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Energy Services Interface

Architecture, Requirements, and Agreements

November 2024

Donald J. Hammerstrom
David J. Sebastian Cardenas
Jaime Kolln

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Abstract

This report continues and extends the development of the Energy Services Interface (ESI) that recently has been led by the U.S. Department of Energy's Grid Modernization Laboratory Consortium. The ESI is intended to facilitate the coordination of multiple, flexible energy resources that work in tandem to satisfy grid objectives by using performance attributes encoded within an *ESI Service Template*. The ESI relies on a pair of interfaces, representing the service requestor (the consumer of a service) and a service provider (who manages its resources per the agreed performance attributes) to achieve what is commonly known as a "grid service". Due to its performance-driven approach, the ESI is hypothesized to be able to satisfy all common grid needs via only six common ESI service types.

This report first reviews the status of ESI development, including its fundamental tenets. The report makes three important contributions to ESI development: First, it recognizes the similarity between service level agreements and the contract-like agreements that would be needed between energy service requestors and providers and recommends that ESI service agreements be modeled after the web services agreement specification. Second, whereas prior development efforts had focused on a flat, five-stage lifecycle, this report asserts that the ESI should have three behavioral layers in its architecture—the discovery, agreement, and service layers. Finally, this report offers concrete requirements that should be useful toward the development of the service requestors' and service providers' respective communications interfaces.

Acronyms and Abbreviations

ACE	area control error
DER	distributed energy resource
ESI	*Energy Services Interface*
GMLC	U.S. Department of Energy's Grid Modernization Laboratory Consortium
GWAC	Gridwise Architecture Council
JSON	JavaScript Object Notation
SEPA	Smart Electric Power Alliance
WS	web service
WS-Agreement	Open Grid Forum's *Web Service Agreement* specification

Acknowledgements

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The authors would also like to thank Karyn Boenker for her invaluable insights and feedback received through the early scoping and the subsequent architectural development process. Her views have greatly improved upon the applicability of the ESI and target use cases.

Contents

Figures

1.0 Introduction

This report advances the development of the *Energy Services Interface* (*ESI*), which is defined as

> "a bi-directional, service-oriented, logical interface that supports the secure communication of information between entities inside and outside of a customer boundary to facilitate various energy interactions between electrical loads, storage, and generation within customer facilities and external entities." (Widergren, et al., 2018)

The *ESI* could potentially tap energy flexibility from vast numbers of controllable distributed energy resources (DER) like battery systems, electric vehicles, thermal energy storage, curtailable processes, and smart appliances that are being connected to our electric power grids today. The *ESI* is first installed as a communications interface module between many and various business entities, thus pairing those who need *energy services* and those who could help provide those *services* (Figure 1). The business entities might range from individual premises to large market operators and electricity wholesalers. Once instantiated, each *ESI* facilitates agreements that commit the paired entities to take actions that fulfil the needed *energy services*. Because an entity may act as a *service requestor* with one entity and as a *service provider* for another, a distributed network of *ESIs* is eventually constructed, facilitating the communication of signals throughout the grid (Figure 2). Access to flexible energy resources is naturally aggregated in this network by *ESI service providers* according to each resource's capabilities and capacities; unmet need for *energy services* is refined and communicated from each *ESI service requestor* in the network to targeted *ESI service providers* who might help mitigate that need.

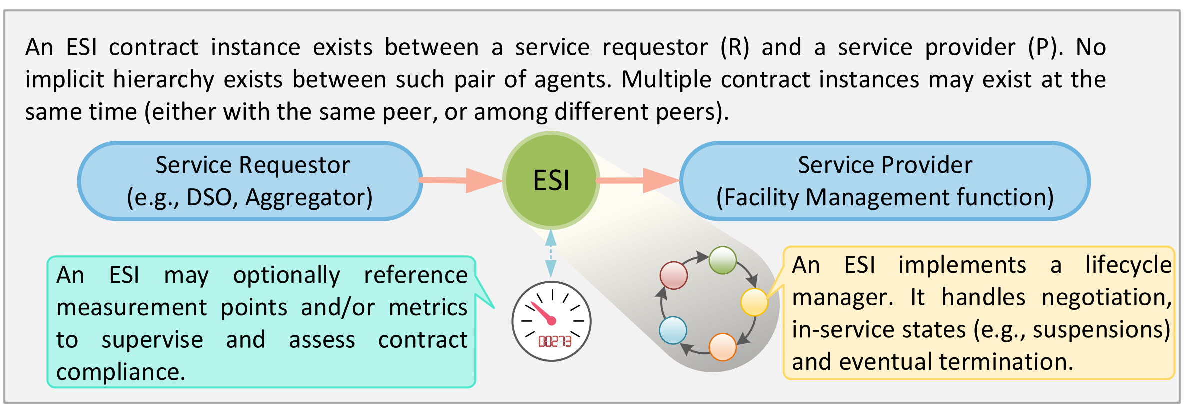


Figure 1. A high-level overview of the *ESI* concept

One of the earliest references to an *ESI* was made by Dave Hardin at the *2011 Grid-Interop Forum* on behalf of several Smart Grid Interoperability Panel Working Groups (Smart Grid Interoperability Panel B2G/I2G/H2G Domain Expert Working Groups, 2011). Remarkably, that white paper and presentation captures many tenets and opportunities of an *ESI* that remain relevant today. The U.S. Department of Energy's Grid Modernization Laboratory Consortium (GMLC) accepted leadership for *ESI* development, and a 2018 GMLC slide presentation (Piette, Schwartz, Brown, Page, & Ehlich, May 14, 2018, p. 19) lists the *ESI's* anticipated benefits (paraphrased here) as follows:

- Creates a service-oriented architecture

- Improves interoperability
- Facilitates evolution of end-use controls
- Improves performance and utilization of responsive loads
- Protects owners' assets and the demands placed on these assets
- Results in an open specification or standard
- Fosters open market competition for resources
- Facilitates procurement of responses from distributed energy resources (DER) by those who need the *service*
- Reduces overall system implementation costs.

An end-to-end vision of the *ESI* model, demonstrating how the *ESI* can be used to manage layered coordination schemes, while also adding support for non-standard participation models. In this distributed control network, *service customers'* operational needs are achieved by relying on performance attributes to describe, execute, and assess the underlying *service* interactions.

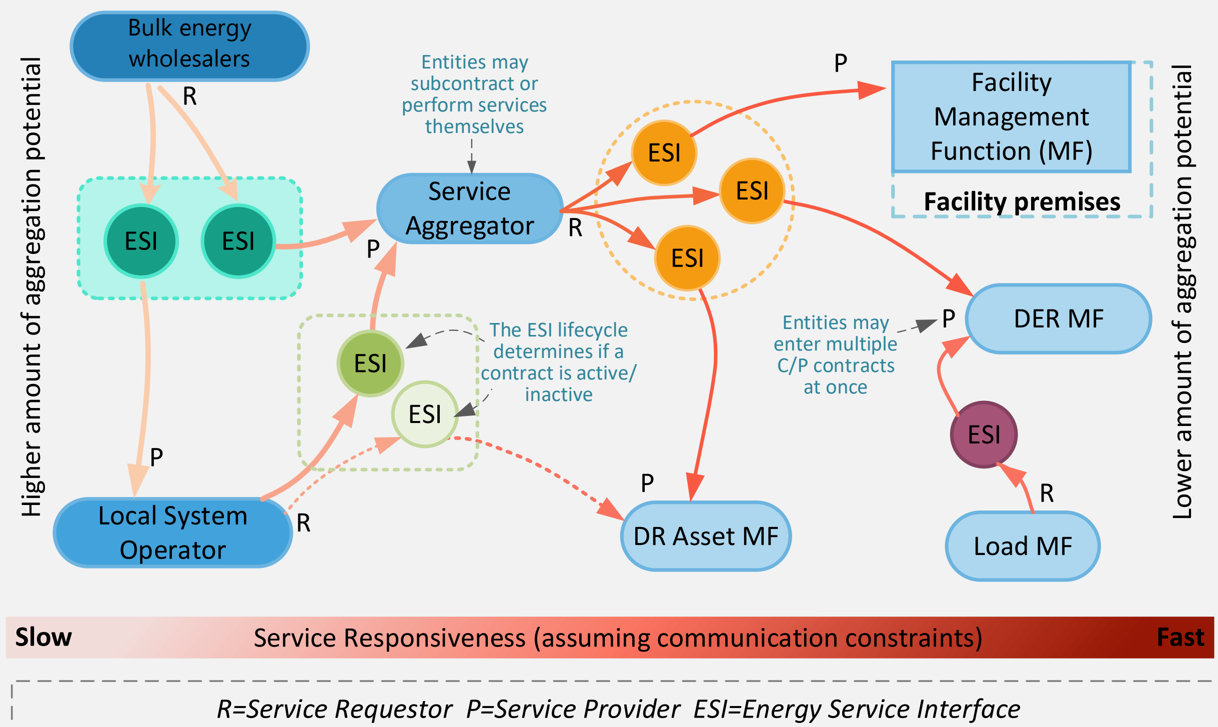


Figure 2. The *ESI* model end-to-end vision

This report builds upon those early documents as well as more recent *GMLC* development efforts. The *ESI* definition is being extended to include not only electricity consumers, but also those who might offer and export excess capacity from their own electricity generation resources. Furthermore, the *ESI* is being generalized to support a wide variety of *energy services* rather than just energy or capacity exchanges.

The GMLC report *State of Common Grid Services Definitions* (Liu, et al., December 2022) makes clear the distinction between the "operational objectives" of electric power grid operators and “grid services” that can, in fact, be instantiated at an *ESI*[*]. Because too many readers may equate “grid services” and the grid’s “operational objectives,” this report will use the word “grid” only when it refers to grid operators’ perspectives, including their operational objectives. The diverse services that can, in fact, be provided at an *ESI* are simply referred to as *ESI services*.

The actions available to be taken by an *ESI service provider* are seldom recognizable as a grid objective. In fact, an *ESI service provider* may have few control options available, for example, turn its flexible energy resources on, off, up, or down. None of these control options are directly implied by grid objectives like “capacity management,” and no benefit is achieved by informing a *service provider* precisely which grid objective it is being asked to help mitigate. Lacking a way to otherwise engage prospective *service providers*, grid operators may assume that their only viable option is to directly control end-use assets toward their operational objectives, which is contrary to emerging *ESI* tenets.

The GMLC *ESI* development is to communicate a service-oriented approach that counter some competing grid-centric efforts that actively leverage or engage in direct control mechanisms to satisfy grid services. A common shortcoming of those grid-centric standardization efforts is their adoption of grid objectives—all the things that must be done to keep an electricity grid operating—as their basic foundation. Interestingly, this report’s sponsor, the U.S. Department of Energy Office of Electricity, concurrently invested in another report *Standard Distribution Services Contract* within this research space (Patel & De Martini, 2023). Like this report, (Patel & De Martini, 2023) seeks to develop a “distribution services contract framework,” but the perspective is based on a traditional grid-centric approach. Their implementation extends upon *conventional grid services*, and applies it to distribution service aggregators, essentially encouraging direct control over DER assets. Additionally, that report does not recognize the similarity between *ESI service agreements* and service level agreements (and in specific the WS-Agreement standard), an important contribution of this report.

Another GMLC report (Liu, et al., December 2022) introduces six services that can be provided at an *ESI. These services have now been standardized under the NASBI* WEQ-025 document (North American Energy Standards Board, Inc, 2023) (see sidebar “*Six Common ESI Services*”). The authors have derived this short list of *services* by mapping defined grid services to the limited types of interactions that must occur at an *ESI* to help supply those grid services. The authors acknowledge that the list may change as the grid evolves, but it should apply to most, if not all services provided today. This report proceeds under such this assumption.

Six Common ESI Services

Energy—Energy price schedules, market prices, demand profile subscription, and schedulable demand response events
Reserve—Reserve of resources that may or may not be called upon at a future time
Regulation—Responses to rapidly changing, unscheduled signals (e.g., area control error (ACE))
Blackstart—*Services* like black start recovery during electricity outages
Voltage Management—Autonomous management of voltage or reactive power
Frequency Response—Autonomous responses to an observable ac voltage frequency signal.

The GMLC’s *Common Grid Services: Terms and Definitions Report* (Kolln, Widergren, Liu, & Brown, 2023) reviews existing grid services to better standardize the terms and definitions to be

[*] “The ESI is a service-oriented interface used to communicate what is needed when, not how to deliver it” (Brown, et al., January 2024)

used by an *ESI*. The report reinforces the use of the *six common ESI services*, suggesting important electrical and timing attributes that will be needed to specify the performance and measurement of each *service*. It also includes an important discussion about the characteristics of these *services*, which can be consolidated into the six common service based on the physical attributes required to satisfy the operational objectives and as can be provided by qualities of various types of responsive assets.

The GMLC report *Energy Services Interface: Requirements Document* (Brown, et al., September 2023) introduces high level requirements for information and communications interfaces and standards that are needed to support emerging *ESI* tenets that it lists (see sidebar "*ESI* Tenets that Guide its Development"). Central to that report's discussion is its introduction of a "facilities management function," the interface that coordinates the control of an *ESI service provider's* flexible energy resources (e.g., DER equipment). However, the report misses the fact that a function also exists at the *ESI service requestor's* terminus where its operational objectives must be translated into conformant *ESI service* messages. For example, an allocation of an *ESI service requestor's* needed capacity cost recovery might be translated into a series of *scheduled* capacity price signals that can be conveyed to the *ESI service provider*. While not actually specifying requirements, the report provides examples how requirements might be derived from the criteria of the *Interoperability Maturity Model* (Knight, et al., January 2020) within each of the lifecycle stages of an *ESI service*. Importantly, the report demonstrates via activity diagrams how provision of an *ESI service* might be qualified or verified using simple Boolean decision logic.

The GMLC report *Guide to Developing Energy Service Interfaces* (Brown, et al., January 2024) reinforces many emerging tenets of the *ESI* and discusses properties that the *ESI* must possess if it is to be interoperable (again, see sidebar "*ESI* Tenets that Guide its Development"). The *ESI* is discussed further in the context of *Interoperability Maturity Model* criteria (Knight, et al., January 2020), and the report recommends a detailed review process that should be followed during the *ESI's* further development. The report also includes some example interactions between the *ESI service requestor* and provider, suggesting the use of a management function to abstract the underlying flexible resource(s). This report's *six common ESI services* are referred to as "grid-DER services" in that report.

