# Implementation Profile:

## *EGoT DERMS Server/Client System*

## Development of an Energy Services Interface for the EGoT

**WORK PERFORMED UNDER AGREEMENT**
DE-OE0000922

Portland State University
1900 SW 4th Ave
Portland, OR 97201

**Period of Performance:** 7/13/2020 **to** 9/30/2023

**Submitted:** January 4, 2024
**Revision:** 1.0

**PRINCIPAL INVESTIGATOR**
Robert Bass, Ph.D.
503-725-3806
robert.bass@pdx.edu

**BUSINESS CONTACT**
Patti Fylling
503-725-6584
spa_mcecs@pdx.edu

**SUBMITTED TO**
U. S. Department of Energy
National Energy Technology Laboratory
DOE Project Officer: Mario Sciulli

## Implementation Profile:

## *EGoT DERMS Server/Client System*

This material is based upon work supported by the Department of Energy under Award Number DE-OE0000922.

# Revision History

| Date | Version | Description | Author |
|---|---|---|---|
| 6/1/21 | 1.0 | Document creation | R. Bass |
| 6/25/21 | 1.1 | ESI, 2030.5 sections, Incorporate QualityLogic feedback | R. Bass, T. Slay |
| 7/27/21 | 1.2 | Finalize ESE section, Added grid services section | R. Bass |
| 8/3/21 | 1.3 | Grid-DER service Dispatch Cases and DER capability assessment subsections | R. Bass |
| 8/6/21 | 1.4 | Sequence Diagrams, finalize Chapters 5 and 8 | R. Bass, T. Slay |
| 8/13/21 | 2.0 | Add product requirements. Submit for partner reviews. | R. Bass, T. Slay |
| 9/15/21 | 2.1 | Product requirements revised after test plan development. | R. Bass, T. Slay |
| 9/16/21 | 2.2 | Revisions from partner reviews | R. Bass, T. Slay |
| 9/17/21 | 2.3 | V2 Final Version | R. Bass, T. Slay |
| 3/4/22 | 3.0 | Align location extent terms with CSIP topological grouping scheme, App A. | R. Bass |
| 3/15/22 | 3.1 | Terminology changes, figure updates | R. Bass |
| 4/6/22 | 3.2 | Change grid-DER service ‘Black Start Service’ to ‘Emergency Service’, update related figures | R. Bass |
| 6/10/22 | 3.3 | Add section 2.5 and tables relating ESI to interoperability maturity model and alignment with project Interoperability Plan. | R. Bass |
| 6/24/22 | 4.0 | Revision from Reascend review. Added Background, rewrote Introduction, updated definitions, rewrote ESI privacy policy. | R. Bass |
| 7/8/22 | 4.1 | Revised all grid-DER sequence diagrams and descriptions. | R. Bass |
| 7/11/22 | 4.2 | Finalize revisions from Reascend review. | R. Bass |
| 7/12/22 | 4.3 | Moved majority of ESI content to its own document. | R. Bass |
| 8/4/22 | 4.4 | Review and revise Design Principles, section 1.1. Other minor revisions. | R. Bass |
| 12/15/22 | 4.5 | Update grid-services references | R. Bass |
| 7/20/23 | 4.6 | Edits in sections 4 and 5 regarding the *DER* function set | R. Bass |
| 9/13/23 | 4.7 | Update references, footnotes | R. Bass |
| 9/25/23 | 4.8 | Grid-DER Services terminology: Energy and Blackstart services, related reference. | R. Bass |
| 12/12/23 | 4.9 | Grid-DER Service simulation use cases, App C : Blackstart, Energy services, Reserve, Voltage Management completed. | M. Adham |
| 12/15/23 | 5.0 | Final Review | R. Bass |

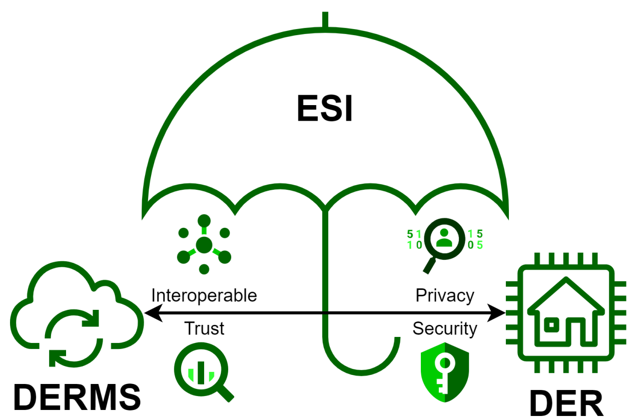
# Implementation Profile:
# EGoT DERMS Server/Client System

# Background

This implementation profile (IP) provides the scope and requirements necessary to implement a distributed energy resource management system (DERMS), which networks large numbers of DER within an energy grid of things (EGoT). This document originated as part of a U.S. DOE-funded project to develop a DERMS based on a set of rules known as the Energy Services Interface (ESI), which

*… establishes a bi-directional, service-oriented, logical interface to support secure, trustworthy information exchange between an aggregator and DERs. These exchanges facilitate energy interactions between the DERs and the aggregator, thereby allowing the aggregator to provide grid services through dispatch of the DERs.*

The objective of the project was to further develop the definition of the ESI and to demonstrate the utility of the ESI when developing a DERMS. The ESI serves as an umbrella, ensuring the information exchange between an aggregator and DER owners conforms to expectations: protect privacy, provide security, develop trustworthiness, and ensure interoperability. DERMS developers use the ESI to ensure that information exchange meets these expectations. This IP demonstrates how that was done using IEEE 2030.5 as the messaging protocol.




The result is a service-oriented DERMS architecture that protects customer privacy by constraining the implementation of IEEE 2030.5 resources and ensuring customer agency over their DERs, provides security by adopting the measures specified by the Common Smart Inverter Profile, develops quantified trustworthiness using a parallel and independent Distributed Trust Model System[1], and ensures interoperability by aligning the design with the categories and cross-cutting issues of the Interoperability Maturity Model.

The ESI promotes DERMS design practices that ensure private, secure, trustworthy information exchange and interoperability between aggregators and DERs, thereby encouraging large-scale DER adoption and stimulating technological innovations within a dynamic EGoT ecosystem of application developers, DERMS operators, and DER manufactures.

[1] *Product Specification: Distributed Trust Model System*, Portland State University, PSU-ECE DOE-02, 2023

# Acronyms

| | |
|---|---|
| **ACE** | Area Control Error |
| **BA** | Balancing Area or Balancing Authority[2] |
| **BIS** | Battery Inverter System |
| **CSIP** | Common Smart Inverter Profile |
| **DCM** | Distributed Control Module |
| **DER** | Distributed Energy Resource |
| ***DER*** | *Distributed Energy Resources* IEEE 2030.5 function set |
| **DERMS** | DER Management System |
| ***DRLC*** | *Demand Response & Load Control* IEEE 2030.5 function set |
| **DTM** | Distributed Trust Model |
| **ECS** | Entity Component System |
| **EGoT** | Energy Grid of Things |
| **ESI** | Energy Services Interface |
| **EVSE** | Electric Vehicle Service Equipment |
| **FOA** | Funding Opportunity Announcement |
| **GenOps** | Generation Operations System |
| **GMLC** | Grid Modernization Laboratory Consortium |
| **GO** | Grid Operator |
| **GSP** | Grid Service Provider |
| **HP(WH)** | Heat Pump (Water Heater) |
| **HTTP(S)** | Hypertext Transfer Protocol (Secure) |
| **IEEE 2030.5** | The open message DER protocol used in this project, aka SEP 2.0 |
| **IMM** | Interoperability Maturity Model |
| **IP** | Implementation Profile |
| **PII** | Personally Identifiable Information |
| **REST** | Representational State Transfer |
| **RWH** | Resistance Water Heater |
| **SEP** | Smart Energy Profile 2.0, aka IEEE std 2030.5 |
| **SOA** | Service Oriented Architecture |
| **SPC** | Service-Provisioning Customer, i.e. a DER program participant |
| **ssl** | Secure Sockets Layer |
| **UCM** | Universal Communications Module |
| **UML** | Unified Modeling Language |

[2] U.S. Energy Information Administration, *[U.S. electric system is made up of interconnections and balancing authorities](#)*, July 2016

# 1 Introduction

An Energy Grid of Things (EGoT) is composed of multiple actors, each with their own responsibilities and objectives, shown in Figure 1.1. The Grid Operator (GO) is responsible for procuring grid-DER services from one or more Grid Service Providers (GSP), with the objective of using these services to maintain power system reliability and provide resilience. The GSP is responsible for aggregating Distributed Energy Resources (DER), with the objective of using the aggregation to provide grid-DER services.

Service Provisioning Customers (SPC) are responsible for registering their DER with a GSP prior to participating in grid services. The SPCs' objectives are to maximize their own utility. SPCs set their comfort limits, which determine how aggressively or conservatively the SPCs would like their DERs to participate in GSP programs. These determinations are managed by the Distributed Control Module (DCM). The DCM is the client of the EGoT DERMS server. It serves as an agent on behalf of the SPC and a gateway between the protocols used by the GSP and the DER, if they are different.

Grid-DER services are essential reliability services that can be provided through dispatch of DER aggregations. Grid-DER services fall into six categories: Energy, Reserve, Regulation, Blackstart, Voltage Management, and Frequency Response. These are discussed in detail within Appendix A[3].

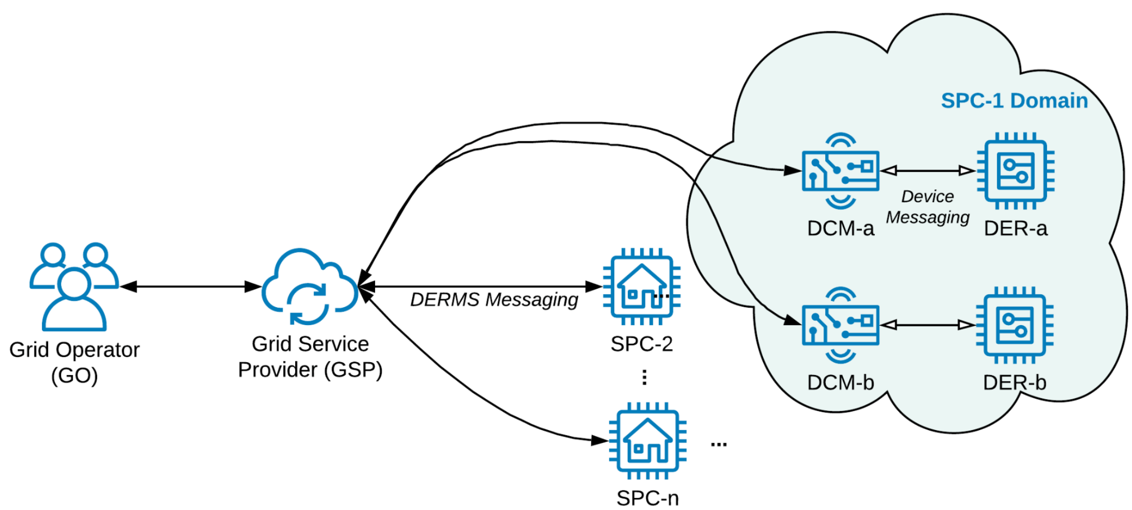



**Figure 1.1** A simplified representation of the EGoT actors and the information exchange pathways between them.

Located at the GSP is an IEEE 2030.5 server that aggregates DERs, herein called the EGoT DERMS server. The DCM facilitates the implementation of IEEE 2030.5 resource logic between a GSP and a DER. To preserve customer data privacy, the EGoT DERMS primarily uses *Flow Reservation request* and *Flow Reservation response* resources to

[3] J. T. Kolln, J. Liu, S. E. Widergren, R. Brown, "Common Grid Services: Terms and Definitions Report," Pacific Northwest National Laboratory, PNNL-34483, July 2023.

estimate DER capacities and abilities to participate in grid-DER services. These estimates are conveyed through four parameters: *energy*, *power*, *interval*, and *duration*. Each DER uses the Flow Reservation request resource to request energy at a specified power from the GSP. The interval of the Flow Reservation request allows the GSP to determine the time period when the DER is available to participate. The duration is the amount of time the DER can be dispatched during the interval.

## *1.1 Design Principles*

The following principles have been used to guide the design and development of the EGoT DERMS server/client information exchange system as a whole.

1. Define a service-oriented, open-source client/server profile that a GSP can use to provide grid-DER services to a GO using DERs.
2. Ensure interoperability between the GSP and DCMs by using the Interoperability Maturity Model to guide the design. Interoperability minimizes implementation costs and maximizes the number of DERs that can participate in grid-DER service programs.
3. Adopt an existing and open protocol, IEEE 2030.5 in the case of this project, to ensure interoperability between the GSP and DCMs.
4. Encourage large-scale SPC participation by addressing customer concerns regarding security, privacy, and trust. Specifically, apply the rules of the Energy Services Interface (ESI) to check that these issues are addressed during design.
5. Expect DER capabilities to improve and adoption to increase over time. The system shall be extensible in anticipation of DER technology innovation and proliferation.
6. Enable a DER aggregation system that accepts all comers; procurement of DERs must not be limited to particular types of DERs.
7. Apply the principle of layered decomposition to (a) GO-GSP communications; the means for articulating requests for grid services shall be determined by the GO and GSP, and (b) to the DER; the methods used by the DER to meet its participation commitments shall be determined by the DER manufacturer.
8. Expect revisions will be made to this IP in future as its shortcomings become evident.

## *1.2 Participants & Definitions*

The EGoT DERMS server/client system encompasses many actors and relies on specific definitions for many terms. An understanding of the system will occur best by studying the *functions & responsibilities* tables and the *definitions* tables presented in sections 1.2.1 and 1.2.2, and referring back to these tables as each new figure is introduced. Tables 1.1 and 1.2 present the main participants that interact through information exchange to enable the dispatch of DER to provide grid-DER services. The number of participants varies depending on the use case.

Participants are classified as *Actors*, which are persons or other external systems; and *Collaborative Objects*, which include interacting components other than Actors.

**Table 1.1** Actors

| **Name** | **Type** |
|---|---|
| Grid Operator | organization |
| Grid Services Provider | organization |
| Service Provisioning Customer | person or organization |

**Table 1.2** Collaborative Objects

| **Name** | **Type** |
|---|---|
| Distributed Control Module | agent & gateway |
| Distributed Energy Resource | device |
| EGoT DER server/client management system (EGoT DERMS) | application |

### 1.2.1 Functionalities and Responsibilities

This subsection presents the functionalities and responsibilities of the system actors and collaborative objects discussed within this document.

**Table 1.4** Grid Operator

| | |
|---|---|
| ***Functionality*** | A GO seeks grid services from GSPs in order to achieve operational objectives, which are 1) maintaining operations within the physical constraints that must be honored in order to prevent damage to grid components and equipment, or 2) operational goals associated with stable, reliable, economical delivery of power at nominal conditions. |
| ***Responsibilities*** | ● Engage with GSPs to acquire grid services to achieve operational objectives.<br>● Design and fund incentive programs to attract GSP and/or SPC participation to implement operational objectives..<br>● Provide DER topological assignment information during the DER registration process |

**Table 1.5** Grid Service Provider

| | |
|---|---|
| ***Functionality*** | A GSP provides grid services to a GO through the dispatch of DER that have subscribed to a GO program. Aggregation and dispatch are achieved using a DERMS. Grid services are the means by which a GO achieves operational objectives. |
| ***Responsibilities*** | ● Provide grid services to GOs.<br>● Evaluate its aggregation of DER assets to determine a menu of grid services to offer to GOs, prioritized based on the priority operational objectives of GOs.<br>● Entice SPCs to subscribe to DER aggregation programs<br>● Exchange information according to the EGoT Server/client IP. |

**Table 1.6** Service Provisioning Customer

| | |
|---|---|
| ***Functionality*** | An SPC is a electric utility customer who owns one or more devices that can serve as a DER, and who is interested in providing those DER to a GSP through an aggregation program. |
| ***Responsibilities*** | ● Subscribe to GO or GSP programs so that their DERs can be managed in order to provide value to the grid<br>● Ensure their DER are available to request services from GSPs<br>● Communicate prioritized operational objectives with the GO |

**Table 1.7** EGoT DERMS Server/Client Management System

| | |
|---|---|
| ***Functionality*** | The EGoT server and client facilitate TLS and HTTP communications using the IEEE 2030.5 resource models. The client and server are also responsible for translating the common IEEE 2030.5 models into the specific DER and GO interfaces to implement controls and energy services. |
| ***Responsibilities*** | ● Authenticate client/server<br>● Encrypt/Decrypt HTTP communications<br>● Validate IEEE 2030.5 resource models using xml schema<br>● Update resources based on polling rates, event status, or pub/sub<br>● The DERMS server interfaces with the DCM client using the *Flow Reservation* resources and *DER* function sets of IEEE Std 2030.5.<br>● The GSP interfaces with a GO to provide grid-DER services. |

**Table 1.8** Energy Services Interface[4]

| | |
|---|---|
| ***Definition*** | 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 an SPC's DER. |
| ***Objectives*** | Establish rules that governor information exchange between the SPC's DER and the GSP so as to<br>● protect privacy<br>● provide security<br>● develop trustworthiness<br>● ensure interoperability |

[4] Chapter 2 discusses the ESI.

## 1.2.2 Definitions: Collaborative Objects

Below are definitions of collaborative objects that are required to properly interpret this document.

**Table 1.9** EGoT DERMS Collaborative Object Definitions

| Name | Definition |
|---|---|
| Distributed Control Module | A DCM is a client that requests resources from a DERMS server. It provides gateway service between communications protocols used by the DERMS and communications protocols used by DER. It serves as a user-agent on behalf of the SPC to autonomously make resource service request decisions. |
| Distributed Energy Resource | DER are customer-owned generation, storage, and load assets that can provide grid-DER services. These resources are located behind a customer meter. |

## 1.2.3 Definitions: *Resources* and *Services*

This EGoT DERMS IP includes technical terms from two disciplines, electric power engineering and network engineering. Inevitably, common terms from these disciplines will have conflicting definitions. Two such terms that are particularly problematic in this IP are "resources" and "services."

