Overview of Functional Technical Requirements for Intentional Islands

David Narang,[1] Sigifredo Gonzalez,[2] Michael Ingram,[1] and Michael Ropp[2]

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2 Sandia National Laboratories

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Preface

The revised Institute of Electrical and Electronics Engineers (IEEE) 1547, Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018), was published in April 2018. This standard is one of the foundational documents in the United States needed for integrating distributed energy resources (DERs), including solar energy systems, with the electric distribution grid.

The revised standard contains 11 chapters (clauses) and 8 annexes that comprise 136 pages. The revision is significantly different from the 2003 version, and it contains new concepts and new technical requirements. Each clause specifies information or requirements that apply to certain aspects important to the interconnection of DERs to the electric power system. Implementing the requirements necessitates a careful study of the underlying technical concept and the appropriate information to calculate relevant settings and configurations.

Various stakeholders have different roles in implementing the standard, and portions of the standard are directed toward a specific audience who must possess specialized information and technical training to use and apply the requirements.

This is one document in a series[1] that aims to (1) summarize a specific portion of the standard as concisely as possible and (2) provide the reader with introductory knowledge and information to support the utilization of the requirements. This document provides an overview of intentional islands. The topics covered include common types of intentional island configurations, high-level summaries of standards that address some aspects of intentional island implementation and interconnection, and a discussion of specific standards that apply during the islanding operational stages of parallel operation—transitioning to islanding, islanding operation, and transitioning back to parallel operation.

Note that the narrative on the implementation and configurability of requirements reflects the authors' interpretations, which in some instances might differ from one person to another, especially at this early stage of implementation; therefore, this work is intended to supplement the existing and growing body of knowledge across the U.S. electric sector on the use and application of this important standard.

[1] Additional educational material is listed at https://www.nrel.gov/grid/ieee-standard-1547/.

Acknowledgments

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List of Acronyms

DER	distributed energy resource
DERMS	distributed energy resource management system
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPRI	Electric Power Research Institute
EPS	electric power system
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
NFPA	National Fire Protection Association
SETO	Solar Energy Technologies Office
UNIFI	Universal Interoperability for Grid-Forming Inverters
VPP	virtual power plant

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Introduction

In the revised Institute of Electrical and Electronics Engineers (IEEE) 1547, Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018), the term *intentional island* refers to "a planned electrical island that is capable of being energized by one or more Local EPSs. These (1) have DER(s)[2] and load, (2) have the ability to disconnect from and to parallel with the Area EPS, (3) include one or more Local EPS(s), and (4) are intentionally planned." IEEE Std 1547-2018 defines two types of intentional islands: a Local electric power system (EPS) island and an Area EPS island (IEEE 2018, 154).

The term *microgrid* is used in IEEE Std. 2030.7-2017, Standard for the Specification of Microgrid Controllers, to describe a particular configuration of *intentional island*. In that standard, a microgrid is defined as "a group of interconnected loads and distributed energy resources with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes" (IEEE 2017).

In practice, the term *microgrid* is widely used to describe a variety of configurations, some of which may not strictly meet the definition given in IEEE Std 2030.7.

Motivations for deploying an intentional island vary. The desire to improve resilience during abnormal grid conditions, extreme weather events, or other prolonged outages are most prominent. In certain locales, environmental stewardship is another motivation through the use of all-renewable-based intentional islands. Yet another motivation is pursuing policies for renewable energy to meet energy security objectives.

There are varying estimates for the current number of installed intentional island systems in the United States. The U.S. Department of Energy (DOE)/ICF Combined Heat & Power and Microgrid Installation Databases (DOE 2022) list 575 installations in the United States.[3] Figure 1 shows the distribution across the country. Wood Mackenzie forecasts that by 2026 the total installed capacity in the United States will exceed 1,000 MW (Maze-Rothstein 2021).

[2] The term *DER* in IEEE Std 1547-2018 includes any type of generation source capable of exporting power to the grid, including traditional rotating machines, such as synchronous generators; inverter-based resources, such as photovoltaic systems; and energy storage devices.
[3] The website notes that data are current as of October 31, 2021.