From a legal perspective, an *ESI service agreement* should serve as a contract between its parties—the participants in an ESI service agreement. A contract provides both parties with mutual assurances by clearly defining the terms and guarantees under which a *service* shall be provided, measured, and compensated. By providing sufficient legal and technical guardrails, a contract can encourage *participants* to confidently participate in *service* exchanges. While an *ESI service agreement* is in effect, its *participants* must abide by the agreed terms and performance expectations and are subject to any agreed penalties if discrepancies or variations arise. These terms and guarantees should be defined within an *ESI agreement* itself (i.e., making it self-sufficient), although common terms and guarantees should be made referenceable to avoid duplications and coding errors.

The goals of this report are to

- Further define a human-readable, machine-interoperable agreement framework that enables *ESI service requestors* and *ESI service providers* to agree upon the performance requirements of the six common *services, as* defined in (Brown, et al., January 2024). Although the nature of the contract should be text-based (to enable human readability), machines must interpret, evaluate, and act upon the variables being defined in an interoperable manner.

- Provide the *ESI service requestor* and *provider* with the necessary mechanisms to define and assert compliance with a standard *energy service agreement*. The framework must provide clear definitions and uniform processes that allow *ESI service participants* to understand and follow terms and conditions using machine-decipherable processes.
- Recommend specific *ESI* technical requirements building on the ESI requirements and guides from prior GMLC work and capture the rationale and design decisions behind the different artifacts that are part of an *ESI service agreement template*.
- Build upon prior *ESI* development efforts carried out by organizations such as SEPA, GMLC, OASIS, and GWAC to ensure their endorsement as the *ESI* evolves.

Some Important ESI Tenets that should Guide its Development*

- The ESI is a service-oriented interface. In a service-oriented architecture, the *service provider* provides a *service* that the *service requestor* consumes.
- The ESI should facilitate six common *ESI services* based on actions that can be taken at an ESI (see sidebar above). *ESI services* are different from grid operators' grid services. The ESI must define data objects and messages that are sufficient to implement the *six common ESI services*.
- The ESI is device agnostic. *ESI services* should never target specific devices or flexible resource types. The ESI is applicable to all types of flexible energy resources that can pass the *service* qualifications (e.g., all DER).
- An *ESI service provider* must aggregate and coordinate the capabilities and capacities of all devices and systems that are under its control, even if the *ESI service provider* owns and controls just one device or outsources to other *service providers* (i.e., acting as a sort of *service* aggregator).
- An ESI facilitates agreements between precisely two parties—an *ESI service requestor* and an *ESI service provider*. This tenet is necessary because of the contractual nature of *ESI service agreements*, which can impose terms and guarantees on these two parties.
- The provision of an *ESI service* is codified at the ESI by a contract-like agreement between the *service's requestor* and *provider*. (Brown, et al., January 2024) refers to these as "grid-DER service agreements." This report refers to them as *ESI service agreements.* The ESI must help manage the lifecycles of these contract-like agreements. An ESI agreement must define the parties' respective responsibilities and consequences for their performance during the provision of *services* at the ESI.
- An *ESI service agreement* defines the performance terms and guarantees of an *ESI service*, but it must never reveal just how those terms and guarantees are calculated, valued, or procured. Neither the *ESI service requestors'* objectives nor the *ESI service providers'* means of providing the *services* are shared across an *ESI*. The *ESI* maintains privacy.
- The ESI intrinsically supports hierarchical and distributed control. The ESI is implemented as a module. An *ESI service provider* may act as an *ESI service requestor* at another ESI and may aggregate responses from that other *ESI service provider's* flexible resources along with its own.

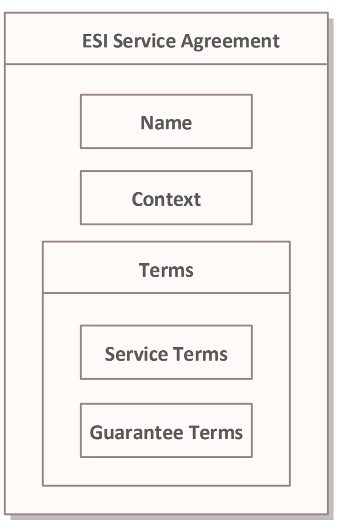
*Many of these tenets were listed in (Brown, et al., September 2023, p. 2) or (Brown, et al., September 2023, p. 4).

2.0 The Structure of an *ESI Service Agreement*

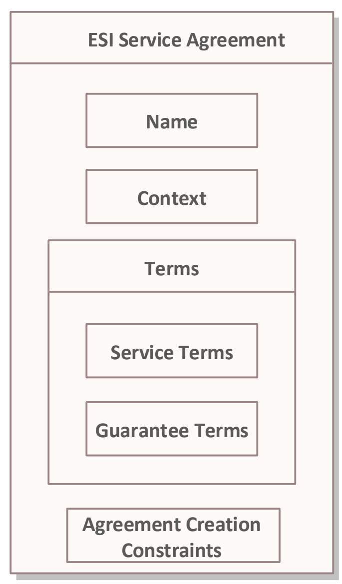
The Open Grid Forum's *Web Services Agreement Specification (WS-Agreement)* (Andrieux, et al., 2006) was developed to standardize and enable automation in web service agreements, a subset of service level agreements. Despite its seemingly, unrelated nature, the specification addresses many of the needs of a *digital service contract,* such as being able to define service specifications (i.e., requirements), and the mechanisms that will be used to make sure that participants adhere to them. Based on this observation, this report proposes that WS-Agreement should serve as the basis for *ESI service agreements*. Hence, an *ESI service agreement* is proposed herein to be an *ESI*-domain-specific profile of *WS-Agreement*.

By adopting *WS-Agreement* as the basis for *ESI service agreements*, *ESI* implementers inherit a wealth of terminology and structure, including its schemas. This section reviews the *WS-Agreement* specification and suggests how it may be used for *ESI service agreements*.

Figure 3 shows *ESI service agreement* and *ESI service agreement template* structures that are adopted directly from the *WS-Agreement* specification. *WS-Agreement* refers to these structures as "documents," and, in fact, these structures could be like contractual documents if developed using human-readable protocols like JSON. Like *WS-Agreement*, this report refers to agreement offers as *agreement templates*. An agreement structure and an agreement template structure are very similar, but the agreement template includes "agreement creation constraints," which might include preconditions and prequalification requirements that must be met before an agreement can take place.



(a)



(b)

Figure 3. The (a) *ESI service agreement* structure (Andrieux, et al., 2006, p. 14) and (b) *ESI service agreement template* structure (Andrieux, et al., 2006, p. 29).

The next bullets describe the components of the *ESI service agreement* and *ESI service agreement template*:

- _Name_. An optional name may be applied to an agreement. An agreement's name does not have to be the same as that of the *agreement template* from which it is derived (Andrieux, et al., 2006, p. 15).

- _Context_. *WS-Agreement* recommends certain contextual information, including the identities of the agreement initiator, agreement responder, and *service provider*, name and identity of the *template* from which the agreement derives, and the time when the agreement will expire. It furthermore allows for the definition of any other contextual information that may be needed by a particular domain (Andrieux, et al., 2006, pp. 15 - 16).

  An *ESI service agreement* profile of *WS-Agreement* should contain contextual information (e.g., service metadata) to facilitate subsequent execution management. For example, the location where an *ESI service* is to be injected into an electrical circuit should be part of the ESI service agreement context to facilitate service mapping (either logically or physically). However, the identities of agreement initiator and responder may not be important if this report's simplified discovery layer recommendation is adopted. If the ESI is defined between just two entities, the identities and contact information for the *ESI service provider* and *ESI service requestor* remain static and might be automatically filled in or simply referenced during agreement creation.

  WS-Agreement's capability to define any new context element should be retained to facilitate future extensions of the *ESI* profile.

- _Service Terms_. In *WS-Agreement*, a new service component may be defined using one or more inline functions called "service description terms." Additionally, references may be made to existing services and service properties and guarantees of the service being defined. Complex service terms may be composed using logical AND, OR, or XOR operators (e.g., to build nested expressions) that represent service terms.

  WS-Agreement allows for any domain-specific definition of service description terms, even allowing references to practices that lie outside the domain of *WS-Agreement*. This feature may help address future extensibility and upgradability needs, but it may also introduce a potential source of misunderstanding when the parties' knowledge of an offline domain-specific practice is not common. To avoid this issue, an *ESI* service agreement profile should include a library of common *service terms* whose definitions can be determined by all system participants (e.g., by making references to industry standards). These terms could be carefully defined once and used multiple times thereafter.

- _Guarantee Terms_. *Guarantee terms* provide a mechanism to specify the level of service or quality of service that must accompany a given *ESI service*. It is a notable strength of *WS-Agreement* that it addresses both service terms and guarantees of service quality. *Guarantee terms* may apply to either the *ESI service provider* or *ESI service requestor*.

  G*uarantee terms* may define variables and variable sets, which should be used in conjunction with *agreement creation constraints* during the agreement creation process to describe the reliability or performance guarantees of the service. A *guarantee term* may also specify rewards and penalties for meeting specified levels of service and not.

- *Agreement Creation Constraints*. This element may exist in *ESI service agreement templates* and address an *ESI service agreement's* preconditions or prerequisites. *Agreement creation constraints* could assert an *ESI service provider's* minimum *qualifications* to provide an *ESI service*, for example.

3.0 *ESI* Architectural Layers

The *ESI* behavioral model has three architectural layers—the *discovery*, *agreement*, and *service layers* (Figure 4). The *discovery layer* addresses how an *ESI service requestor* and *ESI service provider* find one another. The *agreement layer* addresses how an *ESI service requestor* and *ESI service provider*, once connected, agree or contract with one another concerning the provision of an *energy service*. The *service layer* addresses how a *service* is provided at an *ESI* according to an active *ESI service agreement*. The three architectural layers will be discussed in greater detail later in this section.

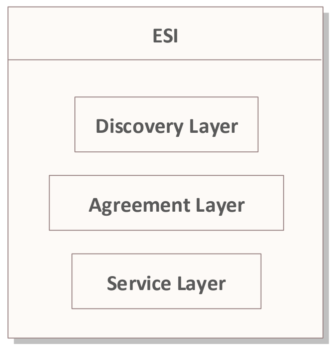


Figure 4. The three architectural layers of the *ESI* behavioral model

In addition to the aforementioned behavioral model, this report builds upon the work carried out during the DOE GMLC (Grid Modernization Laboratory Consortium) "*Standards & Test Procedures for Interconnection & Interoperability"* efforts. Most notably it re-defines the five-stage, *ESI* lifecycle model that was introduced in Section 4 of (Brown, et al., January 2024). Specifically, this report re-casts the five stages into the agreement and service layers to better align each individual stage with the underlying contracting process by differentiating the contract "negotiation" from the contract's "in force" mode (See Figure 5).

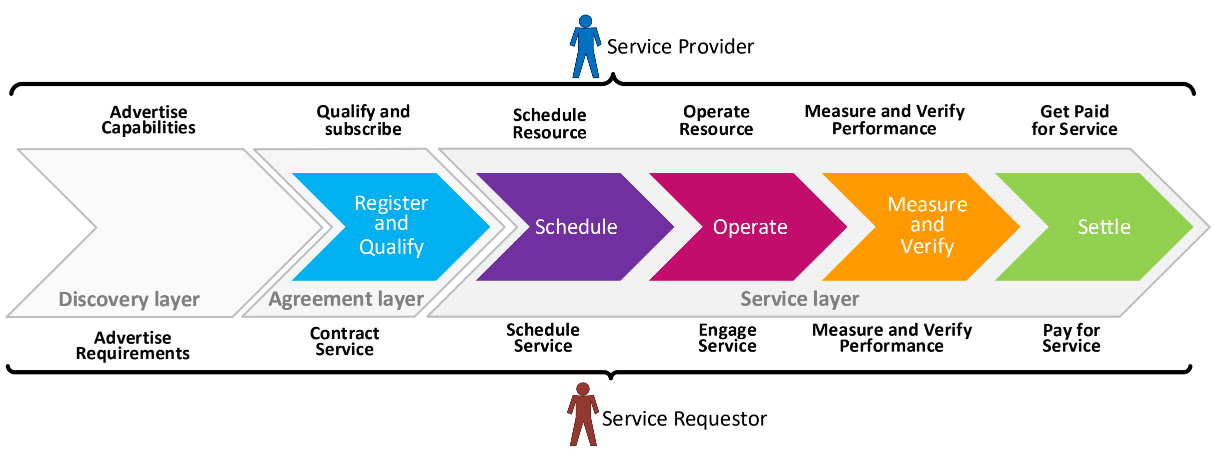


Figure 5. The ESI lifecycle stages and their mapping to the ESI architectural layers, adapted from (Brown, et al., January 2024)

In the context of the *ESI's* three architectural layers, register & qualify are actions that take place within the *ESI agreement layer* as *ESI service participants* formulate and enter into an agreement or contract. The remaining four stages are operational states of *service event* objects within the *ESI service layer* (Refer to Figure 6). The *schedule* or *operate* activities result in *service event* states, and transitions between these states must be specified by an *ESI service agreement's service* terms. The *measure & verify* and *settlement* activities result in still other *service* states. These activities determine whether the provided *service* met the specified quality of service and specify the corresponding compensations or penalties for *ESI service participants'* performances.