### *Resources*

Within a network engineering context, a "resource" is content within a server. This may be a static file such as an xml document, or a software program that provides a service such as a credit card payment. These resources are accessed from the server by the client through resource requests, and provided to the client by the server through resource responses. IEEE 2030.5 defines function sets, such as *Flow Reservation*, that provide smart energy services using request/response resources.

In a power engineering context, "resources" are generation, storage, and load assets that can be used to serve some function. These may be large-scale utility assets like generators, or residential scale assets like customer appliances. The latter can be aggregated by a DERMS to provide grid-DER services. Within this document, "resources" refers to the network engineering definition, and electric power resources are strictly DER.

### *Services*

Within a networking context, a "service" is a uniquely identified application provided by a server, which provides the application to clients via request/response resources. The EGoT DERMS has a service-oriented architecture (SOA), which transacts services between the DERMS server and DCM clients. IEEE 2030.5 defines smart energy resources that use a DNS-registered service instance called *smartenergy*. In this IP, these network services are referred to as "resource services."

In the power engineering context, "service" is often used to refer to the electrical service provided to a customer. "Service" also refers to the use of an electrical system resource to provide a necessary grid function, such as a voltage support service or peak demand mitigation service. These are often called "ancillary services," "essentially reliability services," or simply "grid services." Within this IP, the terms "grid service" and "grid-DER service" are used interchangeably. "Grid-DER service" refers to any of the six grid service categories defined in Appendix A. Grid-DER services transact between the GO and the GSP.

# 2 Energy Services Interface

The objectives of the Energy Services Interface (ESI) are to ensure private, secure, and trustworthy information exchange between GSPs and SPCs and to stimulate technological innovations within a large and dynamic EGoT ecosystem[5]. Large-scale adoption of DERs will be necessary to dispatch effective grid-DER services, and to stimulate technological innovations in DER, DERMS, and grid service programs. The ESI promotes these objectives by advancing a set of rules and interoperability requirements that define bi-directional, service-oriented, logical interfaces between GSPs and DERs, with expectations for privacy, security, and trust[6].

The ESI rules and interoperability requirements establish boundaries between SPCs and GSPs that delineate the functions and responsibilities that must be implemented by the developers of EGoT ecosystem products. The ESI interoperability requirements are based on the Interoperability Maturity Model (IMM)[7], developed by the Grid Modernization Laboratory Consortium Interoperability Project 1.2.2.

The objectives of the ESI are to: 1) ensure private, secure, trustworthy information exchange between GSPs and SPCs in order to promote dispatch of grid-DER services; and, 2) stimulate technological innovations in order to foster a large and dynamic EGoT ecosystem. The rules are intended to

1. ensure trustworthy information exchange between GSPs and SPCs
2. clearly define responsibilities for privacy and security between GSPs and SPCs
3. facilitate automated information exchange between GSPs and SPCs' DERs
4. limit information exchange between GSPs and DERs and other external parties
5. obscure SPCs' management of their DERs from the GSP
6. be extensible to new EGoT technologies

By emphasizing private, secure, and trustworthy information exchange, the ESI promotes the development of an EGoT ecosystem that motivates SPC participation and technological innovation. Interoperability will encourage innovation by reducing barriers to entry and increasing confidence of stakeholders. SPCs will be willing to participate in grid-DER service programs that establish trust and emphasize customer choice. Large-scale SPC participation ensures GSPs have ample DER resources to provide grid services that have significant impact on grid reliability and reduce electricity cost for consumers. This in turn signals economic opportunities that encourage innovation, resulting in the development of a robust EGoT ecosystem.

---

[5] *Energy Services Interface: Privacy, Security, Trust, Interoperability*, Portland State University PSU-ECE DOE-05, 2022

[6] S. Widergren, R. Melton, A. Khandekar, B. Nordman and M. Knight, *The Plug-and-Play Electricity Era: Interoperability to Integrate Anything, Anywhere, Anytime*, in IEEE Power and Energy Magazine, vol. 17, no. 5, pp. 47-58, Sept.-Oct. 2019

[7] M.R. Knight, D. Narang, J.T. Kolln, A. Khandekar, S.E. Widergren, B. Nordman, *Interoperability Maturity Model A Qualitative and Quantitative Approach for Measuring Interoperability*, Pacific Northwest National Laboratory, PNNL-29683, January 2020

# 3 EGoT Client/Server Architecture

## *3.1 Scope of Communications*

Figure 3.1 outlines the communication paths between the GO, GSP, and the control mechanism at the SPC. A GSP will need to conform to the message exchange protocols used by the GO in order to dispatch its DERs. All GOs have a system that profiles, schedules, and dispatches utility assets, referred to generally as a GenOps. A protocol defines the expectations for information exchange between the GO's GenOps and the GSP. This document does not specify a protocol for information exchange between the GO and the GSP.

Communication between the GSP and the DCM of a DER uses just one of the IEEE 2030.5 smart energy resource function sets. This is a consequence of the constraints imposed by the ESI pertaining to both privacy of information and privacy of agency. In contrast to the *Demand Response & Load Control* (*DRLC*), and *Distributed Energy Resources* (*DER*) resource services, the *Flow Reservation* resource service exchanges a minimum amount of information for the request/response messaging between the DCM and the GSP. Privacy of information is preserved since only *energy* and *power* properties are required for *Flow Reservation* requests. No information related to the DER appliance or its unique topological location needs to be conveyed.

The SPC's privacy of agency is also preserved, because the SPC's method of using its DER is not revealed within *Flow Reservation* requests. Only the interval and duration need to be communicated. For example, consider an SPC that has registered its dishwasher for resource service participation. The differences between the "pots & pans", "quick clean", and "water-saver" cycles will have no effect on the ability to participate as long as the *duration* of the selected cycle is communicated within the *Flow Reservation* request.

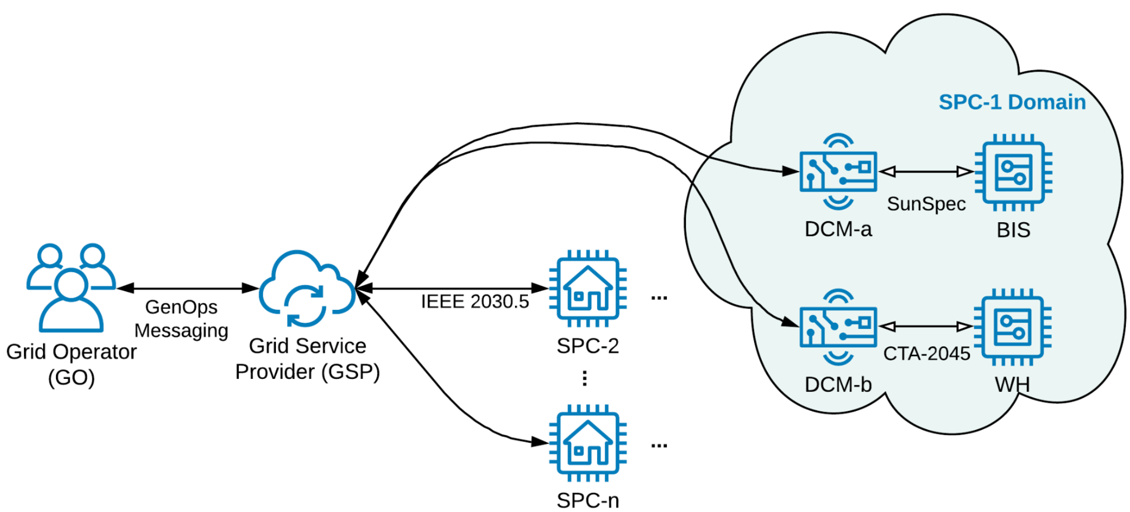



**Figure 3.1** The communication paths between system actors using different protocols. This IP focuses on the GSP-DCM pathway, which uses a subset of IEEE 2030.5 smart

energy resources. The DCM client provides interoperability between the DERMS server and the DER, which may use a protocol other than IEEE 2030.5.

### *3.2 Server*

Within the GSP, an EGoT DERMS server hosts IEEE 2030.5 resource services. These resource services are supported by the DCM clients. The goal of the GSP is to provide grid-DER services to the GO. It does not use its DERMS server to simply relay request/response messaging between the DER and the GO. Rather, the DERMS server aggregates the downstream DCM clients, based on their energy and power characteristics, such that the aggregation provides a grid-DER service for the GO.

### *3.3 Client*

The EGoT client is an IEEE 2030.5 resource-restricted client that simplifies participation and reduces the SPC's private data exposure to outside entities. The DCM hosts the EGoT client and serves as the logical interface between a DER and the GSP server. The ESI rules allow DCMs to connect to a GSP regardless of downstream configuration or communication protocol. If the SPC prefers internal aggregation of its DER, a single DCM could be used to group Flow Reservation requests.

# 4 Relevant IEEE 2030.5 Resources

The EGoT DERMS uses the IEEE 2030.5 Smart Energy Profile application protocol to implement the required information exchange between actors. IEEE 2030.5 is becoming a widely-adopted protocol. The protocol provides a large suite of resources including function sets, subscription processes, and other features. The IEEE 2030.5 protocol may be viewed as a foundation for this DERMS platform, providing mechanisms for device discovery and resource identification, and defining multiple security attributes. The protocol provides an extensive library of resources and support resource services. IEEE 2030.5 is intended to enable information exchange between many types of energy-service devices including consumer appliances, energy management systems, metering devices, and storage systems. It is expansive in its scope, providing multiple resources for interoperability between aggregators and consumer-owned DER.

## *4.1 IEEE 2030.5 Overview*

Considering the OSI network model, IEEE 2030.5 establishes specifications for the application layer. It specifies multiple security attributes at the presentation layer, TCP for the transport layer, and IP for the network layer. Security attributes include certificate requirements, device identifier specifications, and access control lists.

IEEE 2030.5 uses a server/client model based on a REST architecture wherein the server hosts resources and the client acts on those resources. In this implementation, the DCM client initiates resource requests, including requests that allow the server to push resources to the client via pub/sub, which is particularly useful for fast-acting grid services.

IEEE 2030.5 defines sets of Support Resources and Common Resources, which include basic function sets, subscription processes, acceptable responses, device status updates, configuration, logging, and network status. The standard also has an extensive library of Smart Energy Resources that enable utility management of customer-owned DER. This library provides several resource function sets, specifically: *Demand Response & Load Control* (*DRLC*), *Flow Reservation, and Distributed Energy Resources* (*DER*).

IEEE 2030.5 is becoming a widely-adopted protocol for inverter-based systems. It is the specified protocol for CSIP, which calls for an IEEE 2030.5 interface that meets the Phase 2 requirements for California Rule 21. It is also specified as one of only three allowable inverter protocols for grid-interactive inverters by IEEE 1547-2018, with the others being SunSpec Modbus and DNP3 (IEEE 1815). Its adoption by these other standards ensures that 2030.5-compatible devices will become widespread in the EGoT ecosystem.

## *4.2 IEEE 2030.5 Application Under the ESI*

As defined, the ESI requires that the EGoT DERMS:

- limit information exchange between the GSP and SPC's DER.
- obscure the SPC's management of its DER from external parties.

A GSP responds to requests from a GO for grid services by aggregating a large number of DER to act in coordination. This coordinated DER action provides the response profile of the grid service. Upon receiving a request for a grid service, the GSP's DERMS publishes a resource list to which DER may make requests.

DERs, via the DCM client, initiate resource requests, to which the DERMS server then responds. Specifically for this implementation, the DERMS uses *Flow Reservation or DER requests*[8] from DERs to determine available energy and power capacity for grid-DER service participation. The DERMS then creates *responses* to the DER *requests*, thereby building the response profile of the GO-requested grid service.

### 4.2.1 IEEE 2030.5 Flow Reservation Resource

The DERMS uses the DCM client *Flow Reservation requests* to temporarily allow the GSP server to schedule the DER. Each *Flow Reservation request* includes an *interval* during which the DER is anticipated to be available, and a *duration*, which specifies a length of time that the DER may be used within the *interval*. This *Flow Reservation* scheduling process is particularly useful for planning the dispatch of DER during time periods when they are needed by the GSP.

By using the *Flow Reservation* function set, the DERMS limits information exchange and obscures customer DER management better than when using another resource service, such as the *DER* or *DRLC* function sets. Using either of these requires more detail about the customer's DER and its energy use to be exchanged with the GSP. For example, *DRLC* has 34 potential elements, and the use of each increases customer exposure, complicates control, and imposes direct load control. A service requester does not need to know that they are requesting a load reduction from a water heater, only that they can anticipate a certain reduction in load. Consider, a GSP does not need to know or have control of thermal cycle setpoints, which *DRLC* allows, and which violates the device agnostic requirement of the ESI.

When using *Flow Reservation*, information exchange is minimal, consisting only of *power*, *energy*, *interval*, and *duration*. And, the use of this resource can be obscured through how the SPC's DCM chooses to allocate *intervals* and *durations*. The Flow Reservation *interval* improves DER participation, in contrast to *DRLC* which does not guarantee a reduction in load within the service period.

### 4.2.2 IEEE 2030.5 Distributed Energy Resource

The DERMS uses the *DER* function set to provide Voltage Management and Frequency Response grid-DER services to the GO(See Appendix A for grid-DER service

---

[8] When discussing the IEEE 2030.5 *DER* resources, *DER* is italicized. When discussing distributed energy resources, DER is not italicized.

descriptions). Specifically, the DERMS uses the DERProgram, DERControl, DERCurve, and DERCapability resources.

The DCM client uses the *DERCapability* resource to inform the DERMS server of its DER nameplate power ratings (Watts and VArs).  Knowing the power rating allows the DERMS server to calculate aggregate power capacities when responding to Frequency Response or Voltage Management grid-DER service requests from the GO.

DERCurve provides means for implementing curve control within inverter-based DER. The DCM client uses the DERCurve resource to specify inverter-based DER power output, both real and reactive, in response to sensed voltage or frequency at the point of the SPC's electrical service connection. Curve responses occur in real-time and within the inverter controller; they do not require request/response messaging between the DCM and DERMS in real-time. Rather, the DERMS publishes a resource list of *DER* curve-control services in anticipation of needing Voltage Management or Frequency Response services in the near future.  DCMs that request these curve-control services will receive a response from the DERMS that specifies the curve points (grid points that describe the graphical shape of the curve control).

Once a GSP server has committed to provide a Frequency Response or Voltage Management grid-DER service to the GO, its DERMS will create a DERProgram for each of the DERs that are available to participate in a resource service commitment. The DERMS then populated the DERProgram with the desired DERControl resource and the corresponding DERCurve characteristics of the resource service commitment.

The *DER* resources expose significantly more personal information about the DER and the SPC's topological location. However, this information is typically exposed by the SPC to its GO as a precondition for installing an inverter-based system within the GOs balancing area, such as through an interconnection agreement. If so, the SPC has already explicitly agreed to make these information available to the GO.

# 5 EGoT Server/Client IEEE 2030.5 Implementation

The IEEE 2030.5 standard hosts a large number of resources and function sets. The EGoT DERMS server/client system uses a subset of these function sets to reduce information exchange and protect SPC privacy. The subset of resources was chosen for their limited SPC information exposure, with the exception being the *DER* function set, as the information exposed is often required for interconnection between the SPC and its GO. Table 5.1 outlines each function set and the server and clients responsibility for implementation. The DERMS server is responsible for hosting all resources, so it must implement all function sets. However, a client can refuse to expose specific information to the DERMS server by not supporting specific function sets.

The primary function set that DCM clients must support to participate in an Energy grid-DER service is *Flow Reservation*. The *Flow Reservation* function set is unlike other control function sets in IEEE 2030.5 The *Flow Reservation* function set is an element of the End Device resource, which allows the DCM to restrict a large portion of the function sets and still participate in the basic energy resource service.

**Table 5.1** Required Function Sets

| Name | GSP Server | DCM Client |
|---|---|---|
| Device Capability | Mandatory | Mandatory |
| Self Device | Mandatory | Optional |
| End Device | Mandatory | Mandatory |
| Time | Mandatory | Mandatory |
| Function Set Assignment | Mandatory | Optional |
| Distributed Energy Resources | Mandatory | Optional |
| Meter | Mandatory | Mandatory |
| Log Event | Mandatory | Mandatory |
| Flow Reservation | Mandatory | Mandatory |
| Security | Mandatory | Mandatory |
| Subscription/Notification | Mandatory | Optional |

## 5.1 Grid Operator Operation

This IP does not specify IEEE 2030.5, nor any other protocol, for GO-GSP information exchange. Regardless, the GO is responsible for establishing topological assignments of DER, requesting grid-DER services from the GSP, and validating GSP grid-DER service participation. The GO is required to provide DER topological assignments to the GSP. This is the only interaction required from the GO in the process of registering a DER for resource service participation. The primary GO responsibility is advertising grid-DER services to all GSPs and validating GSP participation.

### 5.1.1 Registration

The GO requires three primary characteristics when registering a GSP within its balancing area (BA), Figure 5.1. For each topological assignment, the GSP provides the 1) positive and 2) negative After Diversity Maximum Power[9] values, along with 3) the maximum reactive power. This information gives the GO insight into the potential DER participation throughout the BA.