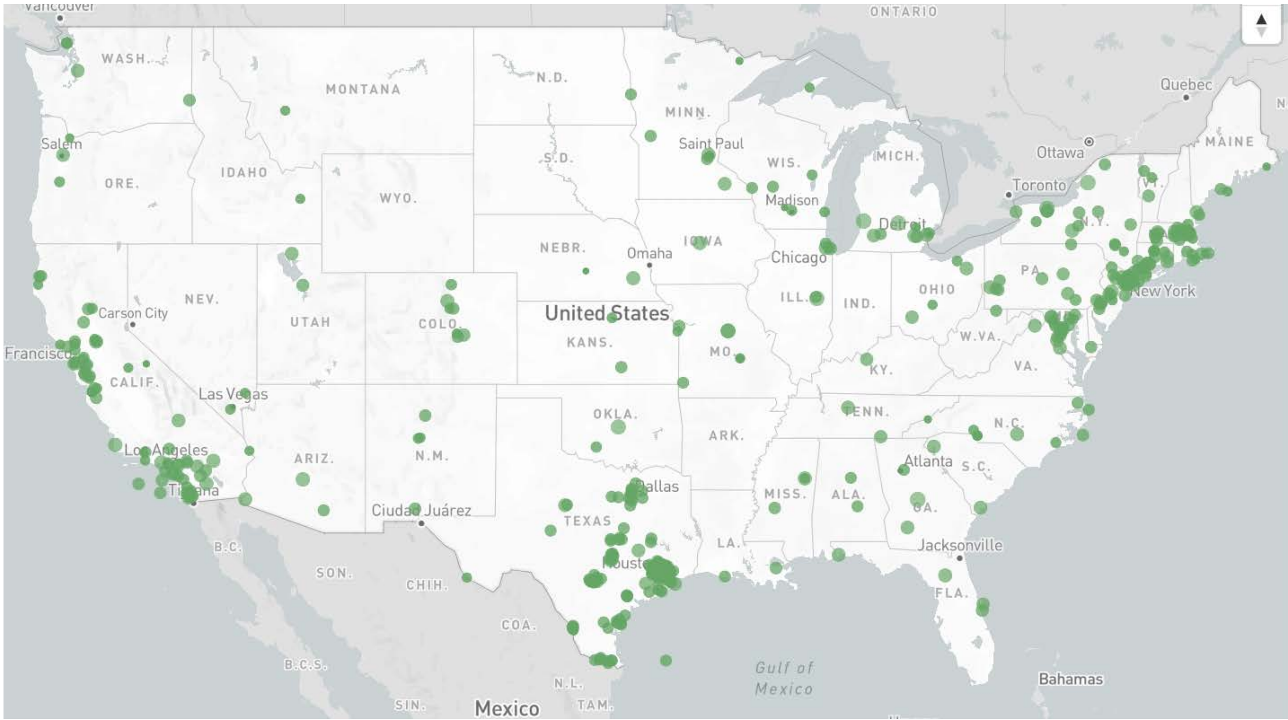

Figure 1. Distribution of installed intentional island systems across the continental United States

Source: DOE (2022)

As noted, the concept of intentional islands has existed for many decades; however, these have traditionally been systems designed to operate in isolation from the main power grid. These are called *off-grid systems*. During the past decade, the deployment of distributed energy resources (DERs) with the capability to operate in both off-grid and parallel mode has become more common and is now becoming commercialized. Due to the dual nature of these types of systems, several standards might apply, depending on the operating mode—on-grid or off-grid. The standards are in the early stages of maturity, and there is little field experience for certain types of intentional islands.

In the United States, these early attempts at standardization consist of the formal interconnection functional requirements in IEEE Std 1547-2018 and the microgrid controller requirements in IEEE Std 2030.7-2017.[4] Additional guidance can be found in other guides and recommended practices, such as in IEEE Std 1547.4-2011, Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems, and IEEE Std 2030.9-2019, Recommended Practice for the Planning and Design of the Microgrid.

Terminology is constantly debated as applications of islanded systems continue to increase. For this report, terms related to islanded power systems are taken from IEEE Std 1547-2018 and IEEE Std 2030.7-2017, unless otherwise noted.

This document provides a high-level summary of the context, requirements, and implementation considerations related to intentional islanding. Topics covered include types of intentional

[4] And associated testing standards.

islands, relevant standards and their scope, intentional islanding operational stages, and high-level implementation considerations. This document is intended as a supplement to material already published or in development.[5] It is not intended as an exhaustive resource on technical implementation. Rather, topics are presented at a level appropriate to serve individuals who require an introduction to the topic.

[5] For example, the revision to IEEE Std 1547.1, Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces.

1 Types of Intentional Electrical Islands

Broadly speaking, there are two types of intentional electrical islands: (1) a Local EPS island or facility island that does not contain any utility equipment and (2) an Area EPS island that does contain utility equipment. Figure 2 shows the boundaries of typical islanding configurations. All types are designed to meet and sustain a certain load-generation balance. An intentional island cannot be sustained unless the generation within the intentional island boundary is sufficient to support all load that must remain powered in the off-grid mode.[6]