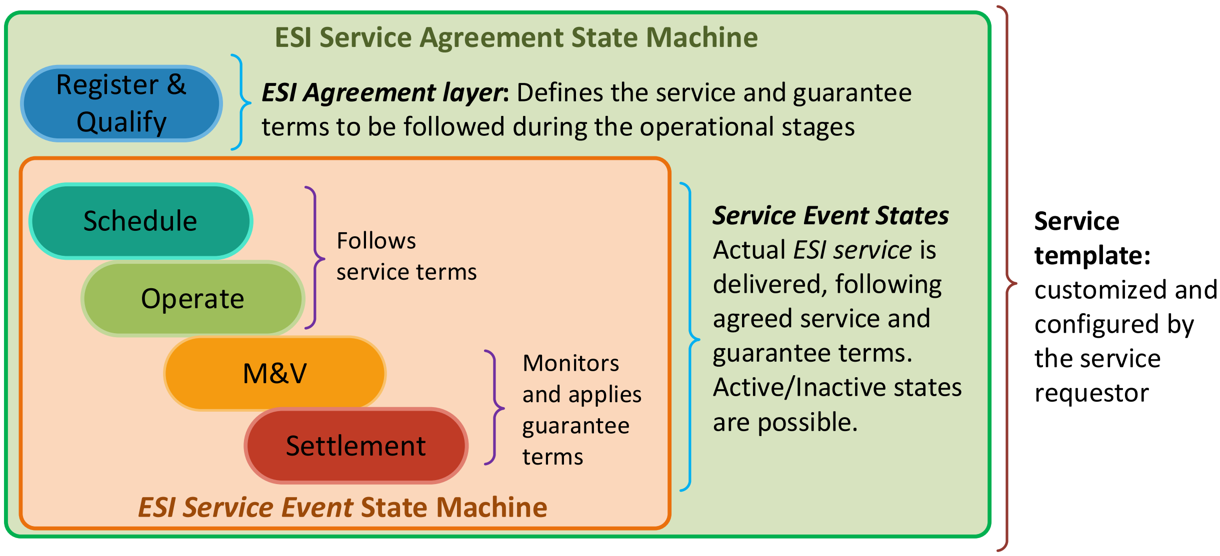


Figure 6. High-level overview of the *ESI service* and *agreement* layers

3.1 The *ESI Discovery Layer*

The *ESI's discovery layer* addresses the process by which *ESI service requestors* and *ESI service providers* find potential matches by announcing or querying ESI services that are either being requested or offered. These processes largely lie outside the scope of the *ESI* framework. An *ESI* must be established between an *ESI service requestor* and an *ESI service provider before any ESI service agreement (other than a rudimentary default one) can be entered*, thus greatly simplifying the *discovery layer* processes.

Nothing prevents future implementers from providing generalized web-service methods that enable participants to announce and find each other's needs or offerings within the *ESI discovery layer*, but discovery methods should not be tied to specific technology providers or functionalities, rather, it should rely on standardized and interoperable protocols to allow for future technology advancements. Additional constraints would be needed to determine the eligibilities of prospective parties to form a valid *ESI* as they discover one another.

1. (Not within the scope of an *ESI*) An *ESI service requestor* solicits or recruits an *ESI service provider*.

   Electricity suppliers already possess a relationship with their electricity customers to whom they supply electricity. Another entity (e.g., aggregator, wholesaler) could also recruit for *service providers* even though the two currently share no direct business relationship.

   Unlike web services, which are not bound by physical connectivity constraints, an *ESI service requestor* must pair with *ESI service providers* whose interests lie within the same electrical grid region. *ESI service providers* who lie outside this target area would be physically unable to address *ESI service requestor's* needs.

2. (Not within the scope of an *ESI*) An *ESI service provider* discovers an *ESI service requestor* needs by responding to its solicitations or recruitment efforts.

   The *ESI* should not limit how an *ESI service provider* might find its *ESI service requestors*, as this could hinder future technological or regulatory advancements. *Service providers* in the electricity domain typically must reside in targeted regions of an *ESI service requestor's* electric circuit.

3. (Not within the scope of an *ESI*) The *ESI service requestor* and *ESI service provider* establish an *ESI* (i.e., the communication interface that will support the contract mechanisms defined in this report).

   ESI functionality resides at the *ESI service provider's* circuit location where its *service*s are to be provided. However, an *ESI's* intelligence and computational capabilities can reside locally, remotely, or in the cloud.

   Tests should be developed and used to confirm that the *ESI* is functioning and conformant to specifications after it has been established (e.g., to enable interface validation and/or certification).

4. A default *ESI service agreement* is assigned between the *ESI service requestor* and *ESI service provider.*

   In the case that a new *ESI service requestor* and *ESI service provider* pair have no existing business relationship, the default *ESI service agreement* should be "None—No service." This practice allows an *ESI* to be established without necessarily creating new obligations for the *ESI service participants while allowing for future arrangements to be enabled as they become available.*

At this point, a business relationship has been established between the *ESI service requestor* and *ESI service provider,* and an *ESI* has been established between the two, meaning that the two may contract and communicate using all the features and capabilities offered by the *ESI*.

3.2 The *ESI* Agreement Layer

The ESI agreement layer facilitates the contracting process between the ESI service requestor and provider. The ESI should adopt and adapt the *WS-Agreement* state model concerning an agreement's lifetime as it offers a standardized and flexible approach to representing Service Level Agreements (Andrieux, et al., 2006). Refer to Figure 7 as the proposed *ESI service agreement* state model is described.

Basic ESI Service Agreement Templates

- *Energy Service Agreement Template*
- *Reserve Service Agreement Template*
- *Regulation Service Agreement Template*
- *Blackstart Service Agreement Template*
- *Voltage Management Service Agreement Template*
- *Frequency Response Service Agreement Template*

The process begins with one of six *basic ESI service agreement templates* (see sidebar "*Basic ESI Service Agreement Templates*"*).* These six *agreement templates* correspond precisely with the *ESI's* six common services that were listed in this report's introduction. An *ESI service requestor* may choose one of the *basic ESI service agreement templates* and specialize it according to its own objectives and needs (a graphical overview of this process can be observed in Figure 8). In this context, "specialize" refers to the population of certain variables within the *service* and guarantee terms of the chosen *basic ESI service agreement template*. This step repeats until the *ESI service requestor* has developed templates for all the types of *ESI service agreements* that it will choose to offer. The state transition model of Figure 7 illustrates the case when only one specialized *ESI service agreement template* object and one *ESI service agreement* object are present.

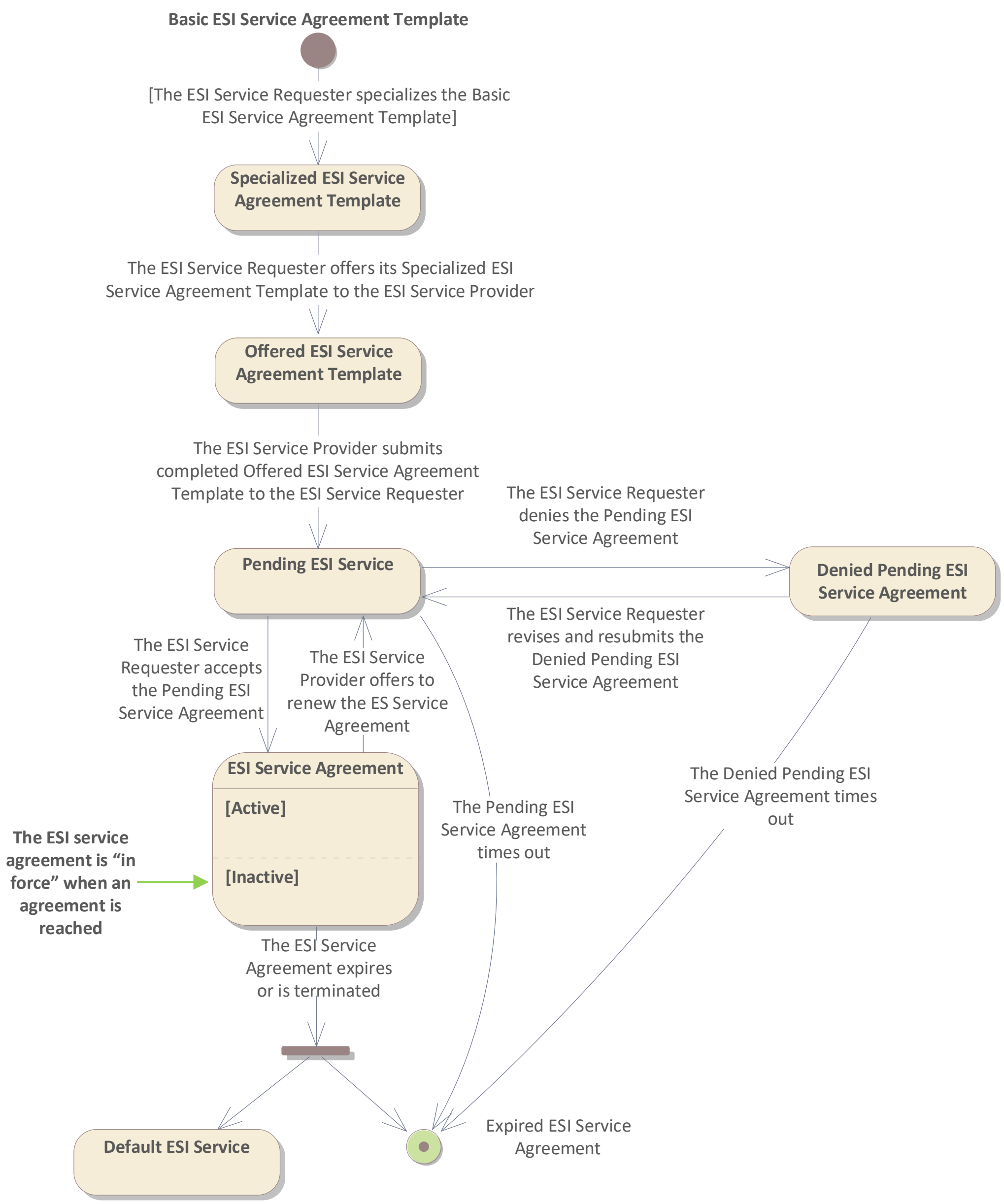


Figure 7. *ESI service agreement* state model

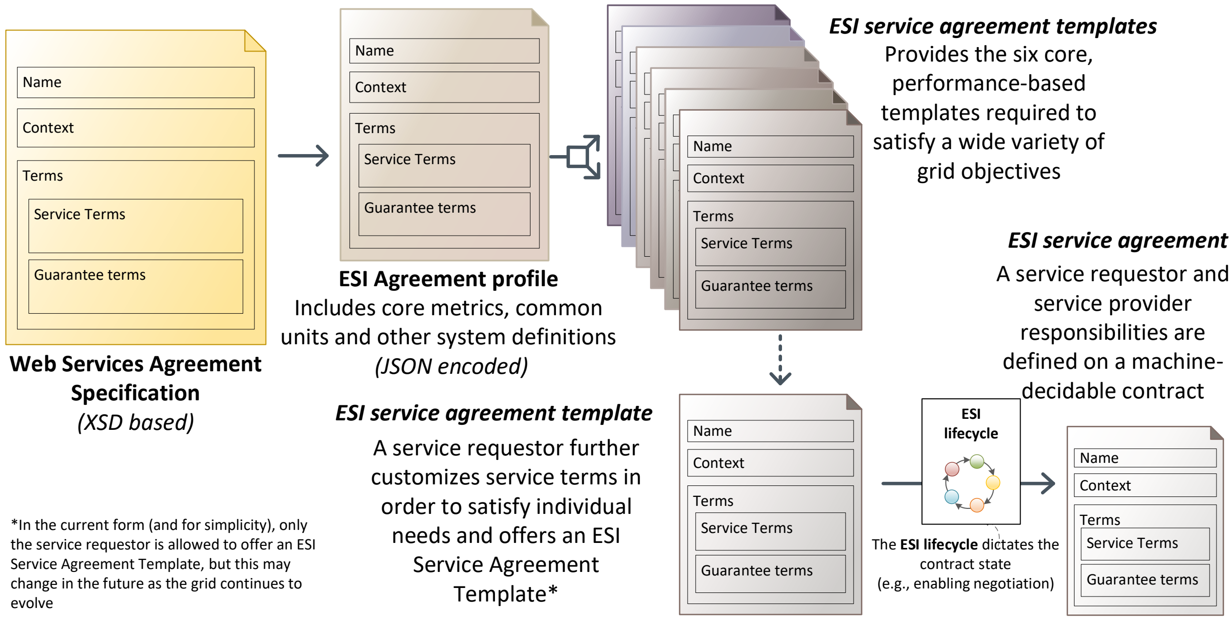


Figure 8. *ESI service agreements* derive from *WS-Agreement* documents.

When the *ESI service requestor* is satisfied with a *specialized ESI service agreement template*, the *ESI service requestor* may make it available to the *ESI service provider* via the *ESI Service Agreement Interface* as an *offered ESI service agreement template (*and in turn initializing the ESI lifecycle itself, by defining the basic *service qualifications)*.

Once the ESI service agreement template is made available, a variety of scenarios may arise (in alignment with the ESI service agreement state model*), which may include:*

- The *ESI service provider* may choose to import an *offered ESI service agreement template*, assess whether it, as a potential *service provider*, meets the specified basic *service qualifications* found among the *template's agreement creation constraints*, fill in the template's remaining variables, and submit the completed *template* back to the *ESI service requestor* as a *pending ESI service agreement*. Ideally, an automated process can match *ESI service provider* capabilities with the required guarantees found in the *template* by using simple Boolean decision logic (An example of such evaluation is presented in Appendix D:"). Once all variables are defined, an ESI service agreement template becomes an ESI service agreement.

- A *pending ESI service agreement may* become *"in force"* if the *ESI service requestor* accepts it. At this point, the parties become obligated to the terms and guarantees found within the *ESI service agreement*.

- Alternatively, the *ESI service requestor* may actively deny the *pending ESI service agreement.* The *ESI service provider* may choose to revise and resubmit the *denied pending ESI service agreement* again. However, if the *ESI service provider* fails to do so within a specified time, the *denied pending ESI service agreement* should set to automatically expire, thereby helping to streamline workflows and facilitate automation.

- Similarly, if the *ESI service requestor* takes no action concerning a *pending ESI service agreement* within a specified waiting period, then the *pending ESI service agreement* should set to auto expire (same reasoning as above).

In order to remove ambiguity and promote uniform, consistent evaluations, logical expression trees or deterministic algorithms should be used to unequivocally assert compatibility or compliance with the *ESI service agreement template's* service and guarantee terms. This requirement ensures that all *ESI* interactions can be automated (both at the execution and enforcement level) with little or no human interaction. As an example of this approach, Figure 9 illustrates the case in which Boolean decision logic can be used to clearly determine whether an *ESI service provider* is qualified to enter into an *ESI service agreement* or not(Brown, et al., September 2023, p. 10).

In addition to establishing formal methods for evaluating compatibility or compliance, there is a need to define common nomenclature that can be used to identify and determine physical attributes or characteristics. The creation of such a nomenclature is outside the scope of this report, but Appendix A: *ESI Service* Qualifications suggests a list of common *ESI service qualifications*.