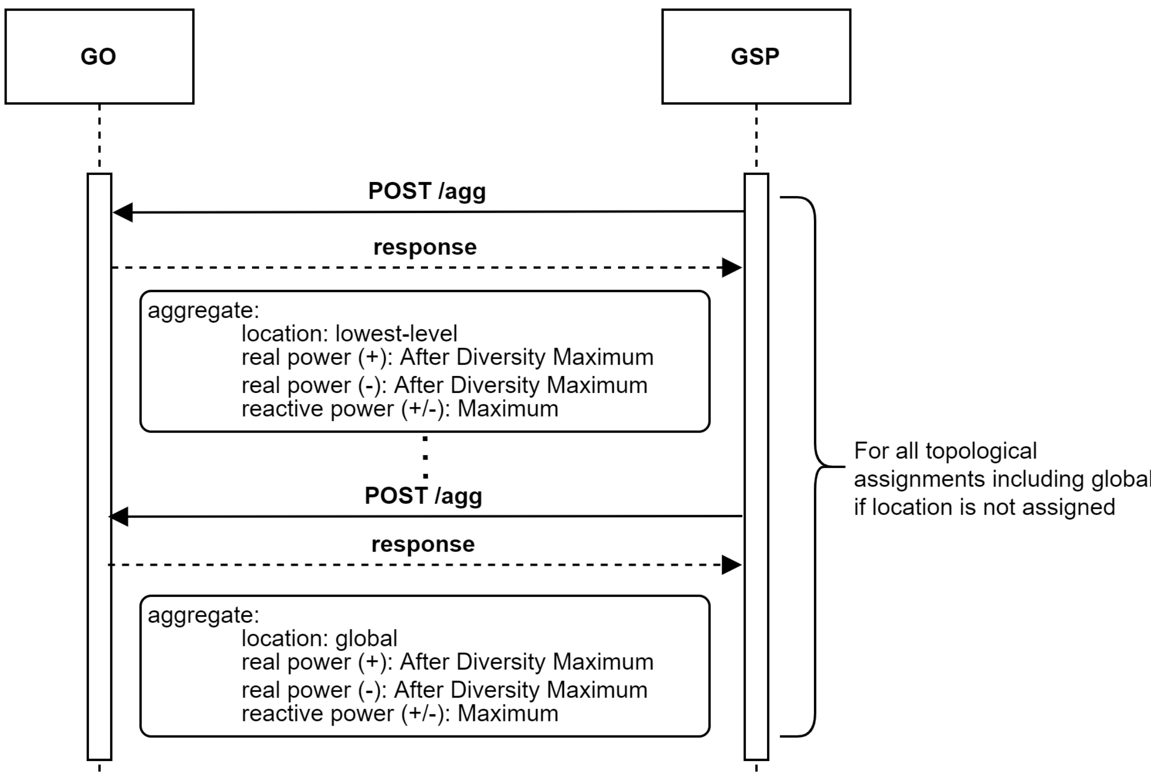



**Figure 5.1** Simplified GSP characteristics for GO registration. The above sequence diagram is generic; this IP does not specify IEEE 2030.5, or any other protocol, for GO-GSP information exchange.

[9] After Diversity Maximum Power represents the maximum concurrent power of an ensemble of DER on a per-DER basis, considering the diversity of their availability. In other words, it is the effective power capability of individual DERs within an ensemble of DERs.

### 5.1.2 Topological Assignment

The topological demarcation is designated by the GO for each DER participating with the GSP, Figure 5.2, though only when the grid service requires location information. The GO may group locations to simplify the dispatch of grid services. The GSP is responsible for passing a resource service for a group to all related topological assignments.

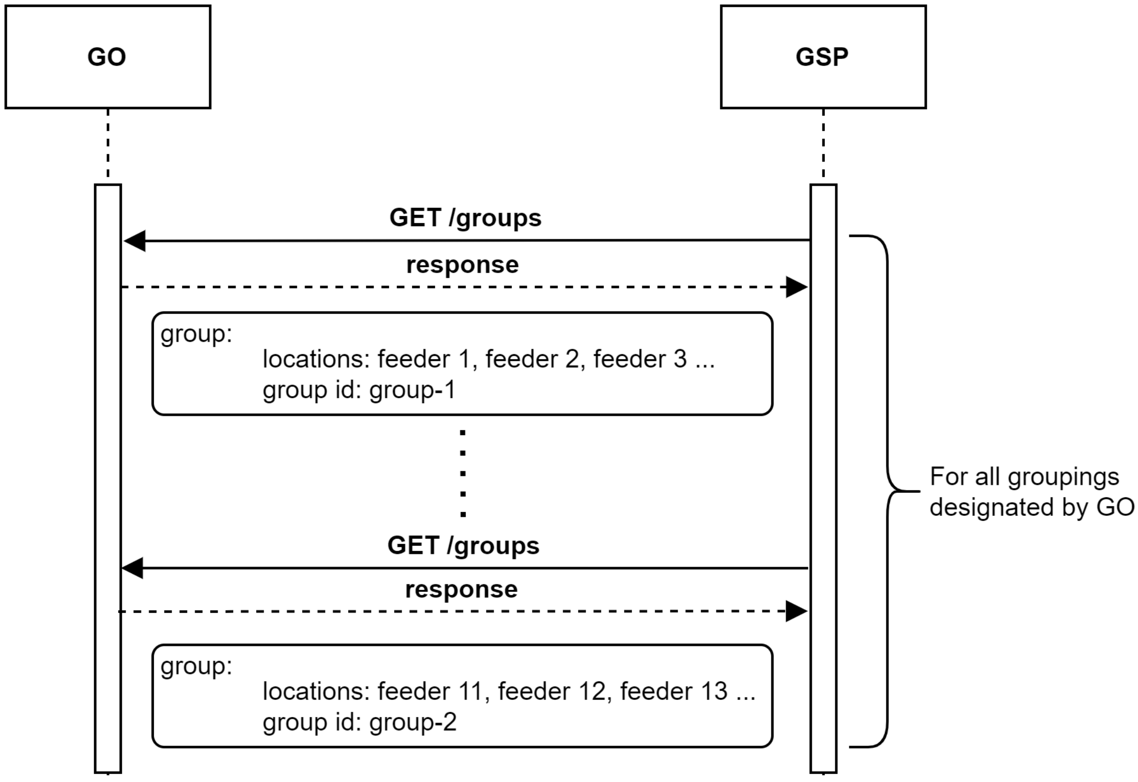



**Figure 5.2** GO topological groupings for participating GSPs.

### 5.1.3 Grid Service Request

The GO is responsible for advertising the BA grid services available to all GSPs, Figure 5.3. The GSP checks which grid services are available for each grouping and submits a commitment of resources to the GO. If the commitment is accepted by the GO, the GSP is required to participate and submit a participation summary at the end of the grid service request.

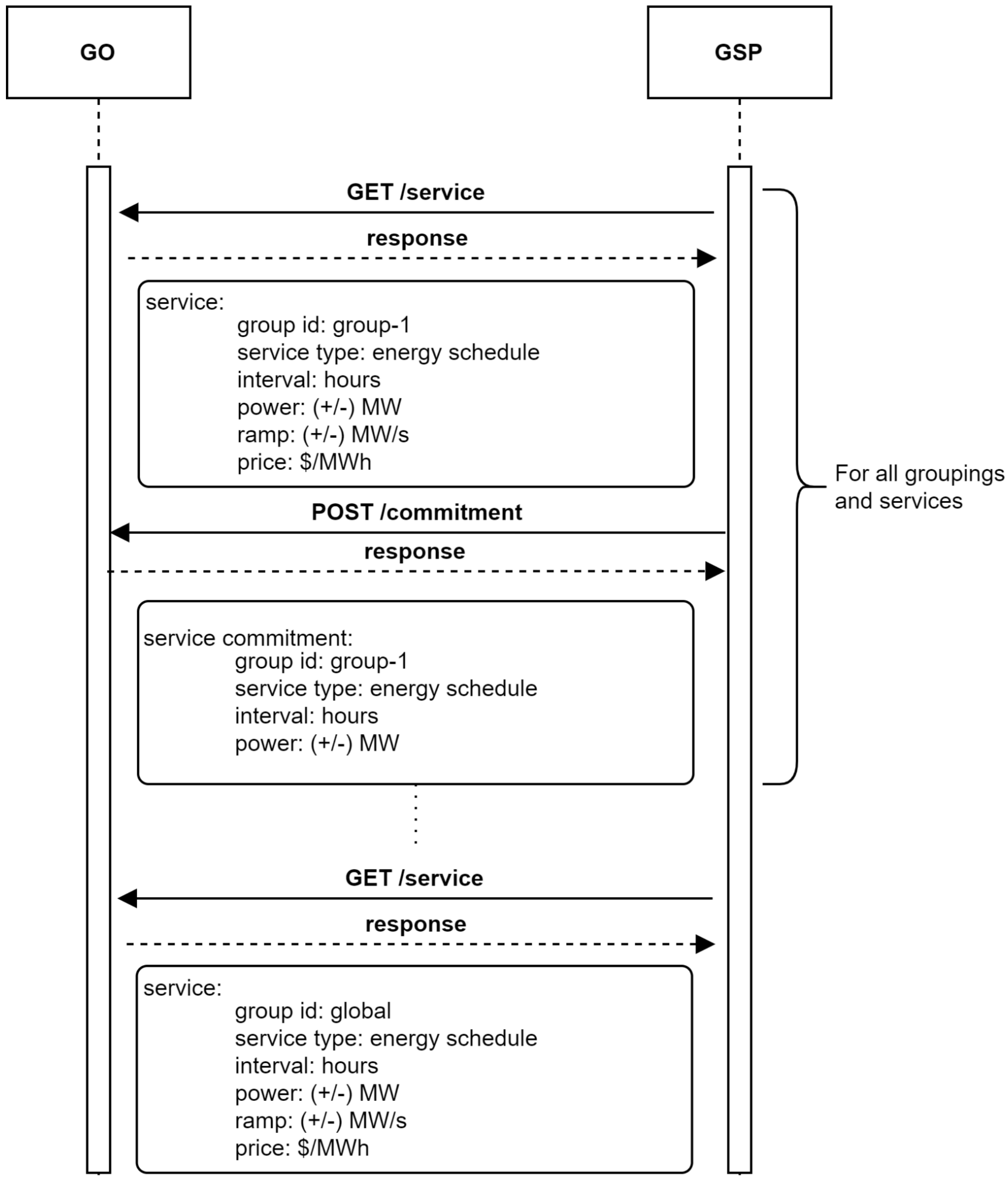



**Figure 5.3** GO grid service request for each designated grouping.

### 5.1.4 Grid Service Settlement

After the grid service period is finished, the GSP will submit the participation records as a group to the GO. The GO is responsible for validating the participation records against system metering. The GO compensates the GSP based on accuracy and duration of participation.

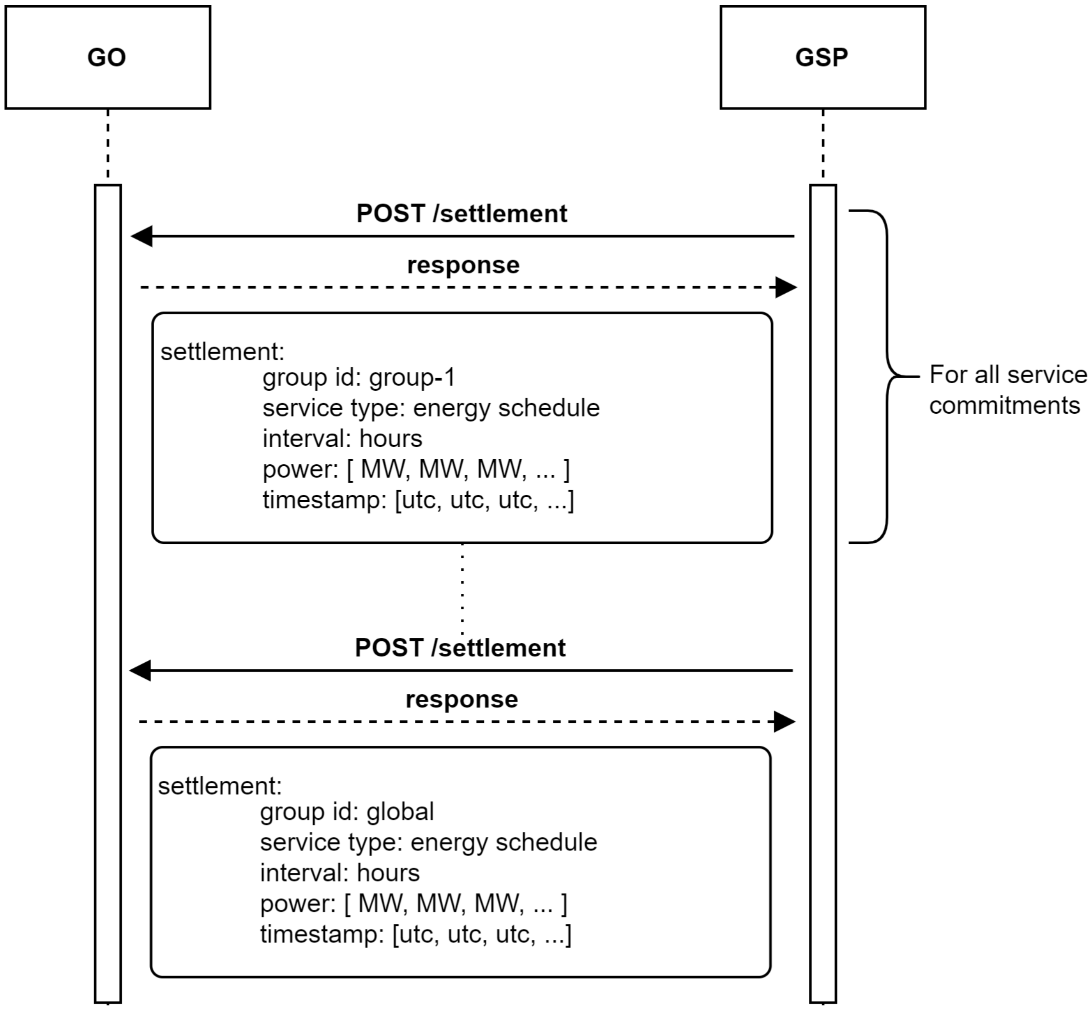



**Figure 5.4** GO grid service settlement GSP groupings after commitment period

## *5.2 Grid Service Provider Operation*

This IP specifies IEEE 2030.5 as the protocol for information exchange between the GSP and the DCM. The GSP is responsible for providing grid service commitments that are requested by the GO. The GSP does this by coordinating aggregate participation from many thousands of DER. The GSP's DERMS creates IEEE 2030.5 resources to secure DER participation commitments. If an SPC has registered its DER with the GSP (done through out-of-band channels), its DCM will have access to the DERMS resource service request lists, and may submit resource service requests to the DERMS.

The DCM submits either *Flow Reservation* requests, which the GSP uses to provide Energy, Reserve, Regulation, and Blackstart grid-DER services, or the DCM submits *DER* requests, which the GSP uses to provide Voltage Management or Frequency Response grid-DER services[10].

### 5.2.1 Registration

The SPC is required to work out-of-band with its local GO (utility) to create the *customer agreement* resource, which establishes the grid location associated with the DER. This also serves to ensure specific DER connection agreements are handled through the utility before connection to the grid. The submission of all registration information to populate the end *device, function set assignments, customer agreement*, and *ssl (secure sockets layer) certificate* are performed out-of-band between the GSP and the SPC.

Once all resources are populated, the DCM of the DER is given access to the GSP DERMS server through its domain name. The DCM verifies it is registered using the CSIP COMM-006 Basic Registration procedure, which uses IEEE 2030.5 to manage registration. CSIP COMM-006 provides an outline of the registration step.

### 5.2.2 Topological Assignments

The topological assignment of DER is designated by the GO during the registration process. The GSP is responsible for creating groupings as indicated by the GO[11]. These groupings are used to manage DER participating in location-based grid services. For non-function set assignment resources such as *Flow Reservation* requests, the GSP is required to manage DER groupings internally to ensure desired DER participation.

### 5.2.3 Flow Reservation Resource Service Requests

The GSP accepts and aggregates *requests* for *Flow reservation* resource services from DCMs, Figure 5.5. These requests are initially scheduled to complete at the latest time within the *interval* of the request, where *interval* is one of the *Flow Reservation* parameters, discussed in detail in Appendix A.1. The GSP commits these requests to a

[10] As specified in the autonomous DER Control Management description within CSIP, Section 6.1.8 CSIP is the *Common Smart Inverter Profile: IEEE 2030.5 Implementation Guide for Smart Inverters*, February 2018, Version 2.0

[11] M. Alsaid, M. Adham, R. Bass, and N. Bulusu, "Distributed energy resource management systems: Preserving customer privacy through K-anonymity," in IEEE Power & Energy Society General Meeting, Orlando, Florida, USA, 2023

specific grid service advertised by the GO and reschedules the *Flow Reservation response* to satisfy the grid service requirements.

