2022

Incentivizing Distributed Energy Resource Participation in Grid Services

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Citation Details

Published as: T. Slay, J. M. Acken, and R. B. Bass, "Incentivizing Distributed Energy Resource Participation in Grid Services," in 9th IEEE Conference on Technologies for Sustainability, 2022

Incentivizing Distributed Energy Resource Participation in Grid Services

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***Abstract*—The bulk power system is experiencing a dramatic shift as renewable generation growth continues to accelerate. Large-scale renewables adoption will help societies transition to a low-carbon, low-cost, and environmental-friendly electrical power system. However, the transition from a paradigm of generation following load to one where load follows generation will require large-scale interconnection and coordinated operation of Distributed Energy Resources (DERs), supported by open communication protocols. In this future grid scenario, DER aggregations will provide critical grid services that enable high penetration levels of renewable generation. This position paper presents an Energy Service Interface (ESI) that defines scope for ensuring secure, trustworthy information exchange between grid service providers and DERs. The goal of the ESI is to encourage large-scale participation of DERs in order to provide grid services through dispatch of DER aggregations. This position paper also presents an open smart energy communications protocol that allows DERs to advertise their characteristics and participate in grid services, within constraints established by the ESI. The paper presents several monetization incentives that grid service providers could use to encourage large-scale DER participation.**

***Index Terms*—Energy Service Interface, Distributed Energy Resource, Smart Energy Profile**

This work was supported by US DOE OE0000922.

I. INTRODUCTION

The goals of this position paper are two-fold. The first goal is to highlight the role of an Energy Service Interface (ESI) in defining information exchange between a Grid Service Provider (GSP) and Distributed Energy Resources (DERs). The second goal is to identify monetization incentives for customers to purchase and offer DERs. Both the ESI and DER monetization are intended to encourage large-scale DER participation in providing essential grid services [1].

With the advent of renewable generation, the power system is experiencing a paradigm shift in the way the bulk electric system operates. The bulk power system has traditionally been controlled with generation following load. System operators use residential, commercial, and industrial load forecasts to determine the day-ahead demand and acquire enough generation to serve the loads. The system operator uses real-time markets to make small adjustments in generation to account for forecast errors and system events to maintain reliable frequency and voltage for all of its customers.

Renewable generation creates new challenges for system operators, as they must now forecast both demand

and generation and acquire enough generation to balance the system. The system operators must also account for the potential increased forecast error between both renewable generation and load. This causes more real-time market interaction, which is generally more expensive than day-ahead markets.

An ESI defines criteria for system operators that want to use DERs to provide grid services. DER owners must be willing to participate in an energy services aggregation program. Owner willingness will be greatly influenced by the security and trust assessment of the system, concepts which are emphasized by the ESI criteria. The ESI concept was introduced by Hardin in 2011, and was adopted by the Grid Modernization Laboratory Consortium (GMLC) in 2018. Our ESI implementation allows any customer-owned DER to participate in grid services, thereby greatly increasing the number of assets available to provide bulk power system reliability. Our implementation uses a service-oriented architecture to provide a bi-directional interface between an aggregation server and DER clients, which exchange information using open-source protocols [2].

In Section II of this position paper, we introduce the concept of an ESI and its primary objectives. In Section III, we present several of the grid services that are used to provide reliability to the bulk power system. In Section IV, we define the term DER. We then present an example of how an open, smart energy protocol, constrained by the ESI, can help aggregate DERs to provide grid services. We explore sample load patterns of a water heater and a clothes washer to expose customer usage affects on load profiles, as well as potential ways to increase the flexibility of participating DER. Finally in Section V, we outline the incentives system operators could use to promote flexibility and DER participation.

II. ENERGY SERVICE INTERFACE

The concept of an ESI was first introduced by Hardin in 2011 [3]. A year later, the National Institute of Standards stated the ESI serves as a *"gateway to the customer premises network."* [4]. Lee *et al.* expanded the concept further, stating the ESI delineates a boundary between a customer and a GSP across which energy data are exchanged, applies security measures to information exchanged between parties, and provides a logically-defined communication interface to allow a variety of implementation architectures [5].

Widergren *et al.* expanded the concept, adding *"service-oriented"* to the definition [6]. Specifying a service-oriented architecture ensures that customers retain the choice to participate in services, thereby leaving them in control of their DER assets and not permitting the GSP to have direct control.