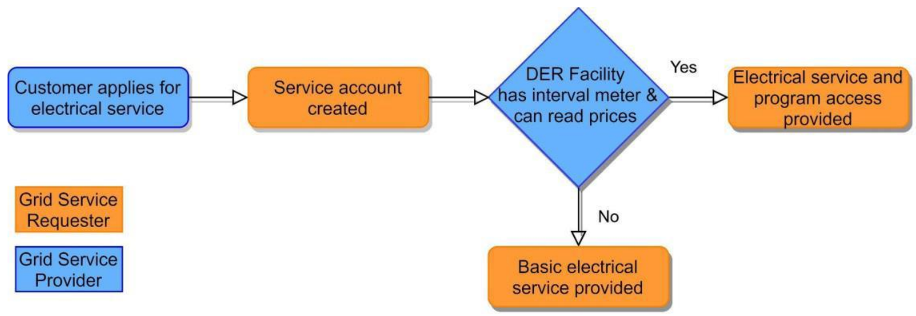


Figure 9. A sample *ESI service provider* qualification criteria for an *ESI service agreement*, taken from (Brown, et al., September 2023, p. 10)

Once the *service agreement* is accepted by both parties (i.e., *"in force"*), *WS-Agreement* provides two substates that can be used to indicate if the *service agreement* is "active" or "inactive." It is not entirely clear how these substates were to be used by *WS-Agreement*, but it is surmised that an *ESI service agreement* might need to become temporarily suspended or inactive during certain unforeseen events. The *ESI's service level activities* (to be described next) all take place while an *ESI service agreement* is active.

- The *ESI service provider* may petition to revise or renew an active *ESI service agreement* by proposing another *pending ESI service agreement*. The *ESI service provider* may alter agreement variables that it is eligible to change in the *pending ESI service agreement*. For example, it may be necessary to point to a new replacement meter or to update a capacity when new flexible energy resources become available. The renewal request must point to the *ESI service agreement* that is to be followed or replaced. As before, the *ESI service requestor* may either accept or deny the pending *ESI service agreement*. If approved by the *ESI service requestor*, the *pending ESI service agreement* replaces the existing referenced *ESI service agreement* at its specified agreement start time.

- An existing *ESI service agreement* should remain in force until such time that it is replaced, expires, or becomes terminated as allowed by the *ESI service agreement* itself. By requiring formal actions to be taken before changes occur, both the service provider and the requestor can rely on a consistent set of expectations over the agreement lifespan.

- If, however, an *ESI service agreement* is either terminated (as allowed within the agreement or is allowed to expire without having been renewed, then the *ESI service agreement* is no longer in force. This is a terminal state. The relationship between the *ESI service requestor* and *ESI service provider* reverts to the *default ESI service agreement* as an *ESI service agreement* expires.

3.3 The *ESI Service Layer*

The *ESI* should facilitate the routine operations necessary for delivery of an *ESI service* while an *ESI service agreement* is “in force”. The routine operations necessary to provide grid services are further defined from the four stages that were presented in Figure 5 as the ESI service layer. It does this by presenting a state machine that describes the operational states and transitions that are in effect while the *ESI service agreement* is active.

Under this context, the term *service event* will be used to refer to activities within the *ESI’s service layer*. One or more *service events* will exist during the term of an *ESI service agreement*. A *service event* is the object that migrates through the *ESI service* state machine (Figure 10).

The granularity of *service events* is determined by how the performance of an *ESI service* is to be measured, verified, and settled according to *service* terms and guarantees found in an *ESI service agreement*. On one hand, a single *service event* may endure throughout the term of an *ESI service agreement*. For example, an *ESI service provider* might agree to provide an *emergency outage recovery service* during the month of January, but no outage occurs that month. The *service event* becomes *armed* and ready, but the *ESI service provider* earns only a base monthly payment as its *ESI service agreement* expires.

Suppose that the same example’s agreement term length was set to two months with settlement occurring at the conclusion of each month. No outages occur the first month as before, but two outages occur during the second month. In this case, there would have been four *service events.* The first *service event* expires at the end of the first month earning the *ESI service provider* its base monthly payment. Two more *service events* complete their transitions through the *ESI service* state machine in the second month while earning a performance-based payment (in accordance with the established *ESI service agreement*). The fourth *service event* terminates as the second month expires, earning the second month’s base payment.

At the other extreme, a billing month could accumulate almost 670,000 *service events* for responses to 4-second ACE signals if the *ESI service participants* had agreed to reward performance in this way and with such fine granularity.* Market price intervals could also cause high numbers of *service events* to accumulate.

A *service event* transitions through four states. Optional handlers may be defined to handle complex transitions among these states (e.g., to define rule-based exception handlers that facilitate state reconciliation when discrepancies arise).

- *Scheduled or armed service event*--this state is entered as soon as a *service event's* delivery interval or contingency has been determined.

- *Operate service event*—this state is entered as soon as a *service event* needs to become active. This means that either a necessary contingency has been met (e.g., an outage occurs) or a *scheduled* time interval begins (e.g. a market interval).

  Note that a *service event's* delivery period does not necessarily imply active engagement of flexible energy resource. *Reserve services* may be delivered during a time interval with or without actuating the reserved resource.

  This state ends after a *service event* has been delivered.

- *Measured and verified service event*. This state is entered after the *ESI service requestor* and/or *ESI service provider* have collected and validated measurements according to the specified in the *ESI service agreement*.

- Settlement *service event.* This state is entered after both the *ESI service requestor* and *ESI service provider* have agreed on the collected measurements and have exchanged rewards and penalties for the *service event* as specified by the *ESI service agreement.* Often, many *service events* will become settled altogether, for example, at the end of a billing month.

* Alternatively, the *ESI service participants* might have offered and accepted a flat monthly participation fee without measuring or rewarding actual *ESI service provider* performance. In this case, a single *service event* might suffice each month. The creation of *service events* could also be tied to durations when the *service provider's* resources are available and not, and performance could be based on cumulative availability. These and many other alternatives remain valid as long as they are considered in the ESI Service Agreement structure.

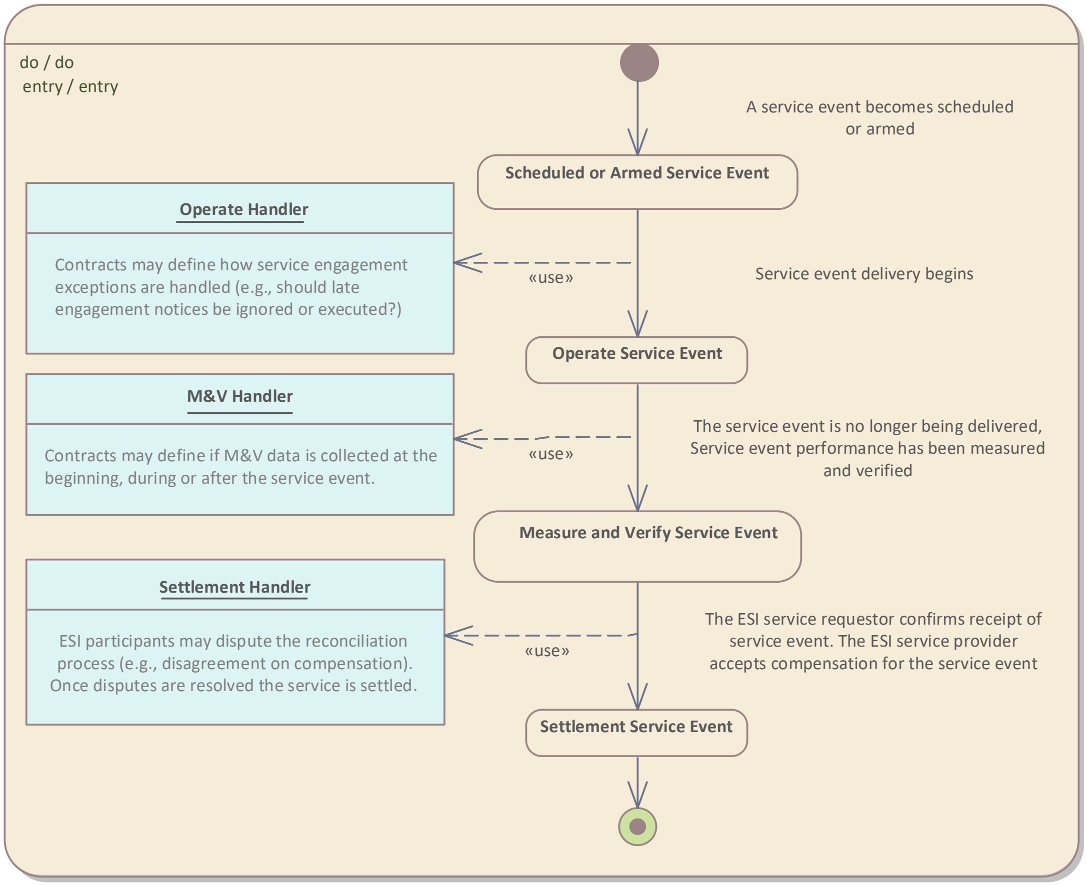


Figure 10. *ESI service event* state machine

See Appendix B: for sets of communication signals and objects that may be needed for states and transitions that occur within the *ESI service layer*.

4.0 *ESI Service Agreement* Requirements

This section proposes and justifies a set of *ESI service agreement* requirements. First, general requirements and terminology are proposed to enforce definitions and principles that have evolved with the *ESI*. The remaining numbered sections address operational or functional requirements for various stages during the provision of an *ESI service* after an *ESI service agreement* is in force.

Requirements may intentionally narrow the scope of the *ESI*. Simplifications are intended to make the immense challenge tractable. The electricity domain does not necessarily need to support all the features possible via generic web services, but may leverage this and other related technologies to facilitate adoption. Discussion is offered to create a roadmap to the formulation of such a profile.

1. General *ESI* requirements

These general requirements address *ESI* domain definitions and describes important *ESI* principles and practices.

1.1. Definitions

1.1.1. *The ESI service agreement interface (SAI)* is a pair of communication interfaces, one representing an *ESI service requestor* and the other representing an *ESI service provider*.

The *ESI* SAI facilitates agreements to provide and consume *ESI services* and facilitates the provision of *ESI services* according to the terms and guarantees within such agreements.

1.1.2. *ESI service agreement*—A digital contract that codifies the *ESI service requestor's* and *ESI service provider's* agreement to consume and provide an *ESI service*.

The *ESI service agreement* is a contract between an *ESI service requestor* and an *ESI service provider.* It must therefore define the provision of an *ESI service*, including the expected quality of service provision, rewards, and penalties for satisfying the *service agreement* terms or not. The *ESI service agreement* may also include obligations of the *ESI service requestor* and may specify expected qualities of *service* as well.

WS-Agreement offers a schema to meet many of these objectives in the web service domain. An *ESI service agreement* is proposed to use a profile of WS-Agreement that has been simplified and, in some cases, extended for the *ESI* and electric energy domain. To enable a balance between human understandability and machine interpretability, this document proposes such a template to be represented using JSON-Schema[*]

1.1.3. *ESI service requestor*—the *ESI service participant* that offers an *ESI service template* and offers to consume an *ESI service* at an *ESI*.

[*] JSON Schema is a standardized data model that allows users to annotate and validate JSON documents. It defines the structure, required data types, and constraints of the JSON data, enabling automated validation, documentation, and interaction with JSON objects.

1.1.4. <u>*ESI service provider*</u>—the *ESI service participant* that may agree to provide an *ESI service* at an *ESI*.

1.1.5. <u>*ESI service agreement template*</u>—the template for an *ESI service agreement* that is offered by an *ESI service requestor* for the provision of one of six *common ESI services* at the *ESI*.

The *ESI service agreement template* may have one or more variables that must be assigned parameters before the *ESI service agreement* becomes "in force". The *ESI service requestor* may assign parameters to template variables concerning *service* properties and according to its own objectives* (e.g. define minimum requirements and qualifications expectations). The *ESI service requestor* may also populate variable fields within the template to prescribe unique *service* terms and further define the required level of performance guarantees. Upon receiving the template offer, the *ESI service provider* must assign parameters to the remaining variables to describe its own capabilities and *qualifications* to provide the *ESI service*.

The use of variables within the *ESI service template* must facilitate a simplified and automated contract negotiation. No human intervention is required if the *service* properties and guarantees can be automatically mapped to the *qualifications* listed at the *ESI service provider's* interface. *A service provider's* qualifications may be issued by a third party and referenced as needed (e.g., via a digital certificate). Simple Boolean logic can then determine whether an *ESI service agreement* can be entered. See Appendix A.

1.1.6. <u>*ESI service*</u>—a set of energy behaviors that is derived from any of six prototypical *services* to be consumed and provided at an *ESI*.

An *ESI service* is specified by terms and guarantees within an *ESI service agreement.* Both the *ESI service provider* and *ESI service requestor* may have obligations toward fulfilling an *ESI service.*

1.2. <u>General architectural requirements</u>

1.2.1. An *ESI* service agreement interface pairs two communication interfaces—one representing an *ESI service requestor* and the other representing an *ESI service provider (see* Figure 11*)*.

WS-Agreement specifically allows for communication with third-party participants. However, allowing for more than two negotiating parties at the same time over an *ESI* may needlessly complicate the *ESI* specification. This report therefore advocates that the number of *ESI service participants* within a contract be limited to two parties. Although this may appear to be a technical limitation, multiparty conversations, such as those required for contract negotiation can be broken into a set of pairwise conversations by using techniques like message forwarding and encapsulation. For instance, party A can communicate with party C via party B by initially sending an encapsulated message to B, who can then forward it to C. Additionally, parties A and B can independently query a trusted party D to obtain a shared or global variable, such as the market state or a meter reading.

* At this point, it is suitable to introduce the concept of *service level performance objective*. A service level performance objective represents a quantifiable measure of the service being provided at the *ESI* interface. Syntactically, it is an assertion over the terms of the agreement as well as performance attributes or qualities that must be met to meet higher-order functional objectives,

As mentioned earlier, third-party verification may be needed to qualify an *ESI service provider* to provide an *ESI service* and to verify the achievement of level-of-service guarantees in a low-trust environment. As noted by the previous examples, this can be achieved by defining a public access end point that can be used to validate conformance (e.g., a digital certificate that provides capability certification) or by breaking contracts into individual relationships (e.g., a contractor and its subcontractors).

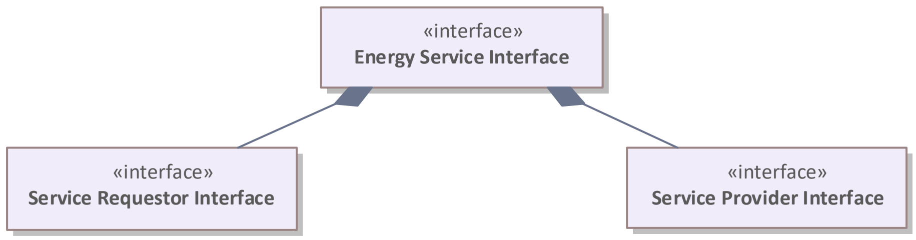


Figure 11. The *ESI* duality. An *ESI* is actually two interfaces — one for the ESI service requestor and the other for the ESI service provider.

