

# **IEEE 2030.5 Common California IOU Rule 21 Implementation Guide for Smart Inverters**

**August 31, 2016**

**Version 1.0**

## Contents

1	Introduction .....	1
2	Guiding Principles .....	1
3	Communications Architecture Overview .....	2
3.1	Scenarios .....	2
3.2	Scope of Communications .....	3
3.3	IEEE 2030.5 Basis of Communications and Security .....	3
3.3.1	TLS and Cipher Suites .....	4
3.3.2	Certificates .....	4
3.3.3	Certificate Fingerprints, LFDI, SFDI .....	4
3.3.4	Authentication .....	4
3.3.5	Authorization .....	4
3.3.6	Access Control.....	5
4	Basic Functions.....	5
4.1	Commissioning of Inverters .....	5
4.2	Group Management.....	5
4.3	Inverter Curve Fundamentals .....	7
4.4	Prioritization of Operations and Conflict Resolution .....	7
4.5	Basic Communication Interactions .....	8
4.6	Scheduling of Future Operations .....	8
4.7	Standard Inverter Status and Alarm Information .....	9
5	CSIP IEEE 2030.5 Implementation Details.....	12
5.1	Certification.....	12
5.2	High-Level Architecture .....	12
5.3	Resources and Function Sets .....	12
5.3.1	Time .....	12
5.3.2	Device Capability.....	13
5.3.3	End Device.....	13
5.3.4	Function Set Assignments (FSA).....	13
5.3.5	Distributed Energy Resource (DER).....	13

5.3.6 DER Controls ..... 13

5.3.7 DER Settings ..... 13

5.3.8 Subscription/Notification..... 14

5.3.9 Metering..... 14

5.4 Identification of Inverters ..... 14

5.5 Utility Server Operation – Aggregator Model..... 15

5.5.1 Group Assignment of Inverters..... 15

5.5.2 Utility Server Start-Up Configuration..... 16

5.5.3 Utility – Aggregator Operations ..... 23

5.5.4 DER Controls and Curves..... 27

5.5.5 Creating DER Controls ..... 30

5.6 Aggregator Operation ..... 31

5.6.1 Use of Subscription/Notification to Optimize Utility-Aggregator Interactions ..... 33

5.6.2 Examples of DER Event Operations..... 34

5.7 Reporting of Meter Data, Status Information, and Alarms ..... 36

5.7.1 Meter Data ..... 37

5.7.2 Status Information ..... 38

5.7.3 Alarms ..... 39

5.8 Error Handling ..... 40

5.9 Maintenance of the Model ..... 40

5.9.1 Maintenance of Inverters (EndDevice, EndDeviceList)..... 41

5.9.2 Maintenance of Groups (Function Set Assignments) ..... 41

5.9.3 Maintenance of Controls (DERControl, DERControlList) ..... 42

5.9.4 Maintenance of Programs (DERProgram, DERProgramList)..... 42

5.9.5 Maintenance of Subscriptions ..... 42

5.10 Utility Server Operation – Plant / Commercial Site Model..... 42

5.11 Utility Server Operation – Direct Residential / Small Commercial Model..... 42

6 Evolution of the CSIP Model ..... 42

Appendix A - Table of Acronyms.....A-1

## 1 Introduction

This guide serves to assist manufacturers, DER operators, system integrators and DER aggregators to implement the Common Smart Inverter Profile (CSIP) for California. CSIP was developed as an outgrowth of the California Rule 21 Smart Inverter process to create common communication profile for inverter communications that could be relied on by all parties to foster “plug and play” communications-level interoperability (outside of out-of-band commissioning) between the California IOU’s and 3<sup>rd</sup> party operated smart inverters or the systems/service providers managing those inverters.

While the scope of this protocol was designed solely to meet the needs of the California IOU’s requirements for communications, the profile implements widely applicable use cases making CSIP generic and likely applicable to other regulatory jurisdictions beyond California’s borders.

## 2 Guiding Principles

The following principles have been used to help guide the development of CSIP. From a communications perspective

1. All smart inverters require communications to achieve their full value as distributed energy resources.
2. Establish a complete profile – To achieve complete interoperability a complete profile is required including a data model, messaging model, communication protocol and security. Without a complete specification it would be impossible to achieve communications interoperability without additional systems integration activities.
3. Leverage existing standards and models from both engineering (e.g., IEEE 1547) and communications (e.g., IEEE 2030.5) standards – The development of a new, stand-alone standard would create additional burden on all parties and only serve to raise costs of both development and maintenance.
4. Assume that future revisions will be necessary – The use of DER will continue to evolve. The SIWG is anticipating likely use cases applicable to the near future (5 years). But, attempting to anticipate all future use cases will add complexity to the specification without commensurate value. As such, extensibility of the specification through future revisions is required.
5. Eliminate optionality and keep to a single base specification – Optionality in the specification can serve to hinder interoperability when parties chose to implement
6. Create a minimal specification – A simple interface serves to lower costs and improve quality
7. Strictly focus on utility to DER owner/operators and aggregators. All other communications are out of scope from the perspective of CSIP.
8. Strictly focus on inverter management, such as setting group changes and basic on/off functions, rather than explicit real time control
9. Implementation of the interface infers no proprietary advantage to any party – Smart Inverter communications between the utility and 3<sup>rd</sup> parties provides a critical, but non-differentiating

service. As such, the costs to all parties should be minimized to drive proliferation of DER in California

10. Provide alternate models of implementation around a single common standard to provide customer choice, 3<sup>rd</sup> party business models and utility needs.

### 3 Communications Architecture Overview

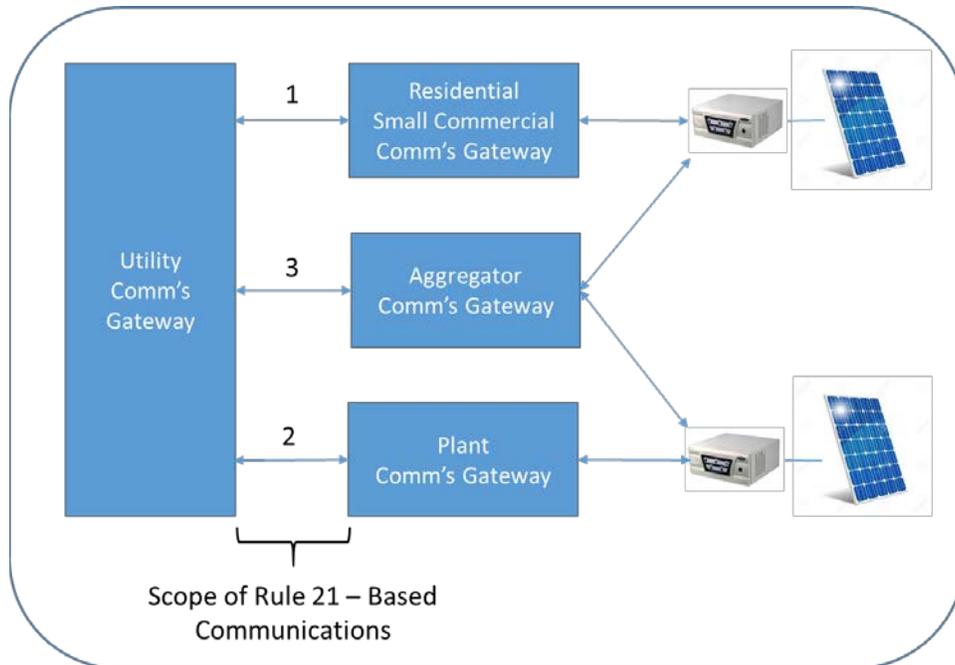


Figure 1. Communication Scenarios.

#### 3.1 Scenarios

Figure 1 illustrates the scope of covered communications within the smart inverter communications between the utility and DER systems. As depicted, three scenarios (also called models in this document) are envisioned:

1. **Direct Inverter Communications** – In this scenario the utility communicates with the inverter system directly. This scenario is envisioned for use when the inverter owner wishes to interact directly with the utility for managing their inverter or when the utility needs to control the inverter for proper system operations. The likely applicability is for small systems with a direct utility connection. Large commercial systems connecting independently will need to follow the model presented in option 2 below.
2. **Inverter Communications mediated by an Energy Management System Controlling the DER** - In this scenario the inverter commands are interpreted by a gateway or management system. This allows the EMS to optimize energy in the context of overall request. The likely applicability is for future residential, commercial, DER plant operations

3. **Inverter Communications Mediated by DER Operator/Aggregator** – In this scenario the utility communicates with an aggregator back end management system rather than with an individual EMS or inverter. A key difference from number 2 above, is that the aggregator is assumed to be managing a fleet of inverters that are widely distributed across the utility’s service territory rather than having a single point of common coupling. The Operator/Aggregator is then responsible for relaying any requirements for inverter operational changes or data requests to the affected systems and returning any required information to the utility. The likely applicability is for fleet operators and DER developers / operators.

Each inverter system shall connect to the utility in one and only one of the models defined above. The utility customer, or a customer-designated service provider/contractor, shall decide the model of smart inverter communication as part of the utility’s inverter provisioning process.

Both utilities and other implementers should note that the scope of communications specified in CSIP is limited to these scenarios only and that other means of communication are likely necessary to complete the end-to-end integration between the utility and the inverter.

### 3.2 Scope of Communications

The CSIP covers the complete set of communications as defined by the Smart Inverter Functionality. The following classes of communication are considered:

1. Update of autonomous functions settings
2. Update of immediate controls, curves, and programs
3. Management and status information
4. Management of inverter grouping (only relevant to inverters managed via DER aggregators)

### 3.3 IEEE 2030.5 Basis of Communications and Security

IEEE 2030.5 provides the foundation for CSIP. In particular, the DER model, which is based in part on the SunSpec and IEC 61850 models, provides the foundation for managing smart inverters with CSIP. However, other IEEE 2030.5 models and functions are required as “building blocks” to support the necessary Rule 21 required functions for smart inverters.

Security is also provided by leveraging the IEEE 2030.5 standard. Use of security is mandatory in all interactions between utility servers and clients. Security is required for both the authentication of clients and services as well as the authorization of all requests. The enforcement of security is the responsibility of utility servers. The composition of any inverter or aggregator access to these servers is managed via contractual relationships. As such, the specific permissible actions across different utility servers may be different. As such, both clients and servers require a capability to administer and maintain authentication and access information in addition to their respective enforcement.

As IEEE 2030.5 provides the foundation for communications in CSIP, implementers are assumed to be fully fluent with the standard and have the necessary skills and technologies required for its implementation. This section provides a brief description of the IEEE 2030.5 security framework.

### 3.3.1 TLS and Cipher Suites

Securing transactions between Clients and Servers is based on using HTTP over TLS (also known as HTTPS) using TLS version 1.2.

IEEE 2030.5 specifies a single, mandatory, cipher suite that must be used for secure communications: *TLS\_ECDHE\_ECDSA\_WITH\_AES\_128\_CCM\_8* using the elliptic curve *secp256r1*.

### 3.3.2 Certificates

Certificates provide a mechanism to authenticate an identity. All CSIP communicating devices must have an IEEE 2030.5 compliant X.509 v3 device certificate that chains back to the Root Certificate Authority (Root-CA) when the Root-CA becomes operational.

### 3.3.3 Certificate Fingerprints, LFDI, SFDI

The certificate fingerprint is the result of performing a SHA256 operation over the whole DER-encoded certificate. The resulting fingerprint consists of 256-bits (32 octets). Truncated versions of the certificate fingerprint, called the LFDI and SFDI, are used for device identification.

#### 3.3.3.1 LFDI – Long Form Device Identifier

The LFDI is the certificate fingerprint left-truncated to 160-bits (20 octets). The LFDI has sufficient entropy ( $2^{160}$ ) to be considered globally unique. The LFDI is used when a globally unique identity is required.

#### 3.3.3.2 SFDI – Short Form Device Identifier

The SFDI is the certificate fingerprint left-truncated to 36-bits. For display purposes, the SFDI is expressed as 11 decimal (base 10) digits, with an additional sum-of-digits checksum digit right-concatenated. The SFDI has sufficient entropy ( $2^{36}$ ) to uniquely identify the device in the context of its usage, and is used to identify a device within a HAN or site domain. It should not be used in a truly global context.

### 3.3.4 Authentication

Clients and Servers perform mutual authentication during the TLS handshake by exchanging and authenticating each other's certificate. Authentication consists of verifying the integrity of the received certificate by checking the certificate has not expired, the certificate chains back to the Root-CA, and the certificate contents conforms to the requirements of IEEE 2030.5. If authentication fails, the Client/Server should issue a TLS Alert and close the communications connection.

### 3.3.5 Authorization

Servers maintain a list of authorized Clients that are allowed to communicate with the Server. The LFDI should be used for this purpose as the SFDI may be susceptible to collisions as the number of entries in the device list grows. After receiving the client device's certificate during the TLS handshake, the Server should calculate its LFDI and verify that the LFDI is in the authorized list. If the LFDI is not in the list, the Server should return an HTTP error code (e.g. 404 – Not Found) to terminate the transaction.

### 3.3.6 Access Control

Once a client device has been authenticated and authorized, it potentially has access to resources on the Server. The Server controls access to resources based on Access Control Lists (ACL). If a device is in the ACL for the resource, it is authorized and has access to that resource. Otherwise, it does not. In theory, every resource on the Server can have its own ACL. Clients and servers shall establish the permissions for read, write, control, and other interactions, based on agreements on which interactions are authorized between each client and each server. For example, role-based access control may be used to establish these permissions for different roles.

Another aspect of Access Control is that the Server may present different resource information based on the identity of the client making the request. This is done for both efficiency and/or privacy reasons.