Hardin stated that the ESI needs to effectively enable customers to actively participate in maintaining electric grid reliability. Beyond enabling customer participation, the ESI needs to define terms for smart energy communications protocols that encourage large-scale customer participation [7]. To achieve large-scale participation, customer concerns must be addressed: privacy must be ensured, information exchange must be secure, and all participating parties must be trustworthy. A DER on its own has a negligible effect on grid frequency and local voltages. To truly impact the electric grid, a large aggregation of DERs must work together to provide grid services. The ESI provides rules for information exchange that encourage large-scale participation of DERs by assuring customers that their privacy, security, and trust are principal architectural concerns.

Harden's perspective is supported by the GMLC, which states that the ESI should simplify interactions between a diverse array of external parties across a wide range of DER technologies [8]. The GMLC also states that an ESI should be respectful of customer privacy. What a customer considers private will vary, but the ESI should limit to a minimum level the information required for energy service participation.

Building on these evolving contributions, from Hardin to the GMLC, we define the ESI not as an interface, but as a set of rules:

> *The ESI is a set of rules that establishes a bi-directional, service-oriented, logical interface to support secure, trustworthy information exchange between a GSP and customers' DERs. These exchanges facilitate energy interactions between the customers' DERs and the GSP, thereby allowing the GSP to provide grid services through dispatch of the DERs.*

The objective of the ESI is to ensure private, secure, and trustworthy information exchange between a GSP and DERs to promote dispatch of grid services through large-scale aggregation of DERs. The ESI does so by providing a set of rules that define bi-directional, service-oriented, logical interfaces with expectations for privacy, security, and trust. The rules establish boundaries between the two parties, thereby delineating the functions and responsibilities of each party. And importantly, the rules impose constraints on information exchange between parties. Below, outline examples of these rules are provided, grouped within the themes of *privacy*, *security*, and *trust*.

A. Privacy: Example Rules

ESI rules prioritize DER privacy by limiting information exchange and the use of data.

- The GSP only engages DERs on an opt-in basis.
- DERs initiate all communication with the GSP.
- DERs are able to decommit from a resource service at any time without penalty.
- The GSP does not record or discern DER usage patterns.
- Exchange of DER information is limited to the minimum required to implement a particular service.

B. Security: Example Rules

ESI rules ensure that the GSP applies state-of-the-art, proven cybersecurity measures.

- Encryption of exchanged information
- Authorization
  - Registration with the GSP to provide explicit DER authorization
  - Access control lists to determine if DER access to a specific resource is permitted
- Authentication of both messages and DER clients

C. Trustworthiness: Example Rules

ESI trustworthiness rules ensure that all parties participating within the information exchange system understand that all other parties are vetted for trustworthiness [9]. To do so, information exchange is overseen by an independent supervisory trust system, which must:

- Monitor information exchange between parties.
- Quantify trust score metrics for every party in the system.
- Identify suspected occurrences of abnormal messaging.
- Notify the GSP when trust scores exceed thresholds.
- and does not exercise direct control of DER.

Figure 1 shows a simplified outline of the parties that would use the ESI. Starting on the right, DERs advertises their capabilities to a GSP. The GSP uses this information to determine for which grid services the DERs can participate. The GSP then bids to provide grid services to a Grid Operator (GO), left. If the GO accept the bid, then the GSP schedules DERs to meet the newly contracted service.

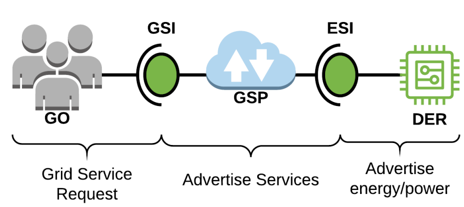

Fig. 1. Energy Service Interface outline

III. GRID SERVICES

A primary objective of system operators is to ensure that grid frequency stays within specified limits. This is done by balancing generation with load over various time scales. On the longest time scale, operators acquire enough generation to meet forecast demand on a day-ahead basis with some reserve capacity to account for forecast error and contingency events. On hourly, sub-hourly, and real-time scales, operators actively interact with markets to acquire more generation or request generation reduce production to maintain balance. If operators are unable to reduce generation, they may send negative price signals or pay external actors to take excess power to maintain system balance.

