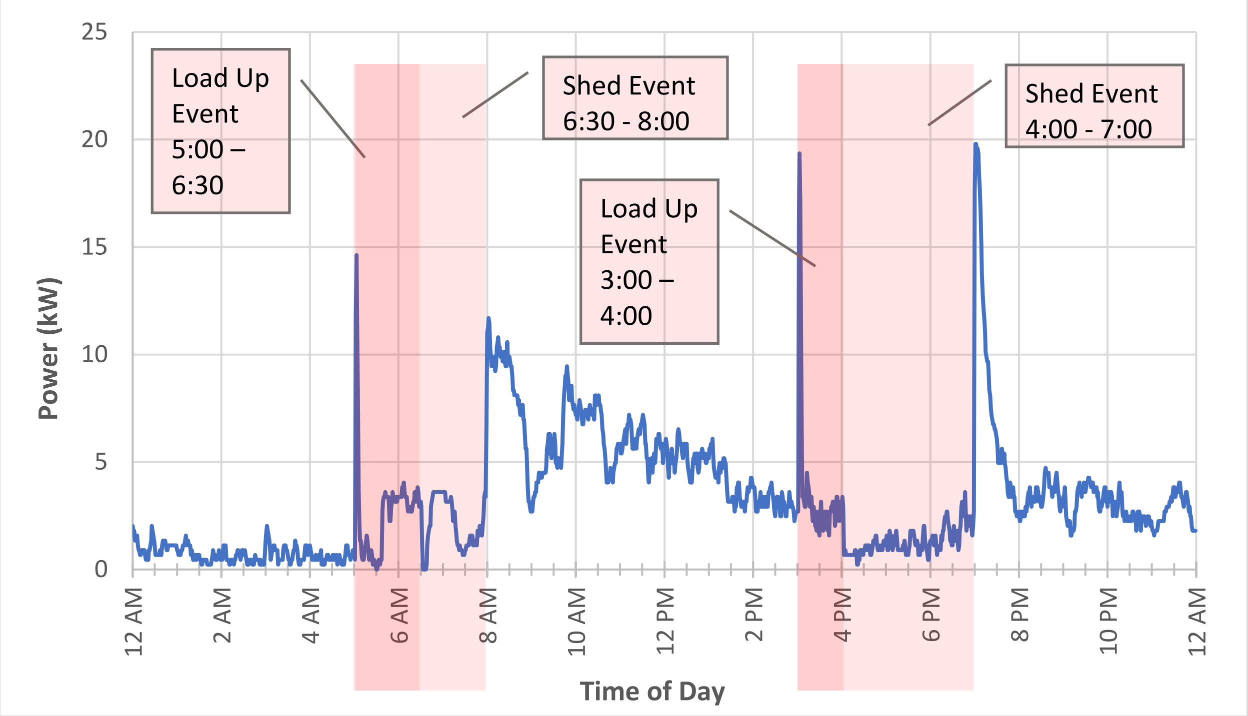
The curtailment commands in CTA-2045 are Shed, Critical Peak, and Grid Emergency, in order of least aggressive to most aggressive (refer to Table 1). The water heater responses to a Critical Peak event are shown in Figure 25 for an event beginning at 4:30 p.m. and ending at 7:30 p.m. Notice that the water heaters responded immediately to the event and initially served customers with stored heat. As the event went on, however, power consumption was gradually increased as the algorithm in the water heater balanced the dispatched grid service with customer comfort. At 7:30 p.m., the event ended, and all water heaters turned on simultaneously to restore tank temperature to the customers' setpoints. While the evening peak was successfully reduced, a new peak occurred immediately after the event that was roughly five times the baseline evening peak. The team exercised two different strategies to reduce this peak, often called "rebound" or "snapback."