#### *Access Control Recommendations*

The Server should return an HTTP error code (e.g. 404 – Not Found) if a device tries to access a resource it is not permitted to access. For example, if an Inverter A tries to access the End Device information associated with Inverter B, the Server should return an HTTP error code. On the other hand, if the Aggregator tries to access the End Device information associated with Inverter A or Inverter B, it should be allowed to do so.

In the Aggregator model, when an Aggregator accesses the End Device list, the Server should only present End Devices (i.e. inverters) that are under the control of that Aggregator. This means the Server will present each Aggregator with a different End Device list. This is done for both efficiency (Aggregators know that all inverters in the list are under its control), and privacy (Aggregators do not see any information related to inverters not under its control).

## 4 Basic Functions

### 4.1 Commissioning of Inverters

The commissioning of inverters is assumed to be outside the scope of the implementation guide and is utility specific. However, each commissioning process will result in the delivery of a unique inverter GUID associated with a particular inverter. The GUID (globally unique ID) will be IEEE 2030.5 Long Form ID and will serve as a resource identifier in the CSIP context for supporting IEEE 2030.5 RESTful interactions between utilities, aggregators and inverters. The Long Form ID was selected to eliminate the possibility of name collisions that are possible with the use of the Short Form ID. Implementers should refer to each Utility's Interconnection Handbook and in the section below regarding commissioning for more information needed to establish this ID.

### 4.2 Group Management

Effective management of DER requires that their location from an electrical system perspective be known. As a result, a special management function is required to align DER operated by aggregators to utility system topology. In certain cases, settings or commands can be sent to the entire system under a specific aggregator's control. In other cases, the settings or commands will be sent on a more fine-

grained basis to limited numbers of inverters due to differences in needs across the utilities distribution system. In IEEE 2030.5, inverters are represented as end devices and the two terms are used interchangeably in this document.

For the purposes of this specification, each inverter/end device can be assigned to a minimum of one group, system, and a maximum of 7 groups. The organization of groups in CSIP is based upon a radial distribution system model:

1. System – refers to the utility service territory in total. All inverters are assigned to this group. It is expected that an inverter’s membership will never change.
2. Sub-transmission – refers to a section of a utility’s service territory where the transmission grid is managed directly by the utility
3. Substation – refers to the substation from which the inverter is electrically connected. Note that this group assignment can change as the electric system topology changes.
4. Feeder– refers to the feeder that the inverter is attached to. Note that this group assignment can change as the electric system topology changes.
5. Segment – refers to a section of a distribution feeder/circuit that cannot be further isolated or modified via switching or other sectionalizing device.
6. Service Transformer – refers to the collection of service points that are electrically connected to a single service transformer.
7. Service Point – refers to the point of common coupling between the utility and a 3<sup>rd</sup> party facility where one or more smart inverters are present.

The hierarchy presented above is illustrative in nature and likely presents a “worst case scenario” in terms of grouping requirements. Each utility can apply the grouping levels as it sees fit to meet its own operational needs. For example, distribution transformer-level grouping is likely to be a future rather than near term requirement. Likewise, other utilities may want to apply these group constructs in support of other distribution system network models.

It is important to note that the notion of an inverter in CSIP is logical concept generally thought of as a one or more physical inverters organized and operating as a single system with a common point of aggregation behind a single point of common coupling (PCC) with the utility. This allows the management of a plant/system possessing a single PCC regardless of whether it is composed of a single inverter or many. It is the responsibility of the client system to manage the underlying inverters to meet the requirements of the settings provided by the utility server. **The specific interpretation of the inverter being a single entity or a related group is established at the time of enrollment with the utility.**

As an IEEE 2030.5 end device, all Inverters will possess a unique identity/GUID assigned by the utility as part of the enrollment of the inverter system with the utility. Identity provides a shared name between the utility and the other party to ensure that operations and data are routed appropriately. As the inverter in CSIP is a logical construct, this identity might not change for the life of the inverter/end

device even though the underlying physical inverter may change. The specifics of GUID management are defined by each utilities interconnection guide.

It is envisioned that group membership may change over the life of the inverter being interconnected to the utility's system. These changes can be the result of system configuration or changes in segmentation or equipment. CSIP clients must be prepared for these changes and be able to support full lifecycle management of group relationships.

Finally, a key concept of CSIP is that an inverter or system can exist in multiple groups to support utility management at differing levels of the system. In all cases, the utility is responsible for maintaining these groups over time and to deliver any changes to groups to the impacted inverters.

### 4.3 Inverter Curve Fundamentals

Smart Inverter curves are used to define the behavior of an inverter in response to a sensed grid condition. These curves are already embedded in the inverter. The curve management functionality is used to update the set points on a specific curve and determine which curves are active at a particular point in time. While only 1 curve per curve-type can be active at the same time, different curve-types can be active at the same time as long as they do not conflict.

These curves are used to provide autonomous control in a predictable fashion. For example, assuming a volt-watt curve is active; if the inverter senses an over voltage situation a volt-watt curve would direct the inverter to lower its power output. Likewise, in an under voltage situation, the same curve would likely direct the inverter to increase its output (if possible).

All curves will be predefined from a utility and inverter perspective. The CSIP specification is used to update these stored set points over time. CSIP expects all communication clients to conform to the IEEE 2030.5 standard which call for each curve to support up to 10 point pairs / curve. In the future, it is expected that CSIP will evolve to supporting the definition of curves as defined by IEEE 1547 and that the base IEEE 2030.5 specification will itself be harmonized with IEEE 1547.

It is assumed that aggregators shall be able to support any number of curve set points at a time in their systems to manage difference in settings between groups. Likewise, plant systems should support multiple curves as needed to support future events. Individual connecting systems should be able to support a single curve of each curve type as defined by the specification.

### 4.4 Prioritization of Operations and Conflict Resolution

All operations are established with an IEEE 2030.5 primacy setting. When commanded in a manner where 2 or more operations are possibly in conflict, the interpreting system should operate against the control operation which has the highest primacy subject to the systems capability and self-protection requirements.

Any default setting or modes for any operation shall be specified in the utility's interconnection handbook. For example, the assumed setting for Dynamic VAr support can be default on for one utility and off for another.

In setting up commands for groups of inverters, it is expected that commands for “finer grain” groups will typically have precedence over “larger grain” groups, i.e., commands at the system level are trumped by commands at a more local level e.g., feeder). In this manner, multiple needs can be managed. For example, a system level group operation might call for a voltage-watt mode of operation at the same time as several circuits might require strict limits on real power. See Section 5.6.2 for more information regarding the management of event priorities.

#### 4.5 Basic Communication Interactions

For aggregators and large systems, communications shall be set up to support notifications and call backs to limit system polling to the greatest extent practical. This means that the utility shall be able to initiate a CSIP operation whenever operationally needed. In IEEE 2030.5, this is achieved via Subscription objects described later in this document.

To simplify communication requirements for individually connected systems leveraging model 1, all communications are initiated by the inverter (i.e., client-side initiation). This model of communication eliminates the need for unsophisticated parties to make changes in networking security based on the needs of CSIP. In these cases, the client system shall initiate communications with the utility according to a pre-defined polling interval to ensure the inverter has up to date settings and the utility understands the operational state of the inverter. Polling times for the device shall be randomized in the inverter itself outside of IEEE 2030.5. The following polling times are recommended but not mandated by this guide:

- New commands and curves – twice daily
- Inverter performance information – every 48 hours

The polling intervals for commands and curves are not necessarily uniform. This allows the utility change settings in day as well as set the baseline operational mode for the following day. All required polling intervals and rates will be defined in the utility’s interconnection guide allowing each utility to achieve its specific operational objectives.

Finally, the utility’s interconnection guide shall indicate which systems are eligible for communications for all operational scenarios and provide the definition of what establishes a party as an aggregator, plant and residential/small commercial connection.

In all cases, any alarm information (as defined by this specification and IEEE 2030.5) arising from the inverter or relevant group is delivered immediately to the utility. By design, low-level equipment health and status information is not part of this interface as the utility does not have maintenance responsibility for these 3<sup>rd</sup> party operated systems.

#### 4.6 Scheduling of Future Operations

Scheduling of future operations in CSIP is enabled through the use of IEEE 2030.5 events. These events allow the server to schedule operations for single inverters/end devices at a future point in time. This capability also extends to groups of inverters. Through events, the utility can send one or more operations (modeled as IEEE 2030.5 events) as a sequence to the inverter, EMS controller or aggregator

(i.e., local controllers) for processing and implementation. The utility server implementations shall be responsible for ensuring that operations are sent to the local controllers with the appropriate time of effectivity – both start date-time and stop date-time. In this way, the utility can implement more sophisticated scheduling regimes. Inverters, aggregators and plant controllers shall be responsible for assuring that all operations received from the utility are processed in the appropriate time sequence as specified by the utility.

In the absence of events, all inverters maintain a default control setting state. This control states is defined by the *DefaultDERControl* of the highest precedence *DERProgram* that is associated with the inverter. All inverters revert back to this default control state whenever a higher precedence event completes or an ongoing associated event has a lower precedence than the default control state.

#### 4.7 Standard Inverter Status and Alarm Information

The following inverter status information leveraging the IEEE 2030.5 specification shall be supported and are mandatory for servers and clients implementing CSIP. The information below documents the required information and the IEEE 2030.5 objects and attributes needed to communicate between the client and server:

1. Date-Time Stamp (*DERStatus::readingTime*): time of the status information
2. Operational State (*DERStatus::InverterStatus*): this is an enumeration having the following values
  - 0 - N/A
  - 1 - off
  - 2 - sleeping (auto-shutdown) or DER is at low output power/voltage
  - 3 - starting up or ON but not producing power
  - 4 - tracking MPPT power point
  - 5 - forced power reduction/derating
  - 6 - shutting down
  - 7 - one or more faults exist
  - 8 - standby (service on unit) - DER may be at high output voltage/power
  - 9 - test mode
  - 10 - as defined in manufacturer statusAll other values reserved.
3. Percentage of rated Capacity – to reflect degradation in performance due to a variety of factors such as maintenance, system faults, or degradation. The *DERSettings* object contains adjusted

**California Smart Inverter Implementation Working Group**

ratings based on factors like degradation. Specifically, the **DERSettings** items in the following table are “percentage of rated capacity” of the corresponding **DERCapability** items.

<b>DERCapability (Nameplate Ratings)</b>	<b>DERSettings (Adjusted Ratings)</b>	<b>Description</b>
rtgMaxChargeRate	setMaxChargeRate	Max rate of energy transfer received by DER
rtgMaxDischargeRate	setMaxDischargeRate	Max rate of energy transfer delivered by DER
rtgVA	setMaxVA	Max apparent power
rtgVAr	setMaxVAr	Max reactive power delivered by DER
rtgVArNeg	setMaxVArNeg	Max reactive power received by DER
rtgW	setMaxW	Max active power
rtgMinPF	setMinPF	Min PF displacement (Positive)
rtgMinPFNeg	setMinPFNeg	Min PF displacement (Negative)

4. Operational Mode(DERStatus::operationalModeStatus) – is represented as an enumeration tied to the active inverter control mode(s) (e.g., Volt-Watt)

0 - Not applicable / Unknown

1 - Off

2 - Operational mode

3 - Test mode

All other values reserved.

5. Real Power Output (meter reading) – For this meter reading, set **ReadingType::uom** with an enumeration of **38 = W (Real power in Watts)**

- a. Min, Max, Avg, Std Dev - Set up **ReadingType::dataQualifier** with an enumeration of **9 = Minimum, 8 = Maximum, 2 = Average, or TBD = Standard Deviation**
6. Reactive Power Output (meter reading) - For this meter reading, set **ReadingType::uom** with an enumeration of **63 = var (Reactive power)**
  - a. Min, Max, Avg, Std Dev. - Set up **ReadingType::dataQualifier** with an enumeration of **9 = Minimum, 8 = Maximum, 2 = Average, or TBD = Standard Deviation**
7. Frequency (meter reading) - For this meter reading, set **ReadingType::uom** with an enumeration of **33 = Hz (Frequency)**
  - a. Min, Max, Avg, Std Dev. - Set up **ReadingType::dataQualifier** with an enumeration of **9 = Minimum, 8 = Maximum, 2 = Average, or TBD = Standard Deviation**
8. Voltage (meter reading) - For this meter reading, set **ReadingType::uom** with an enumeration of **29 = Voltage**
  - a. Min, Max, Avg, Std Dev. -Set up **ReadingType::dataQualifier** with an enumeration of **9 = Minimum, 8 = Maximum, 2 = Average, or TBD = Standard Deviation**

The information from a specific inverter may be limited and reflect only the observed measurement value and prohibit the collection of other measures such as Min and Max values. The specifics of which data intervals and the rates at which they are required shall be determined the specific utility's interconnection handbook. For those situations where specific inverters are not capable of providing all information, the CSIP client shall zero fill any unsupported quantity. CSIP servers, by way of provisioning of invert systems, shall be responsible for determining which data is being provided by the inverter and which data is simply being provided by the CSIP client as a default response.

The following inverter equipment alarms shall be supported:

1. Aggregator Group or Equipment rating – reduced rating due to changes in operational status – e.g. failures, maintenance, etc
2. On line/off line alarms – this alarm reflects on-line/off line status of the inverter system itself rather than as a result of being tripped due to external distribution system considerations

3. Loss of Inverter Communications – cannot reach the inverter, the inverter may still be operational and on-line operating in an autonomous mode.

All alarms require a date-time stamp in addition to the alarm message content

## 5 CSIP IEEE 2030.5 Implementation Details

The following sections describe the specific usage of IEEE 2030.5 commands needed to implement CSIP. It is assumed that the reader has a working knowledge of IEEE 2030.5 concepts and operations. Those requiring more information regarding IEEE 2030.5 are encouraged to review the protocol standard which can be found at <https://standards.ieee.org/findstds/standard/2030.5-2013.html>.

