A Primer on the Unintentional Islanding Protection Requirement in IEEE Std 1547-2018

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

1 National Renewable Energy Laboratory
2 Sandia National Laboratories

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Preface

The revised Institute of Electrical and Electronics Engineers 1547-2018 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, and energy storage 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 that are important to the interconnection of DERs to the electric power system. Implementing the requirements necessitates a careful study of the underlying technical concepts and requires 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 document provides informative material on the requirements related to unintentional islanding in IEEE Std 1547-2018, with the intent to equip the reader with basic knowledge and background information to improve understanding and use of the requirements specified.

Note that this document reflects the authors' interpretations, which in some instances might differ from one person to another; therefore, this work is intended to supplement the existing and growing body of knowledge[1] across the U.S. electric sector on the use and application of this important standard.

[1] Additional educational material can be found at https://www.nrel.gov/grid/ieee-standard-1547/.

Acknowledgments

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List of Acronyms

AGIR	Authority Governing Interconnection Requirements
DER	distributed energy resource
DTT	direct transfer trip
EPS	electric power system
IEEE	Institute of Electrical and Electronics Engineers
PG&E	Pacific Gas & Electric Company
PV	photovoltaic
VAR	volt-ampere reactive

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Introduction

In the revised Institute of Electrical and Electronics Engineers 1547-2018 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018), Clause 8.1 contains requirements for distributed energy resource (DER) responses to unintentional islanding conditions. This is also referred to as anti-islanding protection.

An island is a condition in which a DER continues to energize a portion of the power system when it is electrically isolated from the utility source. If unplanned, this *unintentional islanding* condition could become harmful to connected equipment because the DER might not be designed to maintain frequency and voltage without a utility source. In addition, the unintentional island could present a hazard to utility workers or other people in the area who are unaware of the electrically energized island (Seguin et al. 2016).

IEEE Std 1547-2018 Clause 8.1 is only half a page; however, the topic of unintentional islanding has historically been and continues to be of high concern and debate in the industry. The issues around this phenomena were eloquently stated by Bas Verhoeven in a 2002 study under the International Energy Agency:

> Many international forum discussions have been dealing with 'Islanding'. …
>
> A general conclusion of these discussions was that views on the subject are very polarised. On the one hand, the islanding phenomenon is considered such a rare or improbable event that it does not merit special consideration. On the other hand, the mere theoretical possibility of unintentional islanding, confirmed in laboratory experiments, is sufficient for individuals to have great concerns over the possibility of islanding. The reality probability lies somewhere between the two extremes. An important issue here is the lack of any real data on how often and for how long islanding can occur in practice and the associated risk of occurrence. An important observation in the discussion about islanding is that the discussion is based on "personal feelings" and/or "intuition", which make the discussions even more difficult.

This document is intended to provide an overview of the subject to aid the reader in discussions and understanding. The intended audience includes electric utilities—area electric power system (EPS) operators; testing agencies[2]; solar and other DER developers, integrators, and installers[3]; and Authorities Governing Interconnection Requirements.[4] We hope that other stakeholders will also find it valuable.

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[2] The term *testing agency* includes entities such as nationally recognized testing laboratories.

[3] Solar and other DER device manufacturers are inherently interested in the performance requirements in IEEE Std 1547-2018; however, this document focuses on the application of the standard rather than the manufacturing processes of DER devices.

[4] The term *Authority Governing Interconnection Requirements* (AGIR) is defined in IEEE Std 1547-2018 as a "cognizant and responsible entity that defines, codifies, communicates, administers, and enforces the policies and procedures for allowing electrical interconnection of DER to the Area EPS. This may be a regulatory agency, public

This document is intended as a supplement to material already published or in development,[5] and it is not intended as an exhaustive resource on technical implementation; rather, topics are presented at a level that is appropriate to serve individuals who require an introduction or technical refresher to the material.

IEEE Std 1547-2018 assumes that the reader possesses the appropriate training and experience necessary to understand and apply the stated requirements. This could include foundational electrical engineering knowledge; knowledge of area EPS device settings, parameters, and operational practices; and knowledge of general and specific DER capabilities relevant to the subject.

Anti-islanding protection is required for all DERs that comply with IEEE Std 1547-2018 and UL 1741, Standard for Safety for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources. Specifically, according to IEEE Std 1547-2018, if an unintentional island is formed by the DER, the DER must detect the island and go offline[6] within 2 seconds of the formation of the island.

