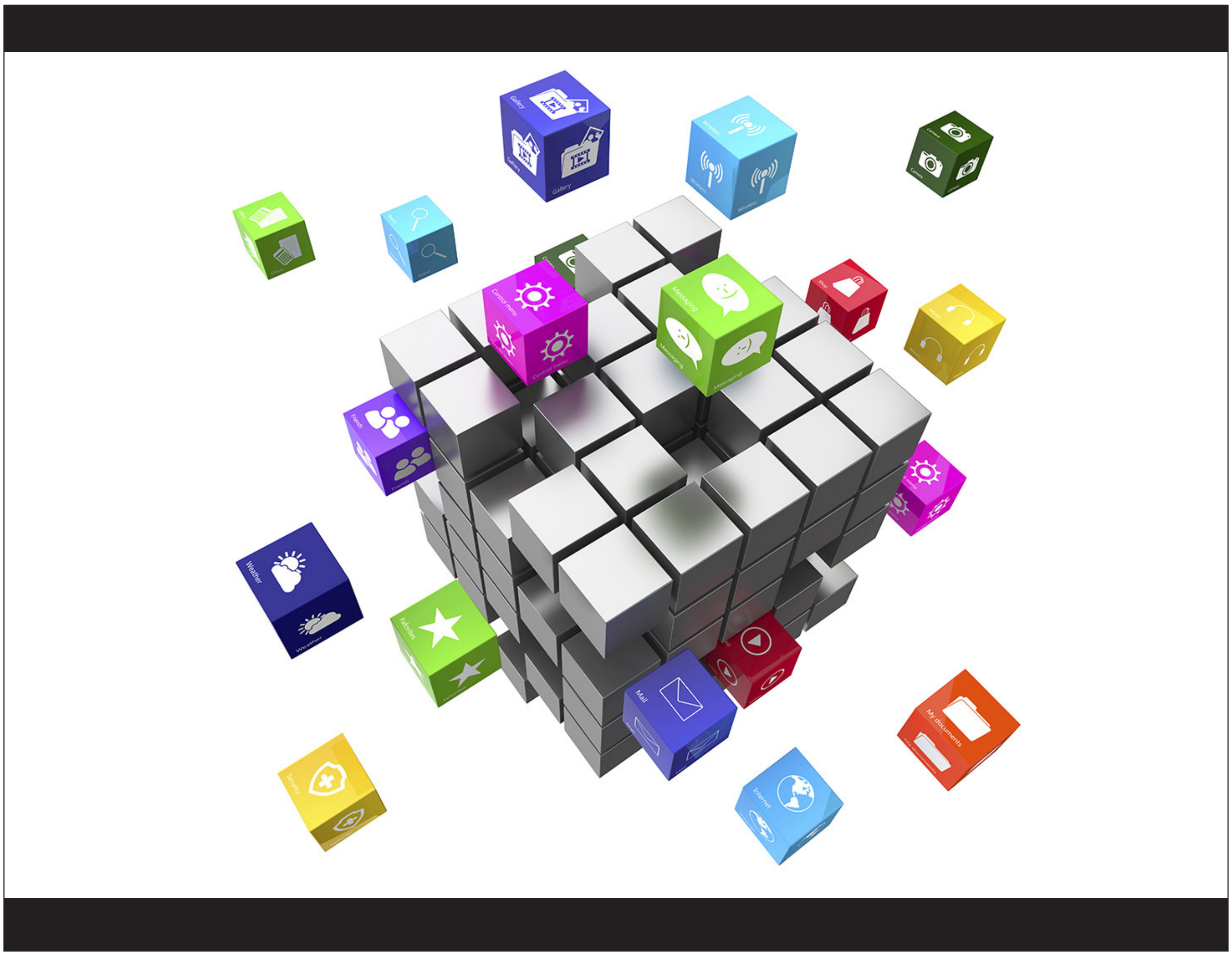
FEDERATED ARCHITECTURE FOR DISTRIBUTED ENERGY RESOURCES INTEGRATION



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Background, Context, Situational Analysis

With advancements in technologies, energy decarbonization plans and policies worldwide continue to trend toward higher utilization of renewable energy resources. In a growing number of cases, goals have been set to achieve 100% renewables, or zero-carbon, both of which involve a substantial transformation of the power system.

From an integration perspective, the significant feature about new clean energy technologies is that they can be deployed in small scales and within the distribution system, unlike traditional coal or nuclear generation that exists as large (e.g., GW scale) central plants within a bulk system. Solar photovoltaic (PV) and battery storage systems are largely being connected to distribution grids, ranging in scale from just a few kW for behind-the-meter (BTM) systems to a few MW for third-party and utility-owned systems.

