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Field Demonstration of Residential DER Service-Oriented Load Participation

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***Abstract*—Amidst a concerning surge in power consumption during peak hours, coupled with heightened power grid instability, and driven by a growing demand for electricity, aggregations of Distributed Energy Resource are becoming a viable means for providing essential reliability services.**

Electric utility companies have proactively implemented Demand Response programs for decades. These programs employ Direct Load Control methods to enhance power grid stability, achieved by controlling customers' Distributed Energy Resource during peak hours to reduce power consumption. However, a notable drawback of Direct Load Control has been high unenrollment rates of DR program participants due to customer discomfort.

Therefore, the underlying issue of over-consumption persists. To address these concerns, this paper introduces a Service-Oriented Load Participation approach to providing grid services such as Demand Response. Leveraging a Service-Oriented Architecture, this method offers the advantage of efficient service management and provisioning within the system. The SOLP approach not only aims to reduce power consumption but also to maintain customer satisfaction by ensuring a comfortable grid service experience.

***Index Terms*—Service-Oriented Load Participation, Direct Load Control, Distributed Energy Resources, Distributed Energy Resource Management Systems, IEEE 2030.5 Smart Energy Protocol, ANSI/CTA-2045-A**

I. INTRODUCTION

As smart household appliances and communication technologies continue to advance, utilities are rapidly embracing the integration of Distributed Energy Resources (DERs) within customer homes. Concurrently, population growth and electric load adoption are driving an unprecedented surge in energy consumption, leading to increasingly challenging grid management conditions. In response to this pressing need, deploying residential appliances as DERs has emerged as an economically viable solution to mitigate grid-related challenges, without needing to update the existing electrical grid. DERs are customer-owned, grid-enabled load, storage, or generation assets that interact seamlessly with the power grid. For instance, grid-interactive inverters play a crucial role in enhancing grid reliability by offering utilities grid service functions such as frequency-Watt and Volt-VAr curve control [1] Utility companies can effectively manage energy consumption patterns through the application of the Smart Energy Protocol (SEP), commonly referred to as IEEE 2030.5 [2], as the communications protocol for Distributed Energy Resources Management System (DERMS).

For decades, utility providers have been enhancing the reliability of their services by using Demand Response (DR) programs. In 1979, the Florida Power Corporation developed a large-scale deployment of grid services by using a Direct Load Control (DLC)-based program for public customers [3]. To this day, this program aggregates various types of Distributed Energy Resources (DERs), including Water Heaters (WHs), Pool Pumps, and Central Air-Conditioners, to reduce power consumption during peak time. DLC has been adopted by utility companies to enable DER management that use a large number of aggregation of customer household appliances to provide DR services [4]–[6]. However, customers who participate in these DLC-based programs do not have control over their DERs. Once enrolled, the utility may cycle or switch off power to customers' units, regardless of customer preference. DLC-based DR programs that use WHs and air conditioners have been shown to cause customer discomfort [7], [8]. Therefore, customer enrollment in DLC programs remains low.

An innovative evolution in grid service programs centers around adopting a Service-Oriented Architecture (SOA) strategy. This progressive approach has paved the way for developing a Service-Oriented Load Participation (SOLP) architectural framework, engineered to facilitate data acquisition, seamless information integration, and effective service management [9], [10]. The distinguishing feature of SOLP is the SOA premise that clients initiate all transactions. In contrast to DLC, the Universal Communications Module (UCM) client is responsible for arranging DER participation in grid service programs. In this approach, a Distributed Energy Resources Management System (DERMS) server publishes a resource list of available grid services, which is read by UCMs. If a UCM determines that its DER can participate in a service, the UCM initiates participation by sending a request to the DERMS server. This is followed by a response from the DERMS acknowledging the request and following up with additional transactions as needed to arrange participation.