### 5.1 Certification

To ensure that all implementations of CSIP are interoperable, certification of all systems directly communicating with the utility shall require certification. This guide envisions the development of a 3<sup>rd</sup> party certification authority to ensure integration at minimal expense for all parties. Until such time as an external certification authority exists, each utility will be responsible for conducting its own certification activities.

### 5.2 High-Level Architecture

The IEEE 2030.5 protocol implements a Client/Server model based on a representational state transfer (REST) architecture utilizing the core HTTP methods of GET, HEAD, PUT, POST, and DELETE. In the REST model, the Server hosts resources, and the Client uses the HTTP methods to act on those resources. The Client typically initiates the action, but the protocol does provide a lightweight subscription mechanism for the Server to push resources to the Client. IEEE 2030.5 subscriptions are used throughout CSIP to minimize the need for polling of resources and thereby improve network utilization efficiency and is mandatory for aggregator (case 3) and commercial plant (case 2) operations.

### 5.3 Resources and Function Sets

In IEEE 2030.5, a resource is a simple piece of information that a Server exposes. These resources are used to represent aspects of a physical asset such as a smart inverter, attributes relating to the control of those assets (e.g., Volt-VAR curve), and general constructs for organizing these assets. IEEE 2030.5 resources are defined in the IEEE 2030.5 XML schema and access methods are defined in the Web Application Description Language (WADL). The schema defines a variety of Function Sets (a logical grouping of resources that cooperate to implement IEEE 2030.5 features), but this implementation guide only requires the implementation of a small subset of them.

#### 5.3.1 Time

The Utility Server uses the *Time* function set to distribute the current time to Clients. Time is expressed in Coordinated Universal Time (UTC). Server event timing is based on this time resource. Coordination of this time and rates for updating this time shall be described in the utility's implementation handbook.

### 5.3.2 Device Capability

The Utility Server uses the *DeviceCapability* resource to enumerate the function sets it supports. Clients use this function set to discover the location information (URL) of the enumerated function sets. The Aggregator uses *DeviceCapability* to locate the *EndDevice* resource.

### 5.3.3 End Device

The *EndDevice* function set provides interfaces to exchange information related to particular Client. In CSIP, each Smart Inverter or plant controller connected to a point of common coupling will be represented with an *EndDevice* instance. The key fields in the End Device record are:

- Information related to the Client's identity (i.e. SFDI, LFDI)
- Location (URL) of the Client's group assignments (i.e. *FunctionSetAssignmentsListLink*)
- Location (URL) where Clients make their subscription requests (i.e. *SubscriptionListLink*)
- Location (URL) where Clients POSTs alarms (i.e. *LogEventListLink*)
- The time the End Device record was last updated (i.e. *changedTime*). *Note that changedTime is a proposed new element for the next draft of the IEEE 2030.5 specification. It does not exist in the current specification.*

### 5.3.4 Function Set Assignments (FSA)

Grouping of Function Sets is accomplished by using Function Set Assignments (FSA). In CSIP, these function set assignments are used to group inverters into operational areas which can be commanded via a single fleet-wide operation.

### 5.3.5 Distributed Energy Resource (DER)

This function set provides an interface to manage Distributed Energy Resources (*DER*). *DER* functions can be divided into two categories: *DER* Controls and *DER* Settings. In CSIP, only *DER* Controls are used as it provides a common interface for sending commands to both individual inverters and groups. *DER* Settings are only available to individual inverters and have been thus excluded from CSIP.

### 5.3.6 DER Controls

A *DER* Control is based on an IEEE 2030.5 event, which is characterized by a definite start time and a finite duration. Examples of a *DER* Control include setting a fixed output power, setting a fixed power factor, setting a Volt-VAR curve, setting a Volt-Watt curve, etc.

Another important characteristic of an IEEE 2030.5 event is that it can be applied to a group of devices, not just a single device.

### 5.3.7 DER Settings

*DER* Settings exist under the *EndDevice* function set. Since they are a part of *EndDevice*, they can only be applied to a single device – that is, you cannot apply a *DER* Setting to a group of devices. Examples of a *DER* Setting include connect/disconnect, maximum output power limit, etc. As stated, the use of *DER* Settings is currently prohibited by CSIP for aggregator interactions

Note: This implementation guide requires group control of connect/disconnect and maximum output power limit which are only currently available as a DER Setting. This guide proposes the existing IEEE 2030.5 specification be updated to add or move these settings to DER Controls.

### 5.3.8 Subscription/Notification

The Utility Server shall provide resources to support subscriptions that allow rapid notification of a change in the resource. For example, the utility might change a Volt-VAr curve to reflect new tolerances based on the level of solar penetration on a feeder. The Client implements a notification resource to receive the notifications sent by the Utility Server. Although technically not required by the base IEEE 2030.5, this implementation guide mandates the use of subscriptions for communications between utilities and aggregators and commercial plants to improve network efficiency.

### 5.3.9 Metering

The Utility server will collect performance information for systems and, possibly groups, via the metering resources. The information collected via these metering resources is intended to support utility operations and analysis only. No assumption of revenue grade data collection is assumed at this time for CSIP. It is currently envisioned that all revenue grade metering information is collected via the utilities existing meter(s).

## 5.4 Identification of Inverters

Each inverter is uniquely identified by the IEEE 2030.5 device certificate it contains or by an ID assigned by the utility in conjunction with the other party at the time of system enrollment/commissioning. The device identity is used to guarantee its authenticity and uniqueness within the scope of a single utility's CSIP server. IEEE 2030.5 uses two identifiers, both of which are hashes of the device certificate. The Short-Form Device Identifier (SFDI) is based on a 36-bit hash of the device certificate and is expressed as 12 decimal digits. The Long-Form Device Identifier (LFDI) is a 20-byte hash of the device certificate.

This guide assumes the Utility can obtain or create an LFDI/SFDI list of all inverters under the Aggregator's control within its service territory. In cases where certificates are not used for the inverter identity, the utility will produce the LFDI/SFDI by generating a SHA256 fingerprint based on a utility-unique identifier using its own method that guarantee the uniqueness of the inverter/system. This unique identifier can be based on the aggregator's own ID prefixed with a utility-specific designator for the aggregator or simply by creating a new unique identity. In all cases, this identity and the associated LFDI/SFDI are returned to the aggregator for their uses in ensuring communications are routed appropriately. Similarly, aggregators need to ensure that any use of the LFDI/SFDI for its own identity purposes internal to its own systems is unique where the aggregator communicates with multiple utilities.

In the rare event that an LFDI/SFDI collision is detected (i.e. two unique certificates or IDs hash to the same LFDI/SFDI values), the utility should replace the certificates or IDs of the offending inverters. This may require returning the inverters to the manufacturer for certificate replacement. Note that the probability of a LFDI/SFDI collision is infinitesimally small. It is much more likely the collision was caused by an accidental duplication of the certificate or ID.

## 5.5 Utility Server Operation – Aggregator Model

In the Aggregator model, the Utility Server uses IEEE 2030.5 to communicate with an Aggregator. An Aggregator is expected to be an entity that is responsible for managing a group of inverters geographically dispersed across the utility service territory. In this model, the Utility does not have direct access or control of the inverters managed by the Aggregator. The Utility sends “high-level” commands to the Aggregator for updating the settings associated with a group of inverters and it is the responsibility of the Aggregator to interpret that command for applying those commands to the individual inverters under its control.

### 5.5.1 Group Assignment of Inverters

This guide assumes each inverter belongs to a minimum of one group and a maximum of 9 groups based upon a hierarchical system model related to a typical radial distribution electric system topology as described above. A final assignment is made for the inverter itself either a single entity or a grouped system connected to the utility at a single PCC.

A sample mapping of this form of group assignment is shown in the Figure 2 below depicting a 6 level hierarchy. This diagram and the IEEE 2030.5 resources it refers to are used throughout the example below depicting the initial creation of aggregator groups. However, each utility is free to create an alternate representation based on its specific topology and control needs.

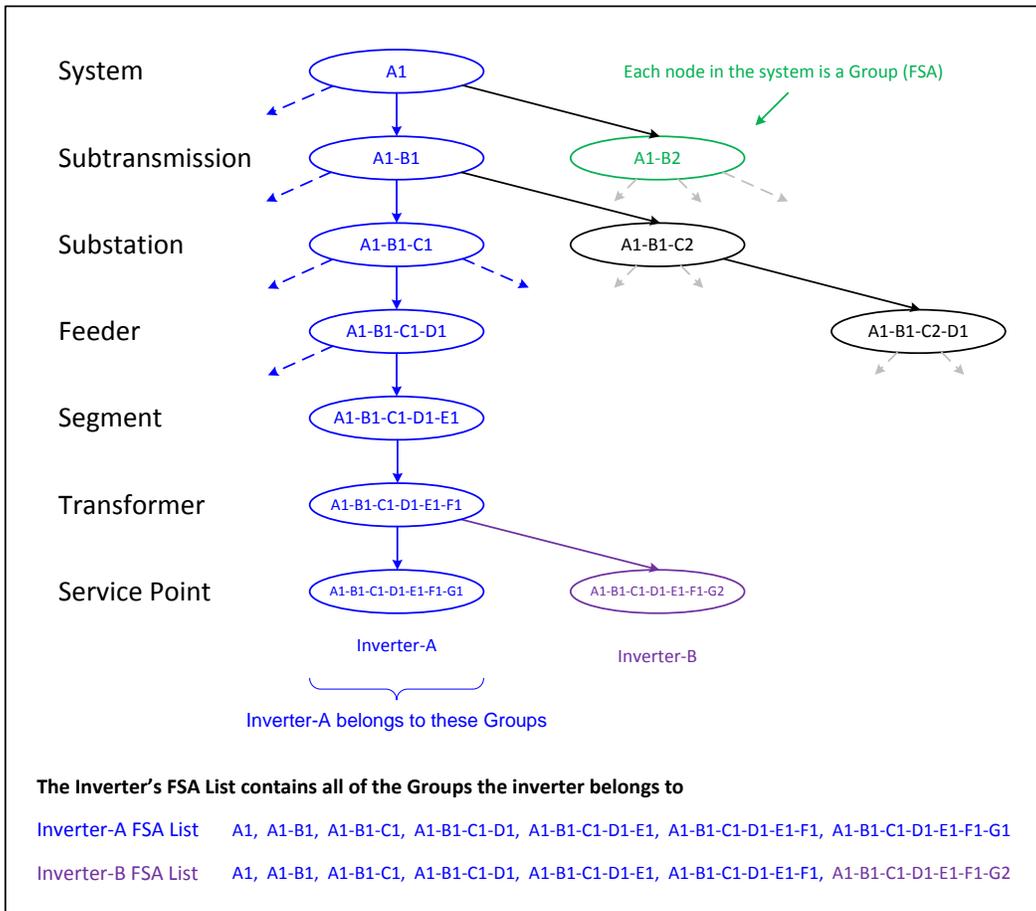


Figure 2. Inverter Group Hierarchy Example.

### 5.5.2 Utility Server Start-Up Configuration

Prior to allowing access, the Utility Server needs to construct the resources needed for Aggregator operation. This process results in the development of the hierarchical structure above in terms of IEEE 2030.5 objects. It should be noted that this is not a “one time” process and is expected to be an ongoing utility process to build and maintain the hierarchy of inverter group assignments. Hierarchy updates can be triggered by the addition and removal of inverters from the system as well as changes to the utility’s own electric system. See below in the Maintenance of Model section below for additional information regarding long-term maintenance of the system.

The following sections describe this as a “step-by-step” process. While this is a utility task, it is useful that aggregators also understand this process as well in terms of understanding how groups are created and maintained. Also note that the example presented is not the only way that a utility might organize inverter resources and that other alternate organizations Note that this is one possible way to create and structure the inverter resources. It may be that utilities develop alternate schemes based on operational needs.

**1. Create a *DERProgram* and *DERProgramList* for Each Group**

Create a *DERProgram* and a *DERProgramList* for each group as shown in Figure 3 below. The *DERProgram* provides a reference to the controls and curves associated with a specific DER management program. The *DERProgramList* defines a collection for storing all of the related *DERProgram* objects. These *DERProgramList* objects are used to define the possible controls for each group. Programs can be defined separately for each group or can be applied generally across multiple groups depending on the needs of the utility.