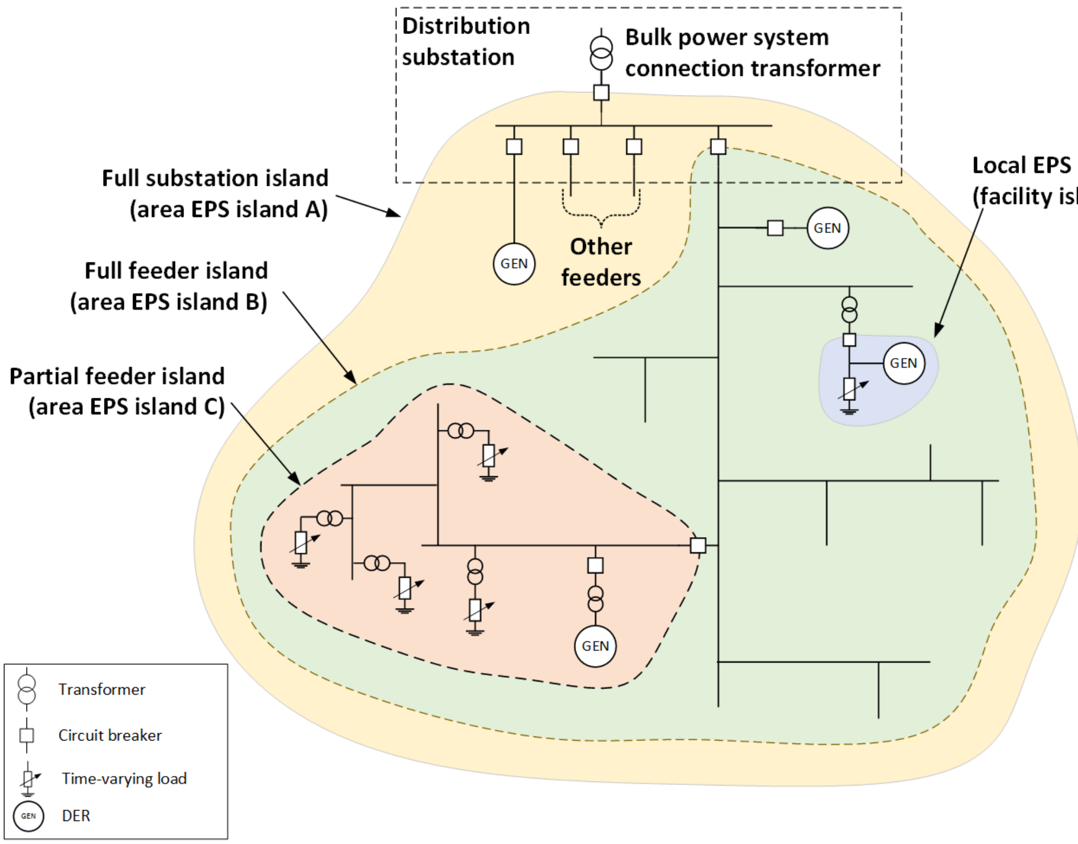

Figure 2. Simple drawing of boundaries of multiple types of intentional islands

Source: Based on McGranaghan et al. (2008)

1.1 Local Electric Power System Island (Facility Island)

A Local EPS island is a very common type of intentional island and is also known as a *facility island* because a single facility is islanded. This term can be applied to a wide range of sizes, such as a single customer residence, a commercial building, a large industrial facility, or a campus. An example of a facility island is illustrated in Figure 2 on the top right, labeled "Local EPS island (facility island)."

[6] This is studied in the planning stages of the intentional island.

1.2 Area Electric Power System Island

An *intentional Area EPS island* is defined as "an intentional island that includes portions of the Area EPS" (IEEE 2018). As shown in Figure 2, EPS islands can comprise only portions of the circuit (feeder)—for example, only one of the lateral line sections (partial feeder island); an entire feeder (full feeder island); or even the entire distribution substation (full substation island).

1.3 Intentional Island Systems Containing a Portion of the Bulk Power System

Some intentional island systems might include a portion of the bulk power system.[7] For example, the entire distribution system in Figure 2 might be wholly or partially served by a resource connected upstream from the bulk power system connection transformer at the top of Figure 2. Intentional island systems of this type can be complex to plan because they cross the distribution-transmission boundary.[8] At present, there are no standards that specifically address intentional island systems that include a portion of the BPS.

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[7] See Reno et. al (2022, (SAND2022-17004) for a discussion on this.

[8] Very large intentional islands at the bulk power system level have been proposed in Puerto Rico. See Docket NEPR-MI-2020-0016 for regulatory discussion on this topic.

2 Other Similar Configurations and Systems

There are several configurations that sometimes sound similar to but are not technically intentional islands per the IEEE 1547 standard definition. This section discusses some of these configurations.

2.1 Stand-Alone Systems (Off-Grid Systems)

The National Electric Code—National Fire Protection Association 70 (NFPA 70)—defines a stand-alone system as "a system that supplies power independently of an electrical production and distribution network" (NFPA 2017). This type of system is sometimes called a microgrid and is often referred to this way by many practitioners. However, stand-alone systems are not intended for parallel operation with the Area EPS and are therefore not considered intentional islands per the definition in IEEE 1547-2018.

2.2 Emergency and Standby Power Systems

The National Electric Code defines *emergency systems* as "Those systems legally required and classed as emergency by municipal, state, federal or other codes, or by any governmental agency having jurisdiction" (NFPA 2020). These systems are installed to provide temporary alternate power in case of failure of the main electrical supply to a limited number of circuits that serve life safety equipment, such as exit and egress lighting, various types of alarms and evacuation systems, fire pumps, and other safety systems. An emergency power system is typically designed to operate for a short duration (i.e., hours). Under IEEE Std 1547-2018, emergency and standby power systems are a special class of power system noted to be governed by other codes and standards (primarily NFPA).