Figure 25. Water Heater Response to Evening Critical Peak Event



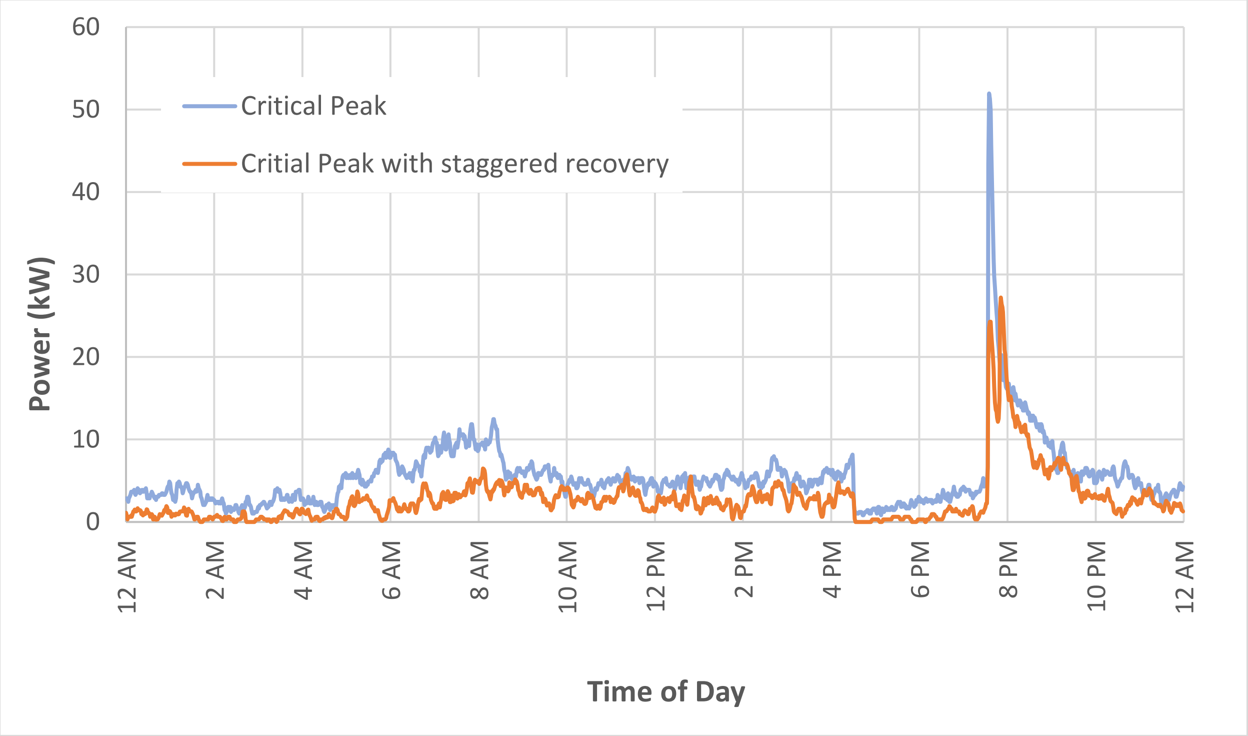
The first of two strategies that attempt to deal with the high peak after a curtailment event involved the use of the CTA-2045 Load-up command, which instructs the water heaters to turn on immediately if they have any reserve capacity to store energy. The Load-up command would prepare the water heaters for a shed command and possibly reduce the peak that occurs at the end of the shed command. An example result from this strategy is shown in Figure 26. The afternoon Load-up event occurs from 3:00 to 4:00 p.m. followed by a Shed event from 4:00 to 7:00 p.m. Note that the data in Figure 26 is from Jamestown, NY, having half the number of water heaters as compared to the prior two figures. Visually, one can observe that the 20 kilowatts (kW) peaks occurring at the beginning and end of the events are roughly four times the baseline of 5 kW. The result suggests that a Load-up followed by Shed was not an effective strategy for reducing the magnitudes of the artificially created peaks in this instance. However, Load-up could effectively reduce the peak that occurs after Shed, but only if the duration of Shed is sufficiently short and if Load-up is also short. Note that the one-hour Load-up in Figure 26 was much longer than necessary for the tanks to respond. Because Load-up was in effect for another 45 minutes after the tanks had responded, its effectiveness was reduced.