A report by North American Electric Reliability Corporation (NERC) defined three primary categories of reliability services: frequency, ramping/balancing, and voltage [10]. Table I highlights the generalized response times for two of these services. The frequency service has been subdivided into response and regulation services. Frequency response is a contingency service that provides resiliency to the grid in the event of sudden loss of load or generation. Frequency regulation service compensates for small deviations in system frequency by making minor adjustments to generation. We have excluded voltage service from this discussion.

TABLE I
ESSENTIAL RELIABILITY SERVICES RESPONSE TIMES [10].

Service	**Response Time**
Frequency Response	$<$ 1 (sec)
Frequency Regulation	$<$ 5 to 15 (min)
Ramping/Balancing	$<$ 1 to 3 (hour)

A. *Demand Response Options*

A report by the Department of Energy outlines several demand response options [11]. Demand response services are subdivided into price-based and incentive-based options. They both achieve a reduction in demand, but the incentive-based option results in a more quantifiable reduction in demand. These options are described below:

B. *Price-Based Options*

- **Time-Of-Use (TOU)**: consistent pricing during predetermined blocks of time that reflect costs of power generation and delivery. Most utilities offer a time of use option. Prices vary between balancing areas, as well as seasonally.
- **Real-Time Pricing (RTP)**: variable wholesale price of electricity at a predetermined interval of time. There are several notable demonstrations of demand response using RTP, including: Olympic Peninsula Demonstration, Ohio gridSMART Real-Time Pricing Demonstration, and Pacific Northwest Smart Grid Demonstration [12].
- **Critical Peak Pricing (CPP)**: occasionally used, CPP is offered during pre-arranged blocks of time, but only during periods when system reliability may be compromised.

C. *Incentive-Based Options*

- **Direct load control**: system operators have direct access to customer devices. Customers cannot interfere with operator controls.
- **Interruptible/curtailable service**: system operators contract with participants to reduce demand as a contingency.
- **Demand Bidding/Buyback Programs**: customers offer a reduction in demand dependent on market prices.
- **Emergency Demand Response Programs**: similar to interruptible/curtailable service, this allows system operators to pay customers to shut off their load during periods of system instability.
- **Capacity Market Programs**: customers offer to reduce load during peak times to defer system generation. Usually incentives are contracted by the system operator with penalties for failure.

IV. DISTRIBUTED ENERGY RESOURCES

DERs have generally been associated with inverter-based systems such as photovoltaic systems and electric vehicle service equipment at the distribution level. We have adopted a broader definition:

DERs are customer-owned generation, storage, and load assets that are grid-enabled. These resources are located behind a customer meter and are not traditionally directly managed by utilities. [8]

It is anticipated that many residential loads will be DERs once there is an ecosystem that supports their participation in grid services [8]. Both an ESI and monetary incentives will aid that transition.

A. Flow Reservation Requests

The rules of the ESI constrain the application of existing smart-energy communications standards. The IEEE 2030.5 smart energy profile adequately addresses the ESI security rules. One resource within the standard that can be used to ensure privacy is the *Flow Reservation* resource. This resource provides a general interface for grid service participation [13]. Figure 2 highlights the key components of a *flow reservation* resource request, which is broadly defined as a request mechanism for "charging" or "discharging" a DER. This resource was originally developed for electric vehicle service equipment, but it can also be used for a much more diverse list of DER, examples of which are discussed below.

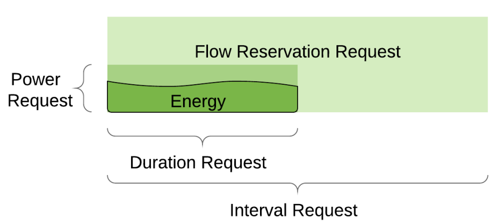

Fig. 2. Representation of the IEEE 2030.5 *flow reservation request* power, energy, interval, and duration properties.

The key *flow reservation request* components are defined as followed:

- **Interval**: the time window during which the duration must be completed.
- **Duration**: the time required for the device to serve the requested energy.
- **Power**: the maximum power capability.
- **Energy**: the integral of power consumed over the duration of the request.