The most common DERs are photovoltaic (PV) or battery energy storage systems, and these DERs are inverter based; therefore, numerous studies have focused specifically on these types of DERs. This document uses the term *DER* to apply to all types of DERs, and the more specific terms *PV* or *inverter* refer to inverter-based DERs.

How Can Unintentional Islands Form?

Several conditions could potentially cause unintentional islanding. Examples given by Bower and Ropp (2002) include:

- A fault on the area EPS that results in opening a disconnecting device, but the fault is not detected by the PV inverter or by local DER protection devices
- Equipment failure that causes an accidental opening of a disconnecting device
- Utility switching of distribution line and loads; intentional disconnection of the distribution line for utility service or repair
- Human error
- Bad actor with malicious intent

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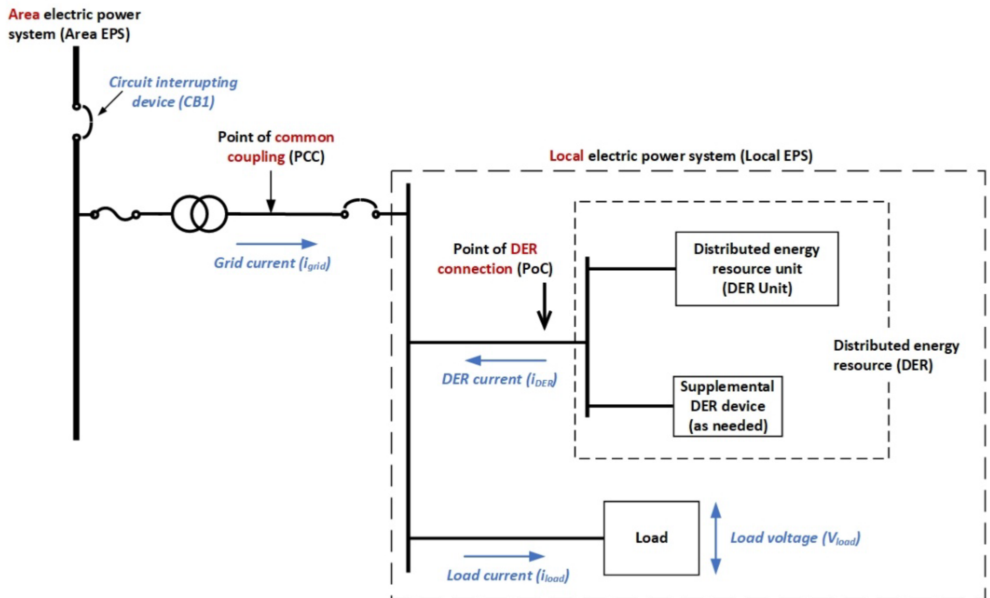
utility commission, municipality, cooperative board of directors, etc. The degree of AGIR involvement will vary in scope of application and level of enforcement across jurisdictional boundaries. This authority may be delegated by the cognizant and responsible entity to the Area EPS operator or *bulk power system* operator. NOTE—Decisions made by an authority governing interconnection requirements should consider various stakeholder interests, including but not limited to Load Customers, Area EPS operators, DER operators, and *bulk power system* operator" (IEEE 2018).

[5] For example, the upcoming revision to IEEE Std 1547.2 - IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems (expected in 2022).

[6] The wording in IEEE Std 1547-2018 is very specialized and includes other defined terms, such as *cease to energize* and *trip*.

- An act of nature.

Consider Figure 1. In a typical local EPS supplied by a DER such as a PV system, the inverter controls its electrical current output magnitude and phase with respect to the voltage it sees at its output terminals, called the "point of DER connection" in IEEE Std 1547-2018. This current is supplied to the local DER load. Note that a local EPS could be configured in a variety of ways. For example, it could contain only load, only a single DER (DER unit), multiple DERs, DERs with or without supplemental DER devices, and so forth. See IEEE Std 1547-2018 Figure 2 for a full explanation.