Figure 26. Water Heater Responses to Load-up Followed by Shed



A second strategy was employed where the turn-on after the Shed command was applied in two stages. The two-stage recovery was set up by dividing the total number of water heaters into two groups, each group being half the number of available water heaters, and then extending the curtailment for an additional 15 minutes for the second group. The result is shown in Figure 27 where the blue trace represents the baseline case with Critical Peak only (this is the same data shown in Figure 25) compared to a staggered recovery for the same type of event, Critical Peak, during the same afternoon time period, 4:30 to 7:30 p.m. Note that the 50 kW peak was effectively reduced to two 25 kW peaks. This was a more effective strategy than the Load-up followed by Shed.

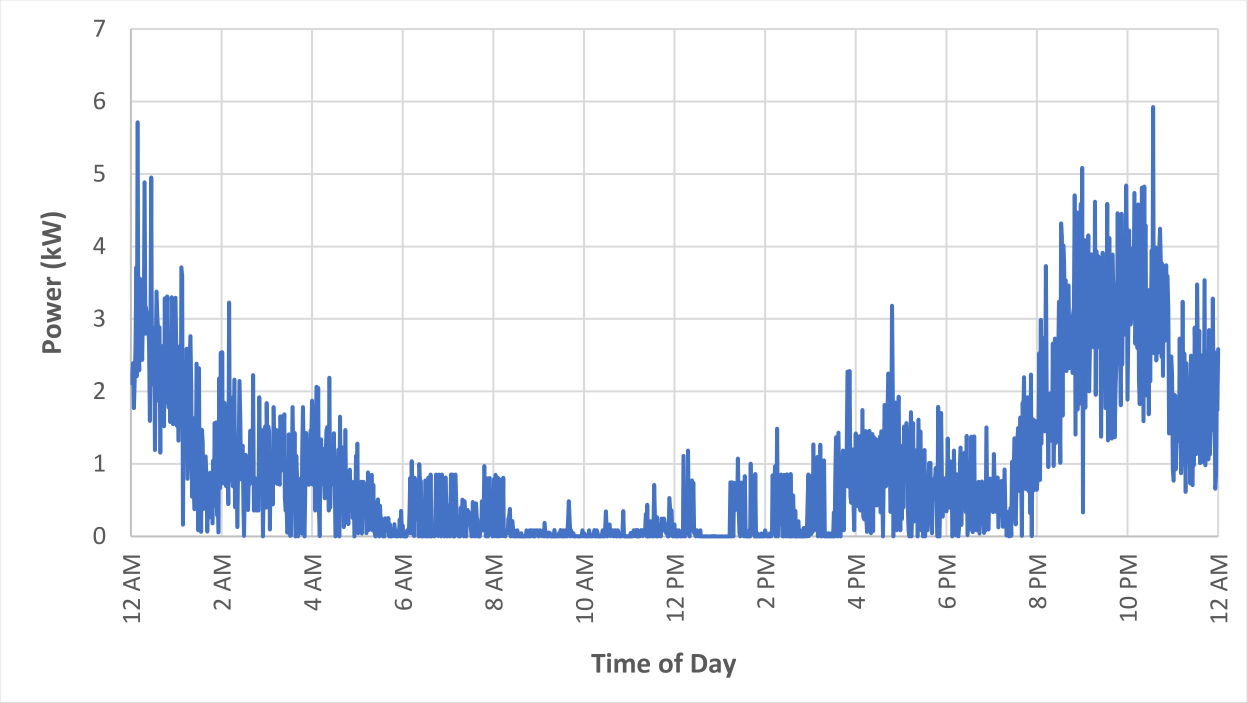
Figure 27. Staggered Recovery for Water Heaters after Critical Peak



7.2 Electric Vehicle Supply Equipment

As mentioned in section 6, during lab tests, the EVSE had a messaging incompatibility with the DRMS causing it to report power irregularly. The data values for power varied randomly between the measured value and zero. As shown in Figure 28, when data is averaged, in this case, over five days from 12 EVSE, noise in the data is reduced and trends are visible. Figure 28 represents a baseline weekday response, where charging appears to be the heaviest during the evening hours and through the night, gradually tapering off during the early morning hours.