B. DER Load Profiles

Two types of residential DERs highlight the importance of how customers operate their DER and how operation affects *flow reservation requests*. Figure 3 shows how changing the mode of a clothes washer affects the overall load profile. The "normal" wash mode and "permanent press" mode have similar consumption profiles, so they would have similar *flow reservation requests*. But, the "delicates" mode has a much shorter duration as well as a high average power, so its *flow reservation request* would be different than the other two. For instance, its duration is shorter, which provides more flexibility for dispatch within the interval.

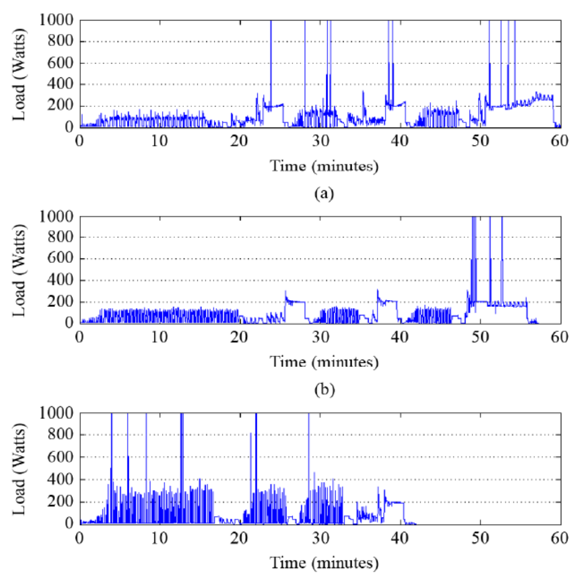

Fig. 3. Load profiles of a clothes washer through different modes: (a) normal; (b) permanent press; (c) delicates [14]

Figure 4 shows how customer water usage affects the energy consumption of a water heater. Random water draw behaviours make determining the interval of a water heater *flow reservation request* challenging. Unlike the clothes washer, the water heater does not go through phases throughout its operation. However, appliance-level communications protocols, such as CTA-2045, provide means for temporarily adjusting the energy storage capacity of residential DER, including water heaters [15], [16], which somewhat decouples the use of an appliance as a DER from consumer consumption patterns.

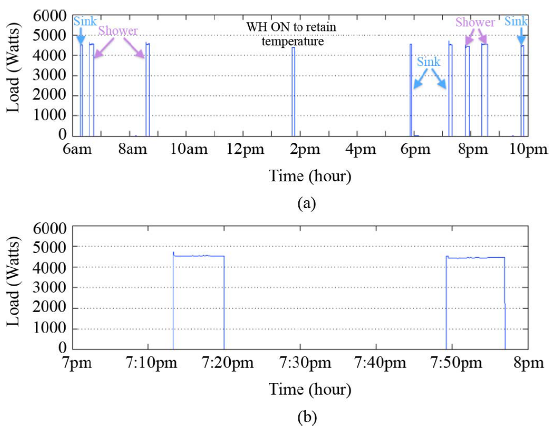

Fig. 4. Load profiles of a water heater: (a) 14-hour; (b) 1-hour [14]

C. DER Phases

Considering the example load profiles of the clothes washer, which clearly goes through multiple phases during its operation. And, some loads, like the water heater, can be interrupted during their operation without consequence. There are two questions that the recorded data cannot answer. Can a phase be interrupted and started again at a future time? And, are the phases independent?

Figure 5 shows how a DER could potentially make several cascading *flow reservation request* to a GSP, if the DER has multiple independent phases. Doing so makes the DER a more flexible resource.

Figure 6 shows that if a phase is interruptible, then its energy consumption can be divided within the requested

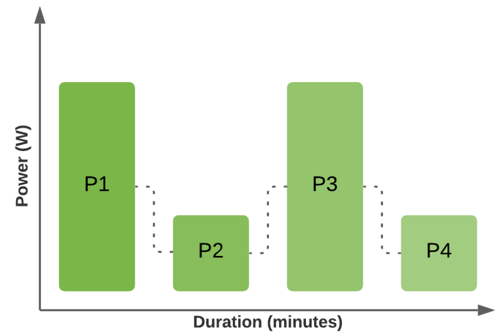

Fig. 5. DER with independent phases P1-P4 allowing individual control without affecting completion of the DER operation

interval, thereby making it a more flexible resource. DER that are either interruptible or multi-phase provide for more flexible dispatch, which will help GSPs provide services to GOs and therefor accommodate greater penetration levels of renewable generation.