1.2.2. An *ESI service provider* may participate in more than one *ESI*.

This requirement allows for an *ESI service provider* to enter into agreements with multiple *ESI service requestors*. Each such pairing is defined as an *ESI*. For example, the *ESI service provider* may contract with its local electric utility for a demand-response program and with a regional electricity operator for dynamic electricity rates. This practice is becoming common as DER owners choose to “stack” their value streams. However, care must be taken to avoid double count issues (see Requirement 1.2.4).

1.2.3. An *ESI service provider* may participate in more than one *ESI service*.

This requirement allows an *ESI service provider* to contract for more than one *ESI service agreement*. However, see Requirement 1.2.5.

1.2.4. An *ESI service provider’s* obligations to an *ESI service requestor* must not be affected by its commitments to any other *ESI service requestor.*

The *ESI service provider* remains independently obligated to all performance requirements and potential penalties to which it has agreed. One *participant* at an *ESI* needs not know how many *ESI service agreements* the other has entered and with whom. Therefore, it cannot be an *ESI service requestor’s* responsibility to plan contingencies for all the *ESI service provider’s* obligations to others, and vice versa.

On a broader note, service requestors need to understand that the quality of a service is dependent on the thoroughness of the parameters that define it, and its performance levels can only be influenced by the incentives and penalties being used. Therefore, the *ESI service requestor* should carefully specify performance verifications and penalties for failing to satisfy the terms of the ESI service agreement, including the recovery of any costs due to underperformance in all its *ESI service agreements*. Similarly, from the perspective of the ESI service provider, it is important to consider that responding to an additional ESI service request might affect the ability to fulfill other requests, which may translate into financial repercussions.

1.2.5. An *ESI service provider's* obligations to perform an *ESI service* according to an *ESI service agreement* must not be affected by its commitments to perform another *ESI* service according to another *ESI service agreement.*

Again, an *ESI service provider's* performance toward one *ESI service agreement* does not alter its obligations under any other *ESI service agreement* (e.g., past obligations shall remain in effect). While an *ESI service requestor* might keep track of and prioritize the conditional responsibilities of an *ESI service provider's* multiple shared *ESI service agreements*, doing so would create contingent performance requirements and guarantees. Addressing all such permutations and exceptions would greatly complicate the *ESI service agreement* and *ESI service templates* and should be avoided.

Within a single *ESI service agreement*, *WS-Agreement* can compose complex terms and guarantees using simple expressions and simple Boolean logic. Each exception or contingency might increase the complexity of expressing and evaluating such Boolean logic and should therefore be avoided wherever possible.

Similar to the considerations given in 1.2.4, an *ESI service requestor* should protect its business objectives by carefully crafting performance terms and guarantees for all its *ESI service agreements,* and the *ESI service provider* should consider the potential impacts of interactions between its multiple *ESI service agreements.*

1.2.6. An *ESI service agreement* must specify the electrical circuit location where *ESI services* are being provided.

Service locations must be clearly identified and must be sufficiently precise to make sure the *service* is provided where it's needed in a circuit. An *ESI service requestor* should be responsible for the locational implications of *ESI* circuit location because it has a more global view of and responsibility for electric power grid objectives than does an *ESI service provider.* When energy delivery infrastructure is owned or operated by others, third party mapping and/or verification systems may be employed.

WS-Agreement provides a *location* attribute for defining *service* variables. A *WS-Agreement location* refers to any context of the variable, however, which may or may not be a physical location. Circuit location belongs among agreement contextual information.

1.2.7. An *ESI service agreement* may be created between any two actors, regardless their roles or domains in an electric power system.

An *ESI* service agreement could exist between a regional operator and a system operator, between a transmission organization and a distribution utility, or between a distribution utility and an electricity customer. An aggregator may assume the role of *ESI service provider*, an *ESI service requestor*, or both.

1.2.8. An *ESI service provider* may fulfill its contracted *services* by using a combination of assets under its own control, plus the responses from other *ESI service providers* that it has subcontracted or aggregated via *ESI service agreements.*

This requirement allows for the formation of rich hierarchies of *ESI*s. Incidentally, OpenADR offers similar support for hierarchical, distributed control using assignments of its VEN and VTN responsibilities (OpenADR Alliance, 2023). Note that subcontracting does not relieve an *ESI* *service provider* from pass-through liabilities and thus appropriate mitigations must be in place to protect against such occurrences.

1.2.9. An *ESI service agreement interface* must support both the pushing (i.e., asynchronous publication) and pulling (i.e., asynchronous queries or function calls) of information at its interfaces.

Use cases are expected to exchange both process and verification data, which invokes a call or pull software architecture, and event driven behaviors, which are best invoked using a push or publish software architecture. An *ESI service participant* may periodically push updates to its capabilities, *schedules*, and other information without receiving an express pull request from the other party. Such self-initiated requests are intended to enable true two-way interactions between *participants*. Communications capabilities should be symmetrically applied at the *ESI SAI* for both its *participants* in order to foster a balanced and collaborative environment.

1.2.10. The ESI *service agreement interface shall* be considered as an application-level interface model, which is independent of the underlying hosting environment or transport mechanisms.

An *ESI service agreement interface* is a software-defined interface that can be implemented in variety of hardware and systems. Specific data transport mechanisms are not specified in this document, but must be sufficiently defined and agreed before implementing a service agreement interface (e.g., through a standard). In the context of this document, the terms *query* and *advertise* terms are used to describe actions that can be performed by a mixture of push, pull, request or other technology specific methods.

1.3. *ESI* service agreement scope

1.3.1. The scope of the *ESI* is defined by the objects and signals that may be communicated between the *ESI service requestor* and *ESI service provider* interfaces.

The *ESI service requestor's* operational objectives, often called “grid services,” explicitly lie outside the scope of the *ESI*. This is an important principle of the *ESI* and may be unique to the ESI. Typically, no lone *ESI service provider* can unilaterally mitigate any grid service, and the grid's operational objectives are typically irrelevant to the limited actions that the *ESI service provider* can, in fact, perform.

The important distinction between grid objectives and *ESI* services can be further found in (Brown, et al., January 2024).

1.3.2. The means by which an *ESI service provider* calculates or otherwise determines the objects and signals that it then communicates via its interface lie outside the scope of the *ESI*.

An *ESI* facilitates *services* while protecting its *participants'* privacy. Underlying practices and objectives are not made public. In time, suites of agents and libraries of methods must be developed to help *ESI service providers* control and represent aggregated capabilities of their assets and any downstream *ESIs*. Similarly, libraries must be developed by which *ESI service requestors* may address their objectives using communicated *ESI* signals and objects.

The sources of metering may be an exception to this requirement. The status of smart energy metering today limits meter access, thus necessitating that the *ESI* adopt collaborative access to meter data and information for its *participants (e.g., via secure, public end-points)*.

1.3.3. An *ESI* is device agnostic.

This is an important distinguishing principle of the *ESI* among multiple emerging efforts to directly control certain classes of flexible energy devices like electric vehicles.

1.3.3.1. The *ESI service requestor* must not offer *ESI service agreement templates* that target any specific device type.

By avoiding controls that are specific to unique classes of devices, the *ESI* gains simplicity, extensibility, and resilience. A predefined set of objects or signals are allowed through the *ESI* (see Appendix B). The *ESI* should naturally be open to new or emergent flexible resources that are invented in the future.

1.3.3.2. The *ESI service provider* must aggregate and manage the various capabilities of assets that are under its control.

The *ESI* keeps *ESI service providers'* resources private. An *ESI service agreement* must be agnostic to the type and number of assets that will be providing the *service*. No specific, unaggregated asset information is to be exchanged through the *ESI*.

This requirement extends to aggregation of any downstream *ESI* capabilities that might be influenced by an *ESI service provider* who is also acting as an *ESI service requestor.*

1.4. <u>General *ESI* service agreement information</u>

1.4.1. *The ESI service requestor* and *ESI service provider* alike must make their respective contact information available at the *ESI*.

An important element of any contract is the clear identification of the obligated parties. Because an *ESI* service agreement interface exists only between known parties, the service requestor should prepopulate such preface matter (helping to reduce burdens on the service requestor).

This requirement can be easily met within the agreement and agreement context content of a *WS-Agreement* preface material.

1.4.2. A timestamp, consisting of date and time, must be applied to all signals and objects using a standardized time frame reference such as UTC at the time such signals and objects are received at the *ESI*.

Certain *service* processes will possess time-critical requirements. The *ESI* timestamp clarifies who knew what and when. References to both absolute time and relative time should be anticipated.

1.4.3. All *participants* in an *ESI* system must be assigned a static, universal identifier which uniquely identifies the *participant*.

Procurement of this UUID is outside the scope of this document but may leverage industry-accepted mechanism, such as the Master resource identifier defined in the Common Information Model (International Electrotechnical Commission, 2022).

1.4.4. *Service terms and Service guarantees must be expressed using logical expression trees or deterministic algorithms that ensure their machine interpretability and decidability.*

An *ESI service agreement* must describe its service terms using machine decidable, first-order logic.

2. *ESI discovery layer* requirements

2.1. The means and processes by which one *ESI service participant* discovers another is not within the scope of the current *ESI architecture*.

The *ESI* exists between two entities that have already formed a business relationship and have set up the means to communicate with one another via an *ESI*.

2.2. Discovery of *services* and *service* incentives by the *ESI service provider* is currently out of scope, yet this requirement may evolve as grid decentralization continues to advance.

An *ESI service provider* may select only from among *offered ESI service agreement templates* that are offered by the *ESI service requestor* at an *ESI*.

3. *ESI agreement layer* requirements

This section addresses requirements for the processes by which *ESI service participants* enter into an *ESI service agreement*. This process lies within the *ESI's agreement layer*. *WS-Agreement* offers a state machine that has been adopted as the basis for an *ESI service agreement* state machine and describes the lifetime of an *ESI service agreement* (See Figure 7).

3.1. Register and qualify agreement processes scopes

3.1.1. The registration and qualification processes refer to the offering, selection, qualification for, and eventual entering of an *ESI service agreement* at an *ESI*.

Service registration entails an *ESI service provider's* selection from among *offered ESI service agreement templates* at an *ESI*.

These requirements are intended to distinguish *ESI service agreements* from the prevailing programmatic approach used today by many demand-response programs, in which a utility invests heavily to identify and recruit willing DER owners for each of its DR programs. By creating *ESI* interfaces at the premises of targeted *ESI service providers*, an *ESI service requestor* should be able to automatically discover and enter service agreements with assets and systems capable of providing the services they are qualified to support. .

3.2. Offered ESI service agreement

3.2.1. An *ESI service requestor* may advertise one or more *offered ESI service agreement templates* to an *ESI service provider* at an *ESI* interface.

This requirement provides for stepwise penetration of *ESI*s. An *ESI service requestor* initially may create even one *ESI* to test a newly *offered ESI service agreement template* (e.g, to field validate the developed service terms against the expected). The penetration of *ESI*s should grow as the need for new services grows (e.g., to increase demand-response). Once an *ESI* has been installed, its *ESI service provider* can easily adopt newly *offered ESI service agreement template*s.

3.2.1.1. An *ESI service requestor* must advertise its offered *ESI service agreement template*s to the *ESI service provider* initially and at any time that such offered *ESI service agreement template*s change.

3.2.1.2. An *ESI service provider* may query from the *ESI service requestor* to receive all *ESI service agreement template*s or a subset thereof.

3.2.2. The *ESI service agreement template*s offered by an *ESI service requestor* to an *ESI service provider* must include a default *ESI service agreement template* (e.g., the currently contracted electricity rates)

This requirement facilitates startup and termination of an *ESI*. When the *ESI* is first established, the *ESI service provider* may be assigned the default *ESI service agreement*, which will may be used to mimic the existing agreement between the *ESI service requestor* and *ESI service provider* prior to establishment of the *ESI*. Then again, if an *ESI service agreement* later expires or becomes terminated, the default *ESI service agreement* becomes active.

3.2.2.1. The default *ESI service agreement template* may be “None” if there normally exists no contract between the *ESI service requestor* and *ESI service provider*.

When an *ESI* becomes established between two entities who did not share any interactions or agreements prior to establishment of the *ESI*, it is appropriate that the default *ESI service agreement* be “None.” For example, a commercial building might establish a new *ESI* with its region’s wholesale electricity market operator, with which it had no prior agreements. The default *ESI service agreement* “None” creates no *service* terms or guarantees between the two entities, so there is no risk of starting in starting in or returning to this default *ESI service agreement*.

3.2.3. An *ESI service requestor* may include additional *ESI service agreement template*s when new or revised *ESI service agreement template*s become available.

This requirement provides for an evolution of *ESI service agreement templates* over time. The *ESI* framework should hasten the adoption and innovation of *ESI service agreement templates* that harness the growing numbers of flexible energy resources. An *ESI service requestor* may offer new rates or incentive programs by making newly offered *ESI service agreement templates* available at the *ESI*.

3.2.4. The provenance of an *ESI service agreement* must be traceable from its offering as an *ESI service agreement template* or program until it expires or is terminated.

Should there be any dispute about an *ESI service agreement*, the parties must be able to trace the various forms of the agreement. This requirement may be met by applying a unique identifier to each agreement and agreement template revision and having each point to its immediate predecessor.

3.2.5. An *ESI service provider* may enter more than one *ESI service agreement*.

The *ESI service provider* may receive all the cumulative incentives and benefits of multiple *ESI service agreements*, provided the *ESI service provider* is qualified and becomes contracted for each such *ESI service agreement template*. However, the *ESI service provider* is obligated by all service terms and guarantees in every *ESI service agreement* that it enters. By participating in multiple, possibly conflicting services, an *ESI service provider* assumes the possibility of legal and financial risks (e.g., program termination and loss of revenues) due to underperformance.

3.2.6. The requirements and expectations specified in an *ESI service agreement template* (i.e., an *ESI service agreement template* offered by the *ESI service requestor*) are inherited by any derived *ESI service agreement* unless specifically overridden in the *ESI service agreement*.

This report recommends a process by which offered *ESI service agreement template*s become contracts at the *ESI service agreement interface*. It is important that service terms and guarantees must be traceable and immutable while a service agreement is in force. The *ESI service agreement interface* accomplishes this by requiring unique identifiers to its *ESI service agreement templates* and *ESI service agreements*. The process itself limits modifications of its *ESI service agreement templates* to a set of variables that must be assigned, thus limiting opportunities to unilaterally introduce or alter service terms and guarantees.