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Another feature of SOLP is the commitment to prioritize the comfort of customers throughout their participation in grid service programs. This is done by using the ANSI/CTA-2045-A (CTA-2045) protocol, which provides function sets that allow utilities to request DER participation while simultaneously ensuring the customers' DER still provides sufficient service; the customers are not left in the cold, so to speak. This empowers customers by ensuring they retain control over their DERs, granting them the flexibility to choose when to participate and to withdraw from participation at their discretion. By adopting Smart Energy Protocol (SEP), the approach also minimizes the exchange of information between DERs and DERMS, effectively addressing concerns related to customer trust and privacy [11].

In the scope of this study, we use electric WHs as representative DERs. This dynamic asset traditionally consumes power and energy on the scale of low kilowatts and kilowatt-hours. Integrating smart energy protocols like CTA-2045 and SEP facilitates information exchange between utility providers and these essential appliances, enabling more effective and responsive grid management. Since DLC programs have been associated with customer discomfort during DR events, a change in approach in the direction of SOLP is warranted. During this SOLP demonstration, we assessed the effectiveness of a SOLP approach using residential WH DERs. An effective grid service program should adjust DER energy consumption in some manner to help provide grid stability, while concurrently ensuring that customers remain comfortable throughout their participation in the program. The advantage of using SOLP instead of traditional DLC methods lies in its capacity to offer enhanced service provisioning, message integrity, security, and improved service management [10]. In this field demonstration, we focus on testing service management, provisioning, and message security using DERMS and multiple UCMs, which facilitate messaging between the DERMS and DER. To safeguard customer privacy and streamline data exchange, only four essential parameters – *Duration*, *Interval*, *Power*, and *EnergyTake* – are shared between the UCM client and the DERMS server using IEEE 2030.5 SEP messaging [12], [13]. While this limits asset information, it is sufficient in enabling utilities to deliver grid services to participating DERs. This approach allows utilities to manage energy consumption while simultaneously prioritizing customer satisfaction and comfort during their engagement in grid service programs.

In this work, Section II provides an understanding of the SOLP demonstration. Additionally, each of its components: DERMS, UCM, and DER are individually detailed for a more comprehensive overview. In Section III, we delve into the system setup, outlining the various configurations of its key components, and elucidate the overarching objectives. In Section IV and V, we elaborate on the testing methods and parameters, while also delving into the findings and outcomes derived from our investigations. Finally, in Section VI we draw the paper to a conclusion, offering a comprehensive analysis of the results stemming from this field demonstration. Additionally, we explore prospective avenues for future study within this subject area.

II. SYSTEM COMPONENTS

In this section, we describe the system components in the field demonstration of SOLP, as well as its architecture, implementation, and hardware description. First, we briefly define grid services. Grid-interactive appliances were originally developed to support demand response services, but the repertoire of grid services that residential DERs can provide has expanded as architectures and technologies have vastly improved.

A. *Grid Services*

The Grid Modernization Laboratory Consortium has classification the many, and not uniformly defined, grid service terms used throughout the U.S. electric power industry into six categories, termed "grid services" [14], [15]. These are generalized categories of grid services that aggregations of DERs can provide. Table I presents the six grid service categories, their purposes, and their actions. Most grid-enabled smart appliances are capable of participating in the first four grid service categories, though only as deferred loads for black start services. Only inverter-based DERs are capable of providing voltage management and frequency response services, and grid-forming support during black start service.

Examples for the energy service category include peak demand mitigation and energy imbalance scheduling. Reserve services include scheduled synchronous & non-synchronous reserves, and tertiary frequency control. Regulation services are sometimes called scheduled regulation or secondary frequency control. Voltage management services include Volt/VAr support, voltage regulation, and conservation voltage regulation.

B. *System Overview*

For this field demonstration of SOLP, we identify three crucial components: DER, UCM, and DERMS. Within this setup, DERs are a customer-owned, grid-interactive load assets, the UCM acts as a gateway linking the DERMS and the DER, and the DERMS is the server that facilitates communication through IEEE 2030.5 using a flow reservation request/response. These three core components collaboratively form a miniature network of DERs with the primary objective of showcasing a service-oriented DERMS aggregation system. Figure 1 is an illustration of the request/response messaging between these system components as they collectively interact with participating DERs.