Emergency and standby power systems are not intended for parallel operation (other than brief transition periods) and are therefore not considered to be intentional islands.

2.3 Virtual Power Plants

Another system that is sometimes called a microgrid is a collection of widely dispersed DERs, including nontraditional DERs, such as demand response assets, connected at different points throughout the grid, but controlled in a collective manner to behave as a single "virtual" power plant (VPP). This is typically considered in the context of bulk power system operations.

VPPs have gained popularity during the past few years. The specifics of a VPP highly depend on the implementation, but, in general, the concept heavily relies on communications and control technologies to orchestrate the overall response of multiple types of DERs to provide various grid services. IEEE Std 2030.11 defines a VPP as a form of a distributed energy resource management system (DERMS).[9] If the VPP is designed to serve a single facility (such as a university campus), then the grid services are consumed internal to the VPP. If the VPP is

[9] IEEE Std 2030.11 defines a VPP as "a distributed energy resources management system (DERMS) that has the purpose of aggregating and controlling distributed energy resource assets in blocks of resources (generation, renewables, energy storage, or controllable demand) that can be remotely and automatically dispatched using meters, a software system, and a communications network" (IEEE 2021, 11).

designed to serve the distribution system or the bulk power system, then the grid services are sold to the grid operator.

The concept of a VPP is sometimes confused with an intentional island because a VPP can include microgrids. Conversely, a microgrid controller can perform several functions of a VPP. But a VPP is not an intentional island because the VPP as a whole cannot island.

3 Selected Relevant Standards and Scopes

Following are summaries of several standards that specify functional requirements and provide guidance or recommended practices.

- **IEEE Std 1547-2018** – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces contains mandatory functional requirements for the interconnection of DERs (including intentional islands). The focus of this standard is specifically on the required capabilities and behavior of DERs[10] under normal and abnormal grid conditions.
- **IEEE Std 1547.1-2020** – IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces contains mandatory test procedures for verifying conformance to IEEE Std 1547-2018 requirements.
- **IEEE Std 2030.7-2017** – IEEE Standard for the Specification of Microgrid Controllers contains mandatory requirements for the management and control functions of a particular class of microgrids, which is defined in 2030.7-2017.
- **IEEE Std 2030.8-2018** – IEEE Standard for the Testing of Microgrid Controllers contains mandatory test procedures for verifying conformance to IEEE Std 2030.7-2017.
- **IEEE Std 2030.9-2019** – IEEE Recommended Practice for the Planning and Design of the Microgrid provides information and approaches to important aspects of the planning and design process. Topics covered include procedures for microgrid planning and design, DER configuration, safety aspects, electrical system design, protection, interoperability, monitoring, and metering.
- **IEEE PC2030**.12 – IEEE Draft Guide for the Design of Microgrid Protection Systems. This is a Guide whose Scope includes "…the design and selection of protective devices and the coordination between them for various modes of operation of the microgrid". As of this writing, PC2030.12 is in the balloting process.
- **IEEE Std 1547.4-2011** – IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems. Although now inactive,[11] this guide provides a good general introductory background and discusses implementation considerations throughout the life cycle of the intentional island.

In addition, the International Electrotechnical Commission (IEC) has published a set of technical specifications under the 62898 series of standards developed to provide requirements and guidance on both grid-connected and off-grid intentional islands. These are not discussed in this document; however, the reader might find them to be useful. Following are summaries:

[10] IEEE Std 1547-2018 lists several levels of functionality of DERs that could be designated as intentional-island capable by the DER operator. These designations include intentional-island capable, black-start capable, isochronous-capable, or uncategorized.

[11] IEEE standards are considered active for 10 years after publication.

- **IEC TS 62898-1** Microgrids – Part 1: Guidelines for Microgrid Projects Planning and Specification (2017) contains recommendations for a procedure to plan and design the microgrid. This includes preliminary study, planning, technical requirements, and overall project evaluation. The document also includes material on typical microgrid configurations, basic technical requirements, and considerations for communications, monitoring, and control.
- **IEC TS 62898-2** Microgrids – Part 2: Guidelines for Operation (2018) contains recommendations and basic technical requirements for microgrid operation, transitions, interoperability, protection, and installation and maintenance. This document contains a chapter specifically on the use of electrical energy storage and discusses the role of energy storage to support a variety of objectives, including transient or dynamic stability control in isolated microgrids and balancing power in grid-connected microgrids. Much of the information in this standard is already covered in the IEEE standards; however, this does contain a set of appendices with use cases that the reader might find helpful as supplemental information. For example, these include (1) improving reliability and securing energy supply, (2) electrifying remote areas and using renewable energy sources, (3) reducing energy costs for microgrid users, and (4) optimizing local resources to provide services to the grid/disaster preparedness.
- **IEC TS 62898-3-1** Microgrids – Part 3-1: Protection and dynamic control (2020) contains recommendations and basic technical requirements for microgrid protection and control. Protection challenges exist for systems with limited fault current or with multiple distributed sources, and since many microgrids have both of these properties, microgrid protection presents unique challenges. This document discusses those challenges and provides a list of potential solutions. Microgrids also often have large, fast responses to dynamic disturbances, and this document also discusses management of these dynamics via proper controls.