3.3. *Service* qualification

3.3.1.1. An *ESI service agreement template* may possess a set of service qualification requirements.

An *ESI service requestor's* qualification requirements for an *ESI service agreement template* may include waiving of the certification process altogether, requesting self-certification, leveraging third-party certification processes, confirming passage of well-defined qualification tests, or combinations thereof.

3.3.1.2. *Service qualification* entails having the *ESI service provider* meet the *ESI service requestor's* qualification requirements for an *ESI service agreement template.*

3.3.1.3. Service qualifications must be able to be described and evaluated according to 1.4.4.

Service qualifications must output a Boolean value (Yes/No), and their evaluation must be deterministic to ensure that all decisions are consistent and verifiable.

3.3.1.4. An *ESI service requestor* may query an *ESI service provider* to learn about all its *ESI* service *qualifications* or a subset thereof.

This requirement provides a means for an *ESI service requestor* to identify flexible energy resources that are exposed at its *ESIs* and to plan to operate (e.g., engage) these resources.

3.3.1.5. *Service* qualification requirements should be derived from a common set of qualification definitions.

This requirement facilitates automated matching of the *ESI service provider's qualifications* with the *ESI service agreement template's* service qualification requirements. See Appendix 1.

3.3.2. Certain *ESI service provider service qualifications* may be prepopulated and available at its *ESI* communication interface.

Pre-populated *service qualifications* can hasten the qualification process by supporting pre- or self-qualification certifications. Furthermore, an *ESI service requestor* may elect to hide *ESI service agreement templates* for which the *ESI service provider* is clearly unqualified or has not prequalified.

3.3.3. An *ESI service requestor* must be able to query an *ESI service provider's qualifications* at its *ESI* i.

3.3.4. An *ESI service provider* must be able to query an *ESI service requestor's* qualification requirements at its *ESI* .

3.4. <u>*ESI service agreement*</u>

3.4.1. An *ESI service agreement* is in place after the *ESI service provider* has registered with the *ESI service requestor* and has qualified for a given *ESI service agreement template*.

An *ESI service agreement* should be in force after an *ESI service agreement template* has been matched with a corresponding service offering, associated *service provider qualifications* have been met, and the *ESI service requestor* has acknowledged (not denied) the agreement. This report's recommended state machine for the lifetime of an *ESI service agreement* meets this requirement while adhering closely to *WS-Agreement*.

3.4.2. An *ESI service agreement* must specify a starting date and time on which the terms of the contract are in force.

Note that *WS-Agreement* recommends that an agreement's expiration date and time be included among agreement context information, but it is silent concerning the agreement's start time and date. An agreement's start date and time may be obvious for web-based services, but not necessarily for the provision of *ESI services*, parts of which may not occur via interactive sessions. Contract start time should be required among agreement context information in an *ESI* profile of *WS-Agreement*.

3.4.3. An *ESI service agreement* may specify a termination date and time, at which the *ESI service agreement* expires, and the default contract comes into force instead.

WS-Agreement recommends including an agreement's expiration date and time among agreement context information. This report recommends clear actions as an agreement expires.

An *ESI* profile of *WS-Agreement* should therefore require inclusion of the agreement's expiration date and time among agreement context information.

4. *ESI service layer* requirements

4.1. *Schedule or arm* state requirements of the *ESI service layer*

The schedule or arm *ESI* state is used by *ESI services* to plan for and arm resources prior to the delivery of services. In some cases, the service may be truly *scheduled*, thus requiring careful specification of what it means to *schedule* an *ESI service*.

4.1.1. A *schedule* is one or more one-to-one pairings of a *scheduled object* with a *time interval*.

4.1.1.1. *Advance notice* is the minimum amount of time that is required to accept a change in a *schedule*.

4.1.1.1.1. An *ESI service agreement* should specify *advance notice* that is required for its *schedules*.

4.1.1.1.1.1. An *ESI service agreement* may specify remediation should a communicated *schedule* fail to provide the minimum advanced notice.

4.1.1.2. A *schedule's future horizon* is the time duration between a *schedule's* latest *time interval's* end time and the *schedule's* earliest *time interval's* start time (see Figure 12).

4.1.1.3. A *scheduled object* is any object that is associated with a *schedule's* time interval.

A *scheduled object* may be a simple Boolean state, integer, or floating-point number, but the word "object" is intentionally chosen here to allow also for complex structs that themselves possess structured information and parameters. For example, a demand curve may be the information object for a time interval in the context of electricity markets. See Appendix B for further detail.

4.1.1.4. A *time interval* is a *schedule* component that is specified by a starting time and either its duration or ending time.

4.1.1.4.1. An *ESI service agreement template* should specify its minimum, maximum, and typical allowed *time interval* durations.

The duration of *time intervals* should be an assignable variable, thus making *ESI service agreements* applicable to different *schedule* granularities. Note that instantaneous information can be specified in a *time interval* having duration 0 or having an ending time that is identical to its starting time.

4.1.1.4.2. An *ESI service agreement* must specify how, if at all, *time interval* start times must align with major clock or calendar transitions.

For example, hourly time intervals are often, but not necessarily, aligned with hh:mm = xx:00. These intervals might be defined in Coordinated Universal Time (UTC) to avoid complications with time zones, daylight saving time changes, or similar events

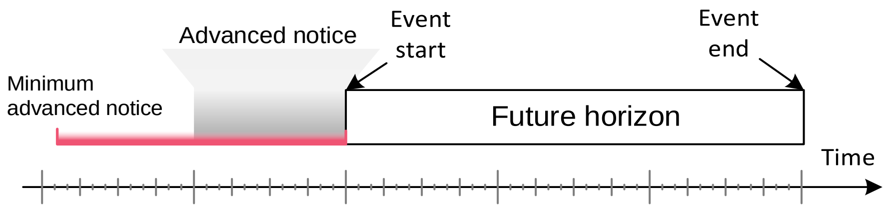


Figure 12. Important points on the timeline of an *ESI schedule*

4.1.2. A *service event* is the object that migrates through the *ESI service* state machine as an *ESI service* is being delivered within the *ESI service layer*.

A *service event* is the object that is *armed*, may be *scheduled*, may induce resources to enter the *operate state*, and may be measured and rewarded. See 3.3 and Appendix B for detail. Because there exist six or more classes of *ESI service agreement templates*, the definition of *service event* must remain abstract and flexible enough to address many diverse use cases.

4.1.2.1. An *ESI service requestor* asserts precisely one *armament status* for a *service event*. *Armament status* indicates the functional condition under which an *ESI service provider* should operate or engage its flexible energy resources during a *service event.*

It is important to understand the distinction between *armament* and *operation*. *Armament* is a planning activity and status within the *schedule and arm* state of the *ESI service layer*. *Operation* may occur during the operate state of the *ESI service layer*. *Armament* may take many functional forms. For example, for an *ESI service* that simply communicates dynamic prices to the *ESI service provider*, *armament* may refer to the advanced electricity price provided in forward time intervals, and the *ESI service provider* may be assumed to be indefinitely in operation—free to respond to those prices as it deems appropriate.

For another example, *armament* of a *voltage management service* may entail functional assignment of reactive power resources when voltage falls below a threshold at the *ESI service provider's* premises. The *ESI service provider's* resources may rest idle for a long time before that threshold is observed and resources enter operation.

4.1.2.1.1. A *service event's armament status* may be, but is not necessarily, *scheduled*.

4.1.2.1.2. An *ESI service requestor* must push a *service event's armament status* to the *ESI service provider* at the time the status is instantiated and at any time such status changes.

A pub/sub architecture like this makes sense while *schedule* content remains asynchronous or changeable. An *ESI service agreement* may specify conditions under which *schedules* become fixed (unchangeable). It may further specify mitigations should changes occur outside these times or conditions.

For example, bids and offers into day-ahead electricity markets today cannot be changed and must be submitted well before the market clears.

4.1.2.1.2.1. An *ESI service requestor* may change a *service event's scheduled* or current *armament statuses* if doing so is allowed by advance notice requirements or other terms of an *ESI service agreement.*

4.1.2.1.3. If specified by the agreement, an *ESI service requestor* must reply with *armament statuses* for any identified service events when polled by the *ESI service provider* to do so.

4.1.2.2. An *ESI service provider* asserts precisely one <u>*availability status*</u> for a *service event*. *Availability status* indicates the readiness of the *ESI service provider* resources to operate.

Service availability may be either binary (e.g., available vs. unavailable) or continuous (e.g., 50%, 8.3 kW, etc.) in nature, as must be specified by the *ESI service agreement.*

4.1.2.2.1. *Availability status* may be, but is not necessarily, *scheduled*.

Availability status can play a role in both the *scheduled or armed* and *operate states*. It is relevant to the *scheduled or armed state* because it may be planned or *scheduled*. For example, it may be known well in advance that flexible energy resources will be unavailable due to scheduled maintenance.

4.1.2.2.2. An *ESI service provider* must query a *service event's availability status* to the *ESI service requestor* at the time the status is instantiated and at any time such status changes.

4.1.2.2.2.1. An *ESI service provider* may change its *scheduled* or current *availability status* if doing so is allowed by advance notice requirements or other terms of an *ESI service agreement.*

4.1.2.2.3. An *ESI service provider* must reply with *availability statuses* for any identified *service events* when pulled by the *ESI service requestor* to do so.

4.2. <u>Operate state requirements within the *ESI service layer*</u>

The requirements in this section address the interplay of statuses while an *ESI service event* is being delivered. These statuses are discussed further in Appendix B.

4.2.1. <u>Availability status</u>

Availability status refers the *ESI service provider's* (or its resources') state of readiness to provide the *service*. It may further include a degree of *availability* should the readiness of the *ESI service provider's* flexible energy resources be defined on a continuum or on a per asset basis. The *ESI service provider* owns and dictates the *availability status.*

4.2.1.1. An *ESI service provider* must promptly advertise (e.g., via push) its current *availability status* any time such status differs from its *scheduled availability status* and whenever such status changes.

4.2.1.2. An *ESI service agreement* may specify mitigations should *availability status* differ from *scheduled availability status* in a *schedule's* time interval.

4.2.1.3. An *ESI service provider* must provide its current *availability status* when requested to do so by the *ESI service requestor* at the *ESI*.

4.2.1.4. Both *ESI service participants* should keep records of *availability statuses* and when the *ESI service provider's availability status* changes.

Availability status may be a determinant in the determination of *service* payments. An *ESI service participant* may elect to verify the other's *availability status records*.

4.2.2. Engagement status

Engagement status indicates whether the *ESI service provider's* flexible energy resources are, or should, in fact, *be* engaged (i.e., actively providing the service). It may further characterize a degree or mode of *operation* when a continuous control variable is used or a plurality of control options exist. From the *ESI service requestor's* perspective, it must infer *engagement status* from *scheduled* behaviors and measurements. The *ESI service provider*, however, should simply indicate whether its flexible energy resources are, in fact, *operated* (and the degree of *operation*, if applicable). These two perspectives can differ.

4.2.2.1. An *ESI service participant* must promptly advertise its current *engagement status* to the other *participant* any time such status differs from its *scheduled engagement status* and whenever such status changes (this enables the other party to identify and implement potential mitigations).

4.2.2.2. An *ESI service participant* must provide its current *engagement status* when requested to do so by the *other ESI service participant* at the *ESI* as defined in the *ESI Service agreement (i.e., enabling on-demand quality of service assessments)*.

4.2.2.3. An *ESI service agreement* may specify mitigations should the *engagement status* differ from the *scheduled engagement status* in a *schedule's* time interval.

4.2.2.4. Both *ESI service participants* should keep records of *engagement statuses* and when the *engagement status* changes, this will help facilitate conflict resolution should a disagreement arise.

Engagement status may be a determinant in the determination of *service* payments. An *ESI service participant* may elect to verify the other's *engagement status records*.

4.2.3. Service status

S*ervice status* indicates whether an *ESI service agreement* is active or inactive, where *inactive* means that terms of the *ESI service agreement* have been suspended. It is presumed that the

ESI service requestor owns this state. Only the *ESI service requestor* can suspend the terms of an *ESI service agreement.*

4.2.3.1. If possible, an *ESI service requestor* must promptly advertise the current *service status* any time such status differs from its *scheduled service event* and whenever such status changes.

The qualifier "if possible" refers to conditions when a *service* must be suspended due to lack of communication connectivity. For communication enabled services, agreements should specify the default actions that must be taken when communications are lost. This will help reduce operational uncertainty and provide safe defaults.

4.2.3.2. Both *ESI service participants* should keep records of *service statuses* and when *service status* changes.

Service status may be a determinant in the determination of *service* payments. An *ESI service participant* may elect to verify the other's *service status records*.

4.3. Measure & verify state requirements within the *ESI service layer*

While measurement and verification processes usually place requirements on the *ESI service provider*, they may impose requirements on the *ESI service requestor* as well. The term *ESI service participant* herein refers to either or both the *ESI service requestor* and *ESI service provider.*

4.3.1. An *ESI service agreement* must specify the source(s) and mechanism(s) that will be used to measure each *ESI service participant's* performance.

WS-Agreement provides *service* terms and term guarantees by which performance can be measured and verified

4.3.1.1. Service guarantees (if implemented) must be specified and be able to be resolved using deterministic processes, these guarantees may reference measurements collected during or after the operate state.

Since the measure & verify state is a key step towards achieving an eventual settlement, the evaluation rules must be machine-decidable (e.g., both the algorithm and its inputs must be accessible, deterministic, and invariant during the life of the contract).

4.3.2. The determinants needed to measure and verify the provision of *services* by the *ESI service provider* or the enactment of *services* by the *ESI service requestor* must be specified in the *ESI service agreement*.

4.3.3. Both *ESI service participants* must be able to access the determinants upon which *ESI service* performance is being measured.

4.3.3.1. *ESI service participants* must be able to query information from the other's *ESI* interface to access the other's version of such determinants.

The smart grid has evolved to provide very uneven and unequal access to energy meters, which has become an impediment to the uptake of innovative energy programs for harnessing energy flexibility. Therefore, in order to encourage fair, and competitive contract practices this report recommends that any metric, value or attribute used to impute a result should be made available to both parties (e.g., via a secure, publicly accessible endpoint).This means that meter information should be assumed to be shared resource, regardless of whether the *ESI service requestor* or *ESI service provider* owns or possess direct access to meters and meter data

4.3.3.2. *ESI service participants'* access to determinants via the *ESI* must endure until performance that is measured or verifiable via the determinant has been settled (See Requirements 4.4 concerning the settlement process requirements).