C. *Distributed Energy Resources Management System*

The DERMS is tasked with aggregating all participating DERs. Functioning as a server in the realm of client and server networking, the DERMS plays a pivotal role in exchanging IEEE 2030.5 messaging with UCM clients using the flow

TABLE I

THE SIX GRID-DER SERVICE CATEGORIES, THEIR PURPOSES, AND ACTIONS.

Grid Service	**Purpose**	**Actions**
Energy	Ensure adequate energy resource supply.	Consume/produce a specified amount of energy over a scheduled period.
Reserve	Reserve source or load capacity.	Adjust real power for dispatched in a contingency.
Regulation	Support area control error.	Adjust real power following an automatic control signal.
Blackstart	Support recovery of a collapsed power system.	Sources supply power and support voltage. Loads defer post-recovery consumption.
Voltage Management	Detect and correct voltage excursions.	Control reactive and/or real power of sources and loads.
Frequency Response	Detect and arrest sudden frequency deviations.	Control real and/or reactive power of sources and load.

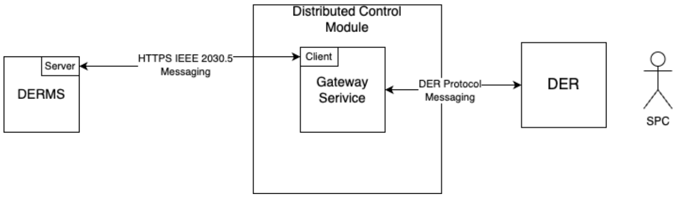

Fig. 1. DERMS, DCM, DER, and SPC communications pathways diagram.

reservation request/response function set. In the context of the physical grid system, the DERMS can be integrated into the Grid Service Provider (GSP) side as a software system. This enables the Grid Operator (GO) to access the DERMS server to request specific grid services, which are provided by the aggregation of DERs participating in the program. An example of such as grid service is reduction of energy consumption reduction during peak hours.

Furthermore, in the SOLP program, customers retain the flexibility to exit the program at their discretion, with their DERs reverting to their original state before program participation. This method allows for an adaptable and responsive approach to managing DER resources, enhancing the overall efficiency and reliability of the grid as well as maintaining customer satisfaction.

D. Universal Communications Module

The UCM plays a pivotal role as a communication gateway between the DER and the DERMS. It manages the interaction between the DERMS by using IEEE 2030.5 SEP, and interacts with the DER by using the CTA-2045 protocol.

In a physical sense, the UCM is linked to the customer's WH, with data exchange occurring using the CTA-2045 communication protocol. The communications uses the device's serial port for seamless information exchange between the WH and the UCM, which involves mandatory *Commodity Read/Commands*. The *Commodity Read* consists of; *Operation State Code, Present EnergyTake (EnergyTake), Total EnergyTake Capacity, Electricity Consumed* as the mandatory messages. The *Commodity Commands* consist of; *Endshed* (Baseline), *Shed* (a light shed request), *Critical Peak Event* (a deep shed request), *Grid Emergency* (a full shed request), and *Load Up* (a request to consume energy)

The UCM uses the IEEE 2030.5 flow reservation request/response function set to assess the capacities and capabilities of DERs prior to scheduling grid service participation. These values are conveyed through four parameters: *EnergyTake* (current *EnergyTake*), *Power* (power consumption of the unit), *Interval* (time available for DER to participate), and *Duration* (amount of time the DER can be dispatched during the interval). Each DER uses flow reservation request resources to request *energy* and specified maximum *power* from the GSP. The *interval* of the flow reservation request then allows the GSP to determine the period when the DER is available to participate in the grid-DER service. The *duration* is the time the DER needs to be dispatched during the *interval* of the grid-DER service. Figure 2 shows the message exchange between GSP and the UCM using the communication protocol IEEE 2030.5.