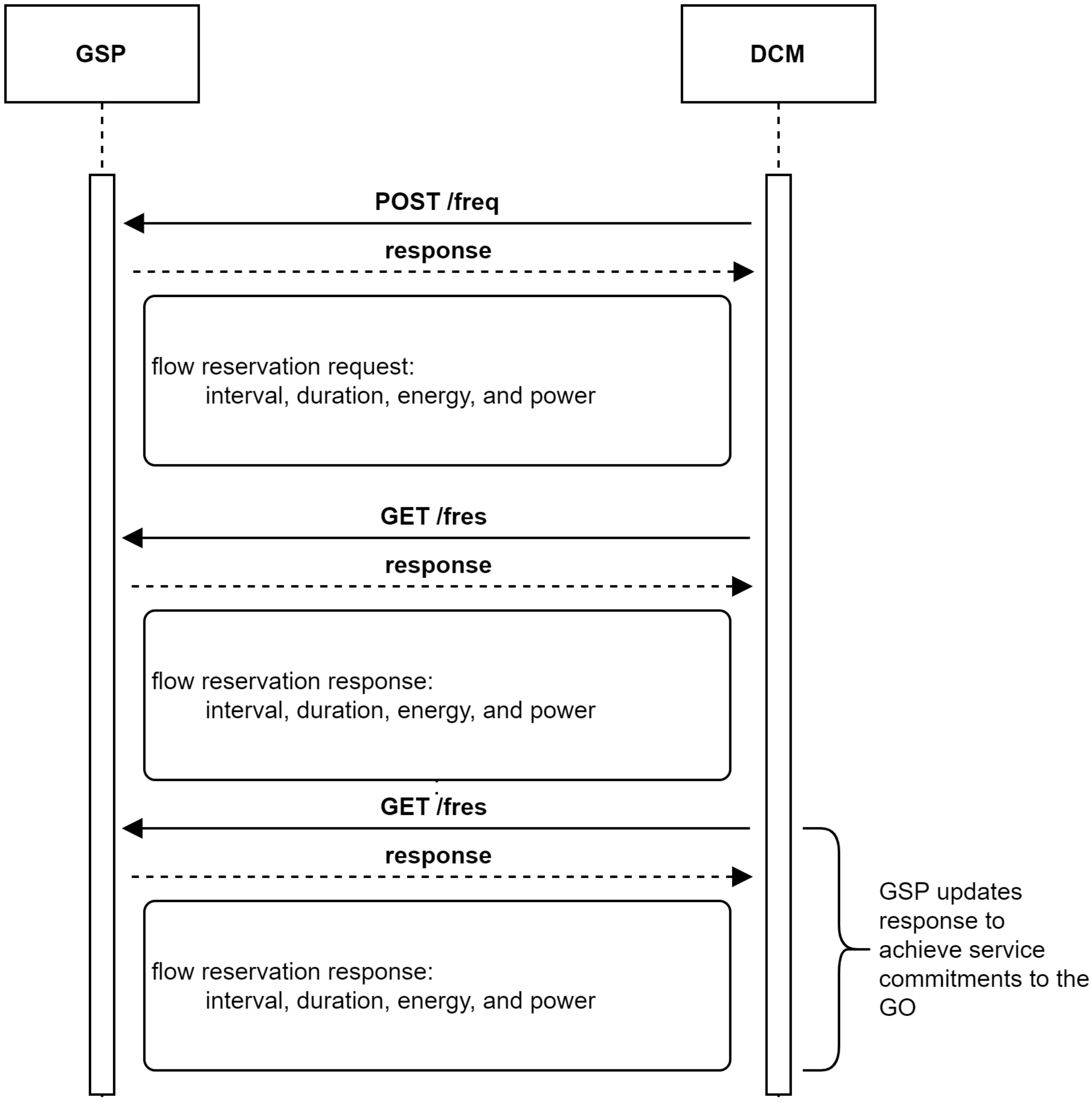



**Figure 5.5** DCM *Flow Reservation* request to the GSP for resource service participation.

### 5.2.4 Resource Service Settlement

The GSP uses the *mirror reading set* resource to validate all DER that participate in resource service commitments, Figure 5.6. After a DER has completed a *Flow Reservation response*, its DCM is responsible for submitting a mirror meter reading. The GSP uses the aggregated DCM *mirror reading set* to submit grid service settlement to the GO.

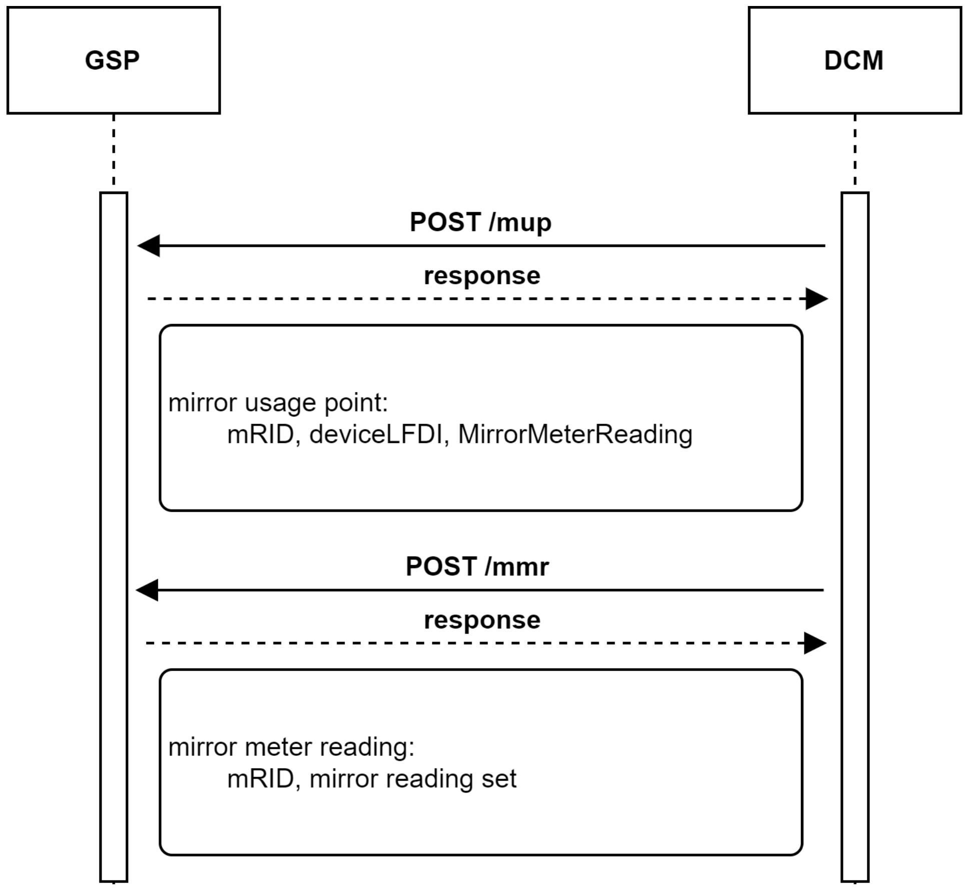



**Figure 5.6** DCM mirror meter reading set for *Flow Reservation* response validation.

## *5.3 Distributed Control Module Operation*

This IP does not specify a protocol for DCM-DER information exchange. The DCM may serve as a pass-through for IEEE 2030.5 messaging or as a gateway to another protocol used by the DER. The DCM is responsible for creating *Flow Reservation* and *DER requests* and participating in *Flow Reservation* and *DER responses* set by the GSP, Figure 5.5. The *requests* are sent to the GSP when both the DER is anticipated to be available, such as when the DER is within a pre-set SPC comfort threshold, and when a time window for DER participation is sufficient to fulfill the request.

When the DCM receives the *Flow Reservation response* from the GSP it starts the DER operation at the scheduled time, Figure 5.7. During this time, the DCM periodically checks the DER's power and energy properties and stores them for the *mirror reading set* that will be sent to the GSP upon completion of the *Flow Reservation response*. After finishing the operation, the DCM returns the DER to the hold operation state so it may be used for another energy resource service. A complete description of the DCM is provided by the Distributed Control Module Product Specification.[12]

[12] *Product Specification: Distributed Control Module*, Portland State University, PSU-ECE DOE-04, 2022

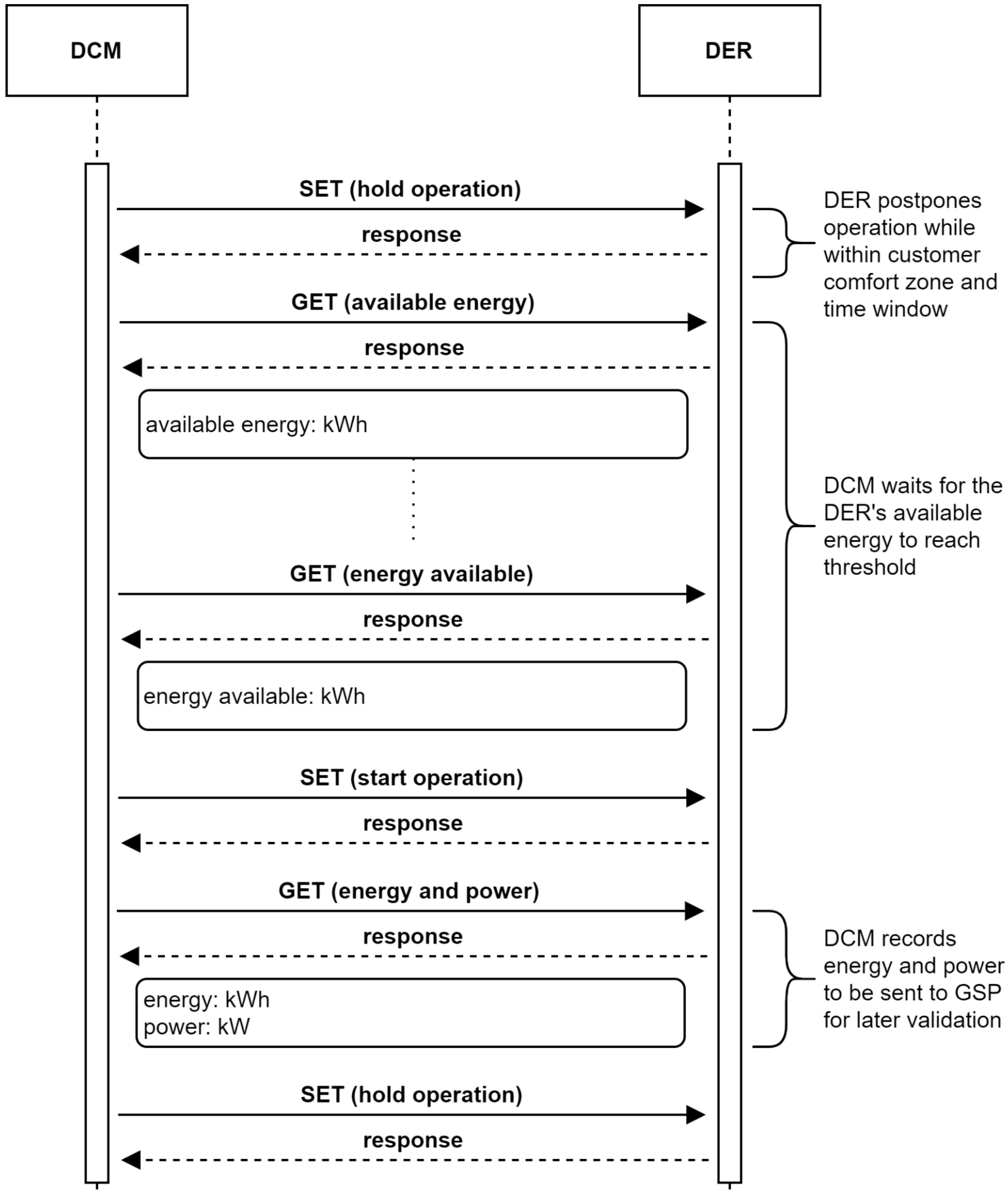



**Figure 5.7** DCM *Flow Reservation* implementation process; gateway service to the DER.

# Appendix A Grid-DER Services

The Grid Modernization Laboratory Consortium (GMLC) has proposed reclassification of the many, and not uniformly defined, grid service terms used in the electric power industry into six categories, termed "grid-DER services."[13,14,15] These are generalized categories of grid services that aggregations of DER can provide. Table A.1 presents the six grid-DER service categories. Table A.2 associates several common grid services with these six grid-DER services. The table also relates the grid-DER service categories with the grid services defined within Appendix H of the DOE EGoT Funding Opportunity Announcement (FOA) that funded the development of this implementation profile[16].

**Table A.1** The six grid-DER services, their purposes and actions.

| Grid-DER Service | Purpose | Actions |
|---|---|---|
| Energy | Ensure adequate energy resource supply. | Consume or produce a specified amount of energy over a scheduled period of operation |
| Reserve | Reserve source or load capacity. | Adjust real power of sources or loads within a 5 to 30 minutes time frame for dispatched in a contingency. |
| Regulation | Support area control error (ACE).[17] | Adjust real power of sources or loads following an automatic control signal. |
| Blackstart | Support recovery of a collapsed electrical power system. | Sources supply power and support voltage. Loads defer post-recovery consumption |
| Voltage Management | Detect and correct voltage excursions outside of defined limits. | Control reactive and/or real power of sources and loads. |
| Frequency Response | Detect and arrest sudden frequency deviations outside of defined limits. | Control real and/or reactive power of sources and load. |

[13] J. T. Kolln, D. Narang, *A Method to Develop an Energy Services Interface*, DOE Grid Modernization Laboratory Consortium, PNNL-SA-177348, December 2022.
[14] J. Liu, S. Widergren, J. T. Kolln, T. Bohn, S. Xue, R. Brown, *State of Common Grid Services Definitions*, DOE Grid Modernization Laboratory Consortium, LBNL-2001497, December 2022.
[15] J. T. Kolln, J. Liu, S. E. Widergren, R. Brown, "Common Grid Services: Terms and Definitions Report," Pacific Northwest National Laboratory, PNNL-34483, July 2023.
[16] Funding Opportunity Announcement: DE-FOA-0002092, *Electric Grid of Things - Attaining Resilience Objectives With Networks of Sensing Intelligent Machines*, U.S. Department of Energy (DOE), Office of Electricity, June 2019
[17] ACE is the sum of the balancing area (biased) frequency error and the net inter-area power error. The ideal ACE is zero.

**Table A.2** Relations between the grid-DER services, the grid services listed in the DOE EGoT FOA, and colloquial grid service names.

| Grid-DER Service | FOA-Defined Grid Services | Colloquial Names |
|---|---|---|
| Energy | Reduce Peak Loading | peak demand mitigation |
| | | energy imbalance |
| Reserve | Scheduled Synchronous Reserve | spinning reserve |
| | Secondary Frequency Control - Contingency | spinning reserve |
| | Scheduled non-Synchronous Reserve | non-spinning reserve |
| | Tertiary Frequency Control | non-spinning reserve |
| Regulation | Scheduled Regulation | frequency regulation |
| | Secondary Frequency Control-Normal | frequency regulation |
| Blackstart | Blackstart Support | blackstart |
| | Blackstart Execute | blackstart |
| Voltage Management | Manage Voltage[18] | Volt/VAr support |
| Frequency Response | Primary Frequency Control | frequency response |

[18] MV includes: voltage regulation, VAr injection, PF correction, peak current reduction, conservation voltage regulation.

## A.1 Grid-DER Service Characteristics

Table A.3 maps grid-DER Services to proposed grid-DER service characteristics. A DER Facility would identify these characteristics among its portfolio of DER in order to determine which of its DER could provide specific grid-DER service requests. These proposed grid-DER service characteristics must be measurable in order for Facilities to be properly compensated for their contributions towards achieving operational objectives. In the interest of preserving privacy, the grid-DER service characteristics are the full extent of DER information that may be exchanged between the DER Facility and the grid service requester.

**Table A.3** Mapping grid-DER services with proposed grid-DER service characteristics. Location extent terms are defined by the CSIP topological grouping scheme.[19]

| **Grid-DER Services** | **Grid-DER Service Characteristics** | | | | | |
|---|---|---|---|---|---|---|
| | **Interval** | **Duration** | **Update Rate** | **Response Time** | **Power** | **Location Extent** |
| Energy | hours, days | multiples of market rate | market rate (minutes) | minutes | real, +/- | System[20], Subtransmission, Substation, or Feeder |
| Reserve | hours | multiples of market rate | market rate (minutes) | minutes | real, +/- | System, Subtransmission, Substation, or Feeder |
| Regulation | minutes to hours | seconds to minutes | seconds | seconds | real, +/- | System |
| Blackstart | hours, days | minutes, hours | market rate (minutes) | (+): seconds (-): minutes | real & reactive, +/- | Substation, Feeder, or Segment |
| Voltage Management | hours | extent of the interval | market rate (minutes) | algorithm-based | max or curves | Feeder, Segment, or Transformer |
| Frequency Response | hours | extent of the interval | market rate (minutes) | algorithm-based | max or curves | System |

Following are six proposed definitions of grid-DER service characteristics.

- **Interval** The period of time within which the DER Facility has committed to providing a grid-DER service.
- **Duration** The cumulative length of time, within the interval, that the DER Facility has committed to providing its DER resource. The duration may be distributed in divisible subdurations with the interval.

[19] See Figure 3 in *Common Smart Inverter 7 Profile: IEEE 2030.5 Implementation Guide for Smart Inverters, Version 2.1, Common Smart Inverter Profile Working Group, March 2018*
[20] Topological level "System" is equivalent to "Balancing area."

- **Update Rate** The rate at which the DER Facility should expect requests from the grid service requester within the interval.
- **Response Time** Response time is the time that has lapsed between the moment when the grid service request (or condition in the case of autonomous behavior) is sent from the grid service requester and the moment when the desired behavior has met the predefined threshold for a given grid-DER service.
- **Power** May be defined as an average power, the points of a curve for curve-based grid-DER service, or +/- maximum power for algorithm-based grid-DER services:
    - The average power, real or reactive, that the DER can provide or defer during the duration. Provided power may be positive (source) or negative (load).
    - A vector of points, each having an independent variable (such as voltage or frequency) and a dependent (+) or (-), real or reactive, power variable.
    - (+) and (-) maximum real and/or reactive power
- **Location Extent** All grid services apply to distinct topologies within an interconnection. In the interest of preserving DER Facility privacy, the DER Facility location shall only be identified to the broadest extent required for each grid service. The topology scheme defined in CSIP V2.1 shall be used to assign unique topological identifications to DERs.

## *A.2 DER Capability Assessment*

Several residential DERs are presented in Table A.4. The Table presents estimates of DER grid-DER service characteristics and the grid-DER services for which they are suited to provide.