Source: Adapted from Kroposki 2016; Ropp and Ellis 2013; and IEEE 2018

Figure 1. Block diagram of DER interconnection illustrating unintentional islanding concepts

The circuit breaker in the diagram (CB1) could be any type of circuit isolation device, and it represents any point on the distribution line between the substation and the DER installation along which normal power flow could be interrupted. If this device is opened, the DER is isolated from the grid. The circuit isolation device is often associated with fault protection and is the most common type of isolation device. The condition that invokes a response from the protection device is a fault that is significant and immediate enough to cause the protection device to trip, open, and isolate the source and loads. This creates a dynamic condition on the circuit, with the voltage and frequency fluctuating considerably, thus making it less probable to match power and meet the reactive power resonance requirements to sustain an islanding event. When the isolation device is operated for a maintenance event, the dynamic variability is mostly removed, and there could be a condition where the current flowing through the isolating device is low enough to maintain sufficient active and reactive power matches; and while the matches are still needed, the variability aspect is removed. For fault conditions that cause the isolation devices to trip, the DERs are designed to turn off to prevent an islanded condition; however, there are some conditions under which an island could form and persist. These conditions must occur at the exact moment the device opens, and they include the following:

- The grid current must be nearly zero—that is, the PV system must be producing nearly the same amount of power that is required for the load to operate.
- The power from the DERs must have the correct amount of active and reactive power required by the load.
- The reactive current must have capacitive and inductive components that resonate near 60 Hz.

DERs use various anti-islanding methods to detect and quickly disconnect in case a potentially stable island is formed. IEEE Std 1547-2018 and related standards IEEE Std 1547.1-2020 and UL 1741 require all DERs to meet robust anti-islanding functional requirements and testing before they can be deployed in the field.

Summary of Inverter-Based Anti-Islanding Protection Methods

Inverter-based DERs, such as PV and storage systems, feature built-in protection mechanisms that detect when they have become islanded from the distribution grid. Inverters have traditionally used a number of anti-islanding protection methods that have been classified as either passive or active. Modern inverters do not rely solely on passive methods.

Passive methods for islanding detection resident in the inverter are designed to monitor the electrical parameters at the point of DER connection. Upon detecting an abnormal condition, the inverter ceases power conversion. As noted by Bower and Ropp (2002), typical monitored conditions are:

- Over-/undervoltage and over-/underfrequency detection[7]
- Voltage phase jump detection
- Voltage harmonics detection
- Current harmonics detection.

Active methods of islanding detection in inverters are based on the logic that the inverter should not be able to affect certain electrical parameters as much as the larger area EPS—unless the inverter is operating in an island. These methods are designed to deliberately create small changes or disturbances at the point of DER connection. The response is analyzed to determine whether the inverter has been able to affect specific parameters—and if so, it is assumed that an island has occurred, and the inverter ceases power conversion. Common methods of active anti-islanding detection noted in literature include[8]:

- **Impedance measurement**
- **Impedance detection at a specific frequency**
- **Slip-mode frequency shift**

[7] Note that the informative footnote 111 in IEEE Std 1547-2018 states: "Reliance solely on under/over voltage and frequency trip is not considered sufficient to detect and cease to energize and trip" (IEEE 2018).
[8] DER inverter manufacturers might also employ proprietary methods that use other techniques or combinations of the techniques mentioned here.

- **Frequency bias/Sandia frequency shift**
- **Sandia voltage shift**
- **Frequency jump**
- **Mains monitoring units with allocated all-pole switching devices connected in series**[9]

[9] Sometimes referred to as *MSD*, "main monitoring device" or *ENS*, the German abbreviation for mains monitoring units with allocated switching devices.

1 Functional Requirements in IEEE Std 1547-2018

IEEE Std 1547-2018 Clause 8.1 is directed primarily to area EPS operators, DER manufacturers, testing agencies, commissioning agencies,[10] and DER operators. A DER connected to the area EPS must meet the unintentional islanding requirements of Clause 8.1 which contains three subclauses.

1. Clause 8.1.1 describes the islanding condition and the requirement for DER response: Upon formation of an island (the moment the DER is separated from the area EPS), the islanding DER must respond by ceasing to energize and tripping[11] within 2 seconds after the formation of an island. The 2-second response time is called the clearing time. By default, the clearing time is set to be 2 seconds. Not only must the DER detect the island within 2 seconds, but it must also trip. Upon trip, the DER will intentionally stay disconnected for a specified time. This intentional delay, called the *return-to-service delay*[12] is by default set to 5 minutes under IEEE Std 1547-2018. The delay can be adjusted by mutual agreement between the area EPS operator and the DER operator.
2. Clause 8.1.2 states the clearing time can be adjusted to be between 2 and 5 seconds by mutual agreement between the area EPS operator and the DER operator.
3. Clause 8.1.3 directs the reader to Clause 6.3, which requires the implementation of "appropriate means" to prevent damage or unacceptable disturbances to the area EPS if it automatically recloses on an islanded circuit. Damage or unacceptable disturbances could result if there are differences in instantaneous voltage, phase angle, or frequency between the islanded system and the area EPS at the instant a recloser operates (IEEE 2018).