Traditional bulk generation plants are closely managed and directly connected to system operators through highly-secure and reliable communication pathways. Their output can be steady, and they can be adjusted up/down in response to generator dispatch signals from a system operator to balance supply with demand. When the number of plants is relatively small, it is practical to integrate in this way, directly and in a single layer with centralized controls. However, if power systems transition to a greater dependency on distributed energy resources (DER), the systems used for integration will be more complex for several reasons:

- DER come in many types (PV, battery storage, fuel cells, electric vehicles, demand-responsive load, etc.), each with their own power characteristics and capabilities.
- DER is deployed in many sizes, from small residential to large commercial and utility scales within the distribution system network.
- DER is connected in diverse locations where supply and power quality constraints may exist.
- DER is owned by a range of entities, each with its own objectives and priorities, which may at times conflict with the goals of grid operators.
- Communication networks for DERs may not be as fast, reliable, or secure relative to those used for bulk generation dispatches.

Utilities are generally aware of the integration challenges posed by 100% renewables, and many are already investigating technologies and architectures to meet future needs. At present, however, large numbers of DER worldwide continue to be connected to the grid without direct monitoring and control or simply using the internet and vendor systems as an interim solution.

DER, especially inverter-based technologies such as solar PV and battery energy storage, is capable of providing a wide range of grid-supportive services, including both autonomous behaviors that respond to local voltage and frequency variations. Grid instructions can be dispatched for DER, such as adjustable export limits. Grid codes are being updated to make these features mandatory, referencing technical standards such as the recently updated IEEE 1547-2018, which is used broadly in the United States (US).

Some technical recommendations include requirements for open standard communication interfaces at the DER, setting the stage for interoperable integration with a diverse set of control systems. At the same time, who establishes these connections and how they will be established is less clear. *If a home or business owner installs a control system that operates at the facility level, will they be able to connect to their local DER to help optimize energy costs? If a DER interconnection was permitted by the distribution utility contingent on the ability to dispatch reactive power or limit active power, will they be able to subsequently access the DER? If advanced communities aim to pool their DER capabilities to add further value to residents, through what paths will they be able to integrate? And if there is interest in providing services to the bulk system operator, how can DER be aggregated and dis-*

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This white paper was prepared by EPRI.

patched in a way that honors the interests of the asset owners and avoids creating violations on local power systems? These and other questions remain largely unanswered by the early DER management systems (DERMS) and grid-connected systems that have been deployed.

EPRI's research over the years has recognized this problem at various level of complexity and includes the work that led to the development of requirements that were reflected in International Electrotechnical Commission (IEC) 61850 standard, IEC 61850-7-420:2009 *Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources logical nodes*, which were also quickly adopted by Sunspec Modbus, DNP3, and IEEE 2030.5 communities. And also the Common Functions For DER Group Management, Fourth Edition,[1] which in turn was leveraged for the development of the IEC 61968-5:2020 standard, *Application integration at electric utilities - System interfaces for distribution management - Part 5: Distributed energy optimization.*

The Challenge of Effective Integration and Avoiding Architectural Debt

Utilities are faced with architectural challenges when it comes to integrating DER. The evolution of smart inverters has progressed from devices with no grid-support functionality to those able to use local sensing to react to changing grid conditions from inverters with proprietary communications capability and vendor control, to the rise of standards for communications, mixed with the complexity of standards versions, model versions, firmware, and communication types. The DER industry has seen the turmoil that comes with a growing market, with some vendors succeeding and others not faring as well. At the same time, some vendors are being acquired, merged, or leaving the market when they cannot operate profitably. This latter notion is what led EPRI to publish, *The Value of Direct Access to Connected Devices* that shows how utilities can interact with the grid-connected devices using open communications.[2] Vendors may come and go, but devices will remain in the field for decades, so it will be important that utilities do not get locked into a device that becomes "bricked" due to the inability to communicate with it. The net is that vendors will want to use cloud-based systems when they provide DER control capabilities (they will often want to lock utilities into this architecture from a self-preservation or revenue standpoint), but utilities will need to insist on local accessibility to maintain some ability to get control should a utility get locked out due to any of the reasons noted earlier.