**Table A.4** Example residential DER, their grid-DER service characteristics, and grid-DER services for which they are suited.

| DER | Grid-DER Service Characteristics | | | Applicable Grid Services |
| --- | --- | --- | --- | --- |
| | **Duration** | **Response Time** | **Power** | |
| Water Heater - Resistance[21,22,23,24] | ~15 minutes | 100’s milliseconds | 1-5 kW | Energy<br>Reserve<br>Regulation<br>Blackstart (defer load)<br>Frequency Response |
| Water Heater - Heat Pump | ~50 minutes | minutes | 1-1.5 kW | Energy<br>Reserve<br>Blackstart (defer load) |
| PV/BIS Inverter | Minutes to hours | seconds | +/-10’s kW<br>+/-10’s kVAr | Energy<br>Reserve<br>Regulation<br>Blackstart (source reserve) |
| | Extent of the interval | algorithm-based | | Voltage<br>Frequency Response |

[21] Bonneville Power Administration, *CTA-2045 Water Heater Demonstration Report*, Technical report, November 2018.
[22] Thomas C., Seal, B., *2017a. Performance Test Results: CTA-2045 Water Heater: Testing Conducted at the National Renewable Energy Laboratory*, 3002011760. Tech. rep., Electric Power Research Institute, Palo Alto, CA.
[23] T. Clarke, T. Slay, C. Eustis and R. B. Bass, *"Aggregation of Residential Water Heaters for Peak Shifting and Frequency Response Services*, in IEEE Open Access Journal of Power and Energy, vol. 7, pp. 22-30, 2020
[24] K. Marnell, C. Eustis and R. B. Bass, *Resource Study of Large-Scale Electric Water Heater Aggregation*, in IEEE Open Access Journal of Power and Energy, vol. 7, pp. 82-90, 2020

**Table A.4** continued.

| DER | Grid-DER Service Characteristics | | | Applicable Grid Services |
|---|---|---|---|---|
| | Duration | Response Time | Power | |
| EVSE[25] (V2G, pending changes to SAE standards)[26] | Minutes to hours | seconds | +10's kW<br>+/-10's kVAr | Energy<br>Reserve<br>Regulation<br>Blackstart (source reserve) |
| | Extent of the interval | algorithm- based | | Voltage<br>Frequency Response |
| Thermostat[27] (HP or AC) | Minutes to hours | minutes | -5-10 kW | Energy<br>Reserve<br>Blackstart (defer load) |
| Clothes Dryer | 10's of minutes | minutes | -5 kW | Energy<br>Reserve<br>Blackstart (defer load) |
| Clothes Washer | 10's of minutes | minutes | -1 kW | Energy<br>Reserve<br>Blackstart (defer load) |
| Dish Washer | 10's of minutes | minutes | -1 kW | Energy<br>Reserve<br>Blackstart (defer load) |
| Pool Pumps[28] | Minutes to hours | seconds | -1 kW | Energy<br>Reserve<br>Regulation<br>Blackstart (defer load) |

# Appendix B Grid-DER Service Dispatch Use Cases

The following subsections outline cases wherein GSPs aggregate DER to provide grid-DER service. These cases include assumptions, required DER capabilities,

[25] Thomas C., Seal, B., *2017c. Performance Test Results: CTA-2045 Electric Vehicle Supply Equipment: Testing Conducted at the National Renewable Energy Laboratory*, 3002011757. Tech. rep., Electric Power Research Institute, Palo Alto, CA.
[26] SAE J3072-202103, *Interconnection Requirements for Onboard, Utility-Interactive Inverter Systems*, Society for Automotive Engineers.
[27] Thomas C., Seal, B., *2017a. Performance Test Results: CTA-2045 HVAC Thermostat: Testing Conducted at the National Renewable Energy Laboratory*, 3002011747. Tech. rep., Electric Power Research Institute, Palo Alto, CA.
[28] Thomas C., Seal, B., *2017a. Performance Test Results: CTA-2045 Variable Speed Pool Pumps: Testing Conducted at the National Renewable Energy Laboratory*, 3002011757. Tech. rep., Electric Power Research Institute, Palo Alto, CA.

sequences of information exchange for each of the six grid-DER services, as well as example sequence diagrams. These diagrams provide the reader with a general understanding of how grid services could be implemented between the various actors, from the GO to the SPC.

The use case diagram in Figure B.1 shows the grid-DER service message exchange between the GO and GSP actors. After grid-DER service messages are conveyed from the GO to the GSP, the GSP seeks DER to provide the requested grid-DER services. The GSP communicates with DCMs, which in turn communicate with their respective DER. The use case diagram in Figure B.2 summarizes information exchange between the GSP and DCM actors.

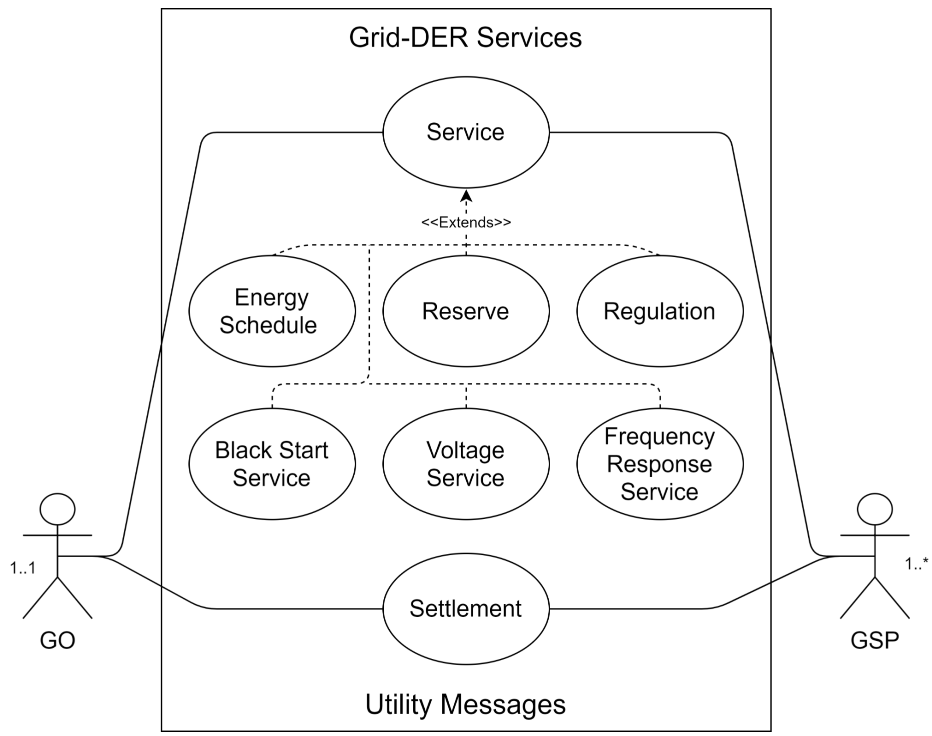



**Figure B.1** Use case diagram for grid-DER services showing message exchange between the GO and the GSP.

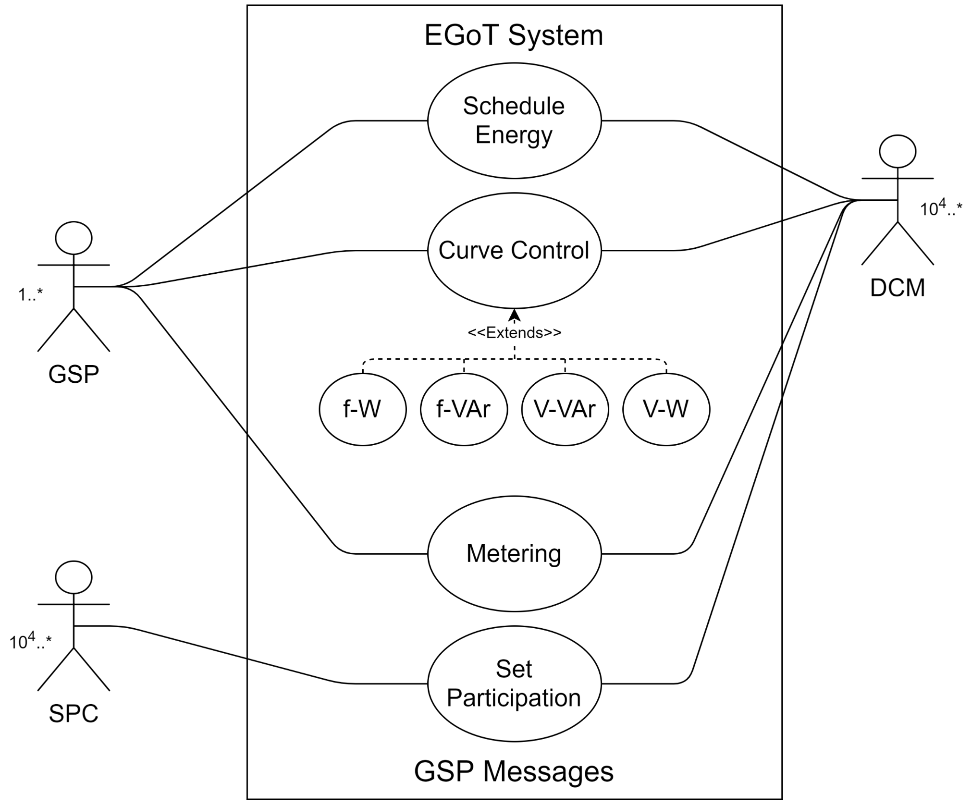



**Figure B.2** Use Case diagram for the EGoT DERMS, which manages information exchange between a GSP and one or more and large numbers of DERs. DCM agents act on behalf of SPCs to request IEEE 2030.5 resource services from a GSP. Tens to hundreds of thousands of DERs will need to be aggregated to provide grid-DER services that have meaningful impacts on power systems operation.

## *B.1 Energy Service Use Case*

A GSP seeks DERs capable of providing Energy Service to ensure a BA continuously provides adequate energy resource supply. Participating DERs consume or produce a specified amount of energy over a scheduled period of operation.

Assumptions

- GSP and other BA members have means in place to coordinate activities that might impact each other's operations.
- GSP provides Energy Service to GO during scheduled Intervals.
- DER response times as long as several minutes are tolerable.
- DER location scope is BA-wide.
- GSP and DCMs exchange information synchronously, using request–response messaging.

DER capabilities

- Loads are non-critical[29].
- Loads are deferrable[30] and/or non-coincident[31].
- Storage resources can pre-charge to prepare for scheduled dispatch.

Sequence of information exchange. Two sequence diagrams are provided in Figures B.3 and B.4**.**

1. A GO seeks Energy Service from qualifying GSPs. Energy Service may consist of two or more intervals of two types:
    a. Deferral period: decrease consumption or increase generation
    b. Commitment period: increase consumption or decrease generation
2. GSP creates an IEEE 2030.5 *Flow Reservation* resource.
3. DCMs of qualifying DERs post requests for the *Flow Reservation* resources, for each of the two intervals. The posts include grid-DER service characteristics:
    a. Interval
    b. Update Rate
    c. Response Time (minimum)
4. DCMs check the status of their DERs.
5. DCMs post a request for participation. For each interval, the post includes grid-DER service characteristics:
    a. Interval (confirm or modify)
    b. Update Rate (confirm)
    c. Response Time (confirm)
    d. Duration
    e. Power

---

[29] Critical loads: loads that a customer is reliant upon for their health or well-being. e.g. heat pumps and air conditioners during extreme climate situations, refrigerators and freezers for extended periods, medical devices.

[30] Deferrable load: a load whose operation can be delayed to another time period. e.g. dishwashers, pool pumps, clothes washers, dryers, defrosters.

[31] Non-coincident load: a load with electrical energy consumption profiles that are not coincident with its use by the customer. e.g. water heaters, heat pumps, air conditioners.

6. Deferral period begins
    a. As needed during the deferral period, GSP updates DER Durations:
        i. source DERs discharge.
        ii. load DERs defer consumption.
7. Deferral period ends.
8. Commitment period begins
    a. As needed during the commitment period, GSP updates DER Durations:
        i. storage DERs charge to 100% capacity.
        ii. load DERs resume consumption.
9. Commitment period ends.
    a. DERs revert to normal operation

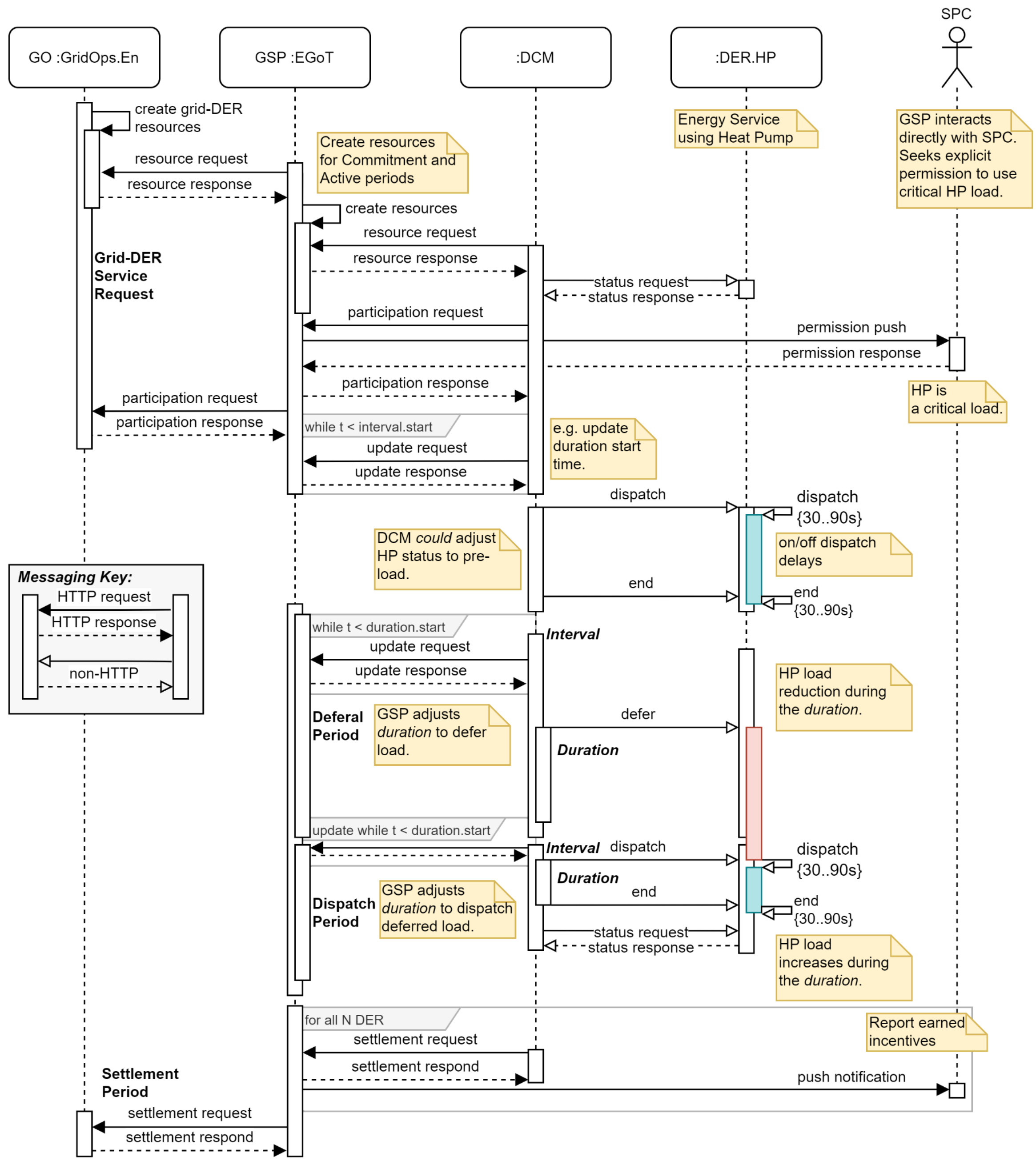



**Figure B.3** Sequence diagram for grid-DER Energy Service provided by a Heat Pump (HP) HVAC system. HP operation is deferred from one period to a later period. In anticipation of deferral, the DCM operates the HP at an adjusted setpoint (e.g. lowered if in cooling mode).

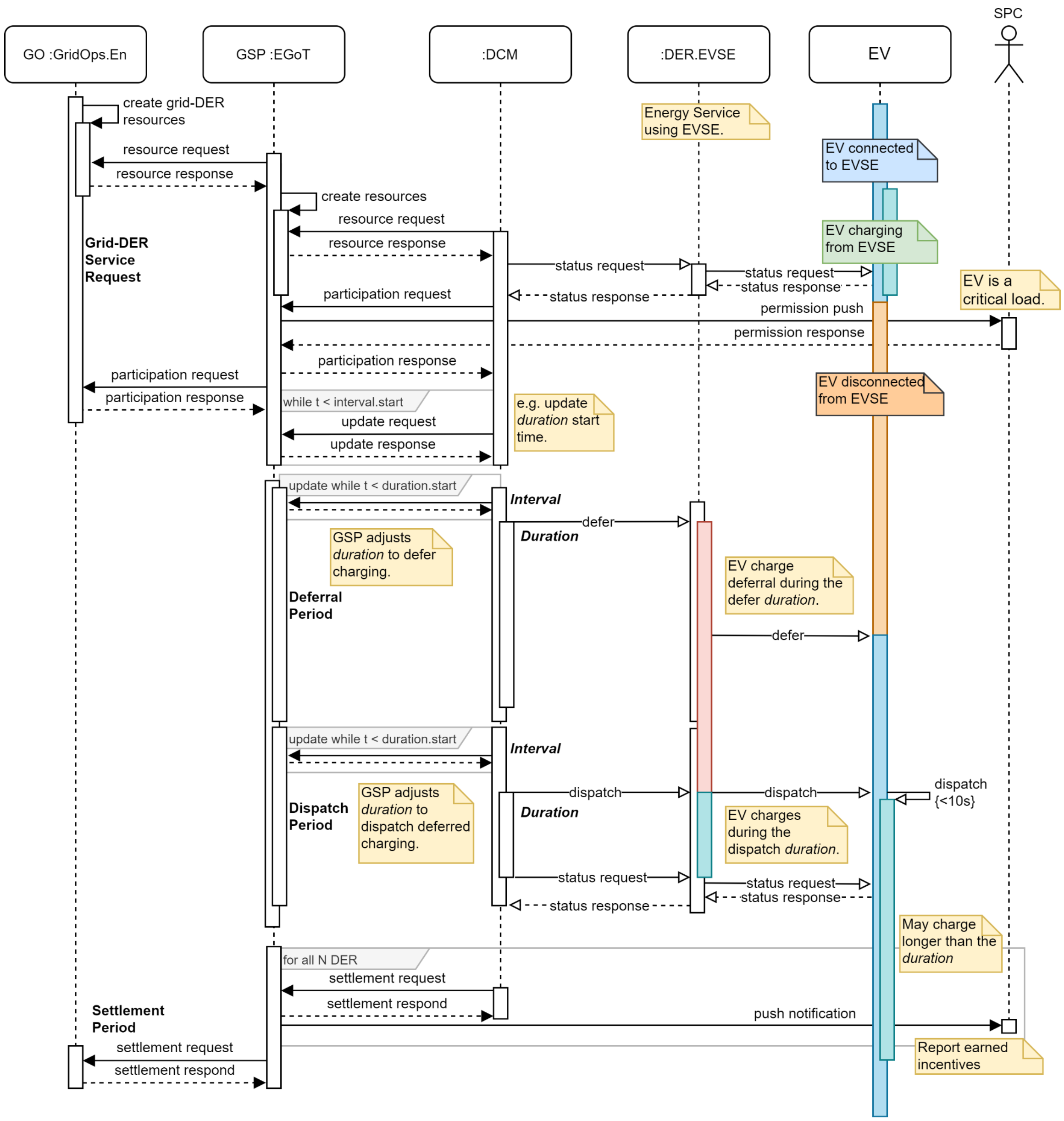



**Figure B.4** Sequence diagram for grid-DER Energy service provided by electric vehicle service equipment (EVSE). Charging requires the EV to be plugged into the EVSE. Operation is deferred from one period to a later period.