A key aspect of program definition is the assignment of the appropriate primacy value according to the priority of each group. IEEE 2030.5 supports up to 256 distinct primacy levels. Lower values of primacy represent higher priority levels. In general, it is assumed that the local primacy level will have higher priority levels than at a higher level in the electric system. For example, a *DERProgram* for a *Transformer* group should have a higher priority level (lower primacy value) relative to a *DERProgram* for a *Segment* group. However, it is also possible that other groups at a more general level might be set up to deal with conditions – e.g., general power curtailment during system-wide over generation conditions. In setting up these primacy levels, the utility should consider all of these scenarios and the maximum number of primacy levels that will be needed to support its concept of smart inverter operations.

```

<DERProgramList href="/sep2/A1/derp" all="1" results="1">
  <DERProgram href="/sep2/A1/derp/1">
    <mRID>B1000000</mRID>
    <description>System-A1 DERP</description>
    <ActiveDERControllistLink href="/sep2/A1/derp/1/actderc" all="0"/>
    <DefaultDERControllistLink href="/sep2/A1/derp/1/dderc"/>
    <DERControllistLink href="/sep2/A1/derp/1/derc" all="0"/>
    <DERCurveListLink href="/sep2/A1/derp/1/dc" all="0"/>
    <primacy>7</primacy>
  </DERProgram>
</DERProgramList>

<DERProgramList href="/sep2/A1-B1/derp" all="1" results="1">
  <DERProgram href="/sep2/A1-B1/derp/1">
    <mRID>B1100000</mRID>
    <description>Subtransmission-A1-B1 DERP</description>
    <ActiveDERControllistLink href="/sep2/A1-B1/derp/1/actderc" all="0"/>
    <DefaultDERControllistLink href="/sep2/A1-B1/derp/1/dderc"/>
    <DERControllistLink href="/sep2/A1-B1/derp/1/derc" all="0"/>
    <DERCurveListLink href="/sep2/A1-B1/derp/1/dc" all="0"/>
    <primacy>6</primacy>
  </DERProgram>
</DERProgramList>
: : : : : : : : : :
: : : : : : : : : :
<DERProgramList href="/sep2/A1-B1-C1-D1-E1-F1/derp" all="1" results="1">
  <DERProgram href="/sep2/A1-B1-C1-D1-E1-F1/derp/1">
    <mRID>B1111110</mRID>
    <description>Transformer-A1-B1-C1-D1-E1-F1 DERP</description>
    <ActiveDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1/derp/1/actderc" all="0"/>
    <DefaultDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1/derp/1/dderc"/>
    <DERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1/derp/1/derc" all="0"/>
    <DERCurveListLink href="/sep2/A1-B1-C1-D1-E1-F1/derp/1/dc" all="0"/>
    <primacy>2</primacy>
  </DERProgram>
</DERProgramList>

<DERProgramList href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp" all="1" results="1">
  <DERProgram href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp/1">
    <mRID>B1111111</mRID>
    <description>ServicePoint-A1-B1-C1-D1-E1-F1-G1 DERP</description>
    <ActiveDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp/1/actderc" all="0"/>
    <DefaultDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp/1/dderc"/>
    <DERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp/1/derc" all="0"/>
    <DERCurveListLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp/1/dc" all="0"/>
    <primacy>1</primacy>
  </DERProgram>
</DERProgramList>

<DERProgramList href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp" all="1" results="1">
  <DERProgram href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp/1">
    <mRID>B1111112</mRID>
    <description>ServicePoint-A1-B1-C1-D1-E1-F1-G2 DERP</description>
    <ActiveDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp/1/actderc" all="0"/>
    <DefaultDERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp/1/dderc"/>
    <DERControllistLink href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp/1/derc" all="0"/>
    <DERCurveListLink href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp/1/dc" all="0"/>
    <primacy>1</primacy>
  </DERProgram>
</DERProgramList>

```

Figure 3. Creation of DER Programs and Program Lists.

## 2. Create the Groups (FSAs)

FunctionSetAssignments are used to bundle specific DER programs for usage. The process of creating the FSAs is shown in Figure 4 below. The basic approach is to store the appropriate DERProgramList link with the FSA. These DERProgramList instances were created in the previous step and provide access to the DER programs associated with the utility groups. Note that IEEE 2030.5 allows other objects to be included in the FunctionSetAssignments but these are never present in CSIP. It is possible, however, that future versions of CSIP might leverage these capabilities and that both clients and servers be implemented in such a way as to support future growth options.

```

<FunctionSetAssignments href="/sep2/A1/fsa/1">
  <mRID>A1000000</mRID>
  <description>System-A1 FSA</description>
  <DERProgramListLink href="/sep2/A1/derp" all="0"/>
  <TimeLink href="/sep2/tm"/>
</FunctionSetAssignments>

<FunctionSetAssignments href="/sep2/A1-B1/fsa/1">
  <mRID>A1100000</mRID>
  <description>Subtransmission-A1-B1 FSA</description>
  <DERProgramListLink href="/sep2/A1-B1/derp" all="0"/>
  <TimeLink href="/sep2/tm"/>
</FunctionSetAssignments>
: : : : : : : : : :
: : : : : : : : : :
<FunctionSetAssignments href="/sep2/A1-B1-C1-D1-E1-F1/fsa/1">
  <mRID>A1111110</mRID>
  <description>Transformer-A1-B1-C1-D1-E1-F1 FSA</description>
  <DERProgramListLink href="/sep2/A1-B1-C1-D1-E1-F1/derp" all="0"/>
  <TimeLink href="/sep2/tm"/>
</FunctionSetAssignments>

<FunctionSetAssignments href="/sep2/A1-B1-C1-D1-E1-F1-G1/fsa/1">
  <mRID>A1111111</mRID>
  <description>Inverter-A1-B1-C1-D1-E1-F1-G1 FSA</description>
  <DERProgramListLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp" all="0"/>
  <TimeLink href="/sep2/tm"/>
</FunctionSetAssignments>

<FunctionSetAssignments href="/sep2/A1-B1-C1-D1-E1-F1-G2/fsa/1">
  <mRID>A1111112</mRID>
  <description>Inverter-A1-B1-C1-D1-E1-F1-G2 FSA</description>
  <DERProgramListLink href="/sep2/A1-B1-C1-D1-E1-F1-G2/derp" all="0"/>
  <TimeLink href="/sep2/tm"/>
</FunctionSetAssignments>

```

Figure 4. Creation of Function Set Assignments.

## 3. Create an FSA List (Group Assignment) for Each Inverter

FunctionSetAssignmentList objects are used to define the relationship individual inverters to the groups created in the previous step. In CSIP, while not explicitly mandated, inverters are most likely part of any and all parent groups.

Create an FSA List for each inverter by adding appropriate FSAs to the list as shown in Figures 5 and 6 below. The FSAs were created in the previous step. Based on the model presented above, the FSA List

can have up to 7 entries which represent the inverter’s System, Sub-transmission, Substation, Feeder, Segment, Transformer, and Inverter group membership. It is important to note that full membership in all group levels is not mandated by CSIP and that other grouping structures may be implemented by utilities. It should also be stated that a uniform implementation of groups is not required and may vary in complexity based on the density of penetration of smart inverters across a utility’s service territory.

```

<FunctionSetAssignmentsList subscribable="1" all="7" results="7" href="/sep2/eDEV/1/fsa">
  <FunctionSetAssignments href="/sep2/A1/fsa/1">
    <mRID>A1000000</mRID>
    <description>System-A1 FSA</description>
    <DERProgramListLink href="/sep2/A1/derp" all="0"/>
    <TimeLink href="/sep2/tm"/>
  </FunctionSetAssignments>

  <FunctionSetAssignments href="/sep2/A1-B1/fsa/1">
    <mRID>A1100000</mRID>
    <description>Subtransmission-A1-B1 FSA</description>
    <DERProgramListLink href="/sep2/A1-B1/derp" all="0"/>
    <TimeLink href="/sep2/tm"/>
  </FunctionSetAssignments>
  : : : : : : : :
  : : : : : : : :
  <FunctionSetAssignments href="/sep2/A1-B1-C1-D1-E1-F1/fsa/1">
    <mRID>A1111110</mRID>
    <description>Transformer-A1-B1-C1-D1-E1-F1 FSA</description>
    <DERProgramListLink href="/sep2/A1-B1-C1-D1-E1-F1/derp" all="0"/>
    <TimeLink href="/sep2/tm"/>
  </FunctionSetAssignments>

  <FunctionSetAssignments href="/sep2/A1-B1-C1-D1-E1-F1-G1/fsa/1">
    <mRID>A1111111</mRID>
    <description>Inverter-A1-B1-C1-D1-E1-F1-G1 FSA</description>
    <DERProgramListLink href="/sep2/A1-B1-C1-D1-E1-F1-G1/derp" all="0"/>
    <TimeLink href="/sep2/tm"/>
  </FunctionSetAssignments>
</FunctionSetAssignmentsList>

```

Figure 5. Function Set Assignments for Inverter A.



### 5. Create an EndDevice Instance for the Aggregator

Create an EndDevice instance for the Aggregator as shown in the Figure 8 below. Note that the Aggregator instance does not have an FSA List link, but does have a Subscription List link. The Subscription List link allows the Aggregator to POST subscriptions for resources which it wishes to receive notifications related to its managed fleet of inverters. As this is a global resource for the aggregator, the utility only creates a single end device instance for each aggregator with which it has a contractual relationship.

```
<EndDevice href="/sep2/eDev/3" subscribable="1">
  <sFDI>424105305501</sFDI>
  <lFDI>9dfdd56f6128cdc894a1e42c690cab197184a8e9</lFDI>
  <SubscriptionListLink href="/sep2/eDev/3/subs" all="0"/>
  <LogEventListLink href="/sep2/eDev/3/log" all="0"/>
  <changedTime>1456339000</changedTime>
</EndDevice>
```

Figure 8. Aggregator End Device Instance Creation.

### 6. Create an EndDevice List for the Aggregator

Create an EndDevice List for the Aggregator that contains the Aggregator EndDevice instance as well as all of the instances for inverters under the Aggregator's control as shown in the diagram below. Note that this list is unique to this Aggregator. Each Aggregator managed by the utility will receive a uniquely tailored EndDevice List reflecting all of its currently enrolled systems with the utility.

```
<EndDeviceList href="/sep2/eDev" subscribable="1" all="3" results="3">
  <EndDevice href="/sep2/eDev/1" subscribable="1">
    <sFDI>050044792964</sFDI>
    <lFDI>12a4a4b406ad102e7421019135ffa2805235a21c</lFDI>
    <FunctionSetAssignmentsListLink href="/sep2/eDev/1/fsa" all="7"/>
    <DERListLink href="/sep2/eDev/1/der" all="1"/>
    <LogEventListLink href="/sep2/eDev/1/log" all="0"/>
    <changedTime>1456339000</changedTime>
  </EndDevice>
  <EndDevice href="/sep2/eDev/2" subscribable="1">
    <sFDI>228273300409</sFDI>
    <lFDI>5509d69f8b353595206ad71b47e27906318ea367</lFDI>
    <FunctionSetAssignmentsListLink href="/sep2/eDev/2/fsa" all="7"/>
    <DERListLink href="/sep2/eDev/2/der" all="1"/>
    <LogEventListLink href="/sep2/eDev/2/log" all="0"/>
    <changedTime>1456339000</changedTime>
  </EndDevice>
  <EndDevice href="/sep2/eDev/3" subscribable="1">
    <sFDI>424105305501</sFDI>
    <lFDI>9dfdd56f6128cdc894a1e42c690cab197184a8e9</lFDI>
    <SubscriptionListLink href="/sep2/eDev/3/subs" all="0"/>
    <LogEventListLink href="/sep2/eDev/3/log" all="0"/>
    <changedTime>1456339000</changedTime>
  </EndDevice>
</EndDeviceList>
```

Figure 9. Aggregator End Device List Creation.

### 5.5.3 Utility – Aggregator Operations

The previous sections described the process by which a utility establishes the necessary objects needed to support operations with an aggregator. The sections below describe the process whereby the aggregator can access this objects to manage its fleet of inverters in accordance with controls provided by the utility.

#### 1. Commissioning

Commissioning is the general process where the Aggregator discovers the Utility Server and can get *EndDevice* information from the Server. Commissioning involves the following sequence of steps.

- a. *Discovery of Utility Server*. In LAN environments, IEEE 2030.5 uses xmDNS/DNS-SD to perform IP address discovery as well as resource discovery. However, xmDNS does not work over the internet, so some other mechanism like DNS/DNS-SD need to be used. Assuming the Aggregator knows the name of the Utility Server (e.g. utility-server.org), it performs a DNS lookup for the IP address associated with that name. It then uses the DNS-SD records to locate the URL path to the *DeviceCapability* resource on the Server. IP address information can also be delivered directly to the aggregator by the utility out of band. With this information, the Aggregator is ready to connect to the Server.
- b. *Establishment of a Secure Connection*. The Aggregator tries to establish an HTTPS (TLS) connection to the Server to get the *DeviceCapability* resource. The HTTPS handshake uses the IEEE 2030.5 cipher-suite (or an equivalent cipher-suite negotiated between the Utility and the Aggregator). The HTTPS handshake involves a mutual exchange of device certificates for each side to authenticate the identity of the other. In particular, the Utility Server uses the certificate to authenticate the aggregator and construct an *EndDeviceList* specific to that Aggregator. If the Utility Server authenticates the Aggregator, it returns the requested *DeviceCapability* response. If the authentication fails, the Utility Server should return an “HTTP: 404 Not Found” response.
- c. *Get the EndDeviceList*. From the *DeviceCapability* response, the Aggregator knows the URL of the *EndDeviceList* resource. It then gets the contents of the entire list. The list contains entries for the Aggregator as well as all of the inverters under the Aggregator’s control.

The Commissioning sequence is shown in the Figure 10.