If not managed well, utilities may face a situation where the connected DER will have different makes and models of smart inverters, using different communications protocols, different firmware, different communications connections, each with differing cybersecurity challenges. The maintenance and remediation that these differences require creates a financial drag and increases the operational costs. This drag is referred to as "architectural debt" [2]. Architectural debt is often overlooked until it becomes overwhelmingly obvious through systems failure or skyrocketing maintenance costs. Understanding the sources of architecture debt, identifying the affected systems, with a methodology to mitigate the debt through well-designed architecture, standards-based interfaces, robust security requirements, and managed asset acquisition, can help alleviate the maintenance costs. EPRI's research to help utilities manage this complex DER deployment and management challenge for an integrated grid[3] is collectively referred to as the Federated Architecture for DER Integration, or FADER.

What is "Federated" Architecture?

Since the dawn of computing, there has been a tension between centralized and distributed control – each approach reflecting the need of the time with inherent features. The first computers were large and expensive and centrally managed and controlled. When time-based sharing was invented, users did not get access through a desktop; they received access through a remote terminal – the processing and control were centralized. Then came the rise of desktop computing, with users having their own local assets that they controlled and managed while still needing access to a server (which gave rise to client-server architecture). A mix of centralized and distributed architecture can be seen today in how some services have been migrated to clouds where they are centrally controlled and accessed by everything from "thin clients" such as browsers to smartphones (AKA pocket supercomputer to desktops.

[1] Common Functions For DER Group Management, Fourth Edition, https://www.epri.com/research/products/000000003002008217.

[2] *The Value of Direct Access to Connected Devices*. EPRI, Palo Alto, CA: 2017. 3002007825. https://www.epri.com/research/products/000000003002007825.

[3] http://integratedgrid.com/.

When designing systems of large complexity and figuring out how to best place intelligence and balance central versus distributed control, system architects have applied a federated approach. Federated architecture does not assume a "one size fits all" approach to a problem but, for each situation, considers the benefits of centralized supervisory control, decentralized capability, and local autonomy. The result is a federated architecture that establishes a framework for what is to be done at each level and how the levels work together. The framework facilitates the use of local capabilities, when and how they might be best employed while informing and receiving feedback from more central authorities. It also recognizes that the more centralized control is, the more readily it can be managed, upgraded, and replaced. If a control action can perform just as effectively and just as reliably from a more central location as it can from a more remote location, then it should happen in the central location.

Important to a federated framework, then, is to have information interfaces well defined "at the boundaries" or "edges" between systems. The interfaces need to support "lossless" and secure information exchange; that is, no information is lost when moving through gateways or intermediate systems. In many cases, distributed elements ACT-THEN-INFORM (as opposed to ASK-AND-WAIT) within the guidelines of the federated system. The decentralized capabilities must also be prepared to make changes based on new information from a central controller that has an awareness of needs across the entirety of a system that may not be visible to a single distributed component.

Federated Architecture for DER Connectivity and Integration

Secure and cost-effective connection and integration of DER is a challenge of immense complexity. Policies and targets that aim for 100% renewables and/or zero-carbon make it clear that the end goal is not just accommodating a few DER but deploying them at scale. The traditional grid has been called "the largest and most complicated machine ever built," and as sources of generation become distributed, the complexity is multiplied. Here, balancing control shifts from a small number of large plants to a vast number of generators, energy storage systems, and demand-responsive loads that exist at the system edge. Renewable resource variability shrinks the control intervals from hours to seconds and necessitates frequent adjustment of both new and legacy devices. Peer-to-peer interfaces rise by N^2, and the cybersecurity attack-surface grows by orders of magnitude.

Further complicating DER integration is that ownership varies, and each type of DER owner has goals of their own that may or may not align with those of other entities. For example, the highest-priority of a consumer with behind-the-meter storage may be to reduce their bill, whereas the local utility may be most concerned about system reliability. Individual DER owners, as well as groups such as smart communities, typically have both comfort and financial incentives that determine how the DER behaves.

While it may be practical to begin integrating DER in a single layer, it is evident that a federated approach to DER integration will become necessary. By recognizing this upfront, action can be taken to prepare for evolution and reduce architectural debt. Two dimensions of extensibility are unavoidable:

1. **Vertical Scalability**: DER integration systems must be designed to accommodate control and optimization at various levels throughout the grid. Home and business owners with multiple resources (e.g., PV, EV, storage, demand response) may employ facility-level controllers that optimize across their set of resources. Similarly, smart communities may own DER resources in common and reserve the right to employ these resources to optimize their own situation. And so it continues upstream, with feeders, smart cities, and entire distribution utilities potentially having DER control needs that are not visible at the next level upstream.
2. **Horizontal Scalability**: DER aggregation and control could be performed by a number of public and private entities at each level. There will be companies such as smart thermostat providers, automobile manufacturers, appliance makers, home security, and automation companies that have connectivity to their products and offer services to the utility. While the utility may or may not wish to utilize these services at a given time, an architecture that recognizes the possibility and plans for how it would be handled is advisable.