## *B.2 Reserve Service Use Case*

DERs capable of providing Reserve Service are either sources or loads that can maintain some real power reserve capacity. This capacity can be dispatched during resource contingency situations. The response time for these resources is intra-hour, within a five-to-thirty minute timeframe, depending on several factors. Contingency situations include unanticipated resource ramping events, loss of committed generation, or erroneous projections of load.

Assumptions

- GSP provides Reserve Service capacity to GO for long periods of time.
- DER response times of up to several minutes are tolerable.
- DER location scope is BA-wide.
- GSP and DCMs exchange information synchronously, using request–response messaging.

DER capabilities

- Loads are non-critical.
- Loads are deferrable and/or non-coincident.
- Storage resources can pre-charge to provide reserve capacity.

Sequence of information exchange. Sequence diagram provided in Figure B.5.

1. A GO seeks Reserve Services from qualifying GSPs.
2. GSP creates an IEEE 2030.5 *Flow Reservation* resource.
3. DCMs of qualifying DERs post requests for the *Flow Reservation* resource. The post includes grid-DER service characteristics:
    a. Interval
4. DCMs check the status of their DERs.
5. DCMs post a request for participation. The post includes grid-DER service characteristics:
    a. Interval (confirm or modify)
    b. Duration
    c. Power
    d. Response Time
6. Prior to active period start,
    a. storage sources pre-charge to 100% capacity
    b. deferrable and non-coincident loads pre-energize
7. Active period begins
    a. If needed during the Interval, the GSP updates DER Durations
        i. source DERs discharge
        ii. load DERs defer consumption.
8. Active ends
    a. DERs revert to normal operation

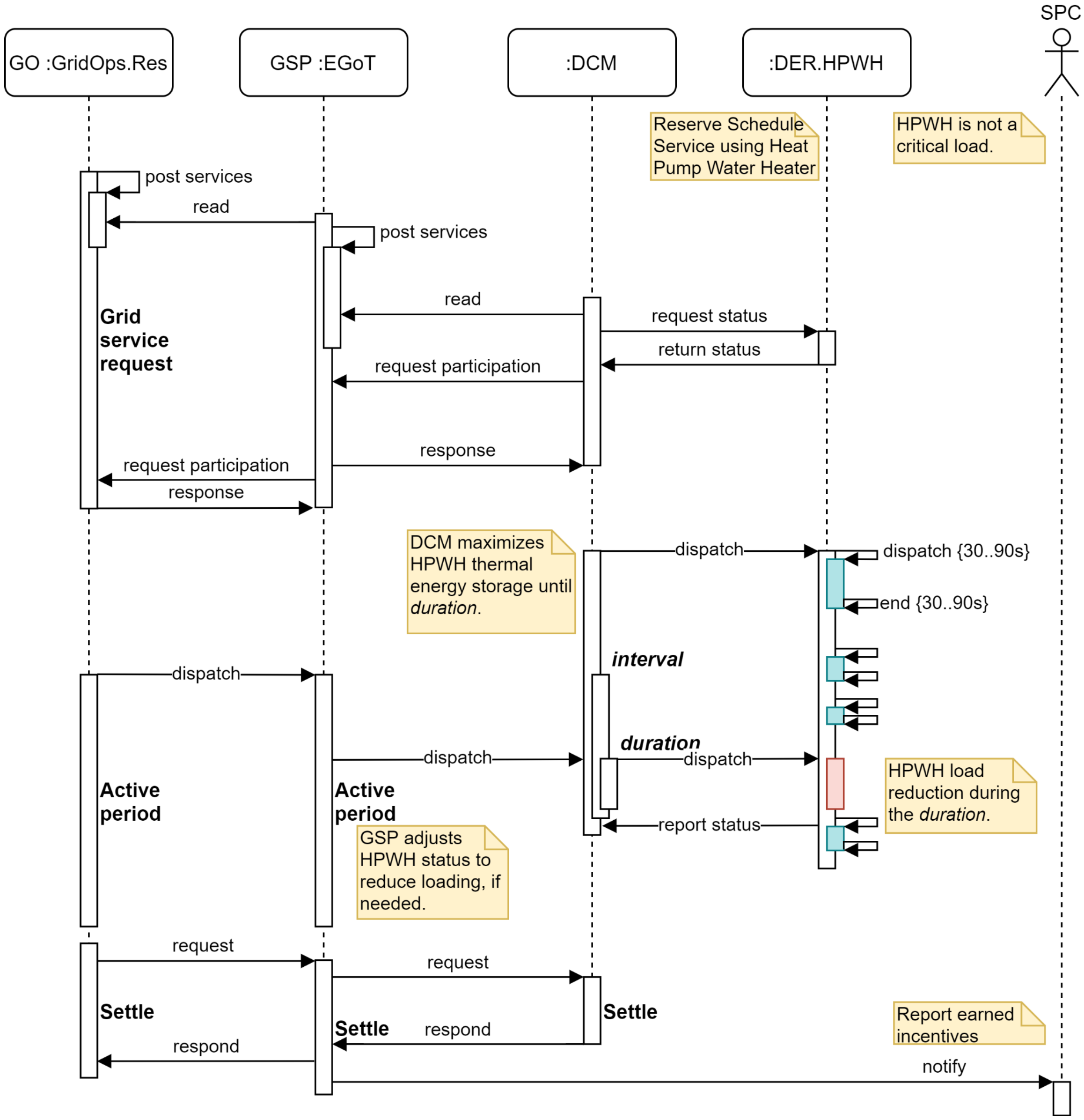



**Figure B.5** Sequence diagram for grid-DER Reserve Service provided by a heat pump water heater (HPWH).

## *B.3 Regulation Service Use Case*

Regulation Service supports control of the area control error (ACE)[32]. The GSP follows an automatic control signal based on the ACE, and uses asynchronous messaging to dispatch participating DERs. Source and load DERs capable of supporting Regulation Service adjust their real power. When the ACE is high, source DERs charge and load DERs consume. When the ACE is low, source DERs discharge and load DERs defer consumption. The Regulation Service update rate is fast, 5 - 15 seconds, and DER response rates must also be fast, 1 - 4 seconds.

Assumptions

- GSP dispatch of DER is governed by deviations in the ACE.
- A storage resource may be both charged and discharged during the duration. The net energy flow is not guaranteed to be zero.
- DER location scope is BA-wide.
- GSP and DCMs exchange information asynchronously, using pub/sub[33] messaging

DER capabilities

- DERs response times are fast (1 to 4 second).
- Loads are non-critical and non-coincident.
- Storage resources allocate sufficient storage to provide both charging and discharging.
- If a load is interruptible[34], then its duration may be divided over multiple subdurations within the interval.

Sequence of information exchange. A sequence diagram is provided in Figure B.6.

1. A GO seeks Regulation Services from qualifying GSPs.
2. GSP creates an IEEE 2030.5 *Flow Reservation* resource.
3. DCMs of qualifying DERs post requests for the *Flow Reservation* resource. The post includes grid-DER service characteristics:
    a. Interval
    b. Update Rate (pub/sub)
    c. Response Time (minimum)
4. DCMs check the status of their DERs.
5. DCMs post a request for participation. The post includes grid-DER service characteristics:
    a. Interval (confirm or modify)
    b. Update Rate (confirm)
    c. Response Time (confirm)
    d. Duration

---

[32] ACE, or Area Control Error, is a metric that quantifies a balancing authority's ability to manage power interchange across its balancing area boundary and to support frequency within its balancing area.

[33] pub/sub: publish/subscribe. A pub/sub resource service provides asynchronous communication. Publishers broadcast events to subscribers, in contrast to request–response messaging, which occurs on a synchronized schedule. Pub/sub latencies are within the order of 100 milliseconds.

[34] Interruptible load: consumption may be stopped or decreased, then continued later, without consequence to the consumer or load. e.g. electric water heater, pool pump.

   e. Power
6. Prior to active period
   a. Storage sources pre-charge to less than 100% capacity
   b. Non-coincident loads defer energizing
7. Active period begins
   a. As needed during the interval,
      i. Discharge/charge source DERs
      ii. Dispatch or defer load DERs
8. Active period ends
   a. DERs revert to normal operation

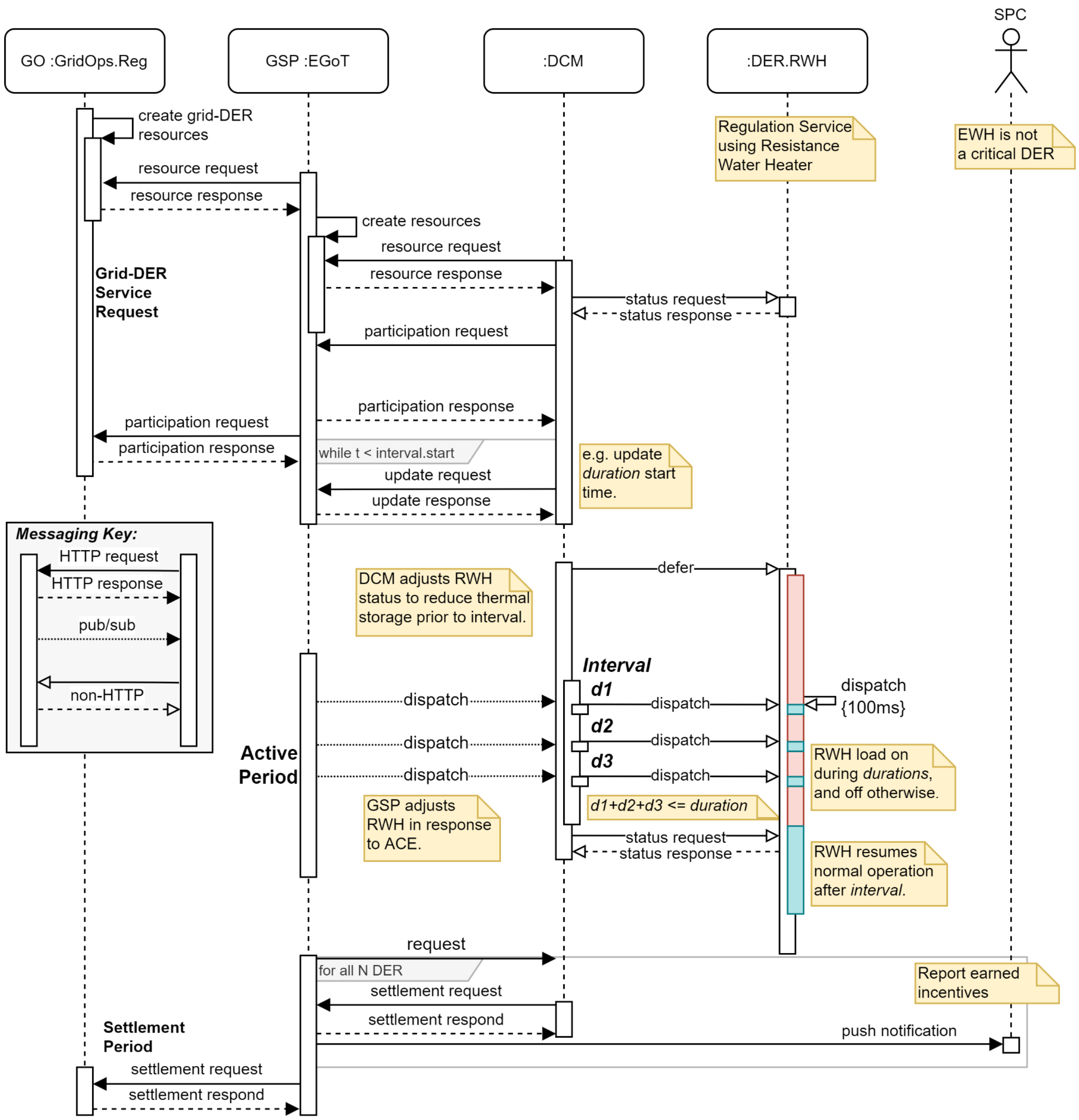



**Figure B.6** Sequence diagram for grid-DER Regulation service provided by an electric resistance water heater (EWH). The DCM reduces EWH loading prior to the regulation period. Since the EWH is interruptible, the GSP may dispatch the EWH as needed in response to positive ACE deviations.

## *B.4 Blackstart Service Use Case*

A GSP seeks DERs capable of providing Blackstart Service in order to help a GO re-energize parts of its balancing area that have experienced a sustained outage. The GSP has two types of DER available for Blackstart Service dispatch: sources capable of independently supplying power and supporting voltage, and loads that can defer consumption to a post-recovery period.

Assumptions:

- Probabilities of outage-inducing events are calculable
- Durations of probable outages are statistically understood
- Locations of probable outages are statistically understood
- DER location scope is at the substation feeder level
- GSP and load DERs exchange information synchronously, using request–response messaging.
- DER commitment intervals are long, up to 24 hours or more.
- DER DCMs maintain power and communication during outages

DER capable of providing a black-start Blackstart Service include two varieties:

- Energy source capabilities:
    - independent energy-delivery capacity
    - voltage management capacity
- Loads can impede blackstart operations. Particularly, large inductive loads draw significant inrush current, and thermostatic loads turn on immediately after restoration of service, both of which can trip overcurrent protection upon re-energizing a feeder.
    - Load resource liabilities:
        - high in-rush[35] current
        - thermostatic loads[36]
    - Load resource beneficial characteristics:
        - deferrable[37]
        - non-critical

Sequence of information exchange. Two sequence diagrams are provided in Figures B.7 and B.8.

1. GO determines that the threat level of outage-inducing events has exceeded a threshold
2. Prior to anticipated outage-inducing events, the GO seeks Blackstart Service support from qualifying GSPs.
3. GSP creates several IEEE 2030.5 *Flow Reservation* resources.

---

[35] High in-rush loads: large inductive loads draw significant in-rush current at start-up, particularly compressor-based loads. e.g. heat pumps, air conditioners, pool pumps, refrigerators/freezers.

[36] Thermostatic loads: loads that are governed by a thermostat. These will turn on immediately after restoration of service if the thermostat registers a temperature outside of the thermostat deadband. e.g. water heaters, heat pumps, air conditioners.

[37] Loads that need not be on immediately after return of service.

4. DCMs of qualifying DERs post requests for the *Flow Reservation* resources. The posts include grid-DER service characteristics:
    a. Source grid-DER service characteristics:
        i. Interval
        ii. Location Extent: substation feeder
        iii. Response Time (minimum)
    b. Load grid-DER service characteristics:
        i. Interval
        ii. Location Extent: substation feeder
5. DCMs check the status of their DERs.
6. DCMs post a request for participation.
    a. Sources: the post provides grid-DER service characteristics:
        i. Interval (confirm or modify)
        ii. Location Extent (confirm)
        iii. Response Time (confirm)
        iv. Power
        v. Duration
    b. Loads: the post provides grid-DER service characteristics:
        i. Interval (confirm or modify)
        ii. Location Extent (confirm)
        iii. Power
        iv. Duration
        v. Response Time
7. Active period coincides with the beginning of the anticipated period of heightened outage probability
    a. Storage sources pre-charge
    b. Deferrable and non-coincident loads pre-energize
8. Outage has occurred.
    a. GSP signals load DERs to defer consumption
9. Safety risks have been mitigated, restoration begins.
10. GO coordinates with GSP to dispatch source DERs as feeders are energized
11. After a suitable period following return of electrical service, GSP signals load DERs may return to normal operation.
12. Active period ends.