Clause 8.1.1, Clause 8.1.2, and Clause 8.1.3 comprise the unintentional islanding requirements in IEEE Std 1547-2018. Because of the safety nature of these requirements, however, extensive effort is made to verify this functionality, and in some jurisdictions, additional safeguards are put into place to supplement these unintentional islanding prevention requirements.

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[10] A commissioning agency could include the DER vendor, the system integrator, the local utility, or other qualified and authorized entity.

[11] *Cease to energize* is a specialized term that applies at the point of DER connection, defined as a "cessation of active power delivery under steady-state and transient conditions and limitation of reactive power exchange." This function can be caused to operate for a variety of reasons. In the case of unintentional islanding, it is followed by a *trip*, another specialized term, which is defined as an "inhibition of immediate return to service, which may involve disconnection" (IEEE 2018).

[12] The return-to-service delay is typically changed to much shorter times when type testing a DER to expedite the unintentional islanding testing procedure.

2 Factory Testing and Certification

IEEE Std 1547-2018 requires DERs to detect and cease to energize the area EPS and trip within 2 seconds of the formation of an island. For most types of residential and commercial DERs, this requirement is built into the DERs by manufacturers, and this capability is thoroughly tested prior to field deployment.[13]

In the United States, this "type testing" typically occurs by an approved testing agency[14] at the DER manufacturer's factory or at a special testing laboratory, and it is carried out on a single piece of equipment (DER unit) that represents the specific model of the manufactured DER. The testing is valid for other DERs in the product family of the same design.

In the United States, type testing is typically done in conjunction with equipment certification. Type tests are completed according to the procedures specified in IEEE Std 1547.1-2020, and the testing agency records the applicable test criteria and results. For DER interconnections, the primary means of equipment certification is via UL 1741, Standard for Safety for Inverters, Converters, Controllers, and Interconnection System Equipment for Use With Distributed Energy Resources.

Certified equipment is installed following the requirements of the National Fire Protection Association 70 (National Electric Code) to ensure that sound equipment installation practices contribute to the safe operation of the equipment. Additional jurisdiction-specific requirements might also be applied via local interconnection rules. This implementation is illustrated in Figure 2.

Under UL 1741, anti-islanding protection testing is conducted after all grid support functions[15] are tested. This ensures that the equipment being tested can perform all the grid support functions as designed and that it can pass the unintentional islanding tests with grid support functions, such as voltage and frequency support functions along with the mandatory voltage and frequency ride-throughs. The IEEE Std 1547.1-2020 test matrix is an exhaustive test procedure and combines various grid support functionalities and power levels to ensure that the DER can detect the loss of the utility under unique balanced conditions. For these tests, the method of isolation is the opening of an isolation device, such as conditions occurring under a routine maintenance isolation condition, i.e., a fault is not introduced to cause a protection device to trip/actuate.

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[13] Certain types of DERs that contain supplemental DER devices might need to be field-certified.
[14] A nationally recognized testing laboratory, certified by the Occupational Safety and Health Administration, is an example of a testing agency.
[15] Examples of grid support functions include active and reactive power control voltage ride-through and frequency ride-through.