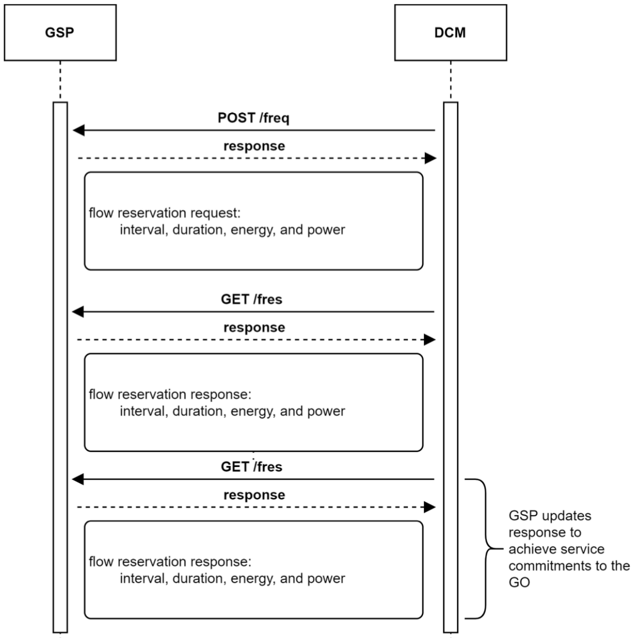

Fig. 2. Universal Communications Module Flow Reservation Request to a Grid Service Provider for Resource Service Participation.

E. Distributed Energy Resource

DERs are sometimes referred to as "smart appliances" or "customer-owned smart assets." In the context of this paper, DERs are customer-owned load, storage or generation assets that can be coordinated to help provide grid services. Examples of DERs include rooftop solar photovoltaic units, battery storage, and air conditioners/heat pumps. In Section III, we demonstrate using grid-enabled electric resistance WHs as well as a heat pump WH from various different manufacturers. There are currently five WHs that have been integrated into our DERMS for testing; four are located in the power engineering laboratory at Portland State University (PSU) and one located in a volunteer's home for remote testing. We have plans to expand this demonstration system in future, particularly off campus.

III. FIELD DEMONSTRATION

A. Project Goal

In this SOLP field demonstration, we showcase the system architecture and perform DER communication compliance testing. We also evaluate how well the DERs perform when they participate in services, a testing process know as "conformance." Our goal is to evaluate SEP information exchange and the efficacy of using SOLP to deliver grid services using customer's DERs. Customers should be able to simultaneously lend their smart appliances for participation in grid service programs and retain sufficient use of those appliances. Meeting these two objectives concurrently will help ensure consumers retain a high level of satisfaction both with their smart appliances and the utility's grid service program.

B. DERMS Configuration

The DERMS is hosted on a physical server located at PSU, supported by a Virtual Machine (VM) powered by UNRAID server technology. Ensuring robust information security, we use a Dynamic Domain Name System (DDNS) in conjunction with a Hypertext Transfer Protocol Secure (HTTPS) website.

Prior to any client-server communication, authentication checks are performed. To establish this trust, both the client and server employ unique encrypted keys and certificates. The server holds the client's certificate and key, while the client possesses the server's certificate. This mutual authentication process culminates in a Transport Layer Security (TLS) handshake, marking the server's readiness for secure and seamless communication between both parties.

C. DCM and DER Configuration

Before demonstrating UCM request/response messaging capabilities, the test operator configures each UCM so that it can communicate over a shared network and facilitate messaging using the CTA-2045 protocol. The UCM is connected to the Wireless Local Area Network (WLAN) and program files that enable wireless communication and CTA-2045 messaging are copied over to the Raspberry Pi (RPi) within the UCM. A lithium-ion battery is connected to the RPi to ensure continued communication in case of short term power losses.