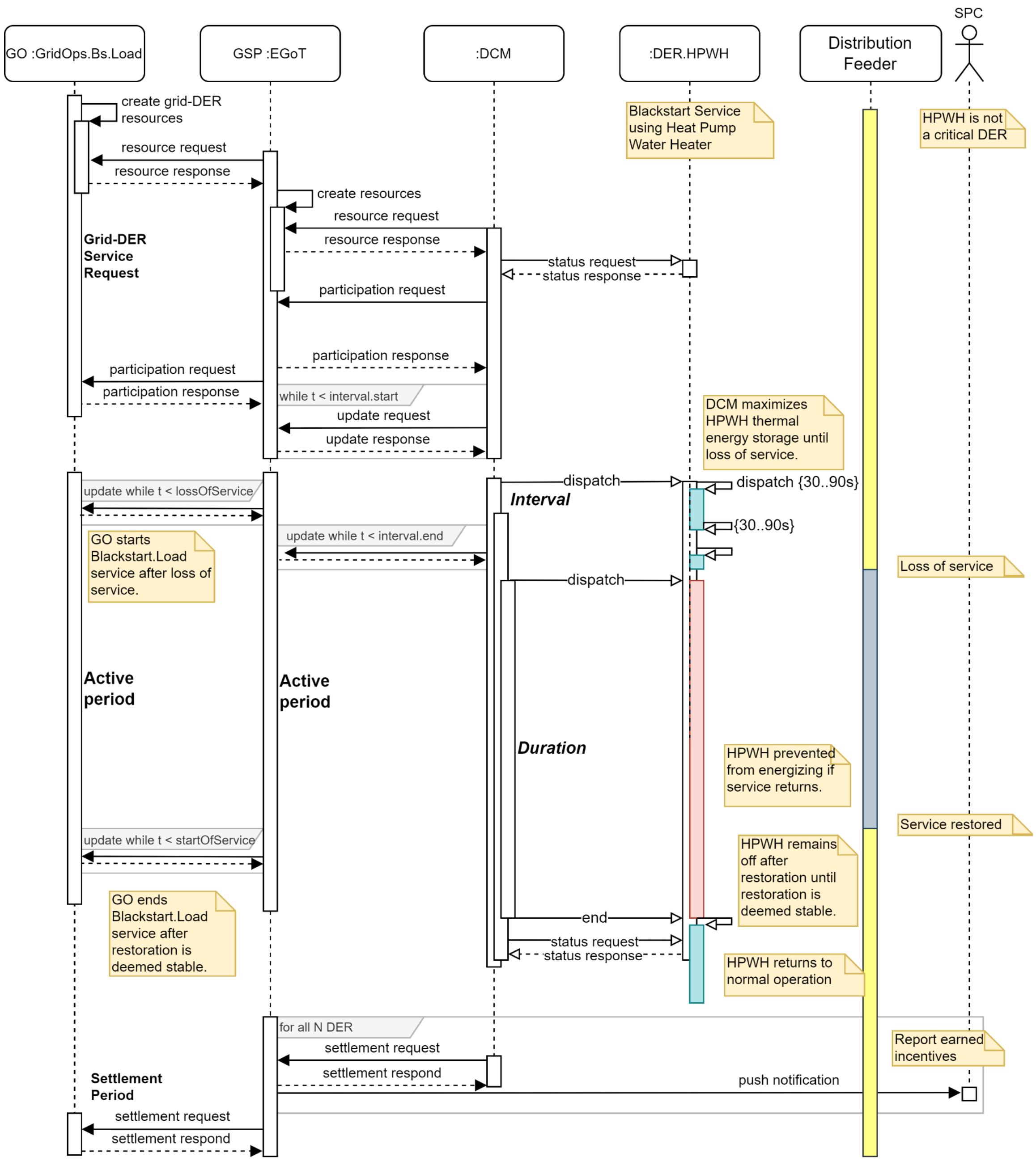



**Figure B.7** Sequence diagram for Grid-DER Blackstart Service provided by a heat pump water heater (HPWH). The HPWH is a non-coincident, non-critical load that presents high in-rush at startup. Deferring the load until after electrical service restoration helps the GO re-energize the feeder.

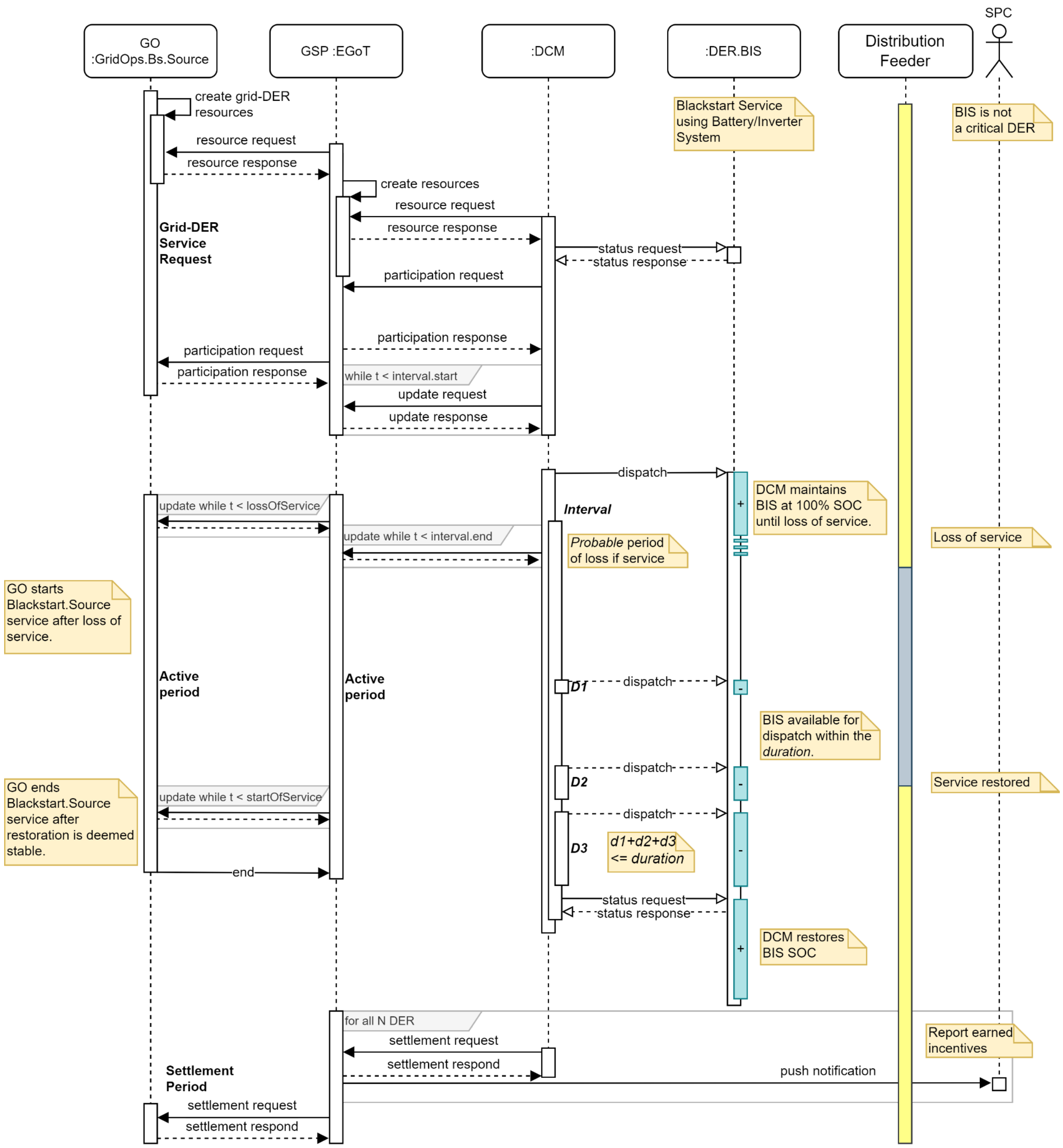



**Figure B.8** Sequence diagram for Grid-DER Blackstart Service provided by a battery inverter system (BIS). The DCM maintains the BIS state of charge (SOC) until loss of electrical service. The BIS may then be used by the GO to help support restoration.

## *B.5 Voltage Management Service Use Case*

DERs that provide Voltage Management Service *automatically* detect and correct voltage excursions when these excursions exceed defined limits, typically +/-5% of nominal. This is typically done by absorbing or injecting reactive power when voltages exceed or drop below these thresholds, though real power may be used too[38]. DERs can participate in Voltage Management Service if they can control reactive and/or real power in response to voltage deviations.

Voltage Management Service is service-oriented; the DER requests participation from the GSP, the GSP does not have direct control of the DER, and the DER will only provide this service for a limited period of time.

Assumptions:

- DERs are capable of following V-VAr and/or V-Watt curves. Or, the DERs have suitable alternative algorithms for providing voltage control.
- DER location scope is at the substation feeder level.
- GSP and DCMs exchange information synchronously, using request–response messaging.

DER capabilities, either/or:

- Automatically inject or absorb reactive power in response to voltage excursions (preferred).
- Automatically inject or absorb real power in response to voltage excursions.

Sequence of information exchange. A sequence diagram is provided in Figure B.9.

1. A GO seeks Voltage Management Service from qualifying GSPs.
2. GSP creates an IEEE 2030.5 *DER* resource.
3. DCMs of qualifying DERs post requests for the *DER* resource. The post includes grid-DER service characteristics:
    a. Interval
    b. Location Extent: substation feeder
4. DCMs check the status of their DERs.
5. DCMs post a request for participation. The post includes grid-DER service characteristics:
    a. Interval (confirm or modify)
    b. Location Extent (confirm)
    c. Power (+/- max)
6. GSP responds to the DCM with
    a. V-VAr and/or V-Watt curve data, or
    b. Nothing, if the DER has a suitable alternative algorithm for providing voltage control
7. Interval period begins, DER curves/algorithms are active
8. Interval ends. DERs revert to default power regulation methods

[38] Considering the power flow Jacobian, $\partial V/\partial VAr$ is significantly more sensitive than $\partial V/\partial W$.

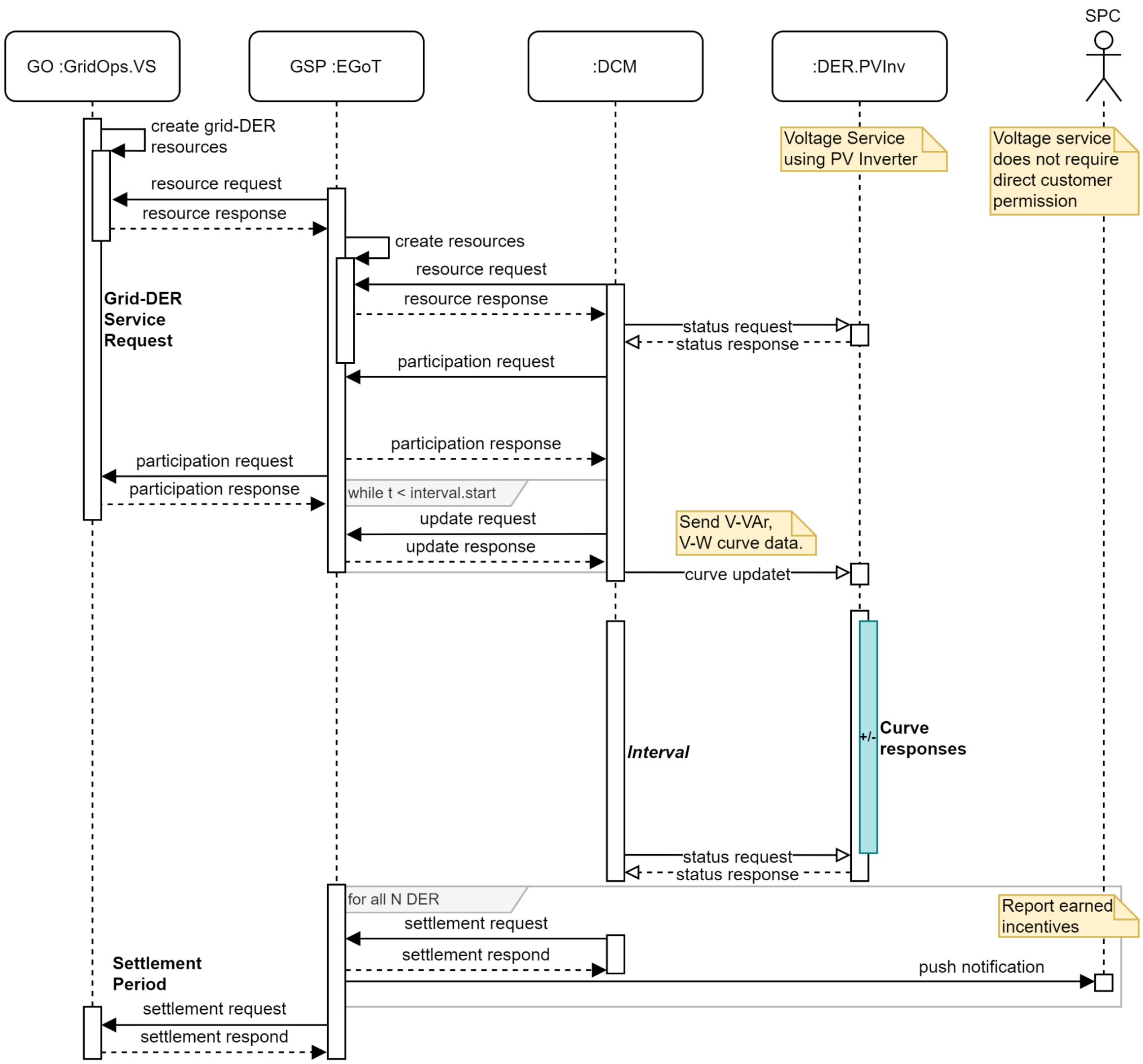



**Figure B.9** Sequence diagram for grid-DER Voltage Management Service provided by a Photovoltaic-inverter system (PVInv). Service is provided by automatic response according to V-VAr and V-W curves loaded into the PVInv. SPC permission for this service would be granted when the SPC initially registers with the GSP program. A PV system coupled with a battery would undergo some additional pre-charge steps, similar to those shown in Figure B.10.

## *B.6 Frequency Response Service Use Case*

DERs that provide Frequency Response Service *automatically* detect and correct frequency deviations when these deviations exceed defined limits. Limits may be frequency thresholds, as used by curve-based responses. Or, other limits, such as rate of change of frequency (ROCOF), may be used by a frequency response algorithm.

Frequency deviations occur continuously within a power system, most of which are minor and can be managed by a Regulation Service. Frequency Response Service is responsible for arresting sudden and drastic deviations in frequency, as described by NERC BAL-003-1 Frequency Response Standard[39]. DERs can participate in Frequency Response Service if they are capable of controlling reactive and/or real power in response to frequency deviations.

Frequency Response Service is service-oriented because DERs request participation from the GSP, the GSP does not have direct control of the DER, and the DER only provides this service for a limited period of time.

Assumptions:

- DERs are capable of following f-Watt and/or f-VAr curves. Or, DERs have suitable alternative algorithms for providing frequency response.
- DER location scope is BA-wide.
- GSP and DCMs exchange information synchronously, using request–response messaging.

DER capabilities, either/or:

- Automatically and immediately inject or absorb real power in response to rapid and sudden frequency deviations (preferred)
- Automatically and immediately inject or absorb reactive power in response to voltage excursions

Sequence of information exchange. A sequence diagram is provided in Figure B.10.

1. A GO seeks Frequency Response Services from qualifying GSPs.
2. GSP creates an IEEE 2030.5 *DER* resource.
3. DCMs of qualifying DERs post requests for the *DER* resource. The post includes grid-DER service characteristics:
    a. Interval
    b. Location Extent: substation feeder
4. DCMs check the status of their DERs.
5. DCMs post a request for participation. The post includes grid-DER service characteristics:
    a. Interval (confirm or modify)
    b. Location Extent (confirm)
    c. Power (+/- max)
6. GSP responds to the DCM with
    a. f-Watt and/or f-VAr curve data, or

[39] Frequency response standard background document, North American Electric Reliability Corporation (NERC), Tech. Rep., November 2012.

b. Nothing, if the DER has a suitable alternative algorithm for providing voltage control
7. Interval period begins, DER curves/algorithms are active
8. Interval period ends. DERs revert to default power regulation methods

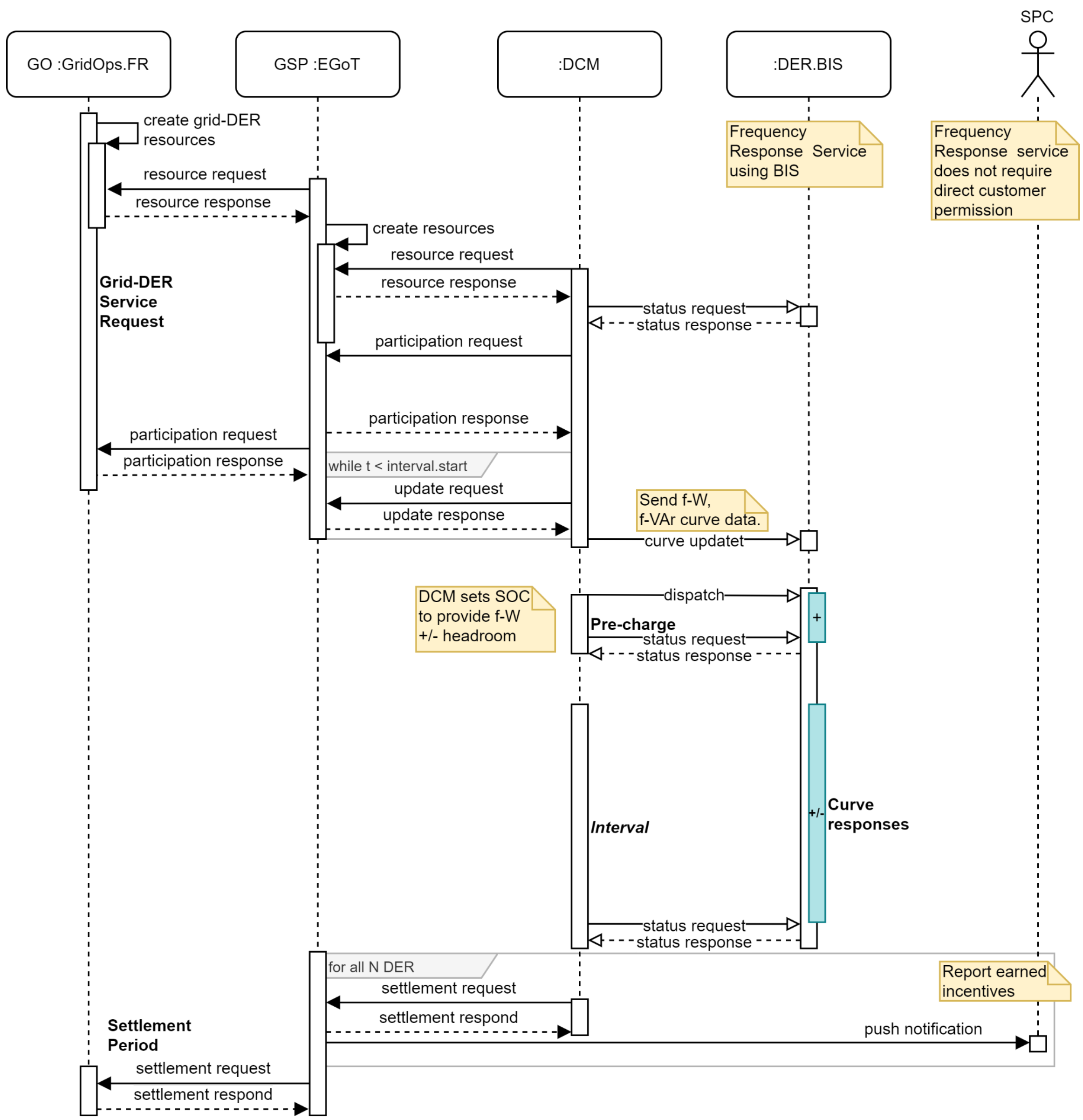



**Figure B.10** Sequence diagram for Frequency Response grid-DER service provided by a battery-inverter system (BIS). The service is provided by automatic response according to f-W and f-VAr curves loaded into the BIS.