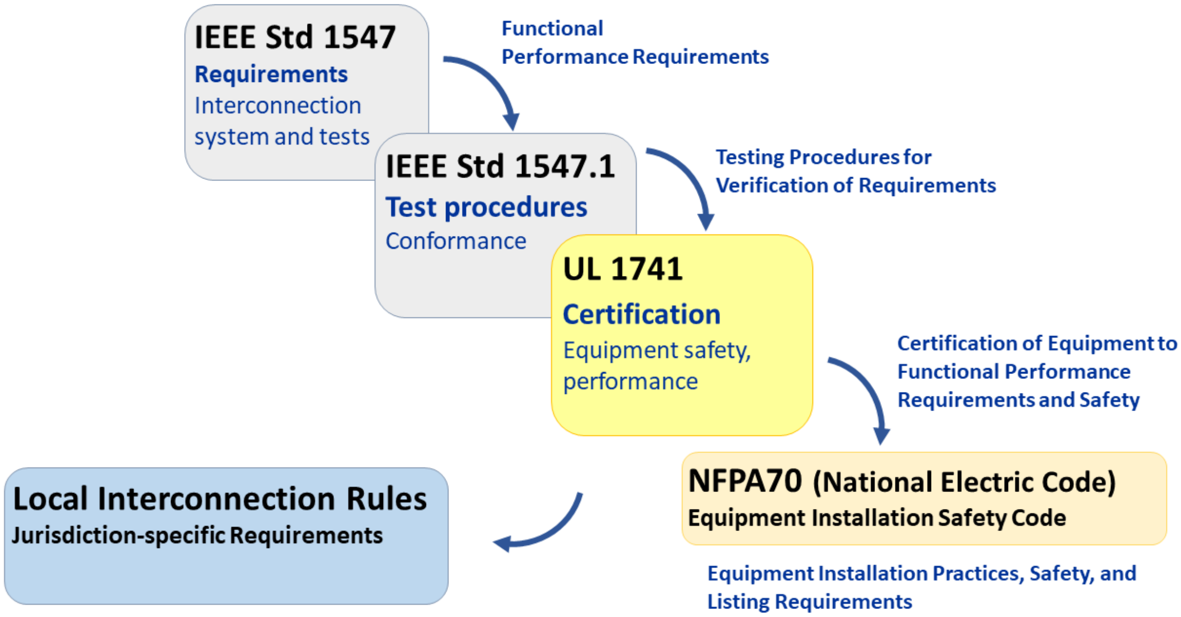

Figure 2. Implementation of IEEE Std 1547-2018 and related standards in the United States

IEEE Std 1547.1-2020, which was approved in March 2020, specifies the conformance testing and evaluation procedures that are exercised to establish and verify compliance with the technical functional requirements of IEEE Std 1547-2018.

UL 1741 was updated to reflect the revised performance and testing requirements in IEEE Std 1547.1-2020. The revision was published on August 3, 2020. The revised testing requirements are included in Supplement B, UL 1741-SB.[16]

As summarized in IEEE Std 1547.1-2020, one or more samples of the DER must pass the applicable type tests. Performance requirements not verifiable through type tests must be verified by other means, such as DER evaluation and commissioning tests. Each DER unit or supplemental DER device must pass all required production tests. The design evaluation phase of the interconnection process will determine whether any additional testing or evaluation must be made either during the design evaluation, through installation evaluations, and/or through commissioning tests. Additionally, any required periodic tests and verifications are to be performed in the field (IEEE 2020).

Most type testing of DER unintentional islanding functionality is performed under worst-case conditions to fully challenge both the capability of the DER to detect when an unintentional islanding event has occurred and to challenge the DER's ability to take the required actions.

[16] Please see https://sagroups.ieee.org/scc21/standards/1547rev/ for a timeline for the rollout of DERs that comply with IEEE Std 1547-2018.

Unintentional islanding testing is conducted with grid support functions enabled and with the DER operating in different modes, i.e., unity power factor, non-unity power factor, and constant reactive power operation. These operating modes coupled with voltage regulating functions and frequency regulating functions can challenge some of the unintentional islanding methods; therefore, voltage and frequency ride-through and voltage and frequency regulating functions must be determined prior to conducting unintentional islanding assessments. If unintentional islanding evaluations result in nonconformance, an investigation must be performed to identity the function that creates the nonconformance.

DER manufacturers can use a variety of methods[17] to detect an islanding condition. IEEE Std 1547.1-2020 Clause 5.10 specifies the required type tests to verify the unintentional islanding functionality.

The DER and any supplemental equipment being tested, referred to as "equipment under test" by IEEE Std 1547.1-2020, may use multiple methods of unintentional islanding detection. Commonly implemented methods[18] use some form of voltage and frequency threshold to detect when an islanding condition exists. Various tests have been designed to evaluate how well these methods perform as part of the type testing regimen.

2.1 Balanced Generation-to-Load Test

The balanced generation-to-load test, described in Clause 5.10.2, can be used for any type of equipment. Passing this test achieves full compliance with the unintentional islanding requirements. This test is conducted to verify that when an unintentional islanding condition occurs, the DER responds correctly—namely, by ceasing to energize the area EPS—and trips. Tests are conducted on a single DER under various power levels.

A simplified drawing of the test configuration is illustrated in Figure 3. The test can be conducted using a power-hardware-in-the-loop approach that allows the testing agency to use software and hardware to simulate some of the devices that are external to the DER.