Figure 28. Baseline Weekday Power Data for EVSE (No DR Events)



The village of Fairport, who hosted the EVSE installations, tested the effects of Shed and Critical Peak events during the spring and summer of 2021. Figure 29 shows an example of an evening Shed event averaged over five weekdays where 35 EVSE were online and responding. A peak reduction is apparent in the data, where the reduction occurs immediately and appears to remain effective for the two-hour duration. However, what is unexpected is that the demand after the shed event did not return to pre-event levels. Figure 30 is another example. In this example, Critical Peak events are averaged over five weekdays. The peak reduction is evident along with a restoration to pre-event demand after the Critical Peak event.

Figure 29. Example EVSE Response to a Shed Event

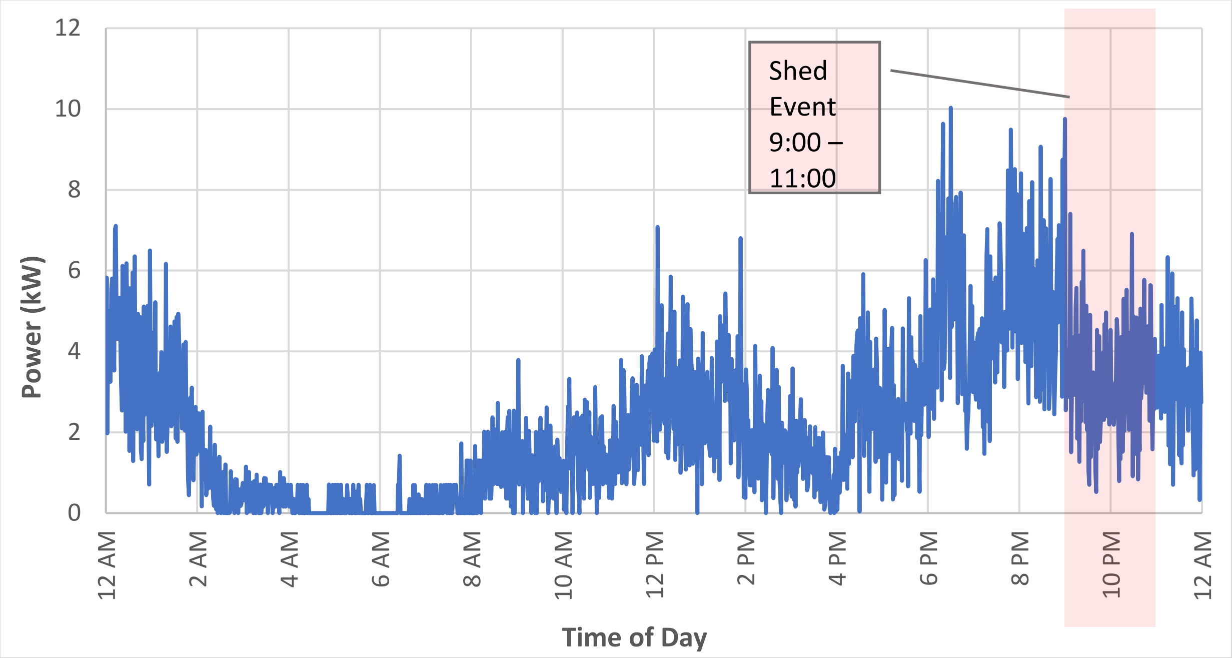
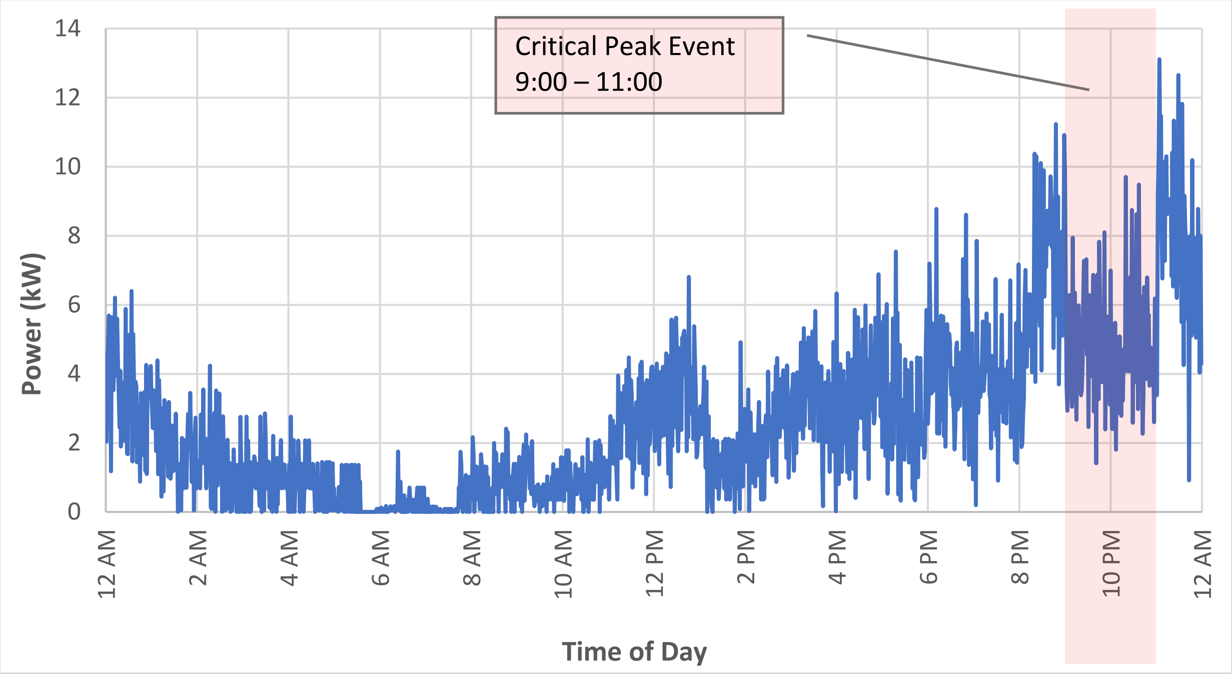