# Appendix C Grid-DER Service Simulation Use Cases

The following subsections showcase a demonstration of four grid-DER service use cases. The illustrated grid-DER services are Energy, Blackstart, Voltage Management, and Reserve. Each use case simulates the actors' interactions shown in Appendix B. The simulation scenarios are managed via the Modeling Environment (ME). Within the ME, the GO evaluates the grid condition for a given simulation time, anticipates any events, and publishes a list of grid-DER services. Externally to the ME, the GSP-DERMS accesses the published list of services and submits a commitment request to the GO. The frequency of the GO-GSP interactions depends on the type of the published grid-DER services.

## *C.1 Blackstart grid-DER Service*

### C.1.1 Service Characteristics

Based on heightened risk assessments, the GO coordinates with the GSP-DERMS to aggregate DERs and schedule their operation before, during, and after the service time using DCMs. Load-type DERs, considered in this use case, defer consumption during the event's time to support the efforts of the blackstart grid-DER service. This deferment is equivalent to sending a CTA-2045 Grid Emergency command to a water heater. Upon restoring the feeder, the GSP-DERMS and DCM take preparatory measures to avoid cold-load pickup by thermostatically controlled loads and inrush current by inductive loads. As such, these DERs are returned to normal operation in a staggering manner.

### C.1.2 Simulation Result

Figure C.1 shows the demand of the aggregated DERs and their State of Charge (SoC) during a blackstart grid service. Further, the Figure highlights the three main characteristics of the blackstart grid-DER service: energize DERs prior to the service time, defer consumption during the service time, and DERs staggeringly return to normal operation as the service time elapses. Since this scenario considers load-type DERs, the sequence of interactions between the EGoT actors in Figure B.7 is simulated. The GO initializes these interactions by publishing a blackstart grid-DER service. A qualifying GSP submits a commitment request to the GO. The DCMs associated with qualifying DERs post a participation request to the GSP. Prior to the active grid-DER service time, the DCMs signal their DERs to energize. As such, the DERs receive this signal and turn on. This energizing behavior is reflected in the DERs SoC, shown in Figure C.1. The DERs remain active until the outage occurs. Once the outage occurs, the GO starts the blackstart grid-DER service. The GSP-DERMS receives the GO signal and instructs all participants to defer consumption, as indicated by the period from 06:56:54 until 08:03:00. Once the GO determines that the risks have been mitigated, it signals the GSP-DERMS to start the feeder restoration. The GSP-DERMS then signals DCMs to return to normal operation in a staggered manner to avoid cold-load pickup from thermostatically controlled loads and high inrush current from inductive loads.

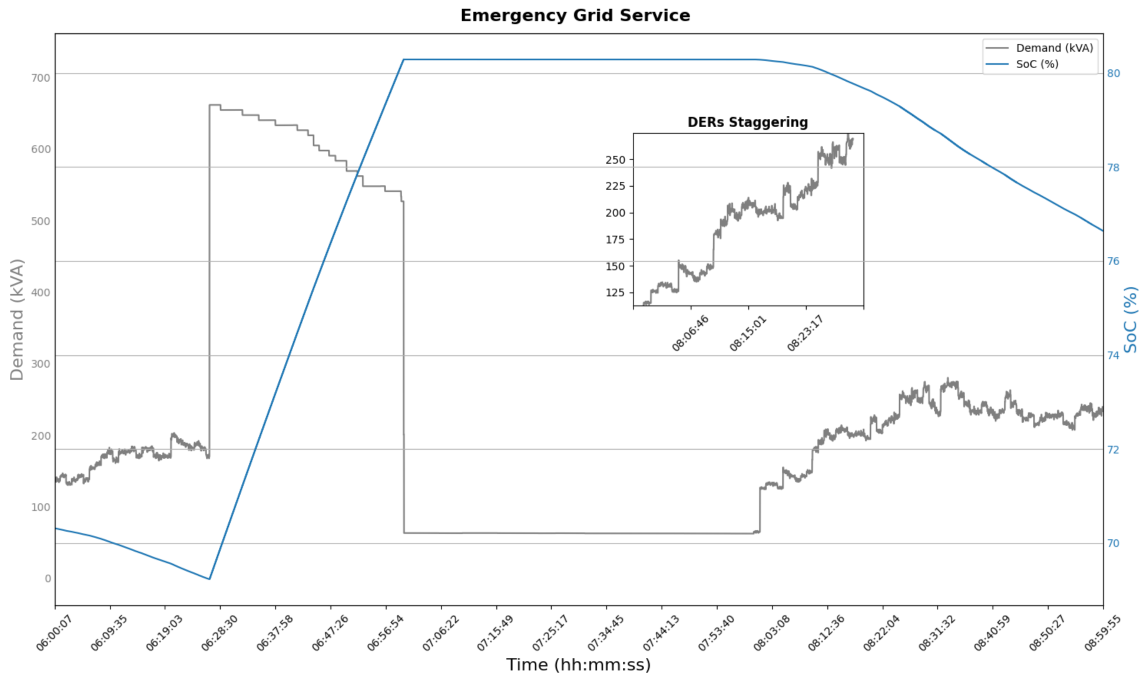



**Figure C.1** Demand (kVA) and State of Charge (SoC) of the Aggregated DERs in a Blackstart grid-DER service Scenario. The main blackstart service characteristics are shown: energize, defer, and return to normal operation in a staggering manner.

## *C.2 Energy Service*

### C.2.1 Service Characteristics

The GO forecasts the demand profile and advertises a peak demand reduction service for qualifying GSPs. In this scenario, the aggregated DERs are non-critical, deferrable loads. These DERs are energized prior to the grid-DER service time. As such, customer comfort is ensured during the grid-DER service time as their operation is deferred.

### C.2.2 Simulation Result

Figure C.2 illustrates two cases: DERs behavior in a base case wherein no grid-DER service is requested, and a test case where the Energy grid-DER service is requested by the GO. The sequence of information exchange between the EGoT system actors in Figure B.3 is simulated. Prior to the grid-DER service time, the DCMs energizes their DERs, shown in the blue-shaded area.  As the grid-DER service period begins, the DCM signals DERs to defer consumption, indicated by the red-shaded area. The diversity of DERs will likely include slow responsive DERs, such as heat-pump water heaters. Therefore, DERs response times as long as several minutes are expected. Further, the DERs defer consumption by narrowing down their window of operation. As such, some DERs are expected to operate during the deferral period, indicating how conservatively they were set prior to participating in the service. As the grid-DER service period ends, DERs turn on as their window of operation is returned to idle mode (see the beige-shaded area).

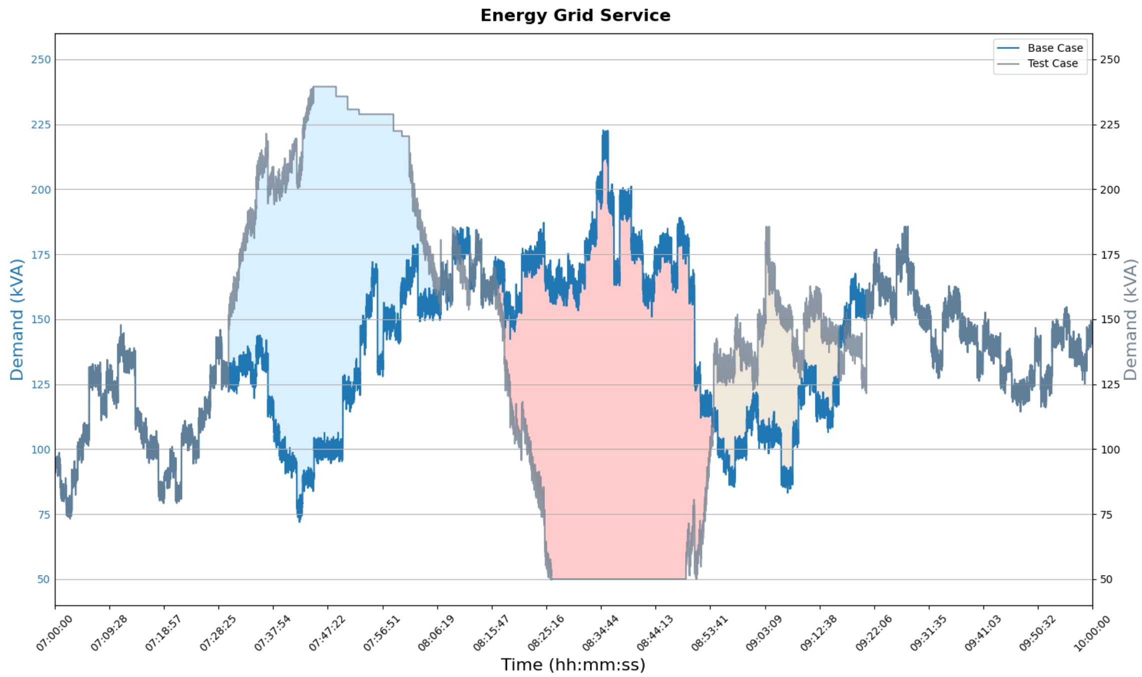



**Figure C.2** Behavior of DERs demand in kVA during Energy Service. The blue line represents the base case. The gray line represents the test case.

## *C.3 Reserve Grid-DER Service*

### C.3.1 Service Characteristics

The reserve grid-DER service is driven by unanticipated events, such as an error in the forecasted demand profiles. The GO seeks reserve grid-DER service from qualifying GSPs. A GSP submits a commitment request and creates an IEEE 2030.5 Flow reservation resource. In this scenario, a set of non-critical and deferrable DERs loads is aggregated and deferred during the service time to reserve generation capacity.

### C.3.2 Simulation Result

Figure C.3 showcases the base case (top plot) and the test case of a reserve grid-DER service. In the base case, the DCMs do not signal their associated DERs to change their normal behavior because no grid-DER service was requested. In the test case, however, the sequence of information exchange between the EGoT actors shown in Figure B.5 is simulated. As the service time begins, the DCMs instructs their respective DERs to defer consumptions. From a generation perspective, this deferment corresponds to a reserved generation capacity. The test case in Figure C.3, lower plot, illustrates a counter-intuitive yet intended trend wherein DERs energize during the reserve grid-DER service time, simulating an augmentation of generation capacity. Further, the test case shows that the net gain energy from deferring DERs operation during reserve grid-DER service is ≈ 480 kWh.

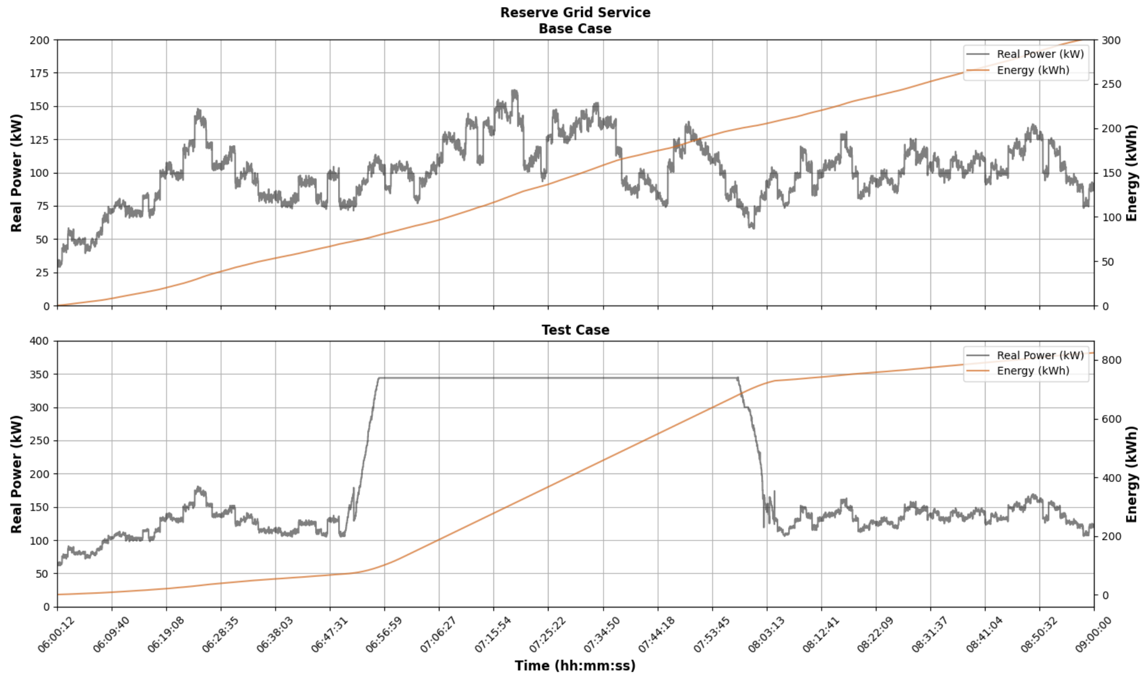



**Figure C.3** DERs demand (kVA) and Energy consumption (kWh) during a reserve grid-DER service. The top plot represents the base case where no grid-DER service is simulated. The lower plot represents the test case wherein DERs simulate an augmentation of generation capacity.

## *C.4 Voltage Management grid-DER Service*

### C.4.1 Service Characteristics

The voltage management is an autonomous grid-DER service. The DERs simulated in this case are Battery-inverter systems (BIS). These DERs are aggregated to respond to voltage variations by updating their associated Volt-VAr curve points. The sequence of information exchange between the EGoT actors in Figure B.9 is simulated. Prior to the service time, the GO publishes a Voltage Management grid-DER service and a GSP with inverter-based DERs submits a commitment request to the GO. The GSP-DERMS updates the curve point of the DERs participating in grid-DER service. This curve is activated as a voltage variation beyond a defined threshold occurs. In this use case, the voltage tolerance is defined as $\pm$5%.

### C.4.2 Simulation Result

Figure C.4 shows the demand and the per unit bus voltage. As the voltage drops below the defined tolerance value, 5%, the DERs' curve is activated and reactive power is injected to the system, thereby correcting the voltage to $\approx\ 0.98\, p.u.$ Note that the DERs response to the voltage excursion is $\approx\ 4\ seconds$. This delay is mainly related to the simulation environment. GridAPPS-D retrieves the grid states measurements once every three seconds. Therefore, the voltage measurements are repeated, and the DERs response is not shown properly.

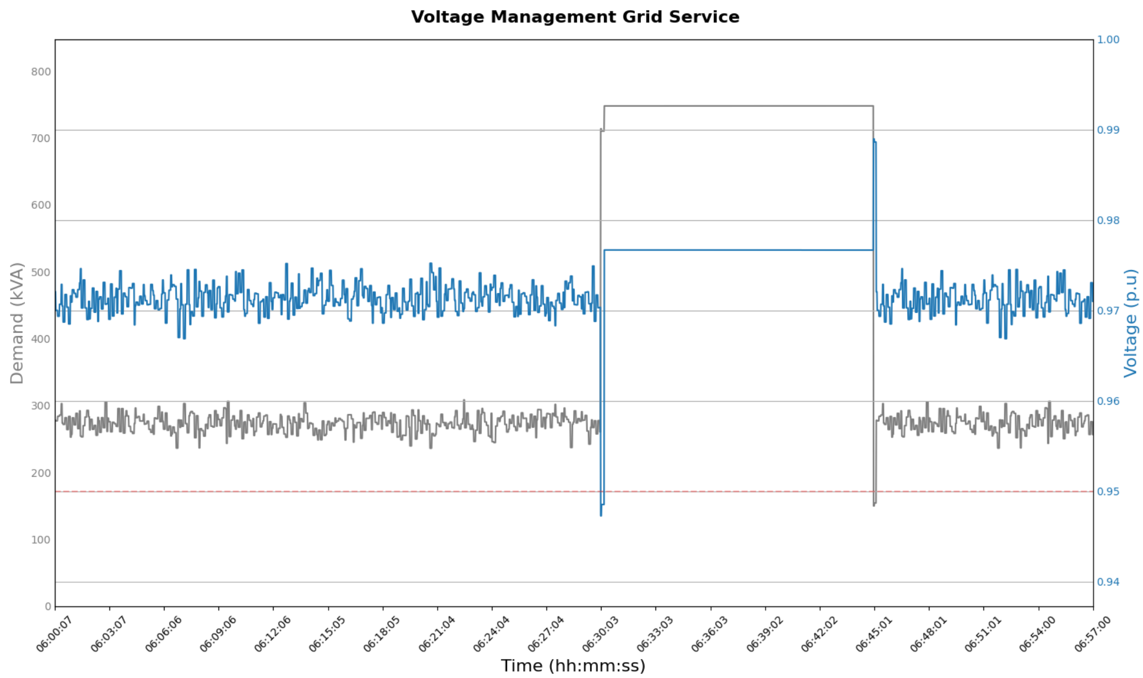



**Figure C.4** The demand in kVA and voltage (p.u) of the aggregated BIS DERs. The response to the voltage drop below 0.95 is > 3 seconds due to GridAPPS-D; it retrieves measurements every three seconds.