The two dimensions of scalability are reflected in the reference diagram of Figure 1.

The EPRI Federated architecture for DER organizes system elements into five logical actor types, interacting with one another via two primary types of interfaces: device- -level, shown in blue, and group-level, shown in green. Each interface is based on open standards, with the goal of reducing integration time and cost and enabling interoperability. These standards are presented at varying levels of maturity with key supporting attributes of interface types, as summarized in Table 1.

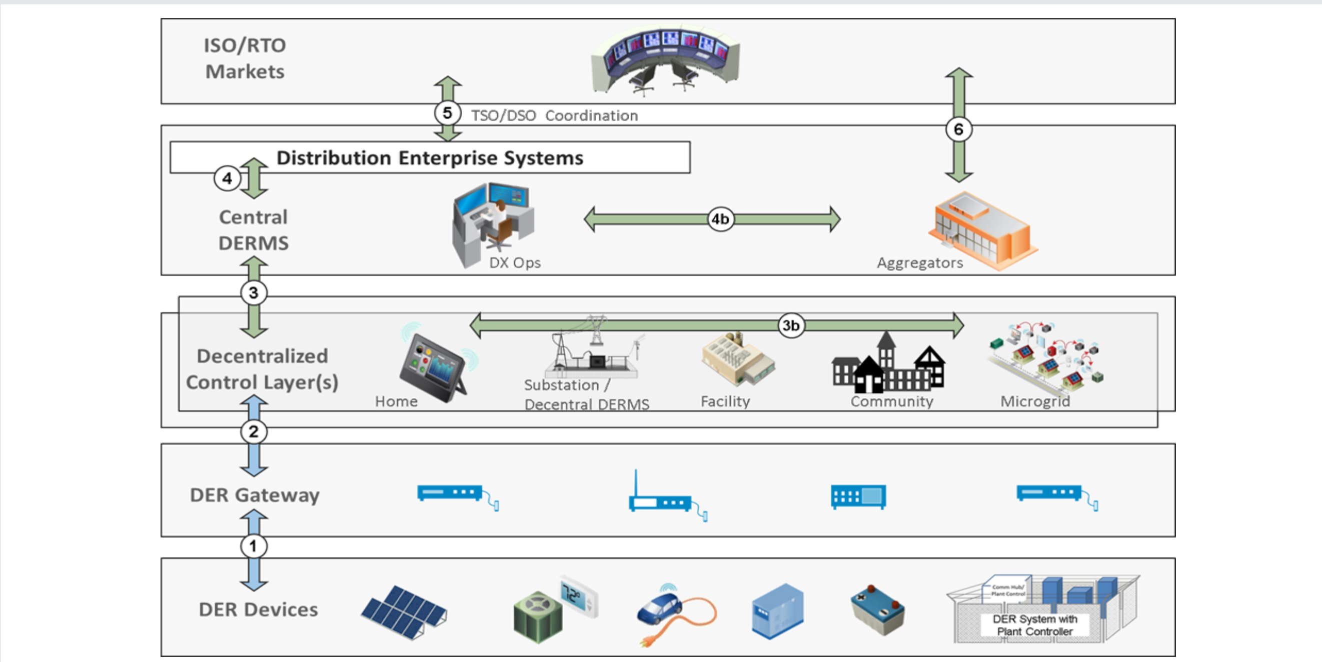

Figure 1. Federated Architecture for DER Connectivity and Integration

Table 1. Device and Group-Level Interfaces in a Federated Architecture

Attribute	DER Device-Level	DER Group-Level
Purpose	Support explicit device-specific commands needed to monitor and instruct devices (unambiguously) on what to do.	Support monitoring and dispatch of groups or DER at any level/scale.
Device-Type Specific?	Yes. For example, thermostats can be offset by 3 degrees, PV inverters can follow a volt-var curve.	No. DER group-level services are defined in a device-type agnostic way, focused on the grid-need or grid-service being provided.
Nestable?	No. While device-level commands may be passed across multiple levels of a federated system, they remain targeted to a specific device type.	Yes. Standard DER group-level functions have been specifically designed to be nestable so that there can be multiple decentralized control layers (groups-of-groups), and overall federated architectures can have as many or as few layers as needed.
Standardization – Interface Functionality and Information Models	Functionality: IEC 61850-7-420 and -520 Communication Protocol(s): Requirements: IEEE 1547-2018 and associated grid codes	IEC CIM 61968-5 Distributed Energy Optimization
Standardization – Interface Protocol(s)	SunSpec Modbus, IEEE 1815 (DNP3 – AN2018-001)	IEEE 2030.5, OpenADR 2.0
Standardization – Maturity	Mature with published standards (IEEE 1547) and testing available	IEC standard published in 2020. Early stages of certification available.
Standardization – Certification and Compliance	UL1741-SB	Utility Communication Architecture International User's Group (UCAIUG) is the ITCA for CIM-based application integration.
Public Reference Documents	Common Functions for Smart Inverters, 4th Edition	Common Functions for DER Group Management, 3rd Edition

Placement of Intelligence in the Federated Architecture for DER

The fundamental principle of federated architecture is to do each of the needed system control functions at the level at which it is most optimal and to do this with consideration of all factors: necessity, performance, cost, readiness/availability, scalability, and sustainability. Depending on the unique circumstances of a particular utility and region, DER management systems may or may not be needed right away and may have many or few levels of control. The five categories of system devices in FADER (Figure 1 above) are described in brief in the following sections and in more detail in the referenced bodies of work. The key factors guiding this placement or the location of intelligence are summarized in Table 2.

Table 2. Guiding Principles for Federated Architecture Intelligence

Factor	Description	Federated Architecture Principle