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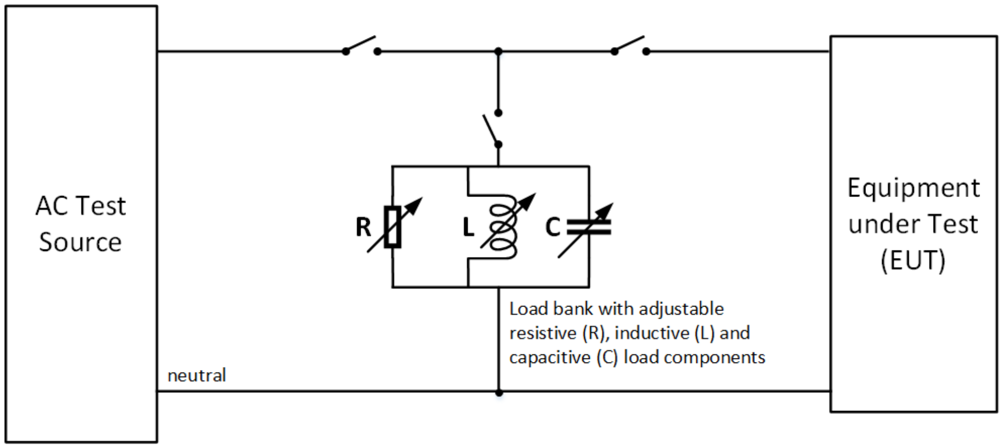
[17] Passive and active methods are not limited to the methods mentioned here; however, some common passive methods include over-/undervoltage and over-/underfrequency, voltage phase jump, voltage/frequency harmonic distortion, rate of change of frequency, and rate of change of active power. Some common active methods include impedance detection, positive-feedback Sandia frequency shift, and impedance detection plus positive feedback.

[18] IEEE Std 1547-2018 notes that additional methods may be used to provide unintentional islanding protection, such as direct transfer trip or radio or cellular communications channels; however, type testing those methods was considered out of scope of the standard.



Source: Based on IEEE Std 1547.1-2020 (Figure 7)

Figure 3. Single-line drawing of the setup for a balanced generation-to-load test

This test relies on the principle that for an island to persist, the DER must be generating at or very near[19] the same active and reactive power that the load requires in the islanded portion of the system, and some mechanism must exist to maintain the islanded frequency at or very near 60 Hz. For testing conditions, therefore, a worst-case condition is a generation-to-load balance that contains both active and reactive power generation with load components that are tuned to match the DER generation power levels and resonate at or near 60 Hz to provide the system frequency.

2.2 Power Line-Conducted Permissive Signal Test

This method of anti-islanding protection relies on a signal conducted on the distribution primary line. As long as the signal is present, the DER has permission to operate. If the signal is discontinued, the DER must cease to energize the area EPS and trip within the required time.

The power line-conducted permissive signal test—applicable to DERs that use this method—is described in IEEE Std 1547.1-2020 Clause 5.10.3. For DERs that use this method, additional evaluation is required because this method uses equipment beyond what is tested in the type test; therefore, passing this test achieves only partial compliance with the unintentional islanding requirements. The additional evaluation needed to obtain full compliance is specified in IEEE Std 1547.1-2020 Clause 8.1.2.

During type testing, the testing agency simulates a permissive signal and its interruption. If the DER responds appropriately within the designated time, it passes the type test. As noted, however, because this test requires the permissive signal to be effective, the type test alone does not verify full compliance with the unintentional islanding requirements. Additional verification is required during the DER evaluation phase, at which time additional required equipment or methods are applied, such as a permissive signal provided by the area EPS operator.

[19] Voltage and frequency operating ranges allow for a slight mismatch, and the output power of the DER is never exactly constant because of maximum power point tracking and variations of the grid voltage and frequency.

2.3 Permissive Hardware-Input Test

The permissive hardware-input test—applicable to DERs that use this method—is described in IEEE Std 1547.1-2020 Clause 5.10.4. For DERs that use this method, additional evaluation is required because this method uses equipment beyond what is tested in the type test; therefore, passing this test achieves only partial compliance with the unintentional islanding requirements. The additional evaluation is specified in Clause 8.1.2.

DERs that use this method of unintentional islanding detection have a dedicated hardware control input that is used to provide permission to operate. (Note that the hardware control signal itself is generated by external means, and it is not tested in this procedure.[20])

Similar to the power line-conducted permissive signal test, this test requires external input to be effective—in this case, the hardware control input; therefore, the type test alone does not verify full compliance with the unintentional islanding requirements. Additional verification is required during the DER evaluation phase, at which time additional required equipment or methods are applied, such as a direct transfer trip (DTT) input provided by the area EPS operator.