Figure 30. Example EVSE Response to Critical Peak Event



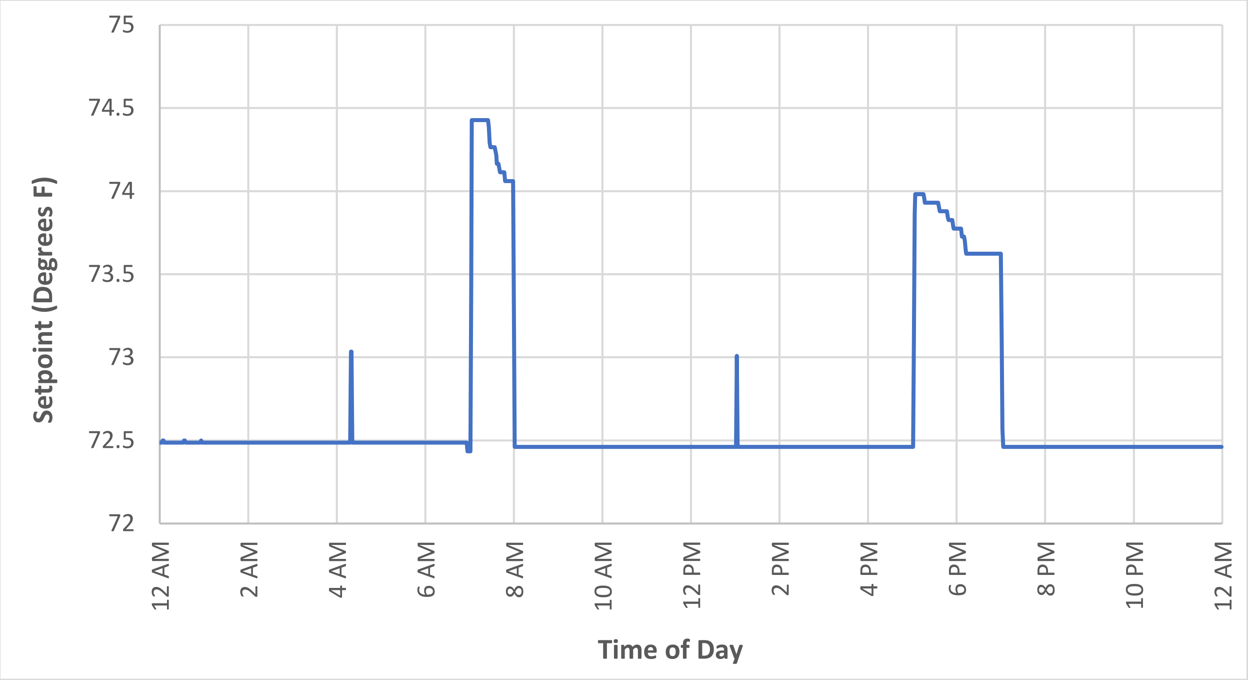
Key takeaways from the EVSE responses had to do with vendor compliance with the CTA-2045 messaging protocol. Lessons learned involved the acknowledgement that an unrelated hardware or firmware upgrade from the manufacturer can result in loss or degradation of function.