Speed & Latency	How fast a function must perform in order to meet its objectives. Example: A one-minute response may be sufficient for a DER curtailment to prevent a thermal violation, but a milliseconds response may be required for DER to provide support for a fast frequency drop.	Move intelligence downstream. Responses are faster when the intelligence is placed closer to the DER devices.
Reliability	How dependent a function is on networks, interfaces, and equipment throughout the system. Fewer dependencies improve reliability.	Move intelligence and autonomy downstream. DER actions that are critically depended-on, rather than just providing economic optimization, should be based on intelligence in DER devices or local gateways.
Awareness & Optimization	The extent to which a function needs to be aware of conditions elsewhere to perform effectively.	Move intelligence upstream. For DER actions that benefit from wide-area visibility, intelligence should be placed at the appropriate central elements. For example, if the action is a feeder-level function, intelligence may reside at a decentralized control at the substation or further upstream such as a central DERMS.
Maintenance & Upgradeability	The likelihood that a function will need reconfiguration, upgrading, or replacement over the system life. The cost and practicality of performing the change.	Move intelligence upstream. More central control systems are fewer in number and more readily upgraded and replaced.
Ownership and Accessibility	The willingness and right of the utility to change, upgrade, or replace a function.	Place intelligence upstream of customer equipment and third-party systems if possible.
Resiliency	Function to autonomously start and operate sections of the grid when the main grid is unavailable	Place intelligence downstream since control actions need to be fast to manage frequency. An appropriate level that benefits more customers without grid forming DER/microgrids and serves critical loads should be considered

DER Devices

DER devices are the actual load, storage, and generation equipment connected to utility systems. DER devices are at the most downstream edge of the system, and intelligence placed there can be the fastest responding and are most reliable. This intelligence is, however, least accessible and least upgradeable due to ownership shifting from a utility- to third-party or customer-owned.

The local interface to DER (① in Figure 1) presents the greatest challenge for interoperability in an overall DERMS system. Millions of these interfaces may exist, and DER devices are provided by a large number of vendors, each with evolving product portfolios and ownerships. The DER devices to be cohesively integrated at any one point in time will be a mix of old and new products, spanning decades.

In large-system architecting, these challenges are dealt with by keeping the interface as simple as possible. For DER integration, this is accomplished by minimizing the functional requirements of the DER, doing inside the DER only those things that can only be done there, and keeping more complex functionalities in the DER gateway or further upstream.

DER devices are becoming increasingly capable, with microprocessors included in even the simplest of devices such as water heaters that have traditionally been electro-mechanical. As this happens, the makers of the products may be motivated to embed intelligence in their devices that be handled just as effectively upstream. In a federated architecture, these features should not be used.