After connecting the UCM to the WH, the test operator initializes the CTA-2045 messaging service to verify mandatory *Commodity Read* messages are being sent by the UCM from the WH to the test operator. Then, the test operator validates two-way communication by observing *Commodity Read* messages being sent to the UCM every 60 seconds after selecting a *Commodity Command*. Figure 3 illustrates the UCM sending a *Shed* command to a DER using a sequence of CTA-2045 messaging.

When the DERMS server is running, it posts SEP *Flow Reservation Resources* to attract DER participation in a grid service. UCMs can request resources and check the status of their corresponding DER. If the status of the DER would be a productive asset to the GSP, the UCM client responds to the DERMS server with a participation request, providing asset capacity and availability. Once the UCM requests participation in the service, the service is scheduled and should run autonomously for the duration of the service.

The service-oriented DERMS architecture constrains SEP messages to request only *Duration, Interval, Power*. These four flow reservation parameter values derive from the CTA-2045 *Commodity Read* log data file, which the UCM requests from its DER. Restricting information exposure to just these four pertinent parameters limits the GSP's view of personal customer information.

To validate the request/response communication required by the DERMS system, the test operator runs the DERMS server and ensures that when the UCM client is in a communicating state with the DERMS server, the test operator receives timely, accurate information about the resource. The test operator also sends service commands to the UCM. Following this curtailment request, the UCM interprets the message for the DER and it provides values that are consistent with the particular curtailment request.

D. System Set up

In this SOLP field demonstration, there are five WHs, donated by three different Original Equipment Manufacturers (OEMs). The four on-site WHs share identical configurations: 50 U.S. gallon capacity, a set temperature of 130°F, and 4.5 kW power consumption. The exception is the remote testing WH located in a volunteer's home, which has a 40 U.S. gallon capacity and a set temperature of 125°F, as per the consumer's comfort preferences. These on-site WHs are equipped with micro-controllers that control valves on the hot water outlers. These valves allow for simulation of household water consumption patterns, based on real customer consumption patterns. Each unit has its own UCM for CTA-2045 and SEP for communications with the DER and DERMS, respectively.

After installing all the WH, we securely mount a UCM onto each. We then initiate CTA-2045 tests to confirm established

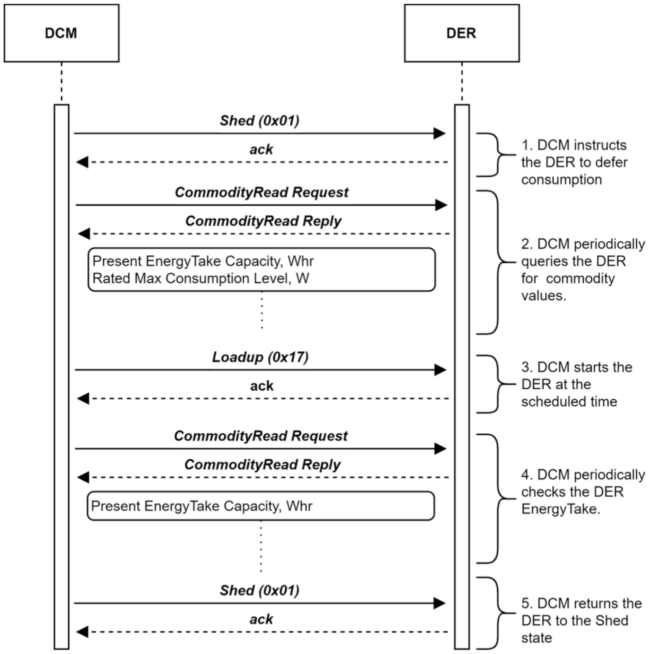

Fig. 3. Implementation of ANSI/CTA-2045-A messaging. The UCM implements SEP flow reservation messages on the DER side of the UCM gateway using CTA-2045 messages.

communication, ensuring the exchange of mandatory messages between the WH and UCM. Upon successful communication, the UCM responds with CTA-2045 Commodity Read messages, including *Operation State Code, Present EnergyTake, Total EnergyTake Capacity, Electricity Consumed*, along with the *Commodity Command*; *Endshed*, *Shed*, *Critical Peak Event*, *Grid Emergency*, and *Load Up*. The test operator selects a command, and *Commodity Read* mandatory messages are received every 60 seconds, with their contents stored in a log file.