Standards developed specifically for other applications—such as off-grid, emergency, and standby power systems—might also contain relevant and useful information that could inform considerations during the islanding mode of operation. Examples of these include:

- **IEEE Std 446-1995 (R2000)** – IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications contains extensive discussion on loads and the classification of loads, generation equipment and configurations, energy storage systems, protection, grounding, and maintenance.
- **IEEE Std 1561-2019** – IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems contains information on battery technology, safety, installation, and remote power system operation and maintenance.
- **IEEE Std 2030.11-2021** – IEEE Guide for Distributed Energy Resources Management Systems (DERMS) Functional Specification describes ways that a DERMS[12] could be

[12] IEEE Std 2030.11 defines a distributed energy resources management system (DERMS) as "an application platform designed to manage device information, monitor and enable optimization and control of distributed energy resources (DER) and demand response (DR)" (IEEE 2021, 11).

used to aggregate DERs for the provision of grid services at the distribution and bulk power system levels.

4 Intentional Islanding Operational Stages

An islanding event can be thought of as four separate modes of operation: (1) parallel (grid-connected) operation, (2) transition to islanded operation, (3) islanded operation, and (4) transition to parallel operation. Typical intentional islanding stages of operation[13] are illustrated in Figure 3.

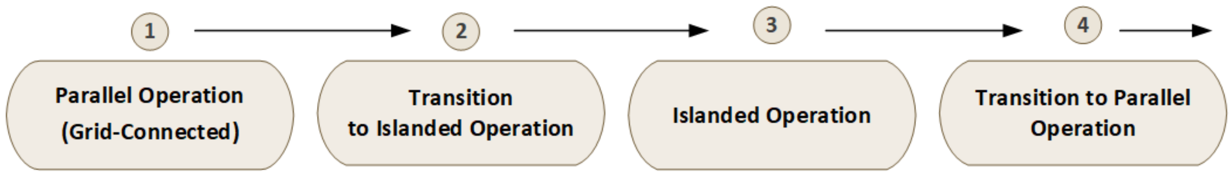

Figure 3. Typical intentional islanding operational stages

During each stage,[14] which can vary in duration, the intentional island must conform to specific requirements and exercise the functions relevant for that mode of operation. The intended behavior during these operational stages must be considered in the planning and design stage of the intentional island life cycle.

Various standards apply for generators, loads, and other equipment for general operation, depending on the equipment installed within the intentional island. This section focuses on the requirements specified in IEEE Std 1547-2018 and IEEE Std 2030.7.[15]

4.1 Distributed Energy Resource Requirements During Parallel Operation

All intentional-island-capable DERs operating in parallel with the Area EPS must meet the requirements of IEEE Std 1547-2018 clauses 4 through 8.1. In addition, the microgrid controller requirements specified in IEEE Std 2030.7 also apply to systems that meet the 2030.7 definition of “microgrid”. Requirements during parallel operation include the following:

- **IEEE Std 2030.7-2017 – General microgrid controller requirements (Clause 4.3)**: These include the requirement that the microgrid controller and the microgrid as a whole must satisfy the technical and operational requirements of the Area EPS operator. In addition, the microgrid must be controllable as a single entity at the *point of interconnection*, which is achieved through the microgrid control system (microgrid controller).
- **IEEE Std 1547-2018 – General requirements (Clause 4):** The reader should consult the standard to review the entire set of requirements. Examples of general requirements include the DER measurement accuracy requirements in 4.4, the cease-to-energize

[13] Another operational state that must be considered during planning of intentional-island systems is black start. This functionality, though acknowledged, is not discussed in detail in any of the standards described in this document.
[14] There are other ways to describe microgrid operational stages. For example, the Electric Power Research Institute’s technical brief titled “Grid Considerations for Microgrids” considers three operating states: grid-connected, islanded, and shutdown. The paper also discusses different types of transitions (EPRI 2021).
[15] Tables 1 and 2 in IEEE Std 2030.7-2017 provide a summary of the requirements during the dispatch and transition functions, respectively.

performance requirements specified in 4.5, the DER control capability requirements in 4.6, the interconnect integrity requirements in 4.11, and the requirement to coordinate grounding schemes with the Area EPS operator.