2.4 Reverse or Minimum Import Active Power Flow Test

The reverse or minimum import active power flow test (including tests for magnitude and time), applicable to the DERs that use this method, is described in IEEE Std 1547.1-2020 clause 5.10.5. Passing this test achieves full compliance with the unintentional islanding requirements.

DERs that use this method have a function that senses the power flow between the point of connection and the point of common coupling. Using this function, the DER is permitted to operate only if power is flowing from the area EPS to the DER installation or if the power is flowing at a predetermined minimum level. If the power flow reverses or falls below the minimum level, the DER is disconnected from the area EPS. Type testing includes verification of the accuracy of the minimum power setting and the speed of the DER response.

[20] Examples of a DTT and a conducted power line signal are given in IEEE Std 1547-2018.

3 Field Evaluations and Verifications

In addition to type testing, verification of performance might be required during the DER's interconnection life cycle. A high-level view of the varieties of testing and verification is illustrated in Figure 4, with type testing shown at the bottom of the figure as the first level of evaluation. Unintentional islanding protection must be verified for all DERs during the design evaluation phase and/or during commissioning tests.

A design evaluation is a desk study typically conducted by electric utility engineers as part of an interconnection review process. The main purpose of the design evaluation is to verify that the overall DER system meets the requirements specified in IEEE Std 1547-2018 and any other interconnection requirements specified by the utility. Evaluations could be as simple as an engineering review of the DER system's design, components, and certification, or it could involve a more detailed study, such as modeling and simulation of the DER system. There could be multiple evaluations if the design of the DER changes any time during the interconnection process.

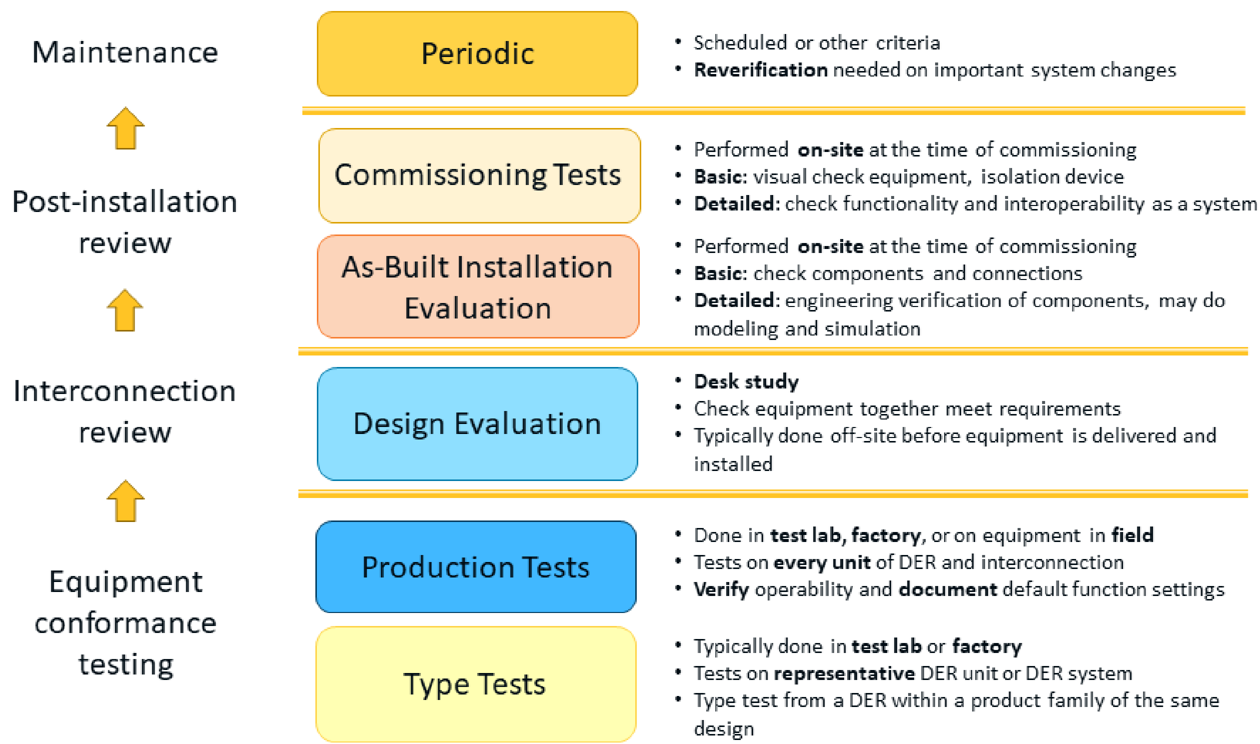


Figure 4. Varieties of testing and verification for DER interconnection

4 Common Concerns

Concerns related to unplanned islands have been noted in several publications, including Bower and Ropp (2002), IEEE (2008), Walling and Miller (2002), Barker and De Mello (2000), and Stevens et al. (2000). The top utility concerns from unintentional islanding are maintaining personnel safety and avoiding harm to customer and utility equipment. Additional concerns are also being debated, especially in locales with high shares of DERs.