A script is used to send the four SEP flow reservation parameters, *Energy*, *Power*, *Duration*, and *Interval* to the DERMS. Before sending these parameters, another script collects commodity data from the DER, including the current *EnergyTake*, which are used to calculate these parameters. The *Power* value is 4.5 kW, and the *Interval*, which can be adjusted by the test operator, is set to 3600 seconds. *Duration* is calculated by dividing *Power* by the current *EnergyTake*, resulting in an hour as the unit.

$$Duration\ (hr) = \frac{Power\ (W)}{Current\ EnergyTake\ (Wh)} \tag{1}$$

Upon gathering flow reservation parameters at the UCM, the DERMS server establishes secure communication via TLS handshake. The UCM generates an XML message, including flow reservation parameter values, current time, and WH identification. These XML messages are received by the DERMS server, which creates a CSV file for each WH. When grid services are needed, a DERMS script initiates services, prompting the GO with service duration and type information. The DERMS server then dispatches XML messages to all participating DERs, specifying *Service Status* (start/stop) and *Service Type* (*Commodity Command* Type). Service begins as directed. The UCMs, upon receiving the service message, interprets the Service Status, and executes the *Commodity Command*.

IV. Field Testing

During field testing, we used WHs from two main manufacturers, referred to as Manufacturer A and Manufacturer B for anonymity, to assess their conformance to participation requests. These WHs were set up identically. We conducted a 24-hour water draw schedule to simulate household water usage with *Baseline*, *Shed*, *Load Up*, and *Critical Peak Event* commands. These commands range from light to deep shed requests, rather than a full shed request. Furthermore, we established a secure TLS handshake for data protection and facilitated the exchange of flow reservation request messages between the UCMs, DERs, and GSP. This laid the groundwork for grid service participation. The DERMS then communicated the Service Status and Type to the UCMs to initiate the requested service for the specified duration.

V. Results

A. DERMS and UCM Communication

In the SOLP system setup, the DERMS is responsible for overseeing the energy consumption of all participating DERs. It transfers flow reservation parameters from UCMs clients to the DERMS server, enabling efficient scheduling of grid services.

Communication between UCMs and the DERMS is established securely with a TLS handshake. Once established, UCMs send their flow reservation requests to the DERMS in *Extensible Markup Language (XML)* format. Code V-A shows the flow reservation request message sent from UCM and it illustrated in DERMS in GSP side.

Code V-A: DERMS receives flow reservation request from UCM:

```
Received Order ID: 78913
Received Customer: SPC_REMOTE
Received Interval: 3600.0
Received Duration: 0.708
Received Power: 4500.0
Received EnergyTake: 3186.0
Received Timestamp: 2023-10-26 16:08:56
```

B. Grid Service

When the DERMS initiates grid-DER services, the GO must relay information to the DERMS. This information pertains to the service's duration and type, including *Shed, Endshed, Load Up, Grid Emergency,* or *Critical Peak Event*.

Once the service duration and type are determined, the DERMS sends an XML message to all participating UCMs, specifying the service's duration and type. Subsequently, the UCM proceeds to execute the service command on the DER via CTA-2045. Code V-B shows the information to be entered by the GO before starting a grid service in the GSP script. The service message sent from DERMS to the participating UCM activates the corresponding command's grid service.