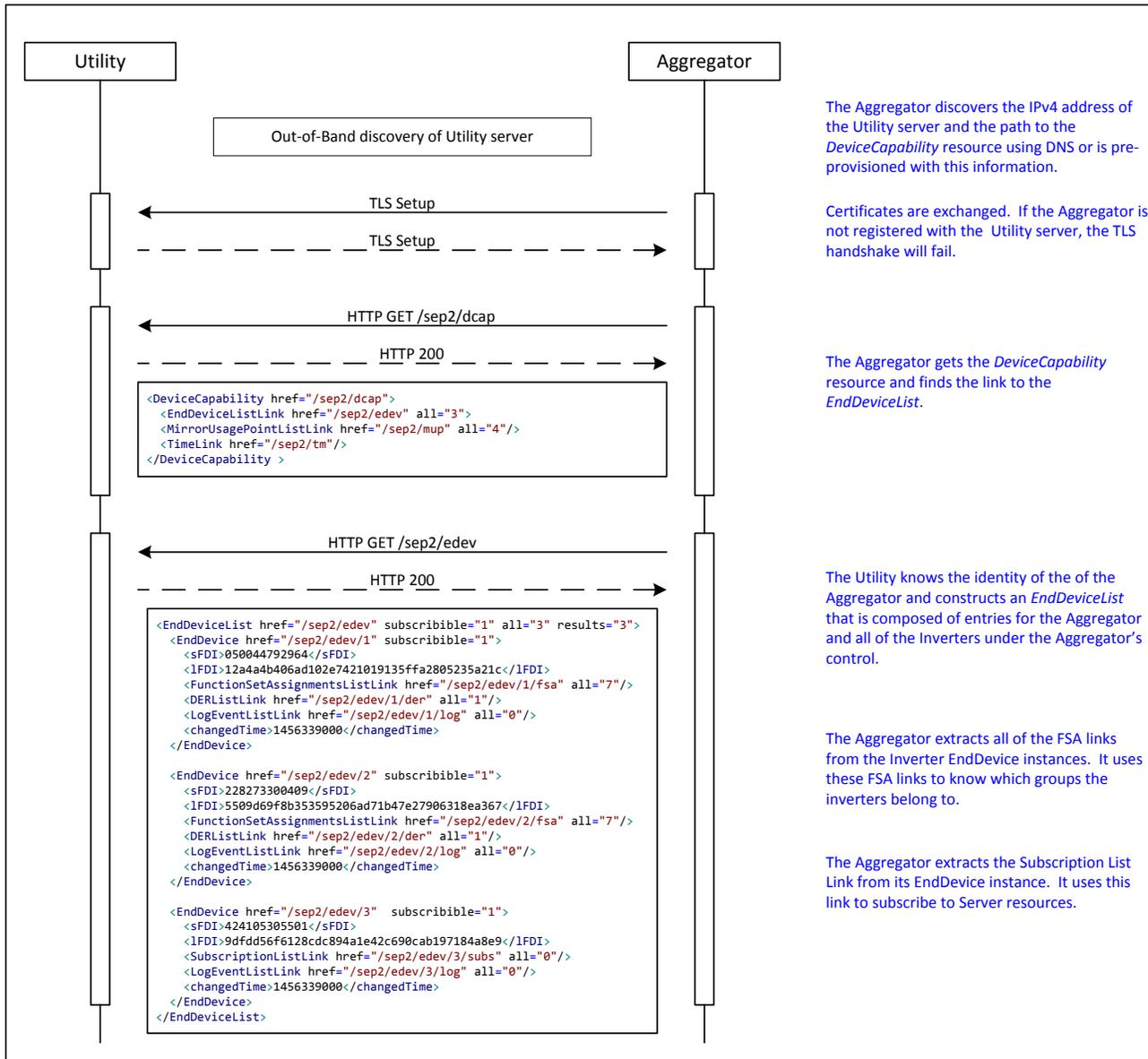


Figure 10. Aggregator Commissioning Sequence.

## 2. Retrieval of Group Assignments

Once the Aggregator has the list of inverters under its control, it now needs to find out the group assignments of each inverter. This group retrieval process involves the following steps.

- d. **Get the FSA List Link.** For each inverter, get the *FunctionSetAssignmentsListLink*. This link is the location where the group assignments for this inverter can be found.
- e. **Get the FSA List.** Using the link, get the *FunctionSetAssignmentsList* for each inverter. Each entry in the list is an FSA (i.e. a group). In this guide's system model, the inverter can belong to 5 groups representing the System, Substation, Feeder, Segment, and Transformer.

The Group Retrieval sequence is shown in Figure 11.



### 3. Retrieval of DER Programs

The Aggregator now has all of the group assignments of the inverters under its control. It now needs to get the DER Programs associated with each group assignment. The DER Program is a container for DER Controls and related information. As stated previously, one important piece of information is the *primacy* field. This field represents the relative priority of the program. The aggregator uses to the primacy field to determine which DER Controls takes precedence if multiple programs commands are in conflict.

- f. *Get the DER Program.* For each FSA, use the *DERProgramListLink* to get the *DERProgramList* and all of the *DERPrograms* in the list.
- g. *Get the DER Information for Each Program.* For each *DERProgram*, get the relevant information like *primacy* and links to the *DERControlList*, *DERCurveList* and the *DefaultDERControl*.

The DER Program retrieval sequence is shown in Figure 12.

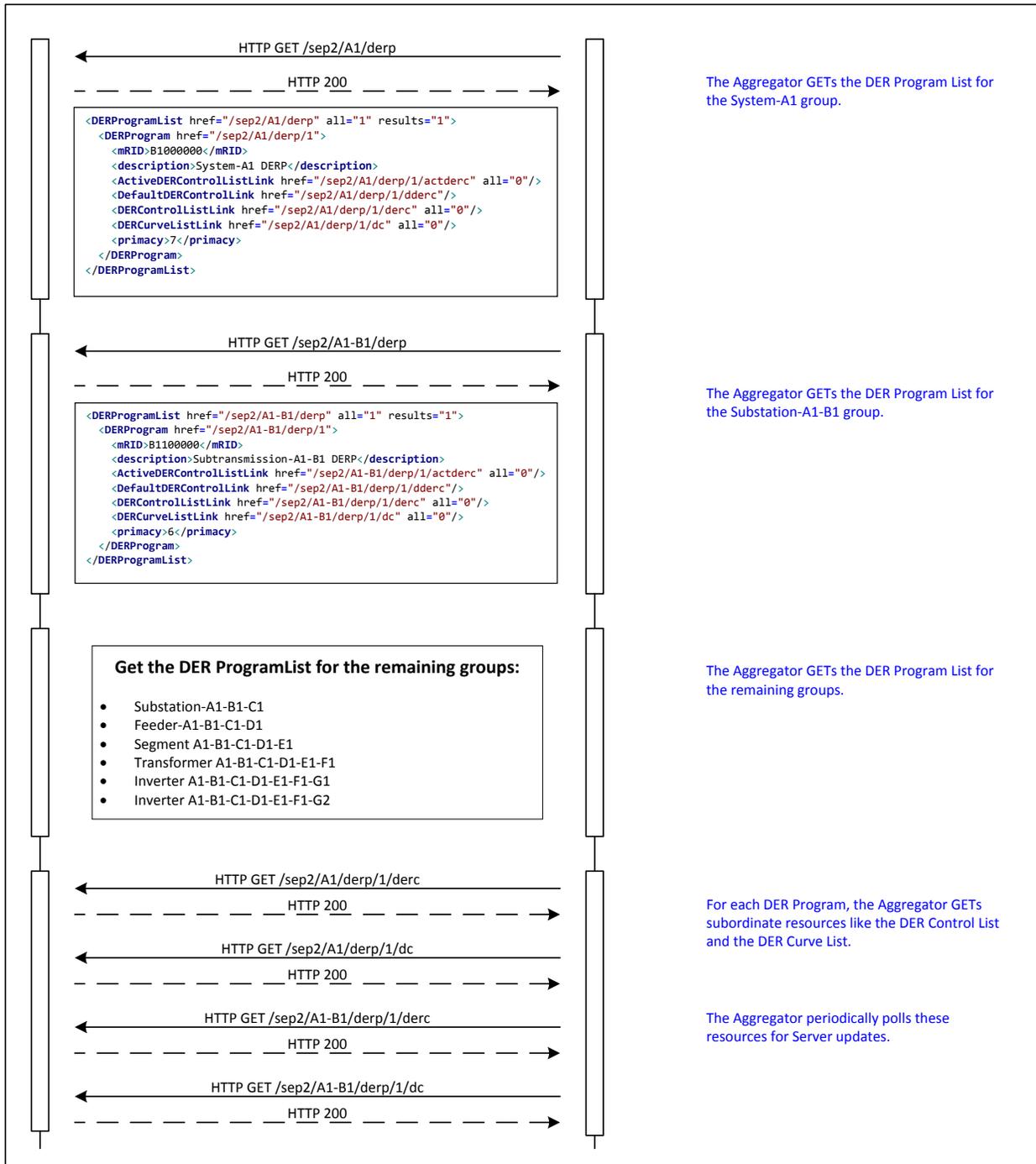


Figure 12. DER Program Retrieval.

### 5.5.4 DER Controls and Curves

Once the Utility Server has been configured, DER Control events for groups can be created. There are two types of controls: Immediate controls and Curves. It is important to note that all controls are not mutually exclusive and that control events can include one or more control operations.

#### 5.5.4.1 Immediate Controls

IEEE 2030.5 supports the following immediate controls.

- opModFixedFlow – Active Power set point
- opModFixedPF – Power Factor set point
- opModFixedVAr – Reactive Power set point

Currently, there IEEE 2030.5 specification is undergoing revisions to include the following immediate controls which have been assumed to exist for this version of CSIP.

- opModMaxLimW – Maximum Active Power output limit. [Replaces opModFixedW]
- opModConnect – Connect/Disconnect
- opModEnergize – Energize/De-energize
- opModTargetW – Active Power set point in Watts
- opModTargetVAr – Reactive Power set point in VARs

#### 5.5.4.2 Curve Controls

IEEE 2030.5 supports the following curves:

- opModVoltVAr – Voltage-VAr curve
- opModVoltWatt – Volt-Watt curve
- opModFreqWatt – Frequency-Watt curve
- opModWattPF – Watt-Power Factor curve

Currently, there IEEE 2030.5 specification is undergoing revisions to include the following curve controls which have been assumed to exist for this version of CSIP.

- opModHVMustTrip – High voltage disturbance response curve
- opModHVMomentaryCessation – High voltage momentary cessation disturbance response curve
- opModLVMustTrip – Low voltage must trip disturbance response curve
- opModLVMomentaryCessation – Low voltage momentary cessation disturbance response curve
- opModHFMustTrip – High frequency must trip disturbance response curve
- opModLFMustTrip – Low frequency must trip disturbance response curve

Curves are defined by a set of (x,y) points. A DER Curve List is a set of curves that are available to a DER Program. Figure 13 depicts a Curve List with a set of 2 curves for the System-A1 DER Program group.

```

<DERCurveList href="/sep2/A1/derp/1/dc" all="2" results="2">
  <DERCurve href="/sep2/dc/2">
    <mRID>C0000002</mRID>
    <description>Volt-VAr Curve 2</description>
    <creationTime>1446141185</creationTime>
    <CurveData>
      <xvalue>90</xvalue>
      <yvalue>60</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>93</xvalue>
      <yvalue>0</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>107</xvalue>
      <yvalue>0</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>110</xvalue>
      <yvalue>-60</yvalue>
    </CurveData>
    <curveType>0</curveType>
    <rampDecTms>5000</rampDecTms>
    <rampIncTms>5000</rampIncTms>
    <xMultiplier>0</xMultiplier>
    <yMultiplier>0</yMultiplier>
    <yRefType>3</yRefType>
  </DERCurve>

  <DERCurve href="/sep2/dc/1">
    <mRID>C0000001</mRID>
    <description>Volt-VAr Curve 1</description>
    <creationTime>1446141185</creationTime>
    <CurveData>
      <xvalue>91</xvalue>
      <yvalue>61</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>94</xvalue>
      <yvalue>1</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>108</xvalue>
      <yvalue>1</yvalue>
    </CurveData>
    <CurveData>
      <xvalue>111</xvalue>
      <yvalue>-61</yvalue>
    </CurveData>
    <curveType>0</curveType>
    <rampDecTms>5001</rampDecTms>
    <rampIncTms>5001</rampIncTms>
    <xMultiplier>0</xMultiplier>
    <yMultiplier>0</yMultiplier>
    <yRefType>3</yRefType>
  </DERCurve>
</DERCurveList>

```

Figure 13. DER Curve Creation.

### 5.5.5 Creating DER Controls

Here is a step by step procedure for creating a DER Control.

#### 1. Creation of a Default DER Control

First, the Utility Server can create a default DER Control. The controls in this object are in effect if when there are no DER Controls active. Figure 14 shows the default DER Control for the System-A1 DER Program group. In this example, the default control consists of a “set output power” command to set the power to 99% of its maximum setting, and a command to apply the Volt-VAr curve located at “/sep2/dc/1”.

```
<DefaultDERControl href="/sep2/A1/derp/1/dderc">
  <mRID>E0000001</mRID>
  <description>Default DERC</description>
  <DERControlBase>
    <opModFixedW>9900</opModFixedW>
    <opModVoltVAr href="/sep2/dc/1"/>
  </DERControlBase>
</DefaultDERControl>
```

Figure 14. Default DER Control

#### 2. Creation of DER Control

To create a DER event for a group, create a DER Control with the appropriate Start time, Duration, and DER control type. This control is then added to the DER Control List for the DER Program group. Figure 15 shows a DER Control event for the System-A1 DER Program group. This event consists of a “set output power” command to set the power to 88% of its maximum setting, and a command to apply the curve located at “/sep2/dc/2”.

```
<DERControllist href="/sep2/A1/derp/1/derc" subscribable="1" all="1" results="1">
  <DERControl href="/sep2/A1/derp/1/derc/1" replyTo="/rsps/1/rsp" responseRequired="00">
    <mRID>D0000001</mRID>
    <description>Scheduled DERC</description>
    <creationTime>1456340000</creationTime>
    <EventStatus>
      <currentStatus>0</currentStatus>
      <dateTime>1456340000</dateTime>
      <potentiallySuperseded>true</potentiallySuperseded>
      <potentiallySupersededTime>1456340001</potentiallySupersededTime>
    </EventStatus>
    <interval>
      <duration>3000</duration>
      <start>1456342000</start>
    </interval>
    <DERControlBase>
      <opModFixedW>8800</opModFixedW>
      <opModVoltVAr href="/sep2/dc/2"/>
    </DERControlBase>
  </DERControl>
</DERControllist>
```

Figure 15. DER Control Creation.