7.3 Mini-Split HVAC

As mentioned in section 6, the commodity data that is reported from Mitsubishi's mini-split systems is not Power (W), but temperature setpoint (°F). Thus, a comparison of mini-split responses to that of water heaters and EVSE is not possible. For the field demonstration the temperature differential was set to +2 °F meaning that when in cooling mode, the mini-splits responded by adding 2°F to their current setpoints. Likewise, in heating mode, they would subtract 2°F rather than add.

Figure 31 shows an example response for approximately 30 mini-splits averaged over 10 weekdays. Two events are shown: Shed from 7:00 to 8:00 a.m. and again Shed from 5:00 to 7:00 p.m. The units responded as expected. The interesting result is the gradual change that occurred while these two events were in effect. Likely, this is the result of customers opting out of the event as it occurs. A sudden temperature offset of +2°F during the summer was likely noticeable and as users adjusted their thermostats, they effectively opted out of the event. Without this human intervention, the setpoints are expected to remain constant over the curtailment period. If the assumptions are correct, that users opted out of the events, this speaks to the effectiveness of +/- 2°F temperature setpoint adjustment as a demand response tool.

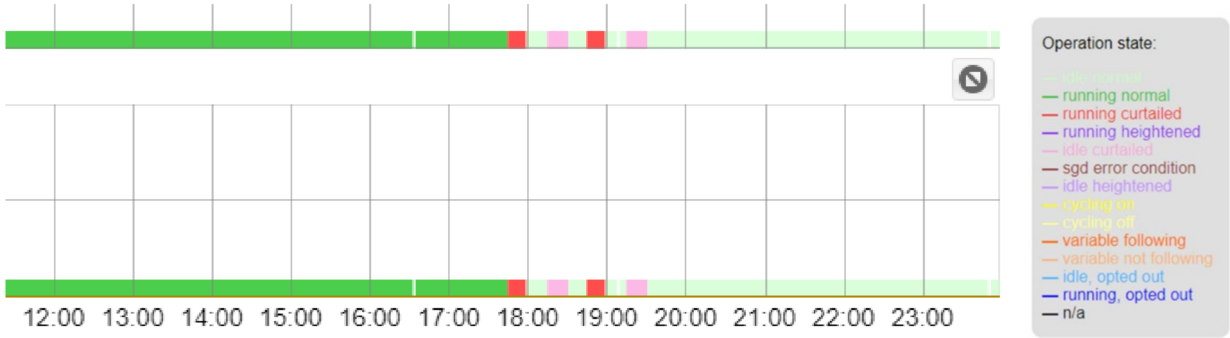
Figure 31. Example Response from Mini-Split Systems



7.4 Pool Pumps

Like the mini-split systems, the CTA-2045 pool pumps from Pentair currently do not report watts. Instead, they report pump speed in RPM. As mentioned in section 6, during lab tests, Pentair had just released a new version of their pool pump controller. Unfortunately, the units did not report any commodity data during lab tests, so while they could respond to events, there was no feedback other than operational state to confirm a response. An example is shown in Figure 32. This figure, taken from the SkyCentrics portal, shows a 12-hour period on July 29, 2022. The pool pump responded to four 15-minute curtailment events in sequence beginning at 5:45 p.m. Unfortunately, the feedback is not helpful for discerning power reduction during events.