DER Gateways

DER gateways are equipment that sits at each DER site, connecting, integrating, and bringing DERs onto the utility control system. DER gateways can be a practical necessity, at a minimum providing the network-interface (e.g., modem, radio, etc.) needed to connect into the communication system being used to connect to an external network. The IEEE 1547-2018 intentionally excluded these local devices from the definition of DER because integrators, including utilities, need the freedom to choose different communication systems and standards for different needs and to upgrade communication systems over time to keep in step with current technologies. To support this, the IEEE 1547-2018 specifies a local wired interface at the DER (Ethernet or RS-485) into which DER gateways can be connected.

While both the DER devices and DER gateways reside at the same physical locations, their attributes in relation to a federated architecture are very different, as summarized in Table 3.

Table 3. Attribute Differences in DER Devices and DER Gateways

Attribute	DER Devices	DER Gateways
Longevity	Long, DER has decades of lifecycles.	Short, telecom technologies such as cellular are rapidly evolving and have short lifecycles.
Ownership	Customer	Utility/Aggregator
Consistency	Diverse (many types, brands, models, product ages)	Uniform (one type of gateway system-wide, deployed together, replaced/upgraded together)
Firmware upgradeability	Difficult due to both ownership and diversity. DER device firmware can only be produced by the manufacturer, who may or may not be in business.	Straightforward. As with present AMI, SCADA, and other utility systems with large numbers of connected devices, DER gateways can be firmware upgraded from upstream head-ends at any time.
Replaceability, physical upgradeability	Not possible by the utility or aggregator.	Straightforward. Can be replaced system-wide when needed or justified.

These significant differences lead to different roles in a federated architecture. EPRI has summarized the potential roles and value of DER Gateways in a separate Technical Brief.[4] The most significant in relation to a federated architecture are:

- **Security**: As customer-owned products that are of diverse origins, DER devices are not trusted, regardless of what protocol or cybersecurity they employ. When vulnerabilities are found, they cannot be readily patched by the utility or aggregator. IEEE 1547-2018 declined to place cybersecurity in DER devices for this reason. DER gateways, on the other hand, are intended to serve as the secure edge of the aggregation system. One design can be used system-wide, and its origin can be consistent and of trusted/traceable design. Their firmware can be centrally managed, and upgrades/patches deployed at any time, as is common with other systems of large scale like AMI and SCADA. In the EPRI federated architecture, security is a required feature of the DER gateway. In addition to providing communication security (e.g., data encryption, role-based access, authentication), gateway designs can include physical/tamper detection, security logging, and alarms.
- **Scheduling**: Utilities may need the settings of DER to change on a regular daily, weekly, or annual schedule. In many cases, it is desirable for these schedules to reside locally at the DER site so that they can be carried out dependably with or without communication from upstream systems. Schedules are known for high complexity and involve a large number of configuration parameters. With a large number of end device makers, it is unlikely that scheduling could be implemented in a cohesive way. The differences result in a lack of interoperability and inconsistency in device behaviors. In the EPRI federated architecture, scheduling is a function of the DER gateway. A scheduling intelligence placed in the gateway is consistent across all products, and the interoperability to manage the schedules is needed only between one head-end design and one gateway design.

[4] *Understanding the Uses and Value of Utility DER Gateways*. EPRI, Palo Alto, CA: 2019. 3002017116.

- **Situational Awareness and Reversion to Defaults**: IEEE 1547-2018 does not require DER devices to store more than their one (present) configuration. This means that they are not able to revert to default settings if communication with upstream systems is lost. Determining that upstream connectivity has been lost can be complex in itself and is different for each communication system. While it is not possible for DER (designed to work for all utilities) to be tuned to the needs of a particular control system, DER gateways as elements of the control system can be tailored to detect and react to loss-of-master situations according to the needs of the utility.
- **Choice of Communication Technologies:** Per certain grid codes, DERs communicating with a utility control system that is using IEEE 1547-2018 need to support a communication standard for interface protocols – DNP3, SunSpec Modbus, or IEEE 2030.5. Due to a divergence in the selection of interface between a manufacturer or a customer and the utility, a DER gateway can essentially become a local protocol translator to enable ease of integration of DERs.

Decentralized DER Controllers

As indicated in the Federated Architecture reference model in Figure 1, it may be desired or become necessary to have decentralized controllers that manage groups of DERs at various levels throughout the system. While optional, decentralized control can benefit the collective owners and the area in which groups of devices reside by providing optimization for the local needs. Grouping also can benefit upstream entities by providing a smaller number of objects to be managed and reducing demands for frequent and uninterrupted interaction.

Decentralized DERMS can be positioned at a variety of levels and serve different purposes, as summarized in Table 4.