4.1 Personnel Safety

The main concern for personnel safety is that if the DER's onboard unintentional islanding detection should fail and an unintentional island occurs and becomes sustained, the connected and energized electrical lines pose a risk of exposure to electricity hazards for utility workers and the public if the lines are contacted and presumed to be de-energized.

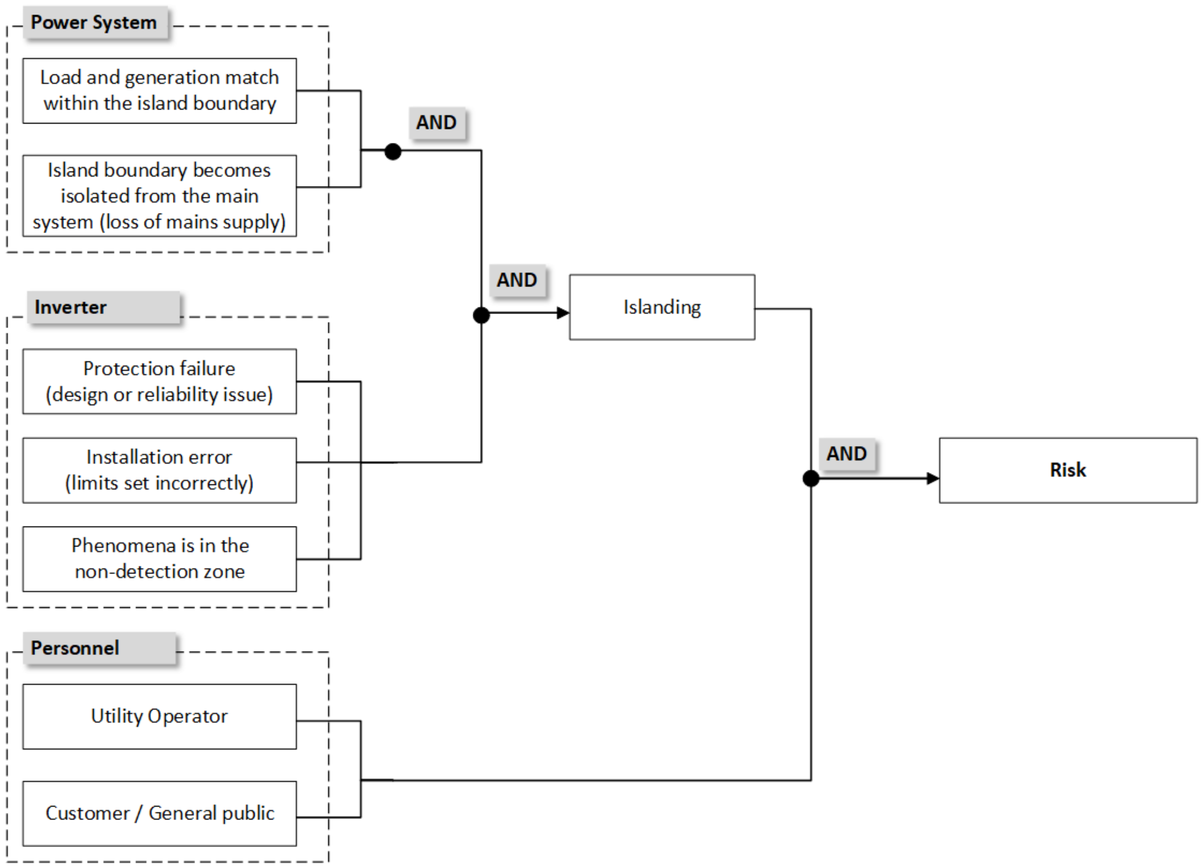
An exhaustive study of personnel risk from all types of DERs has not been identified as of this writing; however, several studies have been done for PV systems. One study conducted in 2002 under the International Energy Agency concluded that the risk of electric shock from an islanded PV system under worst-case PV