Submission Title **Open Distributed Energy Management ESI (OpenDEM)**

Lead Organization Amzur Technologies

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Abstract

The dramatic growth in utility-scale renewable generation and distributed solar systems is radically altering the traditional utility generation portfolio and net load profile. Utility scale variable energy sources can create significant ramping challenges for Transmission System Operators. Large penetrations of distributed solar can increase the variability and uncertainty of system net load, increase the potential for over and under voltage, and introduce new complexities to service restoration for Distribution Operators. (ERCOT)

The rapid market adoption of smart inverters, smart thermostats and other load control devices, grid responsive building automation systems, energy storage and EVs is creating new opportunities to accommodate the shift from dispatchable to non-dispatchable energy sources by providing load shaping flexibility. Properly coordinating Behind the Meter customer-owned Distributed Energy Resources (DER) into grid operations can cost-effectively accommodate the inherent variability and uncertainty of solar + wind generation. A recent Wood Mackenzie Power & Renewables report forecasts 88 gigawatts of residential flexibility potential in the United States by 2023. (Wood Mackenzie)

Yet seamless interoperability between various stakeholders, systems, and devices remains one of the greatest Smart Grid challenges. The power industry has a confusing array of communication and control standards, protocols, and data models. The various systems, standards and technologies were developed at different times to address specific technical challenges or business requirements.

The Plug and Play DER challenge seeks to reduce the cost and complexity of DER integration for utilities, product and service providers, and asset owners and managers by developing a bi-directional Energy Services Interface that "supports the secure communication of information between entities inside and entities outside of a customer boundary to facilitate various energy interactions between electrical loads, storage, and generation within customer facilities and external entities." (DER Challenge)

We propose an Open Distributed Energy Management (OpenDEM) ESI designed to increase market participation of DER assets by driving down the cost and complexity of provisioning devices, systems and buildings. OpenDEM shall support auto-enrollment, distributed coordination, resource aggregation, and optimization across a wide and dynamically evolving range of devices and energy systems at multiple temporal and spatial/grid scales and verify service delivery. This will allow system operators and service providers to schedule and commit a significant capacity of dispatchable DER assets into planning and operational time horizons.

The Energy Services Interface – OpenDEM

ESI Current State of the Art

The Gridwise Architecture Council (GWAC) has identified interoperability has one of the key challenges to incorporating Behind the Meter (BTM) DER assets into power system operations. GWAC characterizes interoperability as follows:

- exchange of meaningful, actionable information between two or more systems across organizational boundaries

- a shared understanding of the exchanged information
- an agreed expectation for the response to the information exchange
- a requisite quality of service: reliability, fidelity, and security.

The result of such interaction enables a larger interconnected system capability that transcends the local perspective of each participating subsystem.

A commonly understood objective for interoperability is the concept of "*plug-and-play*". With plug-and-play, the system integrator is able to configure an automation component into the system simply by "plugging" it in. Behind the scenes, automated processes determine the nature of the newly connected automation component and the component determines the nature of the system so that it is properly configured and can begin to operation properly. The "distance to integrate" for plug-and-play is small (see Figure 1).

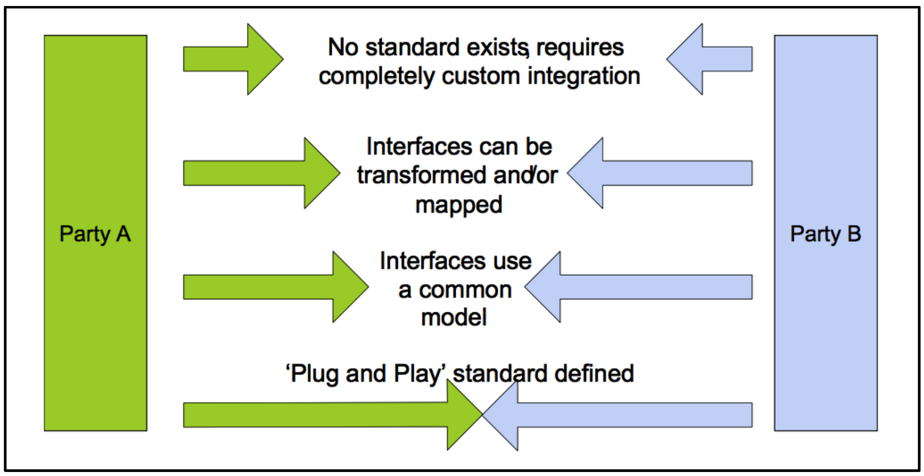


Figure 1 Level of Integration

The current state of the maturity of ESIs is well summarized in the previously cited March 2018 GMLC White Paper:

- Typically, there are proprietary technologies and interfaces between aggregators (traditional DR as well as smart thermostat and energy storage system (ESS) providers) and DER facilities. This translates into reduced competition, high switching costs, and, more commonly, vendor lock-in.
- Grid service descriptions, performance characteristics, and interfaces are not standardized across wholesale market operators. This increases the cost of implementations, deployments, and on-going support.
- Little interoperability and harmonization of communication protocols and capabilities across devices and systems (Electric Vehicles, solar PV inverters, ESS, building and energy management systems, smart thermostats). This increases the cost and complexity of implementations.
- Typically, standards support direct device control rather than service-oriented messaging. This generally lowers participation rates and can increase costs (oversubscribe to resources based on state uncertainty).
- Most DERs operate without meeting any cybersecurity requirements.

Additionally, the current “low-performance hub and spoke (distribution) networks and multiple, non-converged communication systems” are ill-suited to meet the need of “increasingly fast distribution dynamics caused by the insertion of…rooftop solar into the distribution grid, the participation of buildings as sources of services to the grid, and the introduction of market mechanisms.” (Taft, 2016)

In short, the State-of-the-Art is a State of Confusion – a competing mix of open and proprietary communication and control standards, data and information models developed at various times for different communities and Use Cases, a lack of standardized descriptions of grid services and delivery methods, no coherent application of cybersecurity Best Practices, and an outdated network architecture. Implementation complexity is high. Market participation is low.

The ESI Foundation - OpenADR

The OpenDEM ESI is based on the Open Automated Demand Response (OpenADR) framework and specification. OpenADR is a recursive, decentralized architecture where authority and control for distributed assets is delegated to a network of autonomous actors (nodes). An autonomous actor can be a physical device, an on-premise system (e.g. a BMS/EMS), or an aggregation of homogeneous or heterogeneous resources managed by a utility or third-party service provider. Similar functional nodes are distributed over the network in such a way as to control a group of nodes and individual resources in a completely abstract and flexible manner. Each node has identical upstream and downstream functionality. Functionally, the nodes are interchangeable. The OpenDEM ESI specifies a shared layered databus rather than more traditional polling and asynchronous event messaging. This framework can be viewed as a combination of multi-layer hub-and-spoke and peer-to-peer forms arranged in a hierarchical self-similar structure. Coordination frameworks based on the use of layered decomposition and “information in motion” have been designated Laminar Coordination Frameworks. (Taft, 2016)

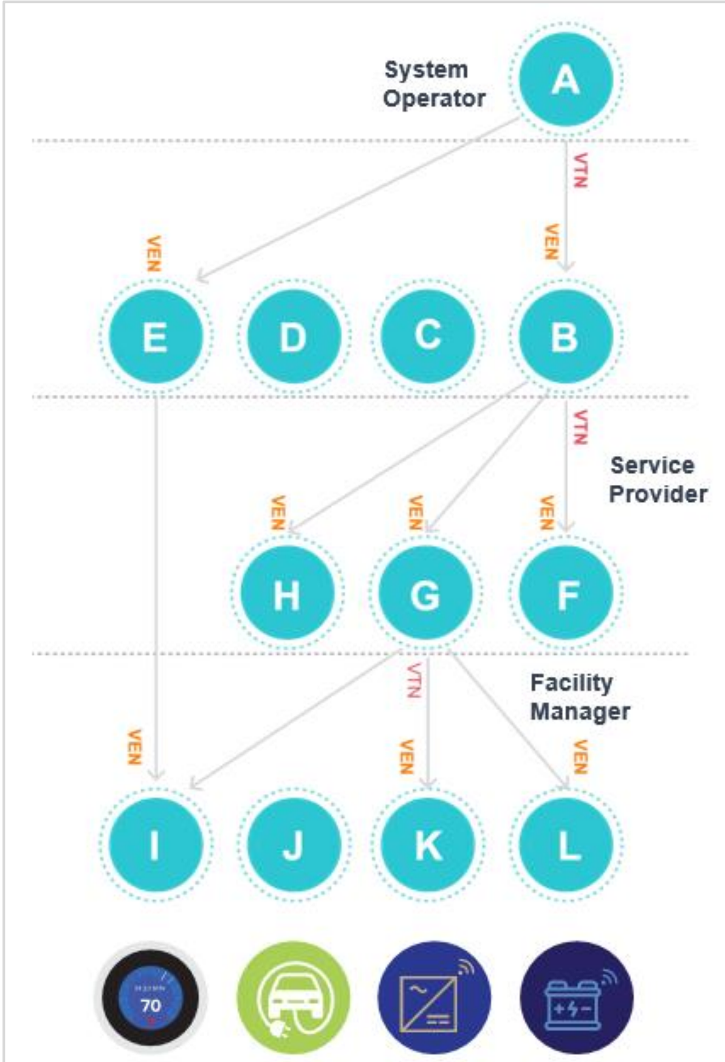


Figure 2 OpenADR Recursive Architecture

A recursive architecture can form arbitrary and ad hoc groups of resources. And a group or resource may belong to one or more groups. The groups may belong to an Regional Transmission Operator, a Load Serving Entity, or a service provider/aggregator or portfolio manager to support any number of business models.

OpenADR is based on OASIS Energy Interop, an information and communication model that is incorporated by reference or consistent with several key DER standards, including IEEE 2030.5, the Facility Smart Grid Information Model (FSGIM/ISO 17800), and the NAESB Energy Usage Information Model. OpenADR includes comprehensive performance and test specifications, Protocol Implementation Conformance Statements, a test harness and appointed test houses. Over 60 utilities and controls vendors have already announced or deployed OpenADR-based systems across the U.S. and internationally (OADR).

OpenADR is well-suited to provide broad support for existing and future DER technologies and building and distribution automation systems. In a two-year, end-to-end DER Communications and Control development and demonstration collaboration between EPRI and NREL, OpenADR was used to abstract DER and DR resource capabilities to integrate with an advanced distribution management system (ADMS). The OpenADR architecture was selected because it supports scaling both horizontally and vertically. (NREL, 2017)

In short, OpenADR provides a mature, field proven, secure, and scalable template for OpenDEM.