Table 4. Examples of Decentralized DERMS

Level	Product	Example Use
Residential	Home Energy Management System	Collectively manage the set of behind-the-meter customer resources (load, generation, and storage) to optimize the customer's bill.
Commercial/ Industrial	Facility Energy Management System, Industrial Control System	Interface to facility control systems and/or plant operators to collectively manage the set of behind-the-meter customer resources (load, generation, and storage) to optimize the customer's bill.
Community	Smart Community Energy Management System	Optimizing the utilization of community resources, increasing self-consumption, and reducing power system demand.
Microgrid	Microgrid Controller	Providing resilient backup power when disconnected and grid services when connected.
Substation	Feeder-Level Controller	Improving DERMS reliability by locating feeder-level optimization at the substation. Reducing central system scale. Positioning the utility to improve system resiliency through feeder-level microgrids.

To support decentralized control needs, EPRI began working with the US Department of Energy and other industry stakeholders in 2012 to define standard group-level services for DER. The need for these standards was first identified by companies that provided centralized DERMS and DMS software, recognizing that the scale and complexity of overall DER management can become immense. Subsequent work has enabled four key roles that can be performed by each layer in a federated DER management system:

- **Aggregate** - take the services of multiple downstream DER (or DER groups) and present them to upstream entities as a more manageable (smaller) number of aggregated virtual resources.
- **Simplify** - handle the granular, device-type specific control of downstream devices and present the grid-supportive capabilities in a form that is simpler to manage and more meaningful to the upstream entity.
- **Optimize** - manage utilization of downstream DER and groups to achieve desired outcomes in an optimal way. For example, achieving a group-level service at minimal cost, minimal asset wear, and/or maximum customer comfort. Optimization may also include honoring contractual obligations and prioritizing between conflicting requests or objectives.
- **Translate** - Downstream DER or systems may speak different languages, depending on their type and scale. Each layer may handle these diverse languages and present to the upstream calling entity in a cohesive way.

The DERMS working group is publicly documenting[5,6] standard group-level functions and coordinating with the IEC to accelerate the availability of standardized messages to support group-level monitoring and control. Common group-level functions and messages are necessary for supporting decentralized intelligence in a federated architecture. The decentralized control layers of Figure 1 are shown in more detail in Figure 2.

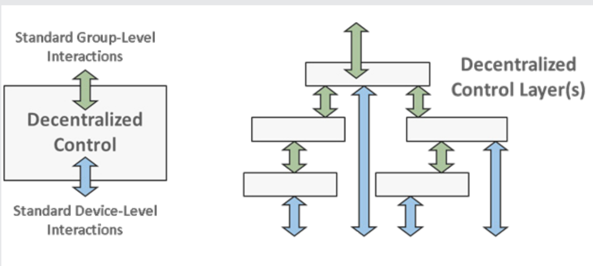

Figure 2. Standard, Nestable DER Group-Level Functionality

The standard group-level functions, both monitoring, and control have been designed to be nestable, allowing groups-of-groups and as many or as few layers as necessary. In this way, systems are made more readily scalable because additional layers can be inserted when needed without changing the control methods further upstream. Examples:

- **Vertical Scalability**: A DER management system is initially set up with only a central DERMS, controlling all DER in the region and providing to a DMS the standard Watt and Var services grouped at the feeder-level. Later, smart communities employ community-level controllers. These controllers support the same standard group-level services and can be integrated seamlessly into the central DERMS. In this case, a feeder-level group may now contain a combination of individual DER and one or more community groups.
- **Horizontal Scalability**: A DER management system is initially set up with only a utility central DERMS. Later, third-party aggregators wish to provide services from PV, storage, and EV fleets. These aggregators support the standard group-level services and can be integrated seamlessly into the central DERMS.

Centralized DERMS

A centralized DERMS is a large-scale control application that resides at the distribution utility. They may operate across wide areas, handling large amounts of data and computations. Like decentralized controllers, a centralized DERMS manages downstream DER devices or groups and provides common group-level services to upstream entities. Typically the upstream entities served by a centralized DERMS are the local DMS and/or bulk system energy markets. The roles and interactions of central DERMS and DMS in the federated architecture are described in the EPRI whitepaper "Understanding DERMS."[7] The communication interfaces between centralized DERMS and DMS are typical via a local enterprise service bus based on the utility common information model (CIM) or MultiSpeak data models. Centralized DERMS may also interface with a range of distributed enterprise applications in the same way:

- **DERMS to Advanced Metering Infrastructure (AMI) Head-End**: exchanging DER generation information to support or verify billing/settlement
- **DERMS to Customer Information Systems (CIS)**: providing customer service personnel with visibility to DER status and health.
- **DERMS to Geospatial Information Systems (GIS)**: discovery of new interconnections and maintenance of the present status and settings of DERs in the field.
- **DERMS to Work Management Systems (WMS)**: flagging needs for field service needs and tracking results.
- **DERMS to Bulk System Markets**: providing (a) market services for DER managed by distribution utilities and (b) providing TSO/DSO coordination to address distribution constraints for all DER that provide bulk system services.
- **DERMS to DER Aggregators**: providing the horizontal interfaces to third party aggregators to (a) include their capabilities in overall distribution services and (b) coordinate regarding constraints on the DX system that limit DER behavior.

Unlike the downstream elements of a DER system that operate unmanned, centralized DERMS may have human operators and extensive user-interface capabilities that include map views, real-time status, and alarms. Central DERMS may have multiple user

[5] *Common Functions for DER Group Management, Fourth Edition*. EPRI, Palo Alto, CA: 2016. 3002008217.

[6] *DER Group Management for Coordinated Operations Across the T&D Interface*. EPRI, Palo Alto, CA: 2019. 3002016174.

[7] *Understanding DERMS*. EPRI, Palo Alto, CA: 2018. 3002013049.

types and support role-based access and activity logging for security. The central DERMS may implement one or more of the protocol interfaces to communicate with downstream systems: aggregators, decentralized DERMS, and/or DER gateways.

Federated Control and Functional Security

As overall DER management systems become more advanced and more multi-level (federated), there is increased opportunity to build-in functional protection against potentially harmful control actions, both accidental and malicious. Decentralized controls that operate at the feeder-level, for example, could be hardcoded with an awareness of the physical constraints of that subsystem and reject commands that would cause harm. Federated control constraints can be a simple fixed go/no-go threshold or a set of limitations, each requiring heightened levels of authority to override. In addition to recognizing harmful control levels, decentralized controls could recognize harmful or abnormal control sequences, such as cycling or reversing controls too many times in a given amount of time. This type of control error could, for example, cause wear and tear on distribution system equipment.

This is presently an active area of research in EPRI's federated DERMS development, with practical constraints being identified through decentralized utility control and DER gateway projects. As reference DERMS and gateway specifications are developed, functional security possibilities are being documented and included.

Status and Next Steps

Architecture for an integrated system is defined primarily by the functionalities of each actor type, the interfaces between these actors, and the service the system is providing. As noted previously and illustrated in Figure 1, the EPRI federated architecture consists of up to five primary actor types and 2 to 8 primary interfaces, depending on the scale of the system. The status of each of these parts is summarized in Table 5.

Table 5. Status of Primary Federated Architecture Elements

	Status					
Architecture Element	**Gap**	**Dev**	**Pilot/Test**	**Commercial**	**Mature**	**Detail**
Device-Level Functionality				X		Standardized: IEEE 1547-2018, IEEE 1547.1-2020
Interface 1: DER Device Level				X		Standardized: SunSpec Modbus DNP3, AN2020-001
DER Gateway Functionality		X	X			Supplemental
Interface 2: DER Gateway		X				Extensions to IEEE 2030.5 DNP3 to support gateway functionality (e.g., scheduling, logging)
Decentralized DERMS Functionality	X					Not standardized, diversity among microgrids, buildings, etc. DOE Funding is accelerating this area
Interface 3: Decentralized DERMS to Central DERMS		X				IEC 61968-5 (CIM for DER)
Interface 3b: Peer-to-Peer Decentralized DERMS	X					An advanced feature not yet addressed. DOE FOA-2243 aims to start work in this area.
Central DERMS Functionality			X			Maturing through utility pilots and RFPs. Consolidated in the EPRI reference DERMS RFP language repository. IEEE 2030.11 activity.
Interface 4: Centralized DERMS to DX Applications		X	X			
Interface 4b: DSO to Aggregator	X					Supplemental Project Planned
ISO/RTO Markets Functionality for DER	X					FERC Order 2222 is aimed to accelerate this area.
Interface 5: TSO/DSO Interface	X	X				
Interface 6: Aggregator to Bulk Market		X	X	X		

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1. Common Functions For DER Group Management, Fourth Edition, Available [Online]: https://www.epri.com/research/products/000000003002008217.

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3. EPRI, The Integrated Grid, http://integratedgrid.com/.

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