## 5.6 Aggregator Operation

The Aggregator uses subscription to monitor each DER Program group's DER Control List for a new control or a change to an existing control. The Aggregator subscribes to the DER Control List. By subscribing, the Utility Server pushes a Notification to the Aggregator when there is a change to the DER Control List. The Aggregator then gets the DER Control list and finds the new DER Control event. Note that in periods of extended off-line periods or for error recovery purposes, the aggregator can perform a full update and completely rebuild its model in the sequential manner described above for startup operations. These rebuilds should be coordinated with the utility to avoid operational problems in the dispatch of normal inverter control events and actions.

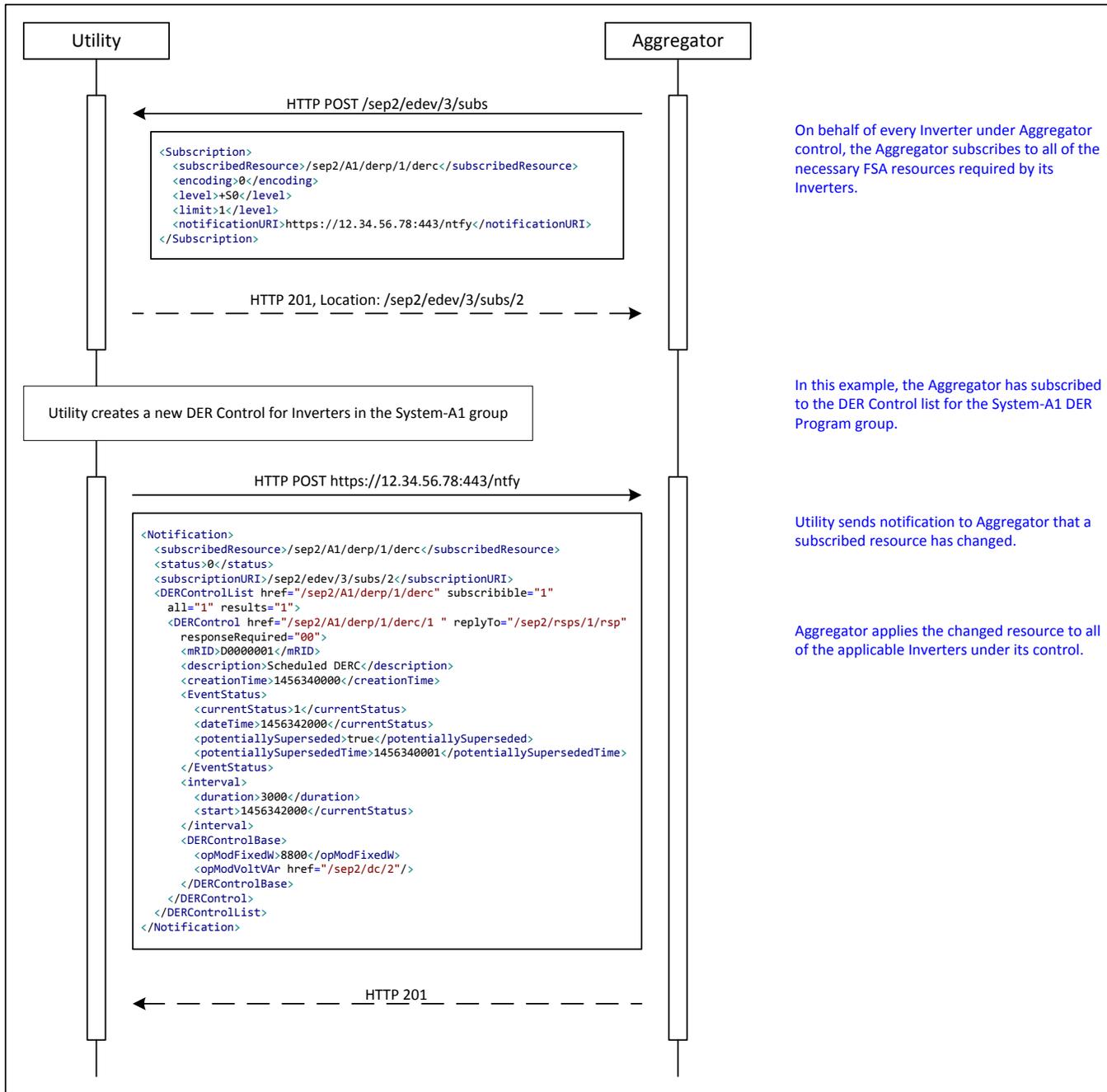


Figure 16. DER Control List Subscription Notification.

### 5.6.1 Use of Subscription/Notification to Optimize Utility-Aggregator Interactions

IEEE 2030.5 provides a light-weight subscription/notification mechanism that allows the Utility Server to push resource changes to the Aggregator. As stated previously, this guide mandates the use of subscriptions to minimize and possibly eliminate the need for periodic polling. This guide mandates that the Aggregator shall subscribe to at least the following resources:

- *EndDeviceList* – to get notification of the addition of an inverter
- *EndDevice* – to get notification of the deletion or change to an existing inverter
- *FunctionSetAssignmentsList* – to get notification of group changes
- *DERControlList* – to get notifications of new DER Controls or changes to an existing DER Control
- *DERProgramList* – to get notifications of new DER Programs
- *DERProgram* – to get notifications when program meta-data like primacy changes

Here is a step-by-step guide to creating a subscription:

#### 1. *POST the Subscription*

The Aggregator POSTs to the Utility Server's subscription resource with the URL of the resource it wishes to subscribe to.

#### 2. *Get the Subscription Confirmation*

If the subscription was successful, the Utility Server returns a confirmation with the location of the confirmed subscription. The Utility Server will now notify the Aggregator if there are any changes to the subscribed resource.

#### 3. *Utility POSTs a Notification*

If there is a change to the subscribed resource, the Utility server notifies the Aggregator by POSTing to the Aggregator's notification resource.

The subscription/notification sequence for an *EndDevice* subscription is shown in Figure 17. In this example, the Aggregator is subscribing to the *EndDevice* resource representing one of its inverters.

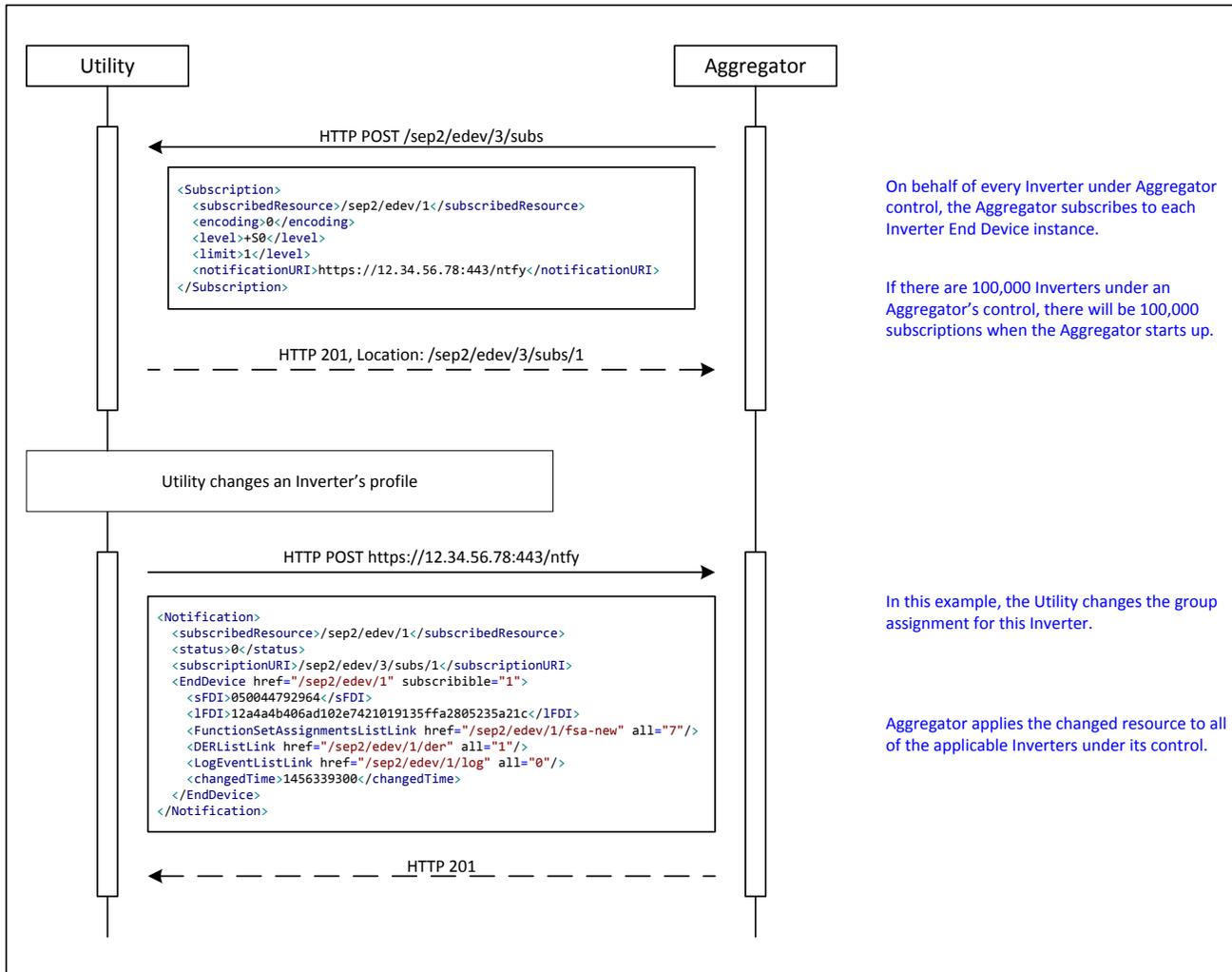


Figure 17. End Device Subscription and Notification Process.

### 5.6.2 Examples of DER Event Operations

An inverter, operating stand-alone or under the control of an Aggregator, can belong to multiple groups and must track the programs and controls associated with those groups. It is possible, and probably quite common, for an inverter to receive overlapping events from different groups. How an inverter handles these situations is determined by the *Event Rules and Guidelines* of section 12.1.3 of the IEEE 2030.5 specification. This document will highlight some of the important rules.

The priority of a DER control is determined by the *primacy* setting of its containing program with a lower *primacy* value indicating higher priority. In the absence of any active events, the inverter executes the Default DER Control of the program with the highest priority (i.e. lowest *primacy* value).

When an inverter receives overlapping DER control events, the DER control whose program has the higher priority (i.e. lower *primacy* value) takes precedence. The following examples describe two very similar overlapping event scenarios that only differ in when the inverter receives the events. These

examples assume the client has discovered the DER programs and subscribed to the DER Control Lists. The process of discovering and subscribing to these resources was discussed earlier in this document.

In the first case, the inverter receives both DER control events prior to the start of either. In this case, the inverter does not execute the lower priority (superseded) event. It only executes the higher priority event as shown in the figure below.

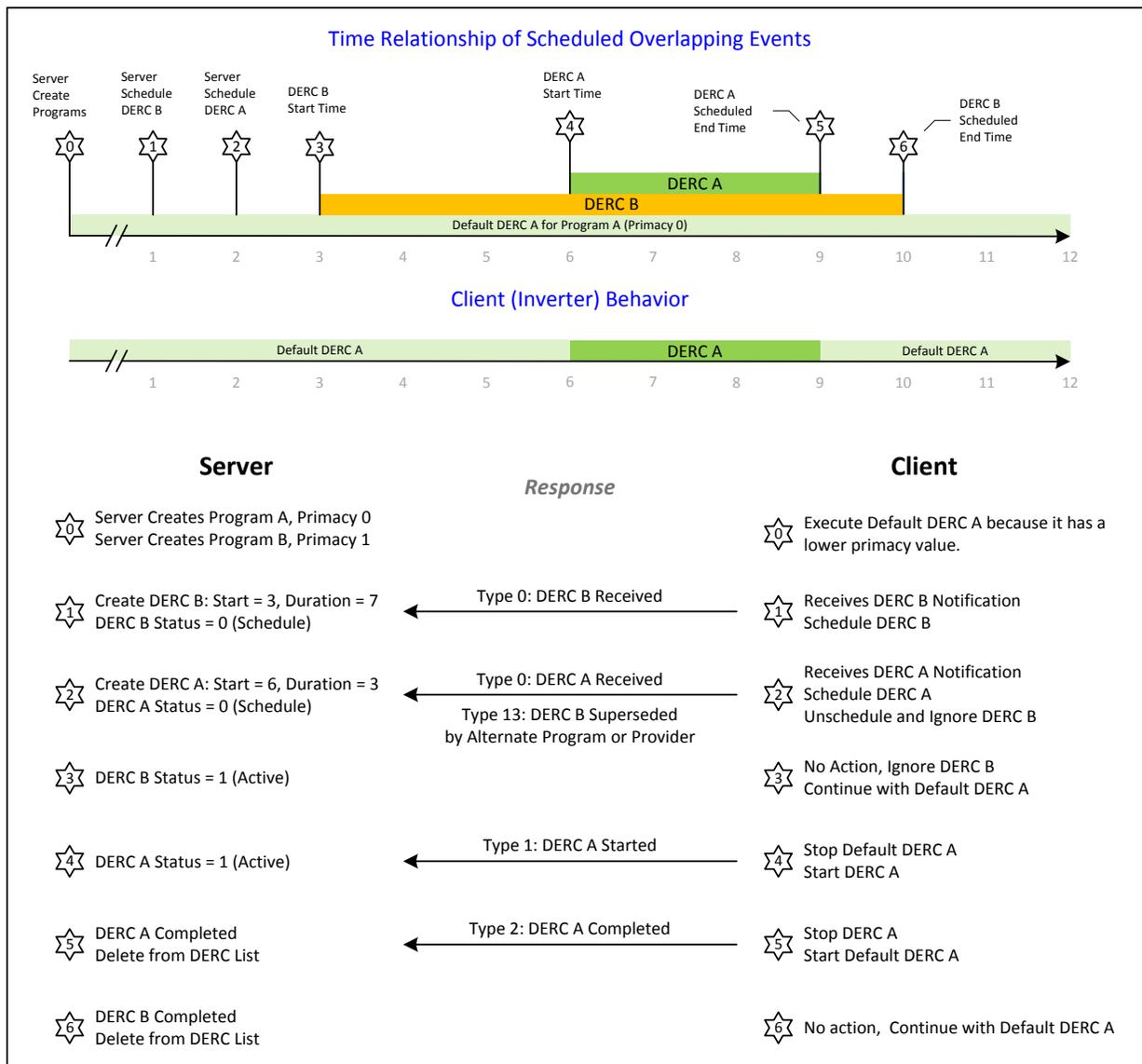


Figure 18. Supersede before Start of DER Control Event

In the second case, the inverter receives the higher priority event while executing lower priority event. In this case, the inverter continues with the lower priority event until the start time of the higher priority event. It then superseded the lower priority event and switches to executing the higher priority event as shown in the figure below.