Code V-B: GO Applies Service Duration & Type Information:

```
Do you want to do a service (yes/no): yes
What kind of service would you like
(Shed = S/LoadUp = L/GridEmergency = G
/CriticalPeakEvent = C): L
How many hours do you want
to allocate the service: 2
You have allocated 2.0 hours of L service.
Service will end at: 2023-10-26 20:37:27
Enter Stop to cancel the service:
```

Code V-C: Single UCM Receiving Service Status and Service Type from DERMS

```
Response from server :
HTTP/1.0 200 OK
Server: BaseHTTP/0.6 Python/3.8.10
Date: Thu, 26 Oct 2023 23:34:11 GMT
Content-type: text/xml
Content-length: 52

<Response>Service Status:
'Service Started'</Response>HTTP/1.0 200 OK
Server: BaseHTTP/0.6 Python/3.8.10
Date: Thu, 26 Oct 2023 23:34:11 GMT
Content-type: text/xml
Content-length: 36

<Response>'Service Type: L'</Response>
Status Code: 201
```

C. DER Scheduled Service

During the *Shed* and *Critical Peak Event* operation of the field testing, a comprehensive assessment was conducted. This included the deliberate execution of a *Load Up* command on two OEM WHs. This deliberate comparison allowed us to gain valuable insights into the performance of these WHs under specific operational conditions. Significantly, the results obtained from the collected data, encompassing key metrics such as *EnergyTake* and *Real Power* values, highlight intriguing variations between the two OEMs. These variations shed light on the intricacies of how different WH units respond to grid service management requests, offering valuable data for future system optimization and enhance understanding of operational behavior in demand response scenarios.

1) Manufacturer A: WH unit operates without the necessity for the *Outside Communication Connection Status* command, which, from a technical perspective, renders the WH unit non-compliant with the CTA-2045 protocol. Furthermore, it is worth noting that the unit response to both *Shed* and *Critical Peak Event* commands exhibits an identical behavior. While this response behavior may be acceptable in some scenarios, it may not align with the preferences of utilities, as they typically anticipate a more distinct engagement with the *Shed* mode for grid services compared to the *Critical Peak Event* mode.

2) Manufacturer B: WH unit necessitates the use of the *Outside Communication Connection Status* command to align with the CTA-2045 protocol and achieve compliance. Notably, the unit exhibits distinct responses to both *Shed* and *Critical Peak Event* commands, a characteristic that utilities would typically find desirable, as they anticipate more frequent engagement with *Shed mode* for grid services, rather than *Critical Peak Event* mode. However, it is essential to highlight that when the unit receives a *Load Up* command, an erroneous *Op State Code* for Idle Heightened is recorded in the logged data. This discrepancy may impact the way utilities perceive and interpret this particular operative mode.

D. Temperature Testing for Customer Comfort

Throughout all of our tests, WHs were uniformly set to a temperature of 130°F. The Manufacturer A unit demonstrated a specific operational pattern wherein the upper heating element would engage once the upper temperature sensor reached 98°F, and it would disengage when the temperature reached 108°F. This pattern was consistent across both *Shed* and *Critical Peak Event* commands. This behavior potentially would fall outside the typical comfort range for most customers, as the temperature might not align with their preferences.

Conversely, the Manufacturer B WH exhibited a different operational characteristic. During *Shed* mode, it maintained a temperature range between 110-111°F, while in *Critical Peak Event* mode, it operated within a range of 106-107°F. These temperature ranges are more likely to meet customers' comfort expectations, making the Manufacturer B unit a more appealing choice in terms of maintaining desired water temperature levels during grid service events.

VI. CONCLUSION

The initial studies of this prototype SOLP field demonstration show that the system successfully exchanges information from a DERMS server to DERs through UCMs clients. These UCMs act as gateways between SEP messaging from the DERMS server and the CTA-2045 messaging used by the DERs. Communication pathways from the DERMS were successfully demonstrated to WH units in the laboratory as well as to a field unit. SEP flow reservation messaging was successfully transmitted between the DERMS and the UCMs and transmitted between the UCMs and their respective DERs using CTA-2045 messaging. This messaging resulted in the successful scheduling of basic grid service participation.