- **IEEE Std 1547-2018 – Reactive power and voltage/power control (Clause 5)**: This includes adherence to the normal operating performance category (A or B) as specified by the Area EPS operator, the maintenance of voltage within the ANSI C84.1 service voltage requirements, the capability for voltage and reactive/active power control as specified in Table 6 in IEEE Std 1547-2018 and in clauses 5.3 and 5.4., and the capability for reactive power injection and absorption as specified in Table 7 in IEEE Std 1547-2018. Note that these capabilities are required in both parallel and islanded mode; however, the utilization of these capabilities is at the discretion of the Area EPS operator.
- **IEEE Std 2030.7-2017 – Microgrid controller voltage regulation functions:** The microgrid controller is responsible for voltage regulation (including the management of traditional voltage-regulating equipment, such as capacitors and transformer tap changers, as well as inverter-based DERs) and for managing real and reactive power exchanges at the point of interconnection.
- **IEEE Std 1547-2018 – Response to Area EPS abnormal conditions (Clause 6):** All DERs must meet the abnormal operating performance categories I, II, or III. This includes the response to Area EPS faults and open-phase conditions, adherence to mandatory voltage trip requirements for overvoltage and undervoltage, adherence to mandatory frequency trip requirements for overfrequency and underfrequency, voltage disturbance ride-through, frequency disturbance ride-through, and other requirements. **Under any conditions specified in Clause 6 that would require or allow the DER to trip, the DER can form an intentional island that isolates the island from the Area EPS.** Coordination with the Area EPS operator is required in the planning stages to jointly agree on how the intentional island-capable DER will respond to abnormal conditions.
- **IEEE Std 1547-2018 – Power quality requirements (Clause 7):** This discusses limitations on DC injection and voltage fluctuations induced by DERs, including rapid voltage changes and flicker, current distortion, overvoltage contribution, and cumulative instantaneous overvoltage.
- **IEEE Std 1547-2018 – Prevention of unintentional islanding requirements (Clause 8.1):** Unintentional islanding requirements are specified in 8.1. In case an unintentional island forms at the Area EPS, the DER must detect that an island has formed, and it must respond by *ceasing to energize the Area EPS and tripping* within 2 seconds. Alternatively, **if the DER detects an unintentional island, instead of ceasing to energize the Area EPS and trip, an intentional island can be formed that isolates the island from the Area EPS.**
- **IEEE Std 2030.7-2017 – Microgrid controller dispatch functions, including emergency transition to islanding:** IEEE Std 2030.7-2017 requires the microgrid controller, under its dispatch function, to balance load and generation under grid-connected and islanded modes and to redispatch based on internal or external orders. Per this standard, the microgrid controller must also have the capability to immediately execute an emergency dispatch order if called upon to transition to an unplanned island, as described below.

- **IEEE Std 2030.7-2017 – Microgrid controller protection coordination functions:** In a Local EPS (facility) island, the microgrid controller is responsible for the operation of the facility's internal protective equipment, such as breakers and switches. An Area EPS island might have additional or different types of protection equipment and configurations.

4.2 Distributed Energy Resource Requirements During the Transition to Islanding

The transition to islanded operation can be scheduled/planned or unscheduled/unplanned. Unscheduled transitions to island mode are automatically created by the intentional island controls upon detection of abnormal grid conditions that trigger the intentional islanding operation. As noted in IEEE Std 1547-2018 Clause 8.2.2, a scheduled transition to intentional island mode is typically formed by manual action taken by the DER operator, the Area EPS operator, or some other dispatching means, such as an energy management system or a microgrid controller that triggers the opening of an isolation device and the transition from being in parallel with the Area EPS to being an islanded system. An important planning consideration is the determination of criteria for the transition to planned islanded mode. There can be several reasons to schedule intentional islanding. Common reasons are improving the reliability of the islanded system, scheduled Area EPS maintenance, and a preemptive action to mitigate outage risk (e.g., due to inclement weather).

- **IEEE Std 1547-2018 – Voltage control during transition (Clause 7.2.2):** It is expected that a scheduled transition to island mode will occur during normal grid operating conditions; therefore, if the voltage and frequency are within normal (continuous operation) ranges, during the transition to island mode, the DER must control the voltage changes within the ranges specified in IEEE Std 1547-2018 Clause 7.2.2, which limits the amount of rapid steps or ramps in voltage.
- **IEEE Std 1547-2018 – Participation of uncategorized DERs (Clause 8.2.8)**: It is up to the intentional island operator to determine whether uncategorized DERs can participate in the intentional island. If permission is not given, uncategorized DERs are to treat the event as an unintentional island and therefore cease to energize the area EPS.
- **IEEE Std 2030.7-2017 – Transition and dispatch functions:** IEEE Std 2030.7-2017 provides a discussion of the microgrid controller logic required for transitions using the transition and dispatch functions in conjunction. The transition to islanding is considered a dispatch function. Under this, the intentional island can be dispatched (transition to) four modes: (1) planned transition to island, (2) unplanned transition to island, (3) reconnection to grid, and (4) black start. IEEE Std 2030.7-2017 contains discussion on developing metrics for transition functions and describes scenarios for testing the transition functions.