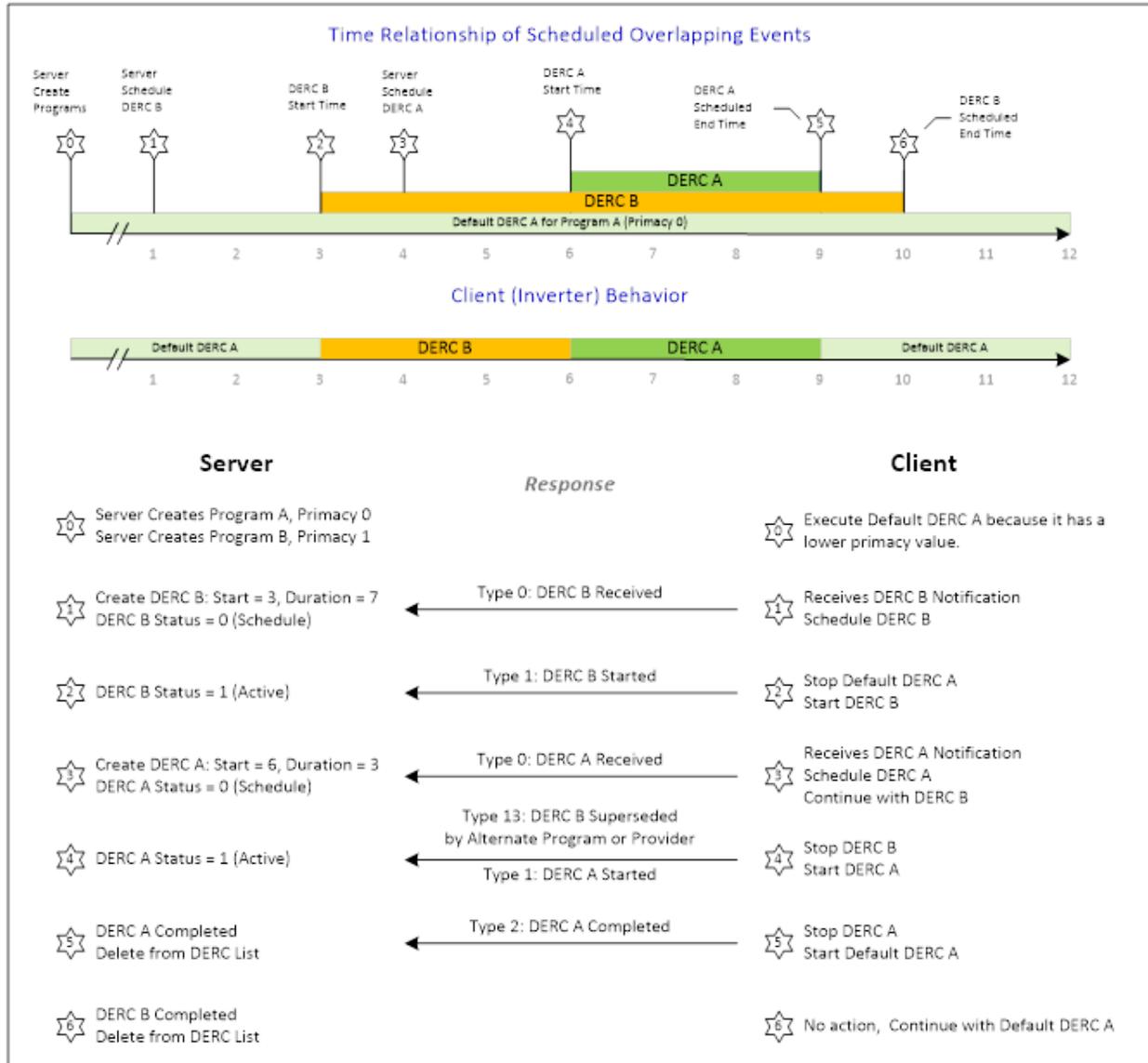


Figure 19. Supersede after Start of DER Control Event

Please note that in both scenarios the inverter **DOES NOT** resume execution of the lower priority (superseded) event after completing the higher priority event. The Utility Server should be cognizant of this behavior when constructing potentially superseding events.

### 5.7 Reporting of Meter Data, Status Information, and Alarms

This section describes how aggregators report performance of the inverters under their control. While CSIP leverages the IEEE 2030.5 Metering Function Set, the assumption is that the data reported are for operational purposes only and are not the basis of any customer billing.

All performance information is reported by the aggregator at the represented end device level only. Any aggregation of performance information (i.e., groupings based on Function Set Assignments) is the responsibility Users of the data.

This section describes the reporting of three classes of information: Meter Data, Status Information, and Alarms by the End Device (i.e. the Inverter). Requirements for reporting information pertaining to groups is still under discussion and is not addressed at this time. Additional requirements regarding which information shall be collected within the total set of the options specified below are identified in each utility's interconnection handbook.

### 5.7.1 Meter Data

Meter data is data that can be reported using the IEEE 2030.5 Metering Mirror function set. Examples of meter data include Real Power, Apparent Power, Reactive Power, Power Factor, Voltage, Current, etc. The information returned is for engineering and operational purposes and is not assumed to support billing or settlement purposes. Metering data is PUT/POSTed to the Utility Server via the *MirrorUsagePointListLink* in the End Device's FSA group. The Utility Server enables/disables the PUT/POSTing of meter data by including or not including the *MirrorUsagePointListLink*. If the link is present, the End Device should PUT/POST meter data to it. If the link is not present, the End Device should not PUT/POST meter data to the Utility Server.

The Utility Server can identify the source of the End Device meter data in a couple of ways. First, it can provide a unique *MirrorUsagePointListLink* to each End Device such that each End Device PUT/POSTs to a different location. Second, the LFDI of the End Device is contained in the *MeterUsagePoint* that is POSTed to the Utility Server.

Is it possible to report aggregated meter data from a group of inverters instead of an individual inverter? IEEE 2030.5 does not have a direct method to do this, but it can be done by using the existing *description* field to report group membership. For example, if the Aggregator wants to report the Real Power generated from all of the inverters in group A1-B1, it would:

1. Create a new *MirrorUsagePoint* for this aggregated reading by POSTing to the Aggregator's *MirrorUsagePointListLink* using the Aggregator's LFDI, and putting the group name (A1-B1) in the *description* field.
2. Periodically, sum up the Real Power from all of the inverters in group A1-B1.
3. Periodically, report the Real Power by POSTing the *MirrorMeterReading*, and putting the group name (A1-B1) in the *description* field.

An example of a Metering Mirror sequence of operations is shown in the figure below.

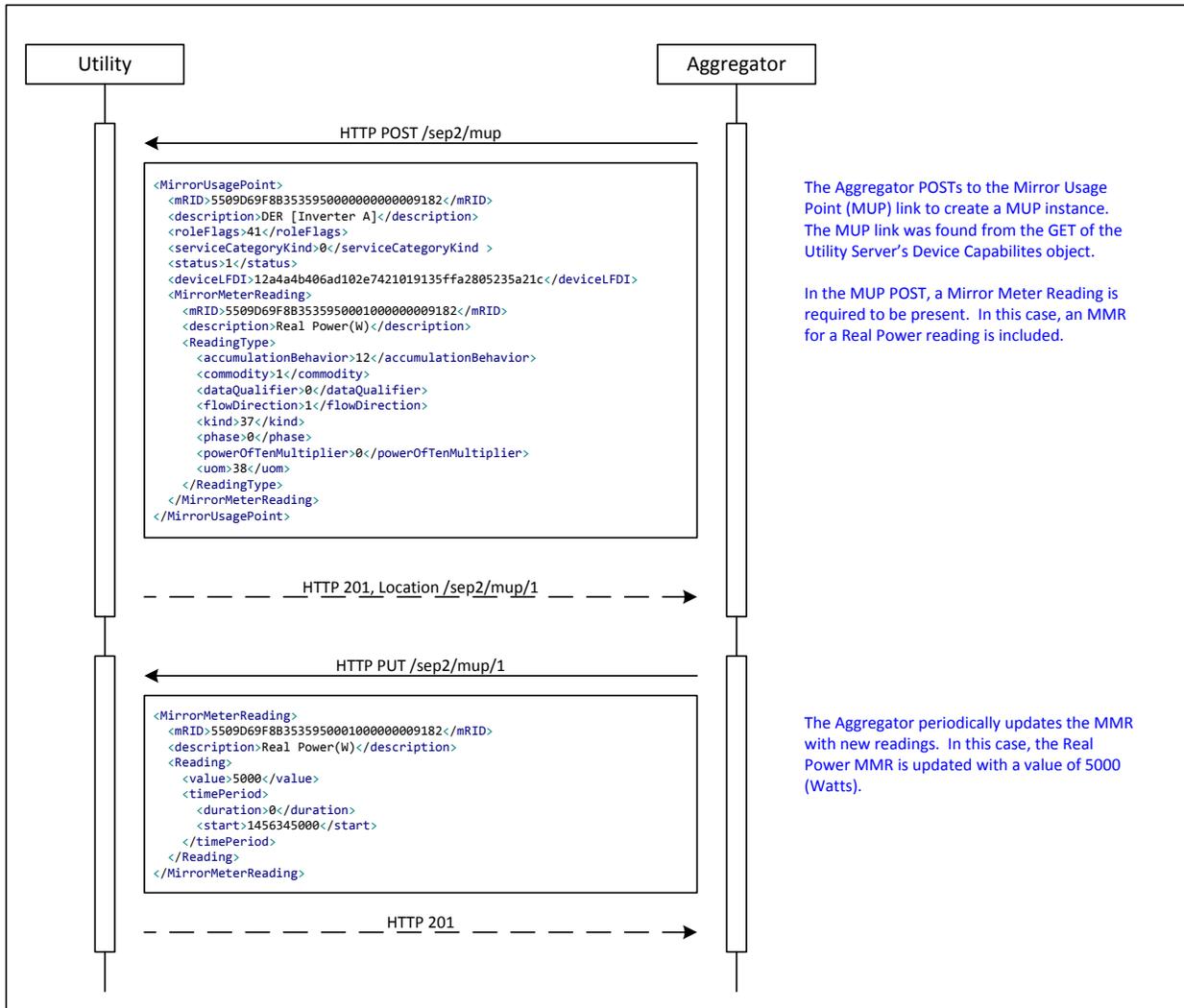


Figure 20. Metering Mirror Sequence.

### 5.7.2 Status Information

End Devices can report their status information via their EndDevice instance. For each EndDevice instance, the Utility Server can include links where status information pertaining to that End Device can be PUT. Examples of possible status links include: *DeviceStatusLink*, *DeviceInformationLink*, *PowerStatusLink*, *NetworkStatusLink*, *DERListLink*, etc. For CA Rule 21 usage, the status information reportable using the *DERListLink* is the most relevant.

The *DERListLink* provides links to available DER status information which include:

- *DERCapabilityLink* – for reporting the nameplate settings of the End Device
- *DERSettingsLink* – for reporting the current settings of the End Device
- *DERStatusLink* – for reporting connection and operational mode status
- *DERAvailabilityLink* – for reporting charge storage (battery) status

The Utility Server enables/disables the PUT of status information by including or not including the appropriate status link. If the link is present, the End Device shall PUT the status data to it whenever the status changes. If the link is not present, the End Device shall not PUT the data to the Utility Server.

An example of the PUT of status information is shown in the figure below.