4.3.4. *ESI service participants* must be able to access any determinant upon which the quality or guarantees of an *ESI service* are determined.

Timing verifications will likely be the main contentions concerning guarantees of *ESI services.* Was the *schedule* pushed early enough and in an acceptable format? Was a *schedule* altered outside of the time window for allowed changes?

4.3.5. If a measurement baseline is prescribed in an *ESI service agreement*, the *ESI service agreement* must specify from where or how the comparison baseline is to be derived.

4.3.6. An *ESI service agreement* must specify remediation steps should *ESI service participants* disagree on their measured and verified performances.

4.3.6.1. An *ESI service agreement* may specify a dispute period and process for the treatment of disputed determinants.

4.4. Settlement state requirements within the *ESI service layer*

4.4.1. A *settlement interval* (e.g., billing period) must be stated in an *ESI service agreement*.

Settlement takes place after a set time interval (e.g., monthly) or after a prescribed event has occurred (e.g., an infrequent reserve resource has been *engaged*).

4.4.2. Monetary and other benefits must accrue during a settlement interval for performance during the reconciliation interval according to terms and guarantees stated in the *ESI service agreement.*

This requirement does not preclude that *ESI service agreement* may specify that no monetary and other benefits shall accrue.

4.4.3. An *ESI service agreement* must specify precisely how measured and verified performances and baselines of the *ESI service requestor* and *ESI service provider* alike translate into monetary and nonmonetary payments and penalties in a reconciliation interval.

This requirement allows that an *ESI service agreement* might require neither measurements nor verifications. An *ESI service agreement* could provide for monetary or nonmonetary payments regardless of its parties' performances.

4.4.4. An *ESI service agreement template* and *ESI service agreement* may specify remediation should either party disagree on the payments made or received for a settlement interval.

4.4.5. An *ESI service agreement* may specify by when parties must complete their respective settlement actions (e.g., make payments).

4.4.6. The *ESI service agreement template* and *ESI service agreement* may specify a dispute period during which payments made or received may be disputed.

A dispute period would probably be specified in respect to either the end of a reconciliation interval or the dates on which payments are made or received.

5.0 Conclusion

This report continues the evolutionary development of the *ESI* by delineating an initial set of specifications that give rise to capabilities and functionalities that aim to address both current and future grid needs. These specifications are primarily driven by a set of foundational tenets that enable the creation of a standardized ESI model that can automate and enforce the fulfillment of *service agreements* in between *service requestors* and *service providers* by using a service-oriented approach. By adopting a contrasting approach to traditional direct-demand-response strategies, the *ESI* can offer both a service and device agnostic solution to enable grid coordination. The ESI centers its use on *service agreements* that have been modeled after the six *common ESI service definitions* presented in (Brown, et al., January 2024), which have been hypothesized to be sufficient to represent all grid needs. The *ESI* developers have converged on these six *common ESI service* definitions based on shared *participant* capabilities rather than electricity providers' grid-centric operational objectives (aka "grid services") that are often irrelevant to those who can provide the *services*. The *ESI* provides *templates* for provisioning each of these six *common ESI services* while respecting *participants'* privacy expectations.

From an architectural perspective, this report seeks to close the gap between a conceptual model and a practical architecture by introducing a series of formal design requirements that define the roles, and processes to which an ESI and its participants must adhere to. At a high level these requirements are driven by a series of fundamental tenets that are intended to be applicable to all future *ESI* implementations. The first of these tenets dictates that an *ESI* pairs precisely one *ESI service requestor* and one *ESI service provider*. This practice allows future developers to focus on the signals and information that must be conveyed across the *ESI* without worrying about either the recruitment of *service providers* or the discovery of *services* to be provided. Secondly, an *ESI* service agreement interface is not one, but a pair of communication interfaces—one representing an *ESI service provider* and the other representing an *ESI service requestor*. This simple tenet paves a pathway to simplify the development of compliant software interfaces.

This work recognizes the similarity between service level agreements, and in specific, how the *WS-Agreement* specification (from the web services domain) can be adapted to satisfy the needs of the *ESI*. Hence, this report advises the adoption of *WS-Agreement* as the basis for *ESI service agreements*. Accordingly, many objects and ESI concepts are now defined in terms of the *WS-Agreement* specification (e.g., the lifetime of an *ESI service agreement* follows the specification). Nevertheless, adaptations and new definitions have been introduced to ensure unique *ESI service agreement* needs are satisfied. For example, this report re-defines the *ESI service agreement* state machine, which dictates the processes and objects that are responsible for fulfilling negotiated ESI *services*. It does this by recasting the registration and qualification lifecycle stage into the agreement layer, where pre-requisite procedures can be captured, while recasting the other four lifecycle stages as sub-states that are applicable when a contract is "in force".

By building upon *WS-Agreement,* the *ESI service agreement* can facilitate service negotiation by offering customizable *templates* that can be parametrized by the ESI participants to describe, and eventually fulfill their operational needs (e.g., once a *service agreement is in place)*. This is done by assigning values to the template parameters, effectively defining the *service* terms and guarantees that the *ESI service requestor* requires and the specific *qualifications* and guarantees that the *ESI service provider* offers. Hence, by adopting *WS-Agreement*, the *ESI* *service agreements* cannot only specify the *service* terms, but also the guaranteed levels of service.

The usefulness of the *ESI* shall be ultimately determined by its ability to facilitate the automated negotiation and fulfillment of ESI services according to the capabilities described within the service and guarantee terms. Consequently, future implementers must converge on a set of common capabilities that can be used to describe and assess an *ESI service agreement's* performance. This will require the development of a common terminology that can serve as the basis for future *service agreement templates*, an effort spearheaded by this report. This will enable *ESI service requestors* to explicitly prescribe required capabilities and guarantees by referencing capability definitions that come from a well-known and well-characterized library, while also enabling *ESI service providers* to describe their capabilities and guarantees using the same common terminology. The common capabilities must be formulated using clear variable definitions and well-defined parameter types and/or ranges. The parameters can then be used to populate the variables concerning *WS-Agreement service* terms and guarantees, each functionally defined using these variables. This activity can probably draw from and extend upon the Common Information Model. Once an *ESI* service agreement interface is in place between an *ESI service requestor* and *ESI service provider*, new *services* may be readily devised and implemented, and agreements are readily facilitated to enact the new *services*.

In addition to the technical contributions, a series of future *ESI* development efforts have been recommended. This includes, encouraging the adoption of deterministic algorithms or more simply, Boolean expression trees to enable participants to achieve machine decidability over the specified service terms and guarantees. The report also recommends that the *ESI* profile of *WS-Agreement* must be defined using a JSON-based schema model, which can bridge the gap between a human-readable contract and a structured data model that enables machine automation. Existing features and terminology of *WS-Agreement* that directly support the *ESI* may simply be adopted by reference. New documentation will be needed for components and behaviors of the *ESI* that were not anticipated by *WS-Agreement*. The *ESI service agreement* state model represents an initial example of such specialization. This report also recommends that all *basic ESI service contract templates* should be drafted and rigorously evaluated before being deployed. Unit test cases must be carefully designed to ensure that terms and guarantees can be satisfied, while also *ensuring* that transitions within the ESI lifecycle operate as intended.

Finally, this report should be seen a first attempt to define the general and functional requirements that support an *ESI* as well as the operational requirements within *ESI operational stages*. This is a clear distinction from prior *ESI* documents that either referred to the *ESI* as a conceptual model or that loosely defined requirements at high, abstract levels. Hence, this report makes concrete proposals concerning many of the *ESI's* tenets that had before only been notional or abstract. The authors' recommendations should be vetted with larger communities like SEPA or GWAC before further development of the *ESI*.

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Appendix A: *ESI Service* Qualifications

If agreements between *ESI service providers* and *ESI service requestors* are to be automated, then the *ESI* must converge on a standard set of *ESI service qualifications*. Only then can an *ESI service requestor's* requirements be automatically compared with an *ESI service provider's* capabilities and *qualifications*. The *ESI service requestor* will require *qualifications* from the *ESI service provider* more often than vice versa, but the *ESI service provider* may require *qualifications* from its *ESI service requestor* as well.

In this appendix, we focus on *service* terms and guarantees within the *ESI agreement layer*. This list should not yet be considered authoritative. It is a draft set of logical *service prequalifications* and categorizations thereof. The final standardized list of *qualifications* is envisioned to be based on the data models available within the International Electrotechnical Commission *Common Information Model* (CIM).

<u>Circuit location</u>—*Energy services* must be supplied at circuit locations that can help fulfil an *ESI service requestor's* operational objectives.

- Electricity supplier (a business entity)
- Substation
- Feeder
- Feeder phase
- Premises circuit (for potential use within premises)

<u>Electrical qualities</u>—These refer to certain important electrical qualities at the *ESI service provider's* electrical point of connection[*].

- Nominal primary service voltage (e.g., 12 kV)
- Apparent power capacity (e.g., 200 kVA)
- Current carrying capacity (e.g., 400 Amperes)

<u>Meter qualities</u>—Certain meter capabilities and qualities may be required, based on a given *ESI service's* measurement & verification, and settlement processes and requirements. It is plausible that more than one meter or meter type may be required for an *energy service*.

- Meter or submeter identifier
- Meter manufacturer
- Meter model
- Meter owner
- Measurement type (i.e., voltage (V), electric power (W), etc.)
- Scaling multiplier (e.g., 10^{-3}, 1, 10^{3}, 10^{6}, etc.)
- Meter precision
- Meter accuracy
- Metered interval granularity
- Meter data accessibility (i.e., which actors may access this meter?)
- Meter communication protocols and versions

<u>Aggregate energy flexibility</u>—An *ESI service requestor* may require aggregate energy flexibility from the *ESI service provider*, and the *ESI service provider* may list its available energy flexibility to qualify to provide an *energy service*. Energy flexibility should be stated as a change

[*] This might be specified differently by flow direction or using terminology such as sink/source.

in respect to the baseline conditions that would exist if the *ESI service provider* did not exercise its flexible energy resources.

Each listed energy flexibility should possess a set of attributes concerning an aggregated ability to either sink (consume) or source (generate) the given energy or power. See sidebar “Attributes of Aggregated Sink or Source Energy Flexibility.” These attributes specify the range of energy flexibility that can be called upon, the statistical variability of doing so, and temporal patterns, should the flexible energy resource capacity change predictably with time. While a sign convention could be used to elegantly distinguish sink and source capacities, this report recommends using separate sink and source capacities to avoid confusion and errors.

Attributes of Aggregated Sink or Source Energy Flexibility

- Typical value
- Maximum value
- Minimum value
- Variability (e.g., variance for time-invariant cases and distributions by hour, weekday, and month for time-variant cases)
- Temporal patterns
    - By hour
    - By day
    - By month
- Responsiveness (i.e., response delays, constraints on rate of response)
- Units of measure
- Advanced systems may rely on capability curves or other suitable mechanisms.

While *service providers* might control energy forms other than electricity, energy flexibility should be stated consistently in respect to its effect on the electric energy or power injected into or consumed by the *service provider* at its point of electrical connection.

- Electricity energy capacity
- Real electric power capacity
- Reactive power capacity

<u>Process capabilities</u>—This set of *qualifications* refers to the *ESI service provider’s* capability to respond to the *six common ESI services* or to accept, interpret, or initiate communication signals that may be required during the provision of certain *ESI services*. It is relatively easy for an *ESI service provider* to assert whether it can provide the *six common ESI energy services*. But as *ESI services* become specialized, *ESI service participants* will need to query the other’s ability to send, receive, and interpret specific messages that are communicated within the *ESI service layer* and corresponding qualities of the *service*. Those *qualifications* should be addressed along with the objects that are to be communicated in the *ESI service layer* (see Appendix B: Signals and Objects needed by the *ESI*).

Appendix B: Signals and Objects needed by the ESI

This appendix proposes a list of communicated signals and objects categorized by states of an *ESI service event* within the *ESI service layer*. A minimum set of such signals and objects might qualify *participants* for the six basic *ESI service agreement templates*. However, as the *basic ESI service agreement templates* become specialized, both communicated signals and objects and corresponding *service* guarantees may evolve. For example, a *schedule* may be defined as a quantity during 24 hourly time intervals. But a *scheduled service* may be specialized to address series of 15-minute time intervals instead, and the *ESI service participants* must then be able to confirm the other's ability to work with the shorter time intervals. An *ESI service agreement* should specify how these signals and objects are to be used in the various *service* states and *service* state transitions.

As for Appendix A:, this list is being offered at a logical, contextual level. A Unified Modeling Language (UML) model should be developed to capture all the necessary details. Many of the signals and objects will be found to have already been addressed by existing standards.

***Scheduled or armed state* objects**

- *Schedule*—one or more pairings of a time interval with a *scheduled object* (i.e., a datum) in that *time interval*.
    - *Time interval*
        - *Time interval duration*—length of the *time interval*. (Note that a datum may be associated with a precise point in time by assigning duration zero.)
        - *Time interval start time*—time at which a *service's* delivery is to begin.
    - *1.1 Scheduled object*—potentially any object that can be associated with a *time interval*.
        - *1.2 Curve*—a point or function defined by one or more coordinate pairs (x, y). When a *curve* has more than one coordinate pair, functional values must be interpolated between the *curve's* successive ordered coordinate pairs.
            - *Demand curve*—a *curve* defined by coordinate pairs (*real power*, *electricity price*). A *demand curve* is typically undefined outside the range [minimum *real power*, maximum *real power*], beyond which *electricity price* might be assumed to approach negative and positive infinity, respectively. A *demand curve* facilitates participation in electricity markets.
            - *Droop curve*—a *curve* defined by coordinate pairs (percent *voltage frequency* deviation, *real power*). A *droop curve* may be used to *schedule ESI regulation services*.
            - *Elasticity curve*—the *curve* formed by switching the axes of a *demand curve.*
            - *Strike price*—a *demand curve* having only one coordinate pair. *Strike prices* (and several similar objects) are used in some electricity auctions.
            - *Inverter control curve*—several power-electronic-inverter-based control modes are being defined especially for the solar photovoltaic industry. The *ESI* should never target specific resource types, but piecewise linear *curves* can be defined to mimic these various modes.
                - *Constant PF curve*—This mode can be emulated by following a curve for which each of its coordinates (*apparent power*, *real power*) exhibits the same *power factor*.