4.3 Distributed Energy Resource Requirements During the Islanded Operation

Note that the scope of IEEE Std 1547-2018 covers the interconnection of DERs (within a Local EPS) operating in parallel with the Area EPS. One could interpret this to mean that the condition of a Local EPS intentional island is out of scope of IEEE Std 1547-2018 because there is no parallel operation with the area EPS. Although this interpretation adheres to the specified scope, one could also argue that the overall intent of IEEE Std 1547-2018 is to define uniform DER behavior as an active element of the power system regardless of the condition of the power system. This logic applies to abnormal grid conditions, including intentional or unintentional islands. This document's authors have adopted the latter interpretation as applying to DER behavior in both facility and Area EPS intentional islands. Certainly, it is acknowledged that IEEE Std 1547-2018 addresses only the interconnection aspects of DER behavior, and many other important topics related to DERs in intentional islands are being actively investigated[16] and may be included in future versions of IEEE Std 1547 or other relevant standards.

- **Unintentional island protection:** In an intentional islanding mode, consideration must be given to methods for maintaining this requirement in island capable DER. Although not specifically stated in 1547, one can expect that uncategorized DER will maintain this requirement regardless of intentional island operational stage and regardless of whether the island is a Local EPS island or an Area EPS island.
- **Reactive power capability:** Under IEEE Std 1547-2018 (Clause 5.2), *capability to generate* reactive power is required for DERs operating in an Area EPS island.
- **Voltage and reactive power control:** Under IEEE Std 1547-2018 (Clause 5.3), *capability to control* voltage and reactive power is required for DERs operating in an Area EPS island.
- **IEEE Std 1547-2018 adjustments to DER control and protection settings (Clause 8.2.7):** It is likely that during islanded mode, alternate ranges and settings will be needed for control and protection parameters. Per Clause 8.2.7, these can be activated only when separation from the rest of the Area EPS has occurred. Alternate ranges for allowable settings are specified in this clause for the following:
  - Mandatory voltage trip (Clause 6.4.1)
  - Mandatory frequency trip (clause 6.5.1)
  - Frequency-droop (Clause 6.5.2.7).
- **IEEE Std 2030.7 – Balancing load and generation:** IEEE Std 2030.7-2017 requires the microgrid controller, under its dispatch function, to balance load and generation under both grid-connected and islanded modes and to redispatch based on internal or external orders.
- **IEEE Std 2030.7 – Maintaining system frequency**: Under IEEE Std 2030.7-2017, during islanding mode, the microgrid controller must perform frequency control to maintain the system frequency.
- **Maintaining power quality**: Under IEEE Std 2030.7-2017, during islanding mode, the microgrid controller is responsible for maintaining the power quality internal to the island. DERs operating in an intentional Area EPS island must adhere to all power quality requirements specified in IEEE Std 1547-2018.

[16] For example, through the U.S. Department of Energy-funded Universal Interoperability for Grid-Forming Inverters (UNIFI) Consortium. https://sites.google.com/view/unifi-consortium/home.

- **IEEE Std 1547-2018 also specifies additional requirements**: It is the responsibility of the intentional island operator to specify any additional requirements needed during islanded operation, such as those for DERs not specifically designed for intentional island operation.

4.4 Distributed Energy Resource Requirements During the Transition to Parallel Operation

Once the Area EPS has established stable operation or the maintenance has been completed, the transition to an Area EPS interconnection may be initiated. This process includes (1) synchronize and match voltages and phase angles; (2) set the energy management system or microgrid controller appropriately; and (3) reconnect and restore noncritical loads as appropriate.

- **IEEE Std 1547-2018 – Enter service requirements (Clause 4.10):** This clause specifies the voltage and frequency ranges that DERs can use to determine whether grid conditions are acceptable to return to parallel operation. During the transition, DERs must control their rate of active power output (or rate of charging, for energy storage), which must gradually increase in a linear way according to the requirements specified in Clause 4.10.3. There are two exceptions allowed:
    - **Exception 1**: For sites smaller than 500 kVA, individual DER units can ramp up power with no limitation or rate of change, if they implement a randomized start time delay within certain specified parameters.
    - **Exception 2**: For sites greater than 500 kVA, alternative ramp rates are possible after discussion and approval of the area EPS operator and coordinated with the regional reliability coordinator.
- **IEEE Std 1547-2018 – Synchronization requirements (Clause 4.10.4):** The resynchronization of the intentional island to the Area EPS is achieved by matching the voltage amplitude and phase angles prior to reconnecting to the Area EPS. An energy management system or a microgrid controller can be used to match these parameters, and a command is sent to the isolation device to close and interconnect the islanded system to the Area EPS.
- **IEEE Std 1547-2018 – Reconnection requirements (Clause 8.2.6):** Reconnection can occur if the enter service requirements (Clause 4.10) and the synchronization requirements are met at the point of interconnection between the intentional island system and the rest of the grid (Clause 4.10.4).