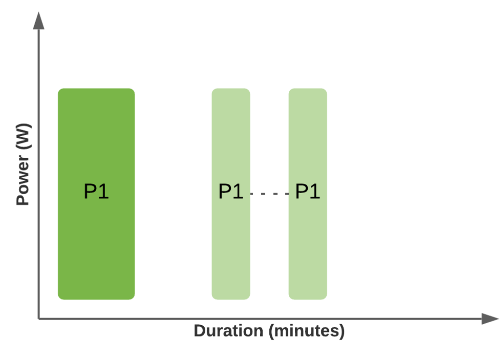

Fig. 6. DER with interruptible phases allowing the whole to be split during operation.

V. MONETIZATION

This position paper does not focus on the actual value of DERs providing grid services, but rather the incentives that GSPs should use to promote participation. The IEEE 2030.5 *flow reservation request* resource provides the GSP with four DER characteristics that can be targeted for monetization: power, energy, duration, and interval.

- **Power**: Since the power in most DERs is a constraint that cannot be modified by the DERs controller, and is negligible by itself to grid services, this would affect monetization by comparing the accuracy of the requested power to the actual power draw of the DER. This incentive would also drive participating DERs to want to make the independent phases of its operation into separate *flow reservation requests* to prevent specific phases from skewing the overall power request of the whole.

- **Energy**: Similar to the power characteristic, the energy characteristic will be a static value, and will depend on the phases of the DER operation. Monetization should incentivize the most accurate energy request.
- **Duration**: The duration characteristic should urge DERs to make their phases independent so the a DER can make separate energy requests for each phase of its operation. It should also disincentivize duration requests that are smaller than the potential services the DER can participate in. As well, if a DER can be interrupted then there should be some incentive to compensate for any degradation of its lifespan.
- **Interval**: This is one of the most important parameters of a *flow reservation requests*. The greater the interval, the more opportunity the GSP has to participate in high value grid services in the real-time market. Monetization should be used to encourage long durations.

A. Incentivized Example

Figure 7 demonstrates the desired outcome of a GSP incentivizing DER participation in grid services. The original DER *flow reservation* request is decomposed into the independent phases to make four cascading *flow reservation* requests. The new *flow reservation* requests benefit from greater accuracy in power, energy, and duration at the cost of a smaller interval at which they can operate.

This cost is offset by the added flexibility of demand, which the increased penetration of stochastic energy generation requires of electrical infrastructure as a whole. Specifically, smaller duration requests give DERs the ability to participate in frequency regulation services and balancing/ramping services simultaneously.

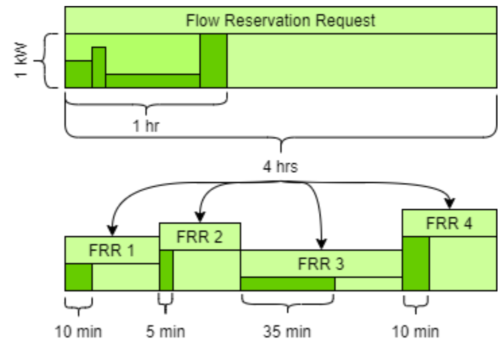

Fig. 7. Example *flow reservation requests* for independent phases. Each phase is assigned an individual *flow reservation request* to increase flexibility

VI. CONCLUSION

This position paper presents an ESI implementation that allows a wide variety of DERs to participate in grid services. The implementation provides security, protects privacy, and maintains trust. IEEE 2030.5 *flow reservation* requests are used to advertise DER characteristics to GSPs so that individual DERs can be aggregated to participate in grid services.

We explored several sample DER load profiles to determine key usage differences and highlighted the various phases a DER may go through during a cycle. These phases provide insight into two potential ways DERs can increase their flexibility by creating multiple *flow reservation* requests within a single operating cycle. Monetization incentives would help increase participation in grid services and could allow DERs to participate in multiple services.

Future work includes discussion of upper and lower bounds for DER monetization and how *flow reservation* requests properties should be weighted to maximize flexibility for grid services. The impact of DER participation on customer comfort and privacy should be determined to ensure customers provide informed consent for use of their DER. And, a simulated energy market should be used to determine what DER mixes and penetration levels are required to achieve optimal grid service participation.

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