Figure 32. Example Feedback from Pool Pump Controller



8 Key Takeaways and Lessons Learned

The current state of the art for Demand Response includes radio-controlled load switches, usually with no feedback, and controllable, but proprietary devices such as Nest thermostats. CTA-2045 offers functional improvement over these technologies because of the data that can be transferred through bi-directional communication with appliances. Additionally, because it is an open standard, utilities can avoid undesirable vendor lock-in.

A distinct functional advantage is the appliance feedback of commodity data, enabling the utility operator to quantify the success of a DR dispatch through measurement of shed demand. This field demonstration project revealed some issues regarding this feedback:

- The ideal feedback parameter for Demand Response use cases is Power (in watts). However, specific feedback parameters (such as power, speed, and temperature setpoint) vary by appliance type and/or the manufacturer's implementation of the standard. Manufacturers are hesitant to add hardware to their off-the-shelf devices unless there is a market or regulatory motivation to do so. For example, in the case of water heaters, power is easily provided as an approximated, rather than measured, value because the internal resistive heater element is a known load that is either on or off. In the case of mini-split systems, however, the unit itself is not aware of the variable power draw and requires additional hardware to make this measurement, so power data is not available.
- The project experienced issues regarding device compliance with CTA-2045 messaging protocol. In two cases, product updates resulted in the loss or degradation of some functionality that had existed before. The solution to this issue is a CTA-2045 certification process. As the standard gains in maturity and foothold, these types of issues are expected to be resolved.

The field demonstration showed that CTA-2045 can reveal details about Demand Response events that might otherwise go unnoticed. For example, the rebound (or snapback) after curtailment events can be significant, especially observed in water heater behavior. The team's observation of this phenomenon yielded two different strategies to resolve the issue: Load-up followed by curtailment, and a two-step staggered return at the end of the curtailment. The staggered return was shown to effectively reduce the rebound peak. Load-up could be staggered as well, to shift some of the peak to the onset of the event, with best results for shorter curtailment events.

One issue worth noting is the reliability of customer Wi-Fi for persistent and long-term applications such as utility DLC. During the field demonstration, an online success rate of 70% was considered acceptable and was roughly the average across the participating munis. Some hardware failures did occur, but most of the offline conditions were attributed to loss of Wi-Fi communication.

Again, the key objective of the project was to demonstrate the technical viability of an end-to-end CTA-2045 system to satisfy both utility mass-market direct load control use cases in New York State and include smart automation features that consumers would find desirable. Further, the project aimed to provide guidance to manufacturers for developing their implementations. All of the capabilities requested by stakeholders were demonstrated including customer interactions with their own devices. Feedback from stakeholders and lessons learned were reported to appliance manufacturers, so that they could continue developing their implementations of CTA-2045.

9 Bibliography

Demand Response-Ready Electric Vehicle Service Equipment Specification: Preliminary Requirements for CEA-2045 Field Demonstration. EPRI, Palo Alto, CA: 2014. 3002002712.

Demand Response-Ready Domestic Water Heater Specification: Preliminary Requirements for CEA-2045 Field Demonstration. EPRI, Palo Alto, CA: 2014. 3002002710.

Demand Response-Ready Programmable Packaged Terminal Air Conditioner Specification: Preliminary Requirements for CEA-2045 Field Demonstration EPRI, Palo Alto, CA: 2015. 3002006951.

Demand Response-Ready Variable-Speed Pool Pump Specification, Preliminary Requirements for CEA 2045 Field Demonstration. EPRI, Palo Alto, CA: 2016. 3002008320.

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