After discussing the overview, setup, testing, and results of the Service-Oriented Load Participation system, it becomes evident that different manufacturers' WHs yield varying conformance behavior results when participating in a grid service program. Although there may be differences in temperature regulation during grid services, it is essential to highlight that customers retain the flexibility to opt out of the service simply by disconnecting the UCM from the WH. They can regain access to their DER immediately and rejoin the program at their convenience.

This flexibility and ease of managing grid services for the GSP, coupled with the convenience of scheduling services for DERs at a suitable time, underscores the practicality of the SOLP system. It demonstrates valuable applications in grid service management while ensuring customer satisfaction and comfort. We believe the SOLP system holds great potential for broader implementation on a larger scale, accommodating various types of DERs in future research endeavors.

In future, our group will expand this prototype field demonstration to include additional field units, as well as units from other OEMs. We will also demonstrate an expanded repertoire of grid services to demonstrate that complex grid services can be provided using residential DERs and a minimal amount of information exchange. Concurrently, the comfort of the customers should not be impinged during dispatch of these services, so the conformance behaviours of DERs within the test space will be monitored.

REFERENCES

[1] Common Smart Inverter Profile Working Group. Common smart inverter profile v2.0.

[2] IEEE standard for smart energy profile application protocol. *IEEE Std 2030.5-2018 (Revision of IEEE Std 2030.5-2013)*.

[3] J Stitt. Implementation of a large-scale direct load control system - some critical factors. *IEEE Trans. Power App. & Systems*, PAS-104(7):1663–1669, July 1985.

[4] J Torriti, M. Hassan, and M Leach. Demand response experience in Europe: Policies, programmes and implementation. *Energy*, 35(4):1575–1583, 2010.

[5] P. Cappers, C. Goldman, and D. Kathan. Demand response in U.S. electricity markets: Impirical evidence. *Energy*, 35(4):1526–1535, 2010.

[6] M. H. Albadi and E. F. El-Saadany. Demand response in electricity markets: An overview. In *IEEE Power Engineering Society General Meeting*, 2007.

[7] M. Obi, C. Metzger, E. Mayhorn, T. Ashley, and W. Hunt. Nontargeted vs. targeted vs. smart load shifting using heat pump water heaters. *Energies*, 14(22):7574, November 2021.

[8] M. A. Adham, M. Obi, and R. B. Bass. A field test of direct load control of water heaters and its implications for consumers. In *IEEE Power & Energy Society General Meeting*, 2022.

[9] J. Pathak, Y. Li, V. Honavar, and J. McCalley. A service-oriented architecture for electric power transmission system asset management. In *Service-Oriented Computing ICSOC*, pages 26–37, Berlin, Heidelberg, 2007. Springer Berlin Heidelberg.

[10] M.P. Papazoglou and W.J. Van Den Heuvel. Service oriented architectures: approaches, technologies and research issues. *The VLDB Journal*, 16(3):389–415, July 2007.

[11] K. Stenner, E. R. Frederiks, E. V. Hobman, and S. Cook. Willingness to participate in direct load control: The role of consumer distrust. *Appl. En.*, 189:76–88, 2017.

[12] N. Henderson, M. Adham, R. B. Bass, and T. Slay. Protecting customer privacy through distributed energy resource anonymization. In *IEEE Power & Energy Society General Meeting*, 2023.

[13] M. Alsaid, N. Bulusu, M. Adham, and R. B. Bass. Distributed energy resource management systems: Preserving customer privacy through k-anonymity. In *IEEE Power & Energy Society General Meeting*, 2023.

[14] S. E. Widergren R. Brown J. T. Kolln, J. Liu. Common grid services: Terms and definitions report. Technical report, Pacific Northwest National Laboratory, PNNL-34483, 2023.

[15] J. T. Kolln T. Bohn S. Xue R. Brown J. Liu, S. Widergren. State of common grid services definitions. Technical report, US DOE Grid Modernization Laboratory Consortium, LBNL-2001497, December 2022.