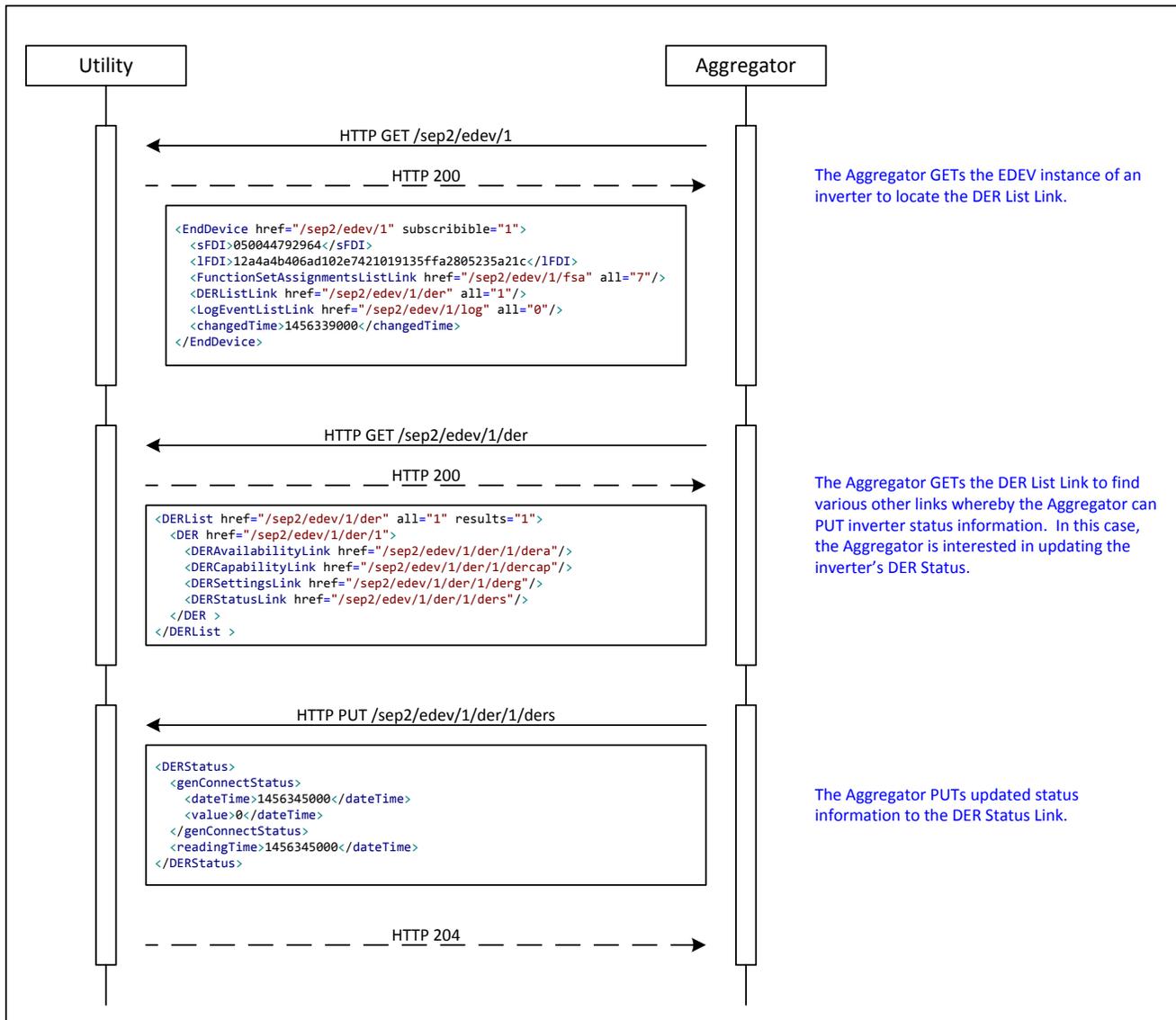


Figure 21. Updating DER Status.

### 5.7.3 Alarms

Alarms are unexpected error conditions that are reported to the Utility Server. This alarm function maps to the IEEE 2030.5 Log Event function set. End Devices can report alarms via their EndDevice instance. For each EndDevice instance, the Utility Server can include a `LogEventListLink` where the End Device can POST its alarm codes.

*LogEvents* contain the following information:

- *createdDateTime* – the time of the alarm
- *profileID* – Uint8 to identify the profile of this alarm (e.g. Smart Energy, Home Automation, etc)
- *logEventPEN* – Uint32 containing the Private Enterprise Number
- *logEventID* – Uint16 profile specific value
- *logEventCode* – Uint8 profile specific value
- *extendedData* – Uint32 profile specific value
- *functionSet* – Uint8 to identify function set if profile is Smart Energy

An example of the POSTing of alarms is shown in the figure below.

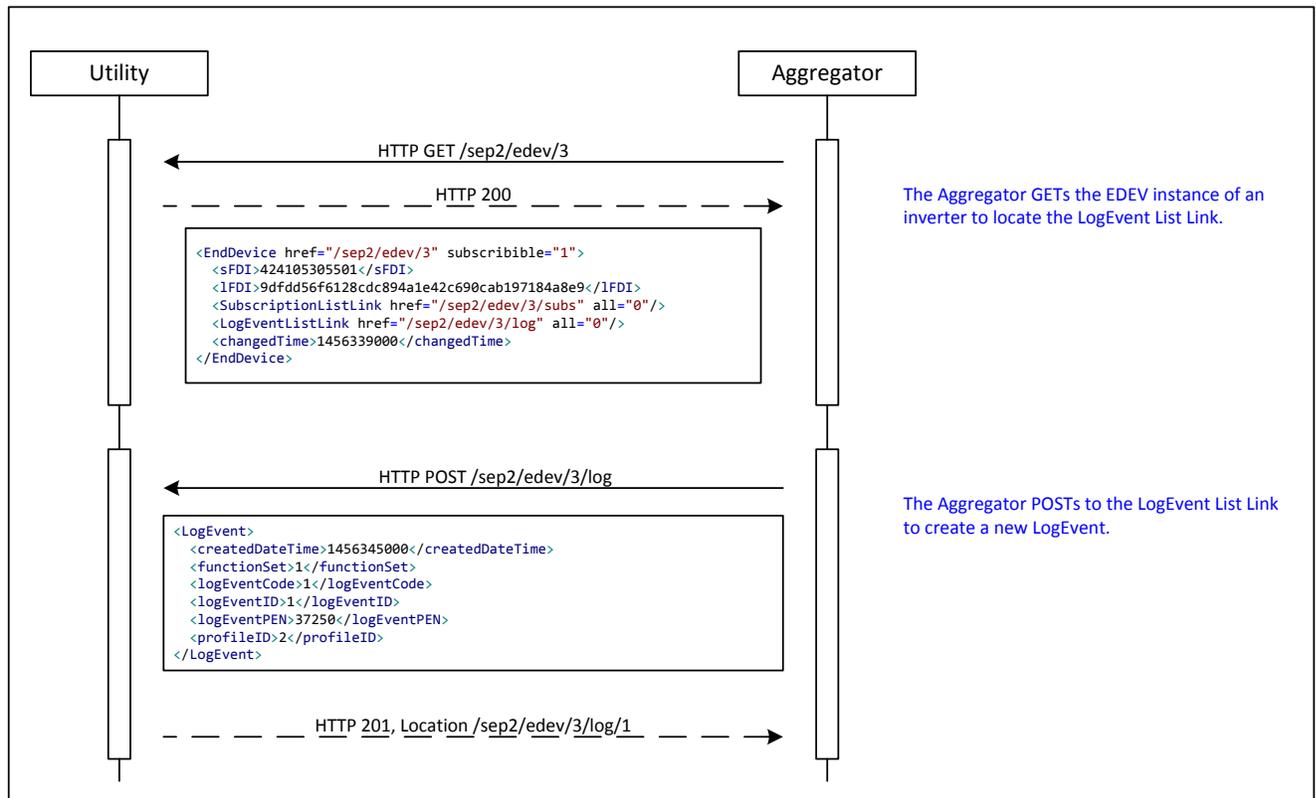


Figure 22. Creating an Alarm (Log Event).

## 5.8 Error Handling

All basic error handling in CSIP is addressed using standard methods of response handling as described in the IEEE 2030.5 protocol definition. More complex error recovery scenarios (e.g., recovery from inconsistent client state) are the responsibility of server and client implementations to develop compensating strategies. For example, a client might re-poll the server to rebuild its inverter hierarchy after communications failure.

## 5.9 Maintenance of the Model

It is assumed that the model of smart inverters will require maintenance over time. For example, the managed population of smart inverters will most certainly grow as customers decide to install or

upgrade DER systems. Likewise, utilities are likely to evolve their distribution systems requiring the changing of inverter grouping and management strategies.

This section describes how the model is updated and maintained over time via subscriptions to reflect changes. The following items are included:

- Inverters
- Groups
- Controls
- Programs
- Subscriptions

### 5.9.1 Maintenance of Inverters (*EndDevice*, *EndDeviceList*)

As part of the initial set up of the Utility Server, CSIP assumes the Aggregator has provided a list of inverters to the utility. The utility uses this list to construct and populate the initial *EndDevice* list for that Aggregator. Over time, this list will change as new inverters are added to the list and others are removed from the list. What are the mechanisms for maintaining this list over time?

#### 5.9.1.1 Out-Of-Band Updates

The utility adds/removes *EndDevice* instances from the *EndDeviceList* using an out-of-band mechanism. If the Aggregator wants to add/remove an inverter from service, it communicates the request to the utility by some out-of-band mechanism (e.g. phone call, email, FTP, etc.). If the utility agrees to this request, the Utility Server adds/removes the corresponding *EndDevice* instance from the *EndDeviceList*. The Aggregator should subscribe to the *EndDeviceList* to receive notifications for any additions or changes to the list. The Aggregator should subscribe to each *EndDevice* instance under its control to receive notifications for any deletions of that instance.

#### 5.9.1.2 In-Band Updates

The utility allows the Aggregator to directly add/remove *EndDevice* instances from the *EndDeviceList*. If the Aggregator wants to add a new inverter, it POSTs this proposed new instance to the *EndDeviceList*. If the Utility Server accepts and approves this addition, it returns a HTTP 201 – Created response along with the location of the newly created instance. Otherwise, the Utility Server returns an HTTP 4XX error response. If the Aggregator wants to delete an inverter, it tries to DELETE the corresponding *EndDevice* instance. If the Utility Server accepts and approves this deletion, it returns a HTTP 200 – OK response. Otherwise, the Utility Server returns an HTTP 4XX error response.

### 5.9.2 Maintenance of Groups (*Function Set Assignments*)

The utility may from time to time make changes to the system topology. This topology change typically results in a change in one or more inverter's group assignments. The group assignments for each inverter is located at the resource pointed to by the *FunctionSetAssignmentsListLink* within the *EndDevice* instance for that inverter. For every inverter under its control, the Aggregator should subscribe to the list pointed to by *EndDevice: FunctionSetAssignmentsListLink* to receive notifications for any changes in the inverter's group assignments.

### 5.9.3 Maintenance of Controls (DERControl, DERControlList)

The *DERControlList* hosts the scheduled and active *DERControl* events for the parent *DERProgram*. Since an inverter typically belongs to many groups, and each group may have one or more *DERPrograms*, an inverter or its controlling Aggregator needs to track many *DERControlLists*. For every inverter under its control, the Aggregator should subscribe to all of the *DERControlLists* associated with its FSA groups and *DERProgram* assignments to receive notifications for any new or changed *DERControl* events.

### 5.9.4 Maintenance of Programs (DERProgram, DERProgramList)

The *DERProgram* is a container for the *DERControlList*. It also contains some meta-data associated with the program. One important piece of meta-data is the *primacy* object, which determines the relative priority of the *DERControls* under this program. From time to time, the utility may want to adjust the priority levels of *DERControls* by changing the *primacy* value. For every inverter under its control, the Aggregator should subscribe to all of the *DERPrograms* associated with its FSA groups to receive notifications for changes to the *DERProgram* meta-data. For every inverter under its control, the Aggregator should subscribe to all of the *DERProgramLists* associated with its FSA groups to receive notifications for additions, deletions, or changes to the list.

### 5.9.5 Maintenance of Subscriptions

Maintenance of various aspects of the CSIP model depends heavily on the proper operation of the Subscription/Notification function set. Maintenance of subscriptions is described in section 10.6.3.4 for the IEEE 2030.5 Specification. In particular:

- The Aggregator Client should renew its subscriptions periodically (e.g. every 24 hours) with the Utility Server.
- The Aggregator Client should fall back to polling on perceived communications errors.

## 5.10 Utility Server Operation – Plant / Commercial Site Model

The CSIP Plant / Commercial Model is identical to the aggregator model except that it shall only receive function set assignments for a single energy connection point reflecting the aggregate capabilities of the plant at its point of common coupling with the utility.

## 5.11 Utility Server Operation – Direct Residential / Small Commercial Model

The CSIP Plant / Commercial Model is identical to the aggregator model except that it (1) shall only receive function set assignments for a single inverter, or inverter collection, at its point of common coupling with the utility and (2) shall poll for its updates on a schedule as specified by the utility agreement with the customer. Due to the fact that some inverter communication modules are unpowered during periods of non-production, polling times may be non-uniform to maximize the opportunity for successful communications link between the inverter and the utility

## 6 Evolution of the CSIP Model

The CSIP standard is predicated on a fully, standards-compliant utilization of the underlying IEEE 2030.5 standard. Any update to this standard which requires components and features not present with IEEE

2030.5 will be coordinated with the revision to the base standard itself. Changes to CSIP not requiring model updates will be handled on a periodic basis as changes to Rule 21 are adopted.

*Appendix A – Table of Acronyms.*

ACL – access control list

AES – advanced encryption standard

CA – certificate authority

CSIP – Common Smart Inverter Profile

DER – distributed energy resource

DNS – domain name service

ECDHE – elliptic curve Diffie-Helman

ECDSA – elliptic curve digital signature algorithm

EMS – energy management system

FSA – function set assignment

GUID – global unique identifier

HTTP – Hypertext Transfer Protocol

ID – identity

IEC - International Electrotechnical Commission

IEEE – Institute of Electrical and Electronics Engineers

IOU – investor owned utility

IP – internet protocol

LAN – local area network

LFDI – long form device identifier

PCC – point of common coupling

REST - representational state transfer

SIWG – Smart Inverter Working Group

SFDI – short form device identifier

TLS – transport layer security

UTC – coordinated universal time

VAr – volt-ampere reactive

WADL – web application description language

XML - extensible markup language