        - *Voltage-reactive power mode curve*— This inverter mode may be emulated by a *curve* having coordinates (*voltage*, *reactive power*).
        - *Active power-reactive power mode curve*— This inverter mode may be emulated by a *curve* having coordinates (*reactive power, real power*).
        - *Constant reactive power mode*—This inverter mode is not well suited to using a *curve*. One may *schedule* a constant *reactive power* instead.
        - *Voltage-active power mode curve*—This inverter mode may be emulated by a *curve* having coordinates (*voltage, real power*).
    - *Electric current*
    - *Energy*—electricity.
    - *Power*—rate of *energy* production or consumption. *Scheduled powers* must be assumed to be averaged or constant for the *duration* of a *time interval* unless defined otherwise in an *ESI service agreement.* For example, *service* terms may allow for a delay while power is ramped from one *time interval's* target value to the next.
        - *Apparent power*
        - *Reactive power*
        - *Real power*
    - *Price*
        - *Electricity price*—per unit cost of electricity.
        - *Event price*—per event cost, where the *ESI service provider's* flexible energy resources become *engaged* event wise (e.g., a call on reserves, or an outage response)
        - *Demand price*—per unit demand cost (e.g., conventional demand charges). The demand determinant must be defined in its associated *ESI service agreement.*
    - *Status*—*scheduled* conditions that are typically assigned Boolean membership (i.e., true, or false) or membership chosen from a small enumeration.
        - *Armament status*—*ESI service requestor's* indication that a *service* should be provided when triggered by its *scheduled* time of delivery or another defined event (e.g., the condition of a communicated or autonomous signal)
        - *Availability status*—indication of the *ESI service provider's* readiness to provide the *service*. *Availability status* may be *scheduled*, but planned *availability* may change.

Operate state objects

- *Performance record*—these are measurements of common determinants that will eventually be used for *service* performance rewards and penalties. These measurements must be recorded during the delivery of a *service* to support later measurement, verification, and reconciliation efforts.
    - *Interval performance*—performance associated with *time intervals*. The *time intervals* will usually have been defined by *schedules*.
        - *Interval energy*—sum *energy* consumed or generated during a *time interval.* A sign convention must be chosen to distinguish net generation (positive) and consumption (negative).

        - *Interval real power mileage*—integrated absolute value of *real power*. Mileage is used as a determinant for rapid charging and discharging of energy storage resources, as it is a measure of total control effort.
        - *Interval power factor*—the (typically averaged) ratio of *real power* to *apparent power* in a *time interval.*
        - *Interval reactive power mileage*— integrated absolute value of *reactive power* generation or consumption in a *time interval.*
    - *Event performance*—performance that is associated with events that are defined in an associated *ESI service agreement.*
        - *Engagement duration*—cumulative time that an *ESI service provider's* flexible energy resources remain *engaged*.
        - *Event count*
            - Overvoltage violation count—number of times that *voltage* exceeds a defined *voltage* threshold.
            - *Service outage count*—number of defined *service outages* encountered.
            - *Undervoltage violation count*—number of times that *voltage* falls below a defined *voltage* threshold.
        - *Minimum power factor*
        - *Peak real power demand*—often the determinant of conventional demand charges.
        - *Service outage duration*—cumulative time that a electrical *service outage* persists.
- *Signal*
    - *Communicated signal*
        - *Area control error (ACE)*—an *ESI service requestor's* indication of accumulated errors concerning energy being imported into or exported from the affected circuit region. This signal's period is typically 2 – 4 seconds. This signal is needed for *ESI regulation services*.
    - *Autonomous signals—autonomous signals* are not communicated during the engage state, although they may affect various *service statuses* that become communicated.
        - *Service outage*
        - *Voltage*
            - *Voltage magnitude*
            - *Voltage frequency*—often called "grid frequency."
- *Signal record—ESI service participants* should record both *communicated* and *autonomous signals* during the *engaged state*, including precisely when such *signals* are received or measured. These histories may be needed later during *measured and verified* or *reconciled states* when *service* performance is to be calculated and verified. Record interval granularity should be specified by the corresponding *ESI service agreement's* terms.
    - *Area control error record*
    - *Voltage magnitude record*
    - *Voltage frequency record*
- *Status*
    - *Armament status*
    - *Availability status*
    - *Engagement status*—indication that an *ESI service provider's* flexible energy resources are, or should be, *engaged*. This *status* is needed for *services* like *ESI reserve services* that can be *armed* without truly *engaging* the *ESI service provider's* flexible energy resources.

    - *Service status*—indication that a *service* is either active or inactive, as introduced in *WS-Agreement*. This status would normally be asserted by the *ESI service requestor.*
- *Status record*—*ESI service participants* should record *statuses* and precisely when statuses change. These histories may be needed during the *measured and verified* or *reconciled states*.
    - *Armament status record*
    - *Availability status record*
    - *Engagement status record*
    - *Service status record*

***Measured & Verified state* objects**

- *Performance record*—these are measurements that should have been recorded during the *engaged state*. Records of these measurements might be communicated and compared as part of the verification process.
    - *Event performance*
        - *Engagement duration*
        - *Event count*
            - *Overvoltage violation count*
            - *Service outage count*
            - *Undervoltage violation count*
        - *Minimum power factor*
        - *Peak real power demand*
        - *Service outage duration*
    - *Interval performance*
        - *Interval energy*
        - *Interval real power mileage*
        - *Interval power factor*
        - *Interval reactive power mileage*
- *Scheduled object*—any *scheduled object* (defined above) may be used during measurement & verification.
- *Signal record*—these *signals* may be performance determinants, and the *ESI service requestor* and provider may need to share these records as part of their verification process.
    - *Area control error record*
    - *Voltage magnitude record*
    - *Voltage frequency record*
- *Status record*—these *records* may be performance determinants, and the *ESI service requestor* and provider may need to share these records as part of their verification process.
    - *Armament status record*
    - *Availability status record*
    - *Engagement status record*
    - *Service status record*

Settlement state objects

- *Cumulative performance*—summed performance indicators within the reconciliation period.
    - *Average power factor in reconciliation period*
    - *Cumulative energy*
    - *Cumulative engagement duration*
    - *Cumulative event count*
        - *Cumulative overvoltage violation count*

        - *Cumulative service outage count*
        - *Cumulative undervoltage violation count*
    - *Cumulative real power mileage*
    - *Cumulative reactive power mileage*
    - *Cumulative service outage duration*
    - *Maximum power factor in reconciliation period*
    - *Peak real power demand in reconciliation period*
- *Cumulative status*
    - *Cumulative armament duration*
    - *Cumulative availability duration*
    - *Cumulative engagement duration*
    - *Percent active service duration*
- *Performance record*—any *performance record* (defined above) may be used to calculate rewards and penalties during reconciliation.
- *Reconciliation period*—a *time interval* marking the precise period that is to be reconciled (e.g., a billing period).
- *Scheduled object*—any *scheduled object* (defined above) may be used to calculate rewards and penalties during reconciliation.
- *Service payment*—the cumulative payment from the *ESI service requestor* to *ESI service provider* for its performance within a reconciliation period. The calculation of this reward (or penalty) should be defined in the associated *ESI service agreement.*

Appendix C: Glossary of *ESI* Terms

The following terms are used in this report to refer to attributes and components of the *ESI*. In many instances, these terms will have been prefixed by "*ESI*" and italicized in this report to indicate their special usage:

agreement layer	Activities of the *ESI* that create an *ESI service agreement* between the *ESI service requestor* and *service provider*
armament status	An indicator that is applied by the *ESI service requestor* to an *ESI service event* in its *scheduled or armed state*. An *ESI service event* is "armed" if any condition exists that would engage the *ESI service provider's* flexible energy resources. *Armament status* may be *scheduled*.
armament status record	Historical *armament status*, including the time that the status began. Both *ESI service participants* should maintain *armament status records*, as these records may need to be verified and may be used during reconciliation.
availability status	An indicator asserted by the *ESI service provider* that its flexible energy resources are available to be *engaged*. *Availability status* may be *scheduled*. *Availability status* may be Boolean, or it may be defined by an enumeration or continuum, should a degree of *availability* be specified among service terms of an *ESI service agreement.*
availability status record	Historical *availability status*, including the time that the status began. Both *ESI service participants* should maintain *availability status records*, as these records may need to be *verified* and may be used during *reconciliation*.
basic service agreement template	The six most basic *templates* for *ESI service agreements*. These *templates* may be specialized by an *ESI service requestor* to request the *six common ESI services* from an *ESI service provider.*
discovery layer	Activities of the *ESI* by which a prospective *ESI service requestor* and *provider* discover one another and establish an *ESI*
Energy Services Interface (ESI)	Communication interface that is under development by the GMLC and is being extended by this report. The *ESI* facilitates the provision of energy services in the electricity domain.
operate state	State of a *ESI service event* while its *ESI service* is being delivered. An *ESI service provider's* flexible energy resources may be, but are not necessarily, *active (e.g., in-operation or engaged)*.
engagement status	An indicator that aggregate flexible energy resources should be engaged (from the *ESI service requestor's* perspective) or are, in fact, *operating* (from the *ESI service provider's* perspective) in an *armed ESI service event*. *Operate status* may be Boolean, defined within an enumeration, or defined on a continuum. The condition(s) under which a *service event* should operate must be defined among service terms of an *ESI service agreement. Engagement* should not be directly scheduled. See *armament status*.
engagement status record	Historical *engagement status*, including the time that the status began. Both *ESI service participants* should maintain

engagement status records, as these records may need to be verified and may be used during reconciliation.

measured and verified state	State of an *ESI service event* reached after its *ESI service* performance has been measured and verified. Exceptions must be handled by service terms of an *ESI service agreement* if such performance cannot be verified.
offered service agreement	The state of an *ESI service agreement* that is being offered by the *ESI service provider.*
settlement state	The state of and *ESI service event* after its *service performance* has been rewarded, compensated, or penalized according to service terms of an *ESI service agreement.*
register and qualify	Activities that occur within the *ESI's agreement layer*. *Qualify* refers to the automated testing of an *ESI service agreement's* requirements with an *ESI service provider's qualifications*.
schedule	The pairing of time intervals with corresponding *scheduled objects*. Scheduling may occur during an *ESI service event's schedule or arm state*.
scheduled object	Nearly any object—simple or complex—that is associated with a time interval in a *schedule*.
scheduled or armed state	State of an *ESI service event* that is reached when its *armament status* has been assigned or *scheduled*.
service agreement	A contract-like, machine-readable document that may obligate the *ESI service requestor* and *provider* to *service terms* and *service* guarantees as needed to fulfil an *ESI service*. *ESI service agreements* are derived from the *WS-Agreement's* standard web service agreements.
service agreement participant	A reference to either the *ESI service requestor* or *provider*
service agreement template	The *template* for an *ESI service agreement*. *ESI service participants* "negotiate" by populating its variables and thereby come to agreement about the terms and guarantees for provision of an *ESI service*.
service requestor	The *ESI service participant* that requests and consumes an *ESI service* at an *ESI*
service event	A unit (of time or other qualities) that is needed to measure, verify, or reconcile determinants of the performance of an *ESI service*.
service layer	Activities of the *ESI* by which an *ESI service* is delivered according to terms and guarantees in an *ESI service agreement*. These activities are modeled using a state machine that models the lifetime of a *service event*.
service provider	The *ESI service participant* that provides an *ESI service* at an *ESI* by controlling its own flexible energy resources and sometimes by requesting *ESI services* from other *ESI service providers*.
service qualifications	An *ESI service agreement template's* requirements and an *ESI service provider's* listed capabilities. This report advocates that a common list of such *requirements* and *qualifications* is needed to facilitate automated qualification of an *ESI service provider* to provide an *ESI service.*

service status	An indicator asserted by the *ESI service requestor* that an *ESI service agreement* is either operating normally and in force (“active”) or has been suspended (“inactive”). This term is inherited from the *WS-Agreement* standard.
service status record	Historical *ESI service status*, including the time that the status began. Both *ESI service participants* should maintain *service status records*, as these records may need to be verified and may be used during reconciliation.
service, or *energy service*	The product delivered when an *ESI service requestor* and *provider* fulfil their respective obligations of an *ESI service agreement*
six common energy services	The six foundational *ESI services* from which all others may be derived: blackstart, energy, frequency response, regulation, reserve, and voltage management.

Appendix D: Boolean Expression Trees

An expression tree represents nested Boolean or algebraic expressions. Each node in the tree can be either an operator (e.g., a function) or an operand (e.g., a constant, variables). An expression tree can be evaluated deterministically by using a depth first approach, and by pushing any computed value towards the root node as layers are transversed from bottom to top. A graphical overview of this process is presented in Figure D.1, where the operation *4*(2+3)* is solved using an expression tree.

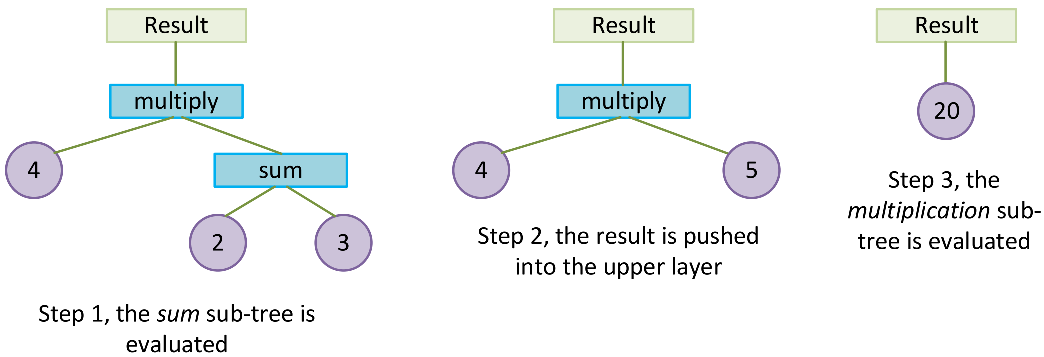

Figure D.1. A graphical example of an expression tree

Expression trees can be instantiated in multiple ways. Figure D.2 demonstrates the use of JSON for encoding the contents of the expression tree presented in Figure D.1. JSON provides a standardized way to represent data structures. JSON helps ensure consistency and reduces processing and interpretation errors while guaranteeing functional interoperability across different systems and programming languages.

```json
{
  "sampleOperation": {
    "arguments": [
      {
        "operand": {
          "arguments": [{"operand": 2},{"operand": 3}],
          "function": "sum"
        }
      },
      { "operand": 4}
    ],
    "function": "multiply"
  }
}
```

Figure D.2. A JSON example of Step 1 in Figure D.1.

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