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Appendix A. Additional Reading

As noted, intentional islands are being considered for a variety of reasons. This selection of resources provides general background as well as information on emerging topics in intentional island implementation.

A.1 Intentional Island Standards and Interconnection Implementation

Electric Power Research Institute (EPRI). 2021. *Grid Considerations for Microgrids*. Palo Alto, CA. 3002020344. https://www.epri.com/research/products/000000003002020344

Greacen, Chris, Richard Engel, and Thomas Quetchenbach. 2013. "*A Guidebook on Grid Interconnection and Islanded Operation of Mini-Grid Power Systems Up to 200 KW*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-6224E. https://eta-publications.lbl.gov/sites/default/files/a_guidebook_for_minigrids-serc_lbnl_march_2013.pdf.

A.2 Intentional Island Planning and Design

Institute of Electrical and Electronics Engineers (IEEE). 2011. IEEE Std 1547.4-2011 – IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems. Piscataway, NY. https://doi.org/10.1109/IEEESTD.2011.5960751.

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Booth, Samuel, James Reilly, Robert Butt, Mick Wasco, and Randy Monohan. 2019. *Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-72586. https://www.nrel.gov/docs/fy19osti/72586.pdf.

Sandia National Laboratories. 2019. *Fundamentals of Advanced Microgrid Design: Coursebook for Advancing Caribbean Energy Resilience Workshop*. Albuquerque, NM. https://www.usaid.gov/sites/default/files/documents/1865/ACER_Coursebook_2019_english.pdf

A.3 Intentional Island Architectures and Configurations

Asmus, Peter, Adam Forni, and Laura Vogel. 2018. *Microgrid Analysis and Case Studies Report: California, North America, and Global Case Studies*. Sacramento, CA: California Energy Commission. CEC-500-2018-022.

Electric Power Research Institute (EPRI). 2021. Test Plan for a Networked Microgrid Controller Palo Alto, CA. 3002021861. https://www.epri.com/research/products/000000003002021861.

Flores-Espino, Francisco, Julieta Giraldez Miner, and Annabelle Pratt. 2020. *Networked Microgrid Optimal Design and Operations Tool: Regulatory and Business Environment Study*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70944. https://doi.org/10.2172/1659812.

A.4 Grid-Forming Inverters

North American Electric Reliability Corporation. 2021. *Grid Forming Technology: Bulk Power System Reliability Considerations*. Atlanta, GA. https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf.

Pierre, Brian J., Hugo N. Villegas Pico, Ryan T. Elliott, Jack Flicker, Yashen Lin, Brian B. Johnson, Joseph H. Eto, Robert H. Lasseter, and Abraham Ellis. 2019. "Bulk Power System Dynamics with Varying Levels of Synchronous Generators and Grid-Forming Power Inverters: Preprint." Presented at the 46th IEEE Photovoltaic Specialists Conference (PVSC 46), Chicago, Illinois, June 16–21, 2019. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-74107. https://www.nrel.gov/docs/fy19osti/74107.pdf.

Universal Interoperability for Grid-Forming Inverters (UNIFI) Consortium. 2022. "Unifying Inverters & Grids." https://sites.google.com/view/unifi-consortium.

A.5 Protection Settings in Islanded Systems

Electric Power Research Institute (EPRI). *Grid Considerations for Microgrids*. Palo Alto, CA. 3002020344. https://www.epri.com/research/products/000000003002020344.

Venkata, S. S. (Mani), Matthew J. Reno, Ward Bower, Scott Manson, James Reilly, and George W. Sey Jr. 2019. 2019. *Microgrid Protection—Advancing the State of the Art*. Albuquerque, NM: Sandia National Laboratories. SAND2019-3167.

A.6 Intentional Islands for Resilience Including Black Start

Alam, S. M. S., A. Banerjee, C. Loughmiller, B. Bennett, N. Smith, T. M. Mosier, V. Gevorgian, B. Jenkins, and M. Roberts. 2021. *Idaho Falls Power Black Start Field Demonstration—Preliminary Outcomes Report*. Idaho Falls, ID: Idaho National Laboratory.

Booth, Samuel, James Reilly, Robert Butt, Mick Wasco, and Randy Monohan. 2019. *Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-72586. https://www.nrel.gov/docs/fy19osti/72586.pdf.

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Rydalch, N. "Idaho Falls Power Discovers Big Value in Small Hydropower." *NWPPA Bulletin,* February 2022, pp. 30–33.

A.7 Intentional Island Policies and Regulations

Cook, Jeffrey J., Christina Volpi, Erin Nobler, and Kyle Flanegin. 2018. *Check the Stack: An Enabling Framework for Resilient Microgrids*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71594. http://www.osti.gov/servlets/purl/1483066/.

Flores-Espino, Francisco, Julieta Giraldez, and Annabelle Pratt. 2020. *Networked Microgrid Optimal Design and Operations Tool: Regulatory and Business Environment Study*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-70944. https://www.nrel.gov/docs/fy20osti/70944.pdf.