Filling in the gaps: OpenDEM

We propose several significant extensions and changes to the OpenADR specification.

OpenDEM enhancements include:

1. Autoenrollment
2. Group Management
3. Short-term forecasting of DER availability and capacity
4. Real-time visibility to hidden load and power quality
5. Simplified market mechanism for autonomous service delivery

Auto-Enrollment

OpenDEM uses the OpenADR Virtual End Node (VEN) pattern as the basis for device communication and control. In the context of OpenDEM, "VEN" will specifically refer to terminal OpenDEM network participants, such as a VEN device (e.g. EV charger, thermostat, inverter, energy storage system) or a VEN software client (e.g. building automation systems or microgrid controller), that are directly associated with one or more pieces of DER equipment. OpenDEM shall require VEN implementations to include a default auto-enrollment configuration with a predetermined initial registration network location (manufacturer or default service provider). At registration, the end user or installer shall select a Service Provider, which may be a manufacturer (e.g. Tesla, NEST), a hardware agnostic third-party aggregator, a system operator or a local facility management device. During registration, the end user or installer will be asked to provide the physical location of the device or system being registered.

Location-Aware Group Management

No interface is an island. Similar to OpenADR, the OpenDEM specification is recursive. Unlike OpenADR, it is tied to the physical topology of the Local Distribution Area (LDA), which includes all assets below a transmission/distribution interface. To support aggregators aligning non-contiguous DER resources to utility system topology, OpenDEM shall require that VENs within an LDA be assigned to Local Coordination Areas (LCAs), which represent subsets of the distribution area based on the physical grid topology. It should be noted that the recursive structure of OpenDEM can accommodate additional layers of Local Coordination Nodes (LCNs). Based on the maturation of a utility's distribution investments or on specific requirements, e.g. implementing a Non-Wires Alternative, LCNs may be fine-grained (at the section level) or represent a specific substation or the entire distribution areas. To aid in VEN assignments, System Operators shall maintain a geospatial databus that publishes Local Coordination Node IDs (LCN_IDs) corresponding to LCAs within their LDAs. During the registration process, the Service Provider shall identify and assign the VEN the appropriate LCN_ID.

The Service Provider shall publish a dynamic and anonymous aggregation of all device and system capabilities within specific coordination areas to the Local Coordination Node databus – See Figure 3.

At the level adjacent to the VENs are Private Coordination Nodes (PCNs), to which all VENs within the same Coordination Area are connected. No device specific information – physical location, ownership, usage patterns, etc – shall be externally published beyond a PCN. A LCN ESI shall only expose (publish) aggregated and anonymous capacity and availability of energy and power services to the Coordination Area bus.

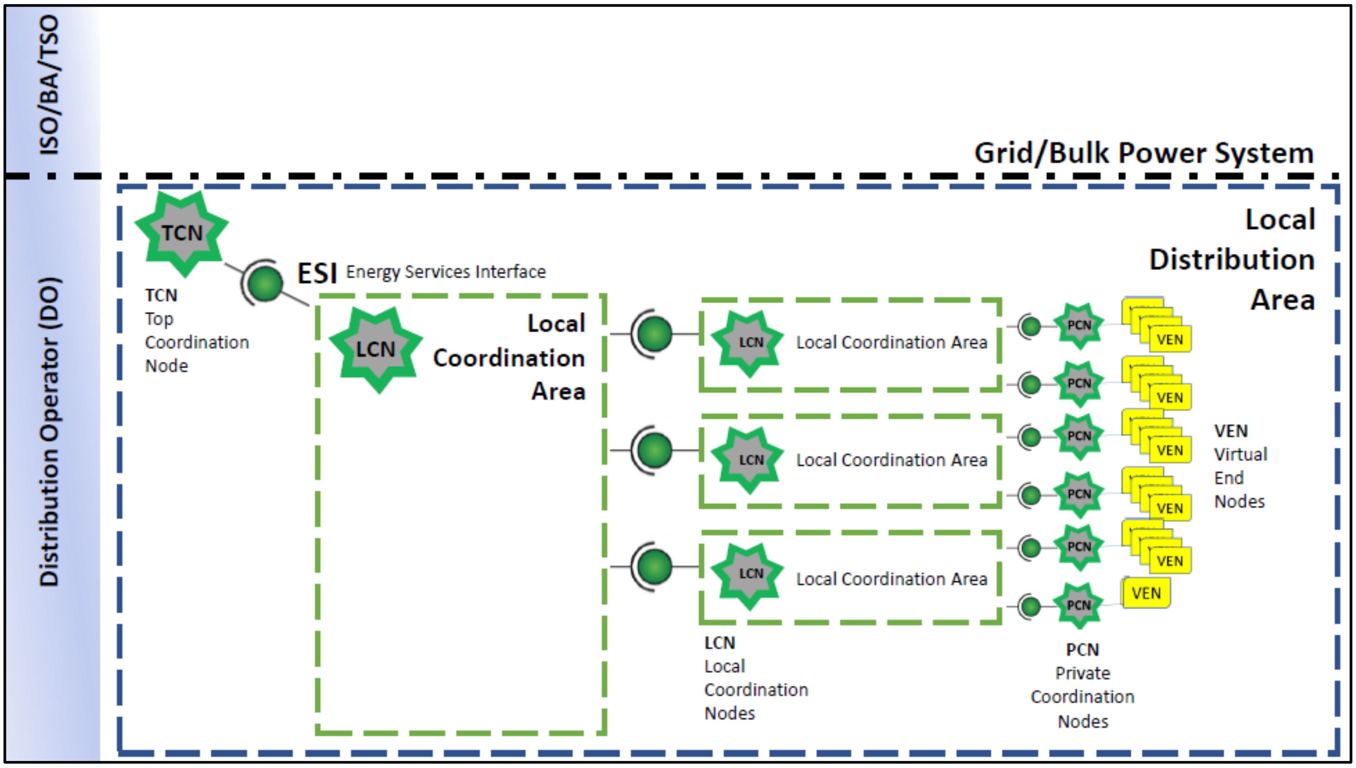


Figure 3 Local & Private Coordination Nodes

In Advanced Networking Paradigms for High-DER Distribution Grids JD Taft outlines a multi-tier distributed architectural framework, consistent with the OpenADR specification, to realize “the full potential for extracting the latent capacity and performance available in distribution systems with DER on a real time basis”.

The properties of the Laminar Coordination Framework include:

- Extensibility – can be built out incrementally and be extended as grid structure changes.
- Boundary deference – allows creation of an interface to accommodate a system or organizational boundary.
- Local objective support (selfish optimization) – local constraints easily introduced at each interface.
- Constraint fusion – by adding constraints at each coordination node, local constraints are accommodated in a distributed fashion. This reduces the amount of information that needs to be communicated to higher coordination levels and reduces computational complexity.
- Scalability – coordination signals do not need to aggregate up or down the coordination chain. New layers can be created if a coordination node gets too large. (Taft, 2016)

Balancing Authorities and Load Serving Entities shall publish a geospatial database of coordination areas.

Service Providers shall automatically, dynamically and anonymously publish aggregated device and system capabilities (energy, power, ramp time, duration, response time) to the appropriate Coordination Node databus. The databus may represent a balancing area, distribution network, or a specific substation depending on the granular level of coordination support implemented by system operators.

It is difficult to overstate the importance of integrating OpenADR, the Laminar Coordination Framework and OpenFMB. Architecturally this integrates a mature, location independent architecture (OpenADR), with an emerging location-specific field message bus that supports near real-time communications without the overhead of polling and verbosity of XML (OpenFMB), with a conceptually powerful schema to reduce the computational intensity of accommodating millions of devices (Laminar Coordination).

Short-term forecasting of DER availability and capacity

OpenADR does not support the publishing of DER availability based on short-term solar and weather forecasting, user-defined constraints and behavioral patterns. OpenDEM shall implement the Availability and Opt schedules, as specified in Energy Interop, which can support these requirements. This granular responsive load and generation, including energy storage, visibility is essential to reduce the inherent uncertainty of short-term forecasting of available resources.

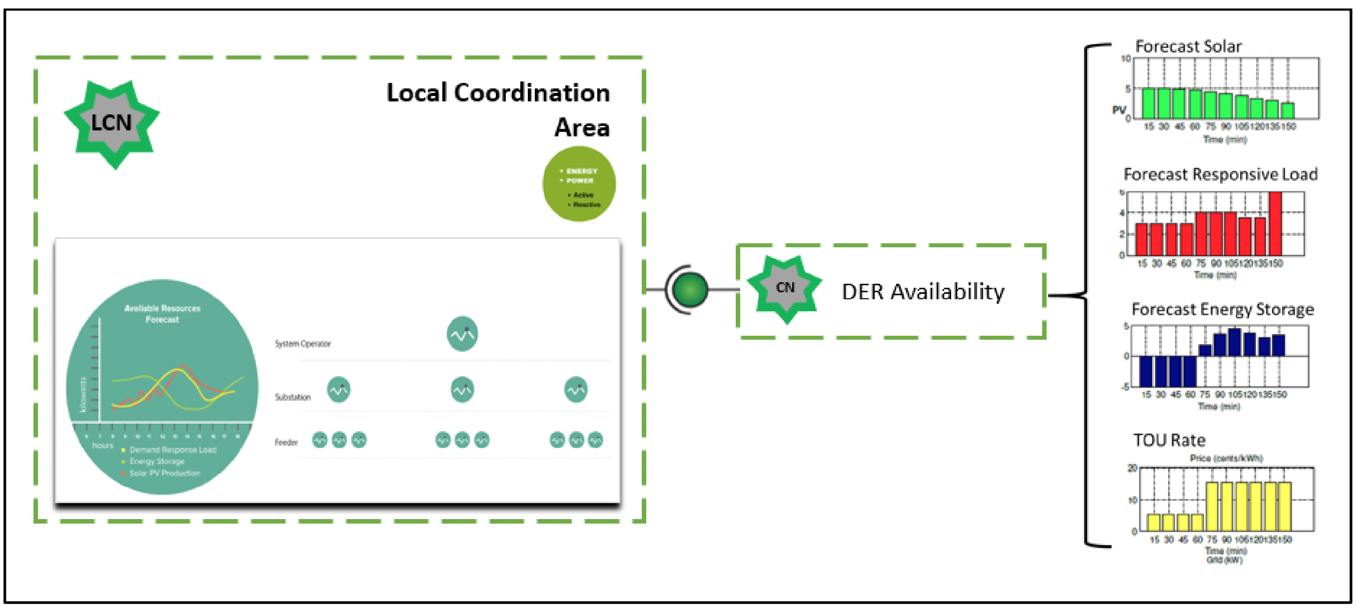


Figure 4 Available Resources Aggregation

Real-time visibility of hidden load and power quality

Currently, rooftop solar generation is operationally invisible to utilities. Greater visibility of instantaneous measurements of real and reactive power, frequency, voltage per phase and operational energy storage can provide essential situational awareness of grid conditions and reduce short-term uncertainties regarding generation variability and actual rather than net load. The data format will be based on the OpenFMB Solar and ESS measurement profiles which include observations and forecast values. The OpenFMB profiles are based on a harmonization of CIM and IEC 61850.

Simplified market mechanism for autonomous service delivery

OpenDEM simplifies grid or distribution service requests. Based on scheduled resource commitments and anticipated balance requirements, the Top or Local Coordination Node shall publish a request via price or a regulation signal for energy supply/demand response for specific time intervals or active or reactive power with specific response guarantees. Based on the availability, capacity and user defined constraints and triggers, Private Coordination Nodes will commit available resources.

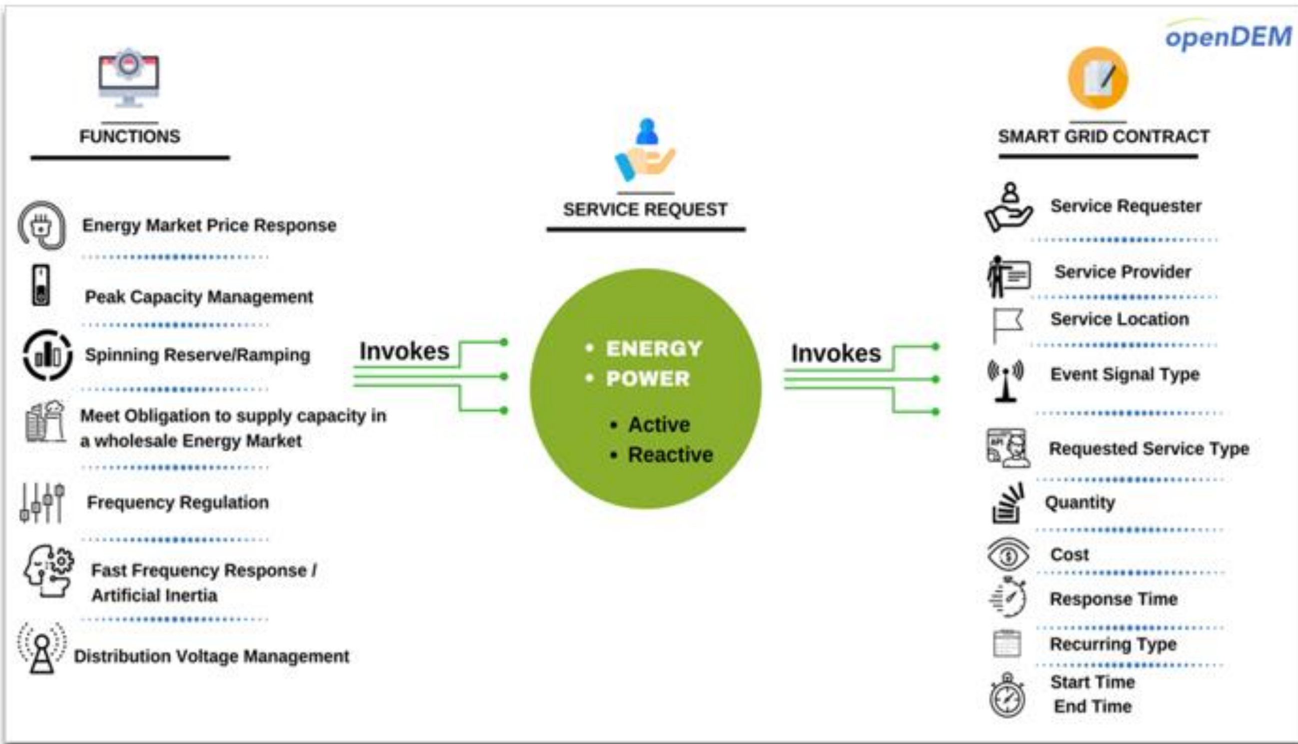


Figure 5 Service Requests

The OpenDEM ESI shall also support smart inverters, energy storage systems and load controllers that can autosense utility supply voltage and autonomously respond to grid conditions based on predefined terms, performance criteria and proof-of-service. VENs will pass service receipts to Service Providers, which will aggregate responses by LCN_ID (and thereby anonymize VEN locations). Service Providers will pass aggregate service receipts to utilities, which can verify the accuracy of the reported actions through comparison with measurements taken from corresponding parts of the distribution system.

The Architecture – An Advanced Distribution Network

Background

An ESI itself is insufficient to address the computational and management complexity of coordinating millions of devices and systems in near real-time given the peculiarities of device types, the inherent latency of communications and control, and the competing operational objectives of a wide and ever-evolving set of stakeholders and technologies. It is also essential to address the physical topology of the grid itself. The traditional Distribution Management Systems (DMS) are ill-suited to accommodate overlapping, multi-player (DER aggregators) coordination and control of Local Distribution Area DER systems and devices. We propose to link a market-oriented recursive architecture, OpenADR, with an architecturally compatible conceptual coordination framework, Laminar Coordination, with a physical field area network, OpenFMB. To be clear, this is not an Advanced DMS, it is an Information Technology *network*. In normal usage, the terms network and system are used interchangeably. In the IT industry a system administrator manages a computer system and a network administrator manages a network of computers, systems and devices.

> **Re-inventing the Wheel**
>
> The wheel is being continually reinvented. The water wheel ignited the industrial revolution. The color wheel revolutionized color science and design. Each re-invention stayed true to the original 360^{o} wheel pattern.
>
> We propose to advance the state-of-the art in DER interoperability by extending two distinct patterns an existing Energy Services Interface, OpenADR, and an industrial architectural pattern, the Industrial Internet Connectivity Framework, that is architecturally compatible with the Laminar Coordination Framework proposed by PNNL.
>
> The new patterns are an *OpenDEM ESI* and an *Advanced Distribution Network*.

Architectural Framework - IICF

ADMS systems are an evolution of the same SCADA master-slave architectural pattern that is well-established in the utility sector. We propose an alternative architecture, based on the Industrial Internet Connectivity Framework (IICF). The Industrial Internet Consortium (IIC) was formed in 2014 to address the shared challenges across many industries in accommodating rapid technological change. With more than 250-member companies, the IIC focuses on three key areas: interoperability between devices and applications from the edge to the cloud, end to end security of the systems, and a common reference architecture across multiple domains and industries. The IIC has published detailed guidance in all of these areas. The IICF represents the accumulated best practices and architectural wisdom learned during the creation of the world's largest and most critical systems. Balancing the needs of scalability, security, reliability and performance while supporting legacy protocols, multiple transports and the integration of brownfield equipment, the IICF lays out the technical and business 'hows' and 'whys' of large-scale industrial networked systems.

Our proposal leverages the guidance of the IICF to address the interoperability requirements in the DER Plug and Play Challenge. Two of the IICF core connectivity standards are used: Data Distribution

Service (DDS) for the software and legacy equipment integration, and HTTP/REST for the web and mobile data interfaces of the ESI. This enables our proposal to meet and exceed the functionality put forth in the challenge, and to be prepared for the foreseeable if not inevitable future expansion beyond the challenge.

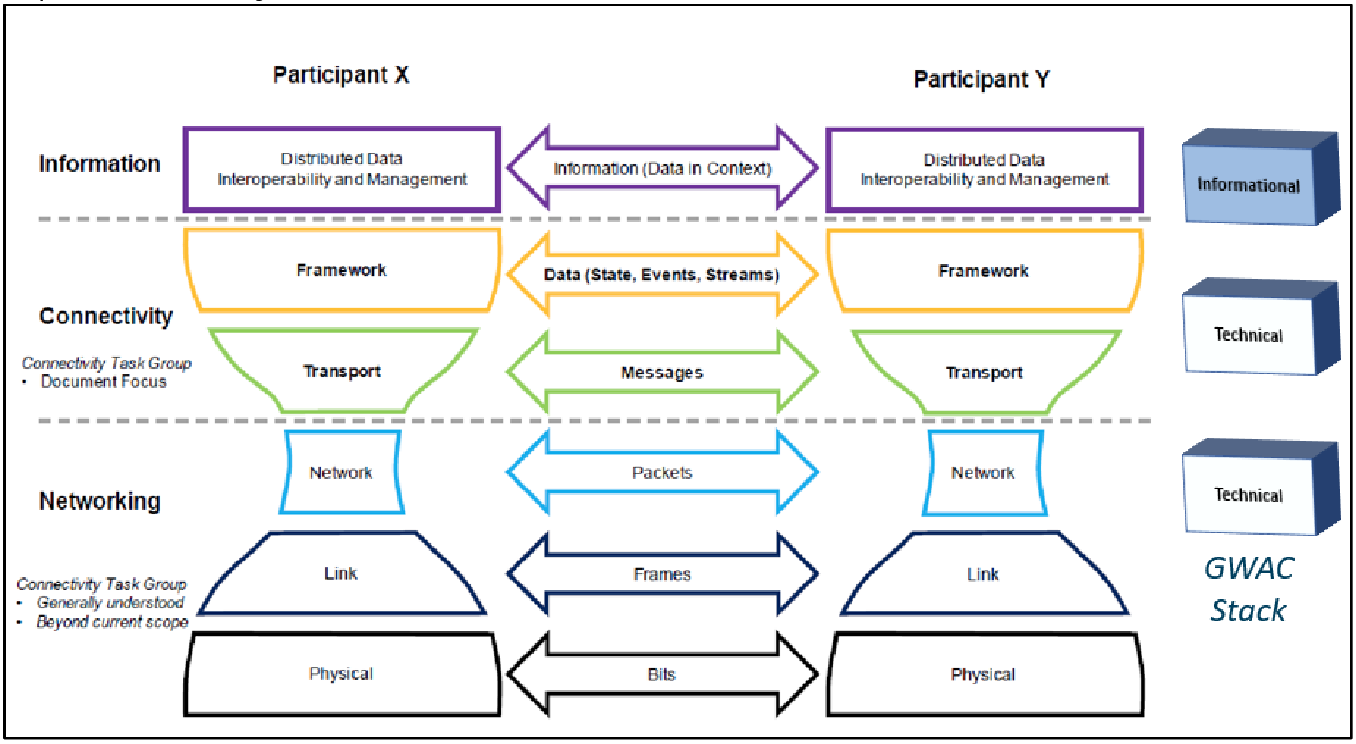


Figure 6 Industrial Internet Connectivity

We see a need for standards that provide for Pragmatic Interoperability (Figure 7) for key DER Management interfaces, in particular for the ESI. Pragmatic Interoperability is reached when the interoperating systems are aware of the methods and procedures that each system is employing. In other words, the use of the data – or the context of its application – is understood by the participating systems.

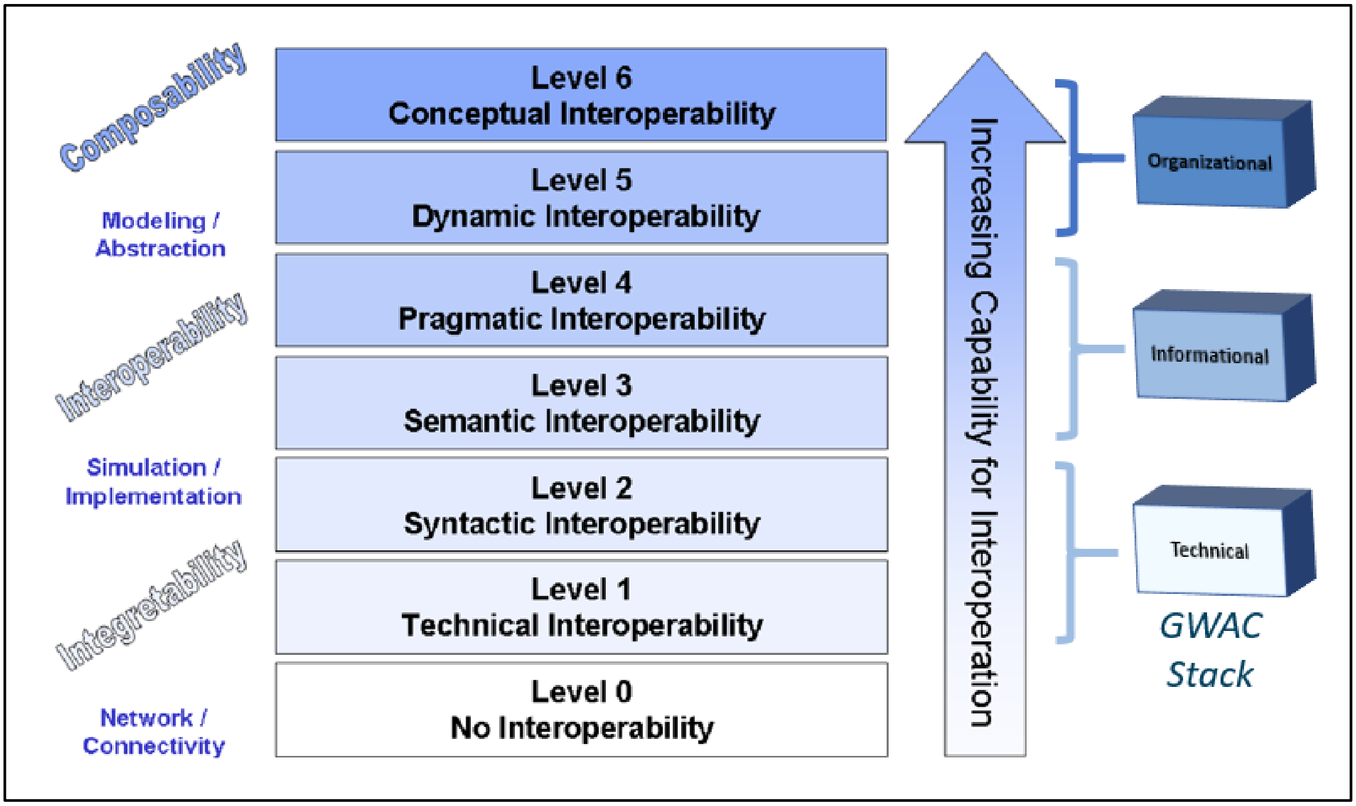


Figure 7 Levels of Interoperability

Our team proposes using an IIoT field deployed and proven *layered databus* approach to the overall architecture. The benefits are numerous:

- Local traffic stays local. Pertinent, secured, valuable information that is needed elsewhere is seamlessly transformed to the location.
    - Inside a building, facility or campus, there may hundreds of DER devices. These devices would be on a shared Databus that is specific to the needs and conditions of the localized ecosystem.
    - Our ESI allows an owner/aggregator/utility/etc to monitor and/or control individual components *so long as agreed and accepted to by all parties.*
- System traffic is securely maintained by the System (or aggregator, or Utility, etc.): Pieces of data from the Local environment will be of high value to [potentially] multiple parties. Through secured “publish and subscribe” functionality – and routable functionality at that, data is placed where needed – acknowledged, and layered with Quality of Service (QOS) configurations that include persistence, durability, acknowledge/not-acknowledged, filtering, and so on.
- Transactional data is stored in secured time series environment (i.e. InfluxDB, OSIsoft PI System, Cassandra – all have DDS integrations).
- The Bulk Power System benefits from data being securely empowered through DDS and the layered databus approach; data can be moved, shared, empowered through fine grained access rather than application file transport mechanisms.

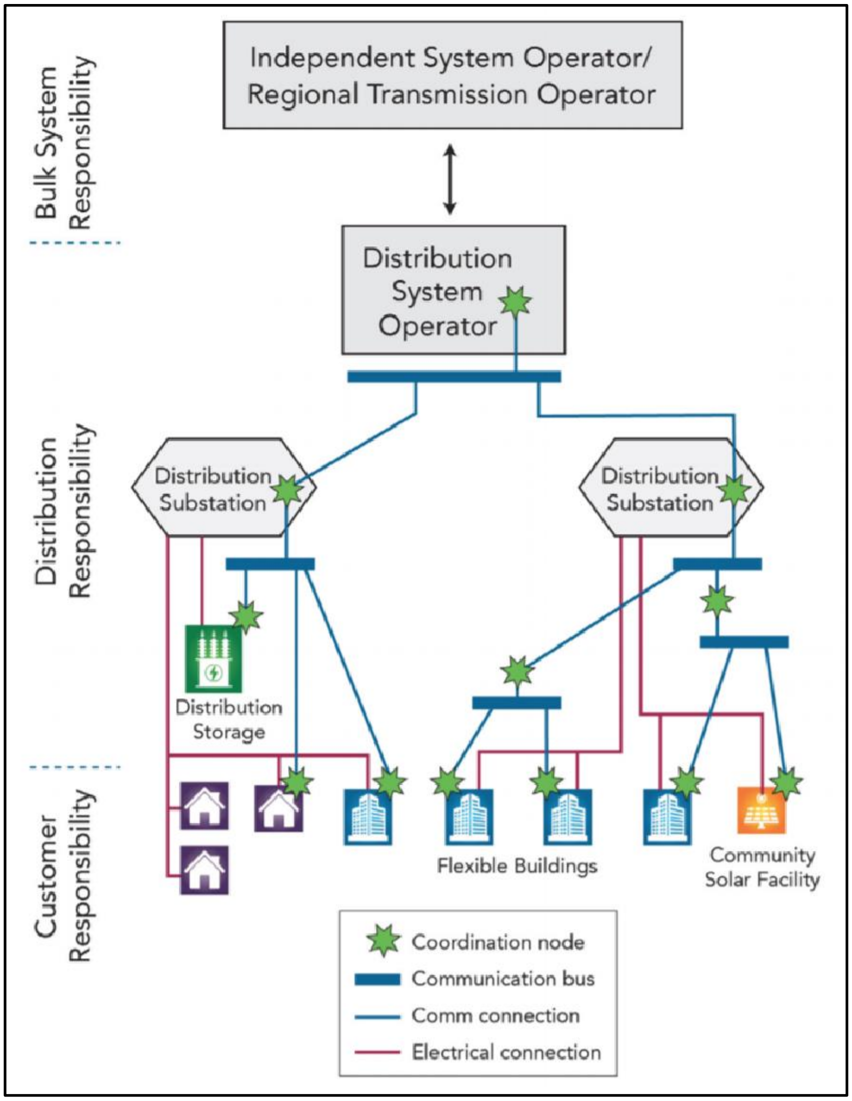


Figure 8 Layered control and interfaces

The DDS databus is fully compatible with the layered architectural pattern envisioned with the Laminar Coordination Framework illustrated in Figure 8 (Taft, 2016). DDS is fully deployed in nearly 1 million installations across the IIoT. Duke Energy has deployed DDS as the messaging bus in their OpenFMB-compliant proof-of-concept DER control and management systems. The OpenFMB standard is now managed by UCAiug (and formerly SGIP/SEPA). OpenFMB is based on the IEC 61850 data model and its peer-to-peer pub-sub reference implementation is consistent with the IIOT architectural principles and Best Practices guidelines. The Use Cases with DDS deployed systems include: Volt/VAR Optimization, Microgrid Islanding & Resynchronization, Peak Shaving with Demand Response, and Demand Smoothing .

Datacentric

The data-centric nature of DDS enables new gateways (nodes) and application modules (apps) to be easily added to support new protocols and internal capabilities. DDS is an IICF core connectivity standard, and it brings more than just simplified interoperability:

- **Discovery** DDS is already a proven 'Plug-and-Play' technology with a built-in automated discovery process. New participants are discovered immediately after joining the network.
- **Security** DDS-SECURITY is a standards-based, granular means of encryption / authentication /authorization of individual data topics and participants. DDS secures the payload, not the pipe.
- **Persistence / History** DDS supports maintaining a history of the last (n) data samples for every participant. Late-joiners to the network are immediately updated with the most recent data values; this can be important when using radio-linked / unreliable connections.
- **Liveliness and Failover** DDS has support for low-overhead "I'm alive" status updates from participants, with an automatic failover to alternate participants if a deadline is missed.
- **Quality of Service** Detailed control over reliability, deadlines, history, filtering, etc. are available on a per-topic / per-participant basis. DDS has been extensively proven in the most constrained and demanding application environments.
- **Transport Independent** DDS operates independently of the underlying transport technology – TCP, UDP, TLS, Shared Memory, Serial, Backplane, IP Radio, etc. – and it offers simultaneous support of multiple transport types. The intrinsic benefits of DDS (Security, Reliability, Persistence, etc.) are available regardless of the underlying transport.
- **Data-Centric** DDS is a data-centric technology, which eases software integration and simplifies bridging to other protocols such as DNP3, IEC 61850, etc. Data values (voltage, phase, status) are handled directly, not wrapped in a protocol-specific command.
- **Portable and interoperable**
    - Based on an OMG standard to assure interoperability at the software API, wire protocol, and security levels.
    - Support for popular programming languages: Java, C, C++, C#, Python, Ada, more. o Supported on most popular platforms and operating systems.
    - Available for constrained platforms (such as embedded microcontrollers) and safety certifiable applications.
    - Professionally-supported commercial and open-source implementations are available.

Information in Motion

A layered databus architecture enables a fundamental advance in distribution area communication and coordination capabilities. In Advanced Networking Paradigms for High-DER Distribution Grids the author underlies the importance of a new paradigm for information exchange – a shift from the traditional hub-and-spoke data transport to an information-in-motion platform.

> *"The information-in-motion paradigm means that sensors can stream data and "publish" their data streams, and user applications can subscribe to sensor datastreams as needed. This is generally referred to as a pub/sub model and is used in enterprise IT systems design."*
>
> *By re-structuring the normally vertically-siloed sensor/network/data collection head end/application stacks of various distribution grid systems such as AMI, SCADA, and DERMS and*

then by partitioning horizontally to group the sensors and communications network into a single structure, it is possible to separate the silos and decouple the applications from each other. This produces a sensor network for distribution grids that eliminates the need for back end exchange of sensor data among application systems and provides flexibility and scalability for both centralized and distributed systems." (Taft, 2016)

The Local Distribution Area communication structure combines a multi-layer hub-and-spoke and peer-to-peer forms in a self-similar structure. At the Transmission- Distribution Interface is a Top Coordination Node (TCN) that has aggregated resource feeds from subordinate LCNs. LCNs can be nested – substation, feeder, circuit. DER resources are anonymously aggregated and published by PCNs that may be on-site single point of controls or Service Provider aggregations representing homogeneous or heterogeneous resources available within a system operator defined Local Coordination Area – see Figure 9.

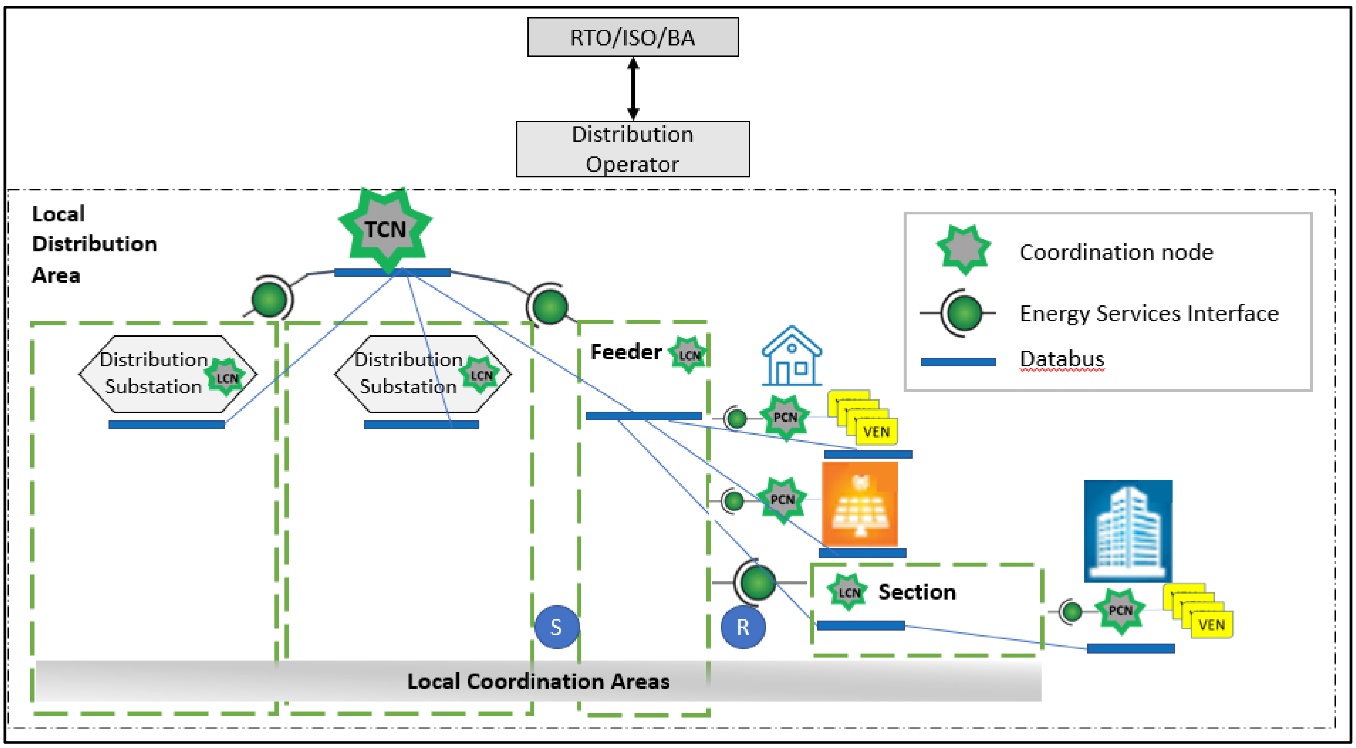


Figure 9 Information in Motion

Relationships between grid and DER facility, and facility management function and DER

As described earlier, the OpenDEM network is aligned with the physical topology of the Local Distribution Area. Device and facility management will be performed by PCNs. A single facility may include multiple PCNs or a local Energy Management System or Service Provider may manage all on-site devices as a single PCN. A PCN may manage one or more VENs and a VEN may manage one or more devices. VENs connected to the same PCN can optionally share a private databus for coordination - see Figure 9.

The Implementation Narrative

Market Service Provider (MSP) works with wholesale energy providers and Distribution Operators to create flexible long-term, 10-day, next-day and same day power and energy service contracts. A contract is initiated with a request and response and executed with a commitment and proof-of-service as shown in Figure 10.

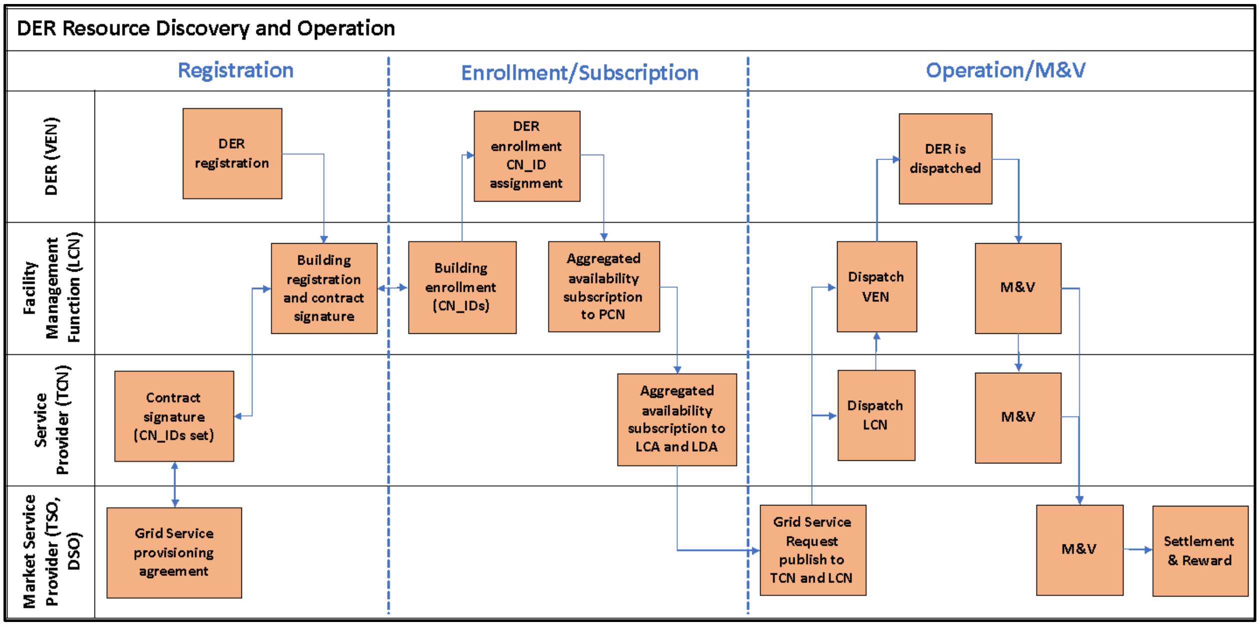


Figure 10 – OpenDEM Process Overview

OpenDEM Overall Integration Process description:

1. Registration
    a. Agreement and Contract signature between utility/aggregator and Aggregator/Building-DER owner
    b. Facility-based PCN registration (if applicable)
    c. VEN registration

2. Enrollment and Subscription
    a. VEN enrollment: LCN_ID assignment
    b. Service providers (SP) publish aggregated availability and capacity of resources to local distribution area and local coordination area databus
    c. VEN subscribes to PCN requests and offers DER capacity and availability consistent with service delivery terms of request

3. Operational Interaction
    a. MSP publishes grid or local requests for energy or power services to TCN and LCN databus
    b. Requests, offers, commitments and proof-of-service are made through agent-based ESI APIs
    c. Each facility-based PCN or VEN can opt out if it will not participate to the service provisioning event

4. Measure and Validation (M&V)
    a. In monthly billing period, MSP, SP and Building Operators (BOs) reconcile contract performance.

Verification and Settlement

A utility revenue meter can only provide proof-of-service for energy agreements to limit total facility demand at the point of common coupling for a specific interval, typically 15 minutes. This limits the applicability of the utility meter for regulation services requiring faster response times. Some areas may have smart meters that can address this issue by offering direct streaming of real-time data. The utility meter may also not be ideal as the source of proof-of-service for an aggregation of a fleet of devices within a Local Coordination Area since specific responsive loads may be difficult to disaggregate from the load profiles of multiple locations. This is of particular concern when a single facility contains DER equipment managed by multiple Service Providers. The facility operator will have difficulty evaluating the relative effectiveness of the different Service Providers by examining only monthly electricity bills. For such cases, we anticipate the need for low-cost revenue grade submetering to ensure accurate proof-of-service delivery. Some DER equipment, such as smart inverters or energy storage systems, will typically already possess internal metering capabilities. Finally, we propose that next-generation OpenDEM-compatible network modules offer an interface for equipment-level meters or be required to provide metering capabilities. And we will explore the potential of implementing self-executing Smart Contracts for automated settlement.

The Demonstration

There will be three demonstration sites: the microgrid located at the School of Engineering at the University of St Thomas in Minneapolis, at the Historic Green Village in Anna Maria, Florida, and at OSIsoft headquarters in San Leandro, California.

System functions

The team will demonstrate the automated enrollment process, scheduled commitments, as well as user opt-in/opt-out capability via a mobile app notification.

The ESI will communicate aggregated Day-Ahead and Real-Time Resource Availability schedules, prices, and bid responses to the next tier Local Coordination Node. The ESI is the same interface at each tier (system boundary) – the DER facility, feeder, substation, DSO, and in the wholesale market.

Demonstrated Grid Services

The demonstration shall require a PC with a web browser to connect to remote sites.

At the Historic Green Village in Anna Maria, Florida, we will demonstrate 8 smart thermostats that shall provide an aggregated capability to provide grid services. The BTM Private Coordination Node (PCN) shall aggregate and publish the BTM DER energy capacity available for Day Ahead and Real-Time Energy trading. To support the aggregation of DER capacity and availability requires accurate generation and load estimations at hourly and 5-minute intervals. The system utilizes advanced data analytics, and artificial intelligence to estimate uncertainty, coordinate heterogeneous devices, and maintain user-defined and physical constraints. Capacity, availability, response time, ramp rate, bids and offers, and Proof of Service are expressed through the ESI. Users may opt-in to Day-Ahead Market schedules to be accessible from their personal iCalendar. iCalendar is supported by Apple, Google, Microsoft and many others. Users may cancel Day Ahead commitments at any time without penalty. Users may opt-out of emergency condition and peak pricing notifications.

Regulation services shall be demonstrated at the University of St Thomas Renewable Energy Facility (USTREF) microgrid, in Minneapolis MN. The inverters will autosense voltage and frequency, automatically provide active or reactive power as needed, and generate/transmit an OpenDEM transaction record (EMIX warrant) based on a pre-determined price for watts or VARs provided. We shall also demonstrate the ESS entering a charge or discharge cycle based on price signals given user-defined economic dispatch rules.

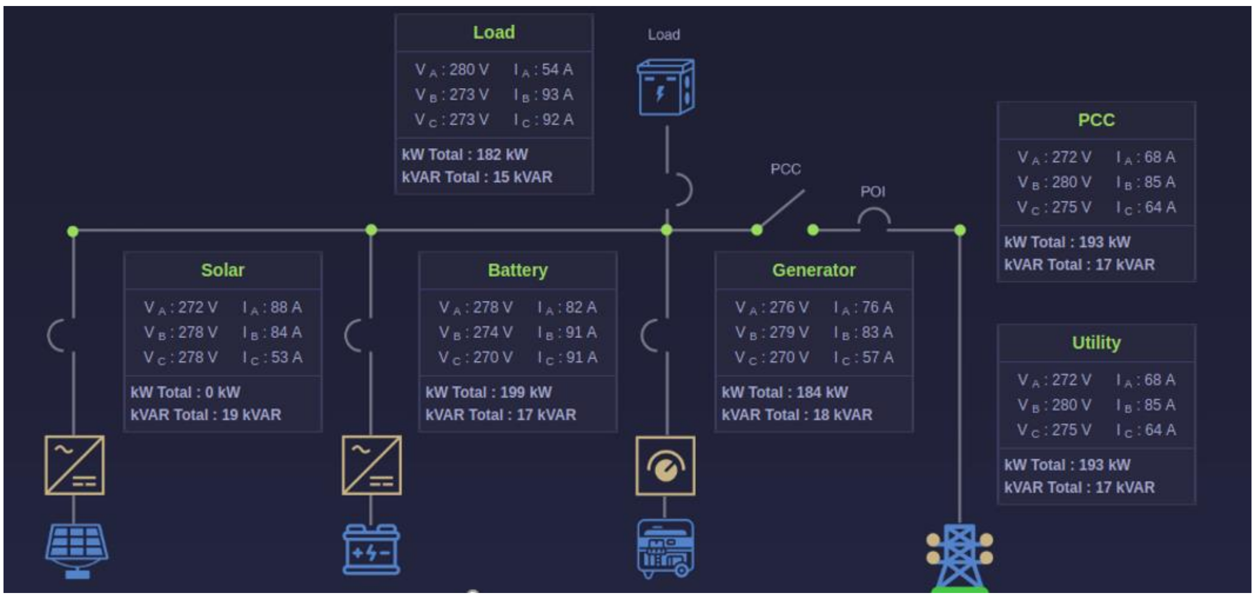


Figure 11 USTREF Microgrid Dashboard

At OSIsoft Headquarter in San Leandro, we will demonstrate several types of Distributed Energy Resources coordinated by a Microgrid Controller that shall provide an aggregated capability to deliver grid services (Figure 12). The BTM Private Coordination Node (PCN) shall aggregate and publish the BTM DER energy capacity available for Day Ahead and Real-Time Energy trading. Due to PG&E Share My Data and Stream My Data service availability, we will be able to show how DER physical location association can be automated to streamline and simplify user experience and how the Measurement and Verification process could be enhanced.

A local microgrid controller will manage locally aggregated DER capacity and availability, estimating local generation and load consumptions at high speed data resolution. Capacity, availability, response time, ramp rate, bids and offers, and Proof of Service are expressed through the ESI. Users may opt-in to Day-Ahead Market schedules to be accessible from their personal Web Application profile. Users may also cancel Day Ahead commitments at any time without penalty. Users may opt-out of emergency condition and peak pricing notifications.

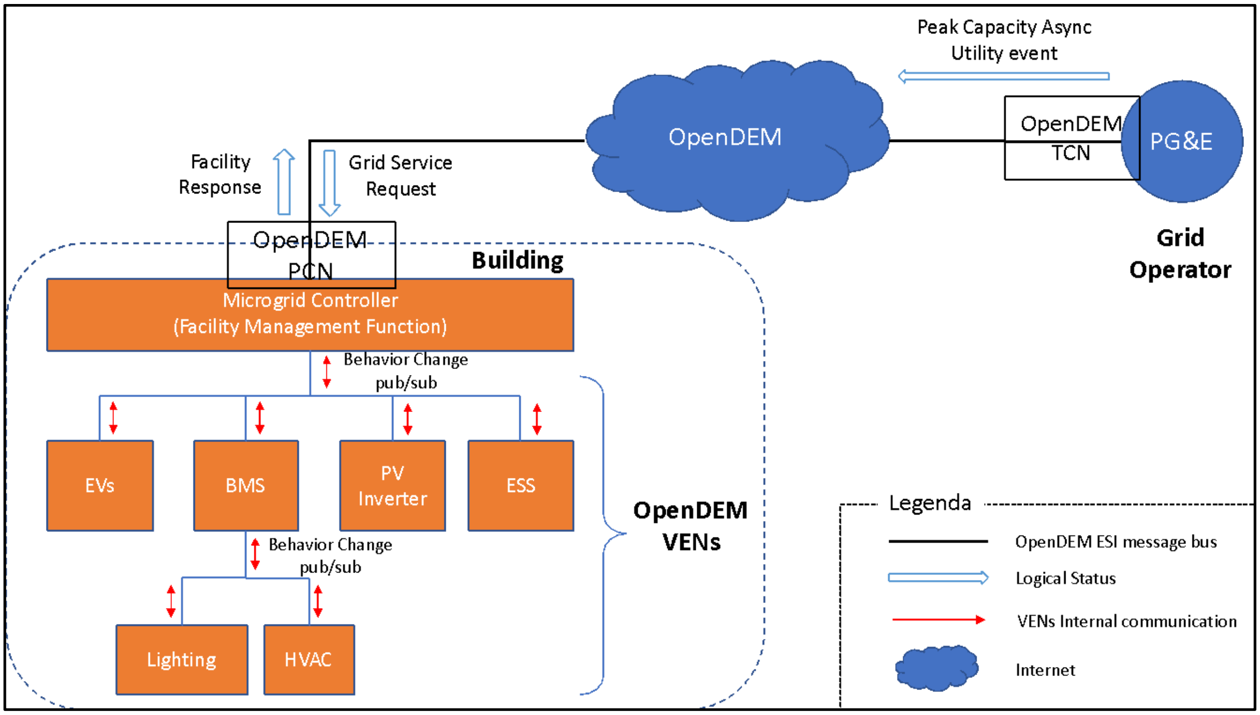


Figure 12 – San Leandro demo use case architecture

Integration Narrative

The elements of OpenDEM model are:

Integrator: The entity/person commissioning the system

- Building/DER owner

Other actors who support the integrator by accomplishing some specific task required for integration (Ideally no one).

- No one if DER is already installed
- Electrician or Implementor if DER is not installed yet

Point of integration – the physical locations for connection using the ESI

- Building owner's internet connection

Interface to be integrated - ESI. This includes a description of the systems or components on either side of the integration:

- External side:
  - Distribution System Operator (DSO)
  - Service Provider (Vendor, Aggregator, Load Serving Entity)
- Facility side: Distributed microgrid controller, facility managers, DER devices, internet routers.

An end user buys a thermostat which complies with the OpenDEM VEN implementation. After physical installation, the user employs the manufacturer (vendor) specific setup routine to wirelessly connect the thermostat to the consumer's broadband internet service. A vendor-provided app or web interface identifies the thermostat on the network and prompts for product registration, during which the user provides the physical address of the installation. The user is given the opportunity to register the device with a Service Provider of their choice. The Service Provider may be the manufacturer, a third-party service provider, or the system operator (all of which will require a service contract), or a Home Automation Network (HAN) or Building Automation System (BAS). Users may switch service providers at any time or cancel participation.

Service Provider managed PCNs shall automatically, anonymously and dynamically publish the aggregated capacities and availabilities of device(s) and systems within a service provider defined local coordination area to the appropriate system operator(s). When a service agreement is executed, the Service Provider shall provide a warrant (proof-of-service) that service terms and conditions have been satisfied. This shall automatically trigger a payment to the Service Provider and DER owner (this is outside the Scope of the ESI).

Much existing infrastructure could be readily modified to be compliant with OpenDEM. Increasingly, utility SCADA ADMS systems are adding BTM management services, often called DER Management Services, or DERMS for short. Typically, these systems fully support OpenADR. OpenDEM is adding additional report types, profiles and service types to the standard OpenADR VTN services.

Toward the end-user side, third-party service providers, BAS and EMS system providers, and equipment suppliers and manufacturers can readily add plug-and-play registration and enrollment services to their PCN systems. Legacy VEN systems can be readily incorporated with OpenDEM PCNs by installing drivers.

Short-term forecast schedules, specifying what capabilities and capacity (watts, VARs, watt hours) are available where, when, how soon, and at what cost, can be incorporated into grid planning and operating schedules.

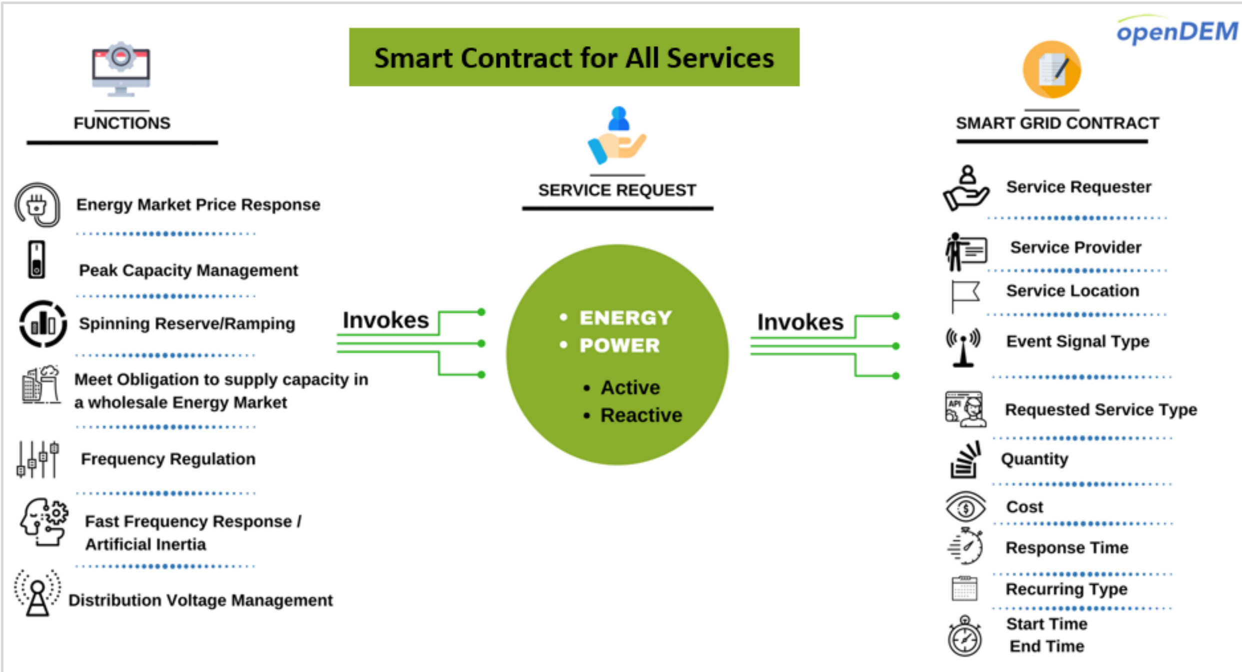
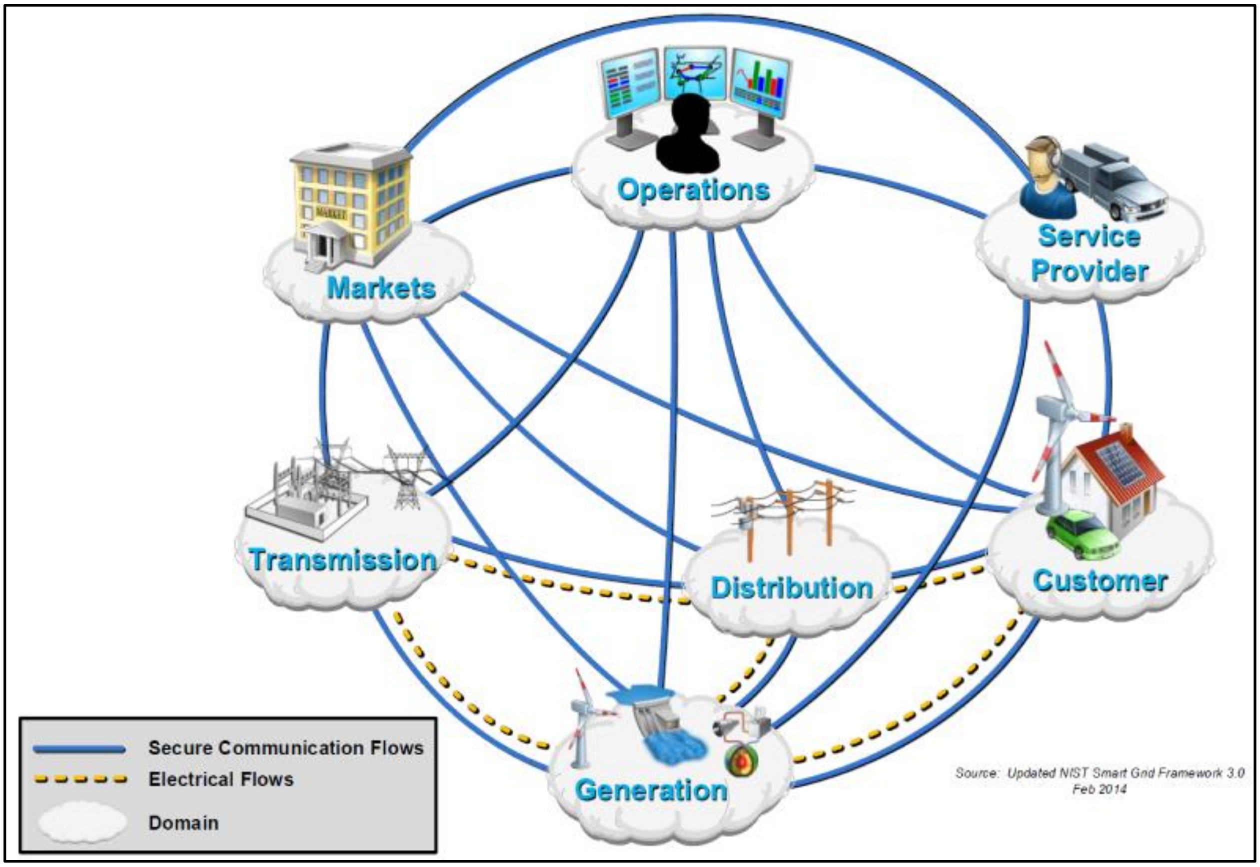


Figure 13 Smart Grid Contracts

ESI Implementation

Organizational Characteristics

OpenDEM leverages a multi-tier natural hierarchy based on the physical characteristics of the T&D topology as well as an overlapping set of transactional relationships based on the regulatory environment, competing and complementary business models, and vendor and service provider selections made by various market participants. In short, organizationally the physical layer is hierarchical, and the information, communication, coordination and control layers are distributed and decentralized.



Informational Characteristics

The ESI interface is based on the Energy Interop Information Model and the OpenADR reference implementation.

> "Energy Interoperation describes an information and communication model to coordinate energy supply, transmission, distribution, and use, including power and ancillary services, between any two parties, such as energy suppliers and customers, markets and service providers.
>
> Energy Interoperation defines messages to communicate price, reliability, and emergency conditions over communications interfaces. Energy Interoperation is agnostic as to the technology that a communications interface may use to carry these messages.
>
> Energy Interoperation messages can concern real time interactions, forward projections, or historical reporting. Energy Interoperation is intended to support market-based balancing of energy supply and demand while increasing fluidity of transactions. Increased deployment of distributed and intermittent energy sources will require greater fluidity in both wholesale and retail markets. In retail markets, Energy Interoperation is meant to support greater consumer choice as to energy source.

Energy consumers will need technologies to manage their local energy supply, including curtailment, storage, generation, and time-of-use load shaping and shifting. Consumers will respond to Energy Interoperation messages for emergency and reliability events, or price messages to take advantage of lower energy costs by deferring or accelerating usage, and to trade curtailment, local generation and energy supply rights. Energy Interoperation does not specify which technologies consumers will use; rather it defines a technology agnostic interface to enable accelerated market development of such technologies.

To balance supply and demand energy suppliers must be able to schedule resources, manage aggregation, and communicate both the scarcity and surplus of energy supply over time. Suppliers will use Energy Interoperation to inform customers of emergency and reliability events, to trade curtailment and supply of energy, and to provide intermediation services including aggregation of provision, curtailment, and use.

Energy Interoperation relies on standard format for communication of time and interval [WS-Calendar] and for energy price and product definition [EMIX]. This document assumes that there is a high degree of symmetry of interaction at any Energy Interoperation interface, i.e., that providers and customers may reverse roles during any period." *Energy Interoperation Version 1.0*.

Technical Characteristics

Rather than seek to represent a range of grid services and the characteristics peculiar to specific wholesale and retail markets the OpenDEM specifies standard units (kWh, kW, VAR) and delivery terms (specific coordination node location, start, ramp and response time, and duration,) .

Energy and ancillary services are represented as aggregations of the future, next day and same day positive or negative availability of watt hours, and active (watts) and reactive (VAR) power at specific time intervals with a performance guarantee (response time, uncertainty, and ramp rate). For energy services, the default service delivery intervals are 4 hours, 1 hour, and 15 minutes. For power (regulation services), the default response times are 15 minutes, < 5 minutes and 4 seconds.

Constraining the service provided by DER assets to simply energy (wH) and power (w or VAr) plus time and location will simplify the ability to leverage machine learning to cost-effectively dispatch the lowest cost resource at multiple temporal and spatial scales.

The OpenDEM ESI is technology agnostic but operationally it is important to accommodate the property differences between different DER types, to distinguish between the capacity and capabilities of DER of the same type, and to acknowledge that there will be a rich ecology of service providers and consumer choices even within vertically integrated electric power markets.

The ESI shall present only the availability and geospatial location of energy and power resources and not specific device characteristics. But solar and energy storage resources and weather sensitive loads (primarily heating & cooling) shall be distinctly aggregated and published to reduce forecasting uncertainty for system operators and service providers.

The ESI will provide granular visibility of the "hidden" load due to solar variability and enable entrepreneurs to offer a rich array of services, inducements, and interfaces (e.g. voice activated notifications) to integrate BTM generation, storage and responsive loads.

There are three distinct technical components to publishing the availability, capabilities and market prices, service delivery and settlement.

For real-time measurements and service availability, the OpenDEM Reference Implementation uses DDS as the messaging protocol over a TCP/IP stack. The data interchange encoding is Concise Binary Object Representation (CBOR) based on the JSON data model.

Service delivery (device control) is downstream of the ESI. A Virtual End Node (VEN) may use an industry standard mechanism (e.g. OpenADR or IEEE 2030.5) or a vendor specific platform (e.g. Google Nest or Tesla PowerWall) for node to device communications.

Interoperability Maturity Model Criteria Coverage

The Interoperability Maturity Model (IMM) proposes a way to measure the level of maturity in several dimensions associated with capabilities that ensure interoperability and simplify the technology integration experience. The model has roughly 30 criteria for measuring interoperability maturity and these criteria are designed to be applied to the ecosystems of technology suppliers, purchasers, industry consortia, standards organizations, and other stakeholders to gauge and advance interoperability.

The following tables show how the OpenDEM ESI covers such IMM criteria to demonstrate its advanced interoperability capability.

Criteria from Interoperability Maturity Model (most important)

Configuration & Evolution

Criteria	**Coverage**	**Coverage Description**
What configuration methods exist to negotiate options or modes of operation (including support for user overrides if applicable)?	Full	• Auto Enrollment process • User opt-in/opt out operational performance
How they have the capability to revise and extend capabilities over time (versioning), while accommodating connections to previous versions of the interface?	Full	Web service-oriented architecture and cloud approach guarantee efficient software upgrade management with minimal impact on both sides of the ESI. That approach supports full ESI backward compatibility.

How they accomplish unambiguous resource identification and management?	Full	The system will use the OpenADR resource identification mechanism. Additionally, all resources inside the system are given their own respective unique identification number.
How it implements resource discovery methods?	Full	See Datacentric - Autodiscovery

Safety & Security

Criteria	Coverage	Coverage Description
What features address concerns for privacy and security, including how policies are defined, maintained, and aligned.	Full	The four security and privacy concerns – confidentiality, integrity, availability, and accountability – are fully addressed.
How are failure modes dealt with, including policies and how they support the safety and health of individuals and the overall system	Full	Failure management implemented by standard HTTPS status codes (i.e. status code 200 – result is OK). The ESI generates a *request* to provide power and energy. Physical device control and power flow constraints are not within the scope of the ESI. Device manufacturers, energy management systems, and system operators are responsible to ensure that requests can be safely executed within the capabilities of the devices and the constraints of the distribution systems.

Operations & Performance

Criteria	Coverage	Coverage Description
How the devices address time order dependency and sequencing of interactions.	Full	Built on event-driven runtime environment for web applications that optimizes time order dependencies and scalability.
What time synchronization requirements exist and how they are managed	Full	All PCNs shall implement NTPv4.

What capabilities the system has for managing transactions and device state	Full	The ESI is designed to manage HTTP transactions, internet interactions in a stateless manner. This means that the state needs to be managed so that a connection can be reestablished for an interactive session to continue and this is done by storing information about the state of the session with an identifier of the interacting party. All participating nodes in OpenDEM combine to form a decentralized virtual machine. The virtual machine provides the runtime environment that regulates state and transition across the system for all nodes.

Informational

Criteria	Coverage	Coverage Description
How information models (i.e., semantic ontologies) are used in information exchange	Full	OpenDEM is based on existing, mainstream, modern information exchange technologies. The semantics are based solely on Energy Interop, OpenADR, and OpenFMB. The latest UML version of OpenFMB represents a harmonization between CIM and 61850 data structures. OpenADR and OpenFMB have well-defined processes for extended their data models and were designed to be transport agnostic. The message contents in the information exchange are based on the Energy Interoperation information model described using UML.

Technical

Criteria	Coverage	Coverage Description
What the structure and format is of the communication transport used and its management	Full	There is distinct separation of the organizational layer (market design) with the informational layer (semantics) model and technical layer (syntax and transport) protocols.

Criteria from Interoperability Maturity Model (intermediate importance)

Configuration & Evolution

Criteria	Coverage	Coverage Description

The accommodation and migration path for integration between legacy and new components and systems shall be described	Full	Web service oriented architecture and cloud approach guarantee efficient software upgrade management with minimal impact on both sides of the ESI. That approach makes possible a full ESI backward compatibility.
How regional and organizational differences are supported shall be described.	Full	The ESI is designed to be flexible enough to manage regional and organizational difference through configuration changes mostly on the user management, system operator program and tariff management.
The ability of overall system operation and quality of service to continue without a disruption as parties enter or leave the system shall be supported	Full	The ESI is designed to handle this complexity because it is built on web APIs architecture and is easy to deploy on distributed and scalable hosted cloud service platform, such as Amazon Web Services or Microsoft Azure. Such architecture allows to manage system evolution and growth over time without impacting the quality of service.

Safety & Security

Criteria	Coverage	Coverage Description
The requirements and mechanisms for auditing and for logging exchanges of information shall be described.	Full	OpenDEM specification shall include diagnostic information on ad-hoc terms inspired from establish crash reports sharing method prevalent in platform independent software projects.
Performance and reliability requirements shall be defined	Full	

Operations & Performance

Criteria	Coverage	Coverage Description
The way errors in exchanged data are handled shall be specified	Full	The ESI is designed to manage HTTP transactions, internet interactions in a stateless manner. This means that the state needs to be managed on both side so that

		a connection can be reestablished for an interactive session to continue. Settlement is the business process which take core of data reconciliation for DER final reward.

Organizational

Criteria	Coverage	Coverage Description
Business conducted across the interface shall be aligned with jurisdictional economic and regulatory interoperability policies defined for the community	Full	OpenDEM is designed to support multi-party transactions at the distribution (retail) and bulk power system (wholesale) level regardless of market structure. Yet there is a significant gap between the current and rapid pace of technological capabilities and innovation and the historic caution of utilities and the traditional lengthy regulatory processes. Therefore, interoperability and market transformation initiatives should support both incremental investments as well as anticipate the introduction of disruptive technologies, business models, and policy shifts. The OpenDEM multi-tier architecture is suitable for vertically integrated utilities that seek to integrate third party service providers such as Nest and Tesla.

Informational

Criteria	Coverage	Coverage Description
Information models relevant for the interface shall be formally defined using standard information modeling languages	Full	OpenDEM is based on existing, mainstream, modern information exchange technologies. The semantics are based solely on Energy Interop, OpenADR, and OpenFMB. The latest UML version of OpenFMB represents a harmonization between CIM and 61850 data structures. OpenADR and OpenFMB have well-defined processes for extended their data models and were designed to be transport agnostic.

Community

Criteria	Coverage	Coverage Description
What existing, mainstream, modern information exchange technologies are specified in the interface specification to maximize the longevity of interface definitions	Full	● OpenADR ● OpenFMB ● 61850 ● DDS ● https ● Restful APIs ● JSON ● CBOR OpenADR is supported by the OpenADR Alliance, an international community of utilities, service providers, equipment and solution providers and other stakeholders to support the development, testing and demonstration of OpenADR certified products. OpenFMB is supported by the UCA international Users Group, a not-for-profit corporation of utility user and supplier companies dedicated to supporting integration and interoperability. TCP/IP, https and Restful APIs are cornerstones of internet communications. DDS is widely supported across a wide range of industries. JSON and CBOR are IETF RFC standards.

Organizational

OpenDEM is designed to support multi-party transactions at the distribution (retail) and bulk power system (wholesale) level regardless of market structure. Yet there is a significant gap between the current and rapid pace of technological capabilities and innovation and the historic caution of utilities and the traditional lengthy regulatory processes. Therefore, interoperability and market transformation initiatives should support both incremental investments as well as anticipate the introduction of disruptive technologies, business models, and policy shifts.

The OpenDEM multi-tier architecture is suitable for vertically integrated utilities that seek to integrate third party service providers such as Nest and Tesla.

OpenDEM

OpenDEM is designed to increase market participation of DER assets by driving down the cost and complexity of provisioning devices, systems and buildings by supporting automated enrollment.

OpenDEM will allow system operators and service providers to schedule and commit a significant capacity of dispatchable DER assets into planning and operational time horizons.

OpenDEM is a market-based mechanism to unleash balancing capacity, particularly from flexible consumption, to reduce the physical and economic impacts of constrained solar generation and variability

OpenDEM allow consumers, DER owners, and service providers to securely and reliably participate in the Day-Ahead and Real-Time Energy Markets with system operators at the distribution and wholesale level.

OpenDEM will enable fleets of distributed and diverse DER assets to respond to pricing signals and grid conditions in real-time while maintaining customer choice.

OpenDEM will enable a single control point mechanism at a facility to aggregate and offer as a service the capacity, availability, and capabilities of a heterogeneous mix of DER devices and systems.

In short, OpenDEM shall support distributed coordination, resource aggregation, and optimization across a wide and dynamically evolving range of devices and energy systems at multiple temporal and spatial/grid scales and verify service delivery.

References

ERCOT (2017). *DISTRIBUTED ENERGY RESOURCES (DERS) Reliability Impacts and Recommended Changes.* Electric Reliability Council of Texas . Retrieved from www.ercot.com/content/wcm/lists/121384/DERs_Reliability_Impacts_FINAL.pdf Sept 5, 2018.

Wood Mackenzie, Power & Renewables, *Residential Flexibility Potential in the U.S,* Sept 2018.

DER Challenge, Plug & Play DER Challenge Call for Concepts, GMLC, July 2018.

NREL (2017). National Renewable Energy Laboratory (NREL) Topic 2 Final Report, End-to-End Communication and Control System to Support Clean Energy Technologies, EPRI, Palo Alto, CA: 2017.

OpenADR Alliance web site accessed August 24, 2018 https://www.openadr.org/faq#5

Interoperability Strategic Vision: A GMLC White Paper, Grid Modernization Lab Consortium, US Dept of Energy, PNNL-27320, March 2018

JD Taft, Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes, DE-AC05-76RL01830, June 2016.
Energy Interoperation Version 1.0. Edited by Toby Considine. 11 June 2014. OASIS. Latest version: http://docs.oasis-open.org/energyinterop/ei/v1.0/energyinterop-v1.0.html.

JD Taft, Advanced Networking Paradigms for High-DER Distribution Grids, Version 3.0, PNNL-25475, May 2016

Taft JD and A Becker-Dippmann, Grid Architecture, U.S. Department of Energy. PNNL-24044, Pacific Northwest National Laboratory, Richland, Washington, January 2015. Accessed February 2018 at https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.

Key Node Concepts

Node	Actor	Functions
Virtual End Node (VEN)	DER Owner or Facility Manager	• Represents single device or *n* devices at a single facility • Each facility has a shared VEN databus • VEN is automatically assigned to Private Coordination Node (PCN)
Private Coordination Node (PCN)		• VEN data collection, device and site properties and user-defined dispatch rules • Intermediary between VEN and LCN(s). • Optimization, scheduling and forecasting • ESI aggregates availability and capacity of VENs and publishes to LCN databus • ESI subscribes to grid events published by LCN and sends dispatch signals to VENs as needed
Local Coordination Node (LCN)	DSO or Service Provider	• Intermediary between PCNs and TCN. • Subscribes to Local Coordination Area (LCA) databus • Maintains status and availability of resources within Local Coordination Area (LCA) • Subscribes grid and local requests and schedules LCA resources
Top Coordination Node (TCN)	DSO or Balancing Authority	• Publishes Local Coordination Areas (LCAs) geospatial data • Schedules Location Distribution Area (LDA) resources • Publishes LDA and grid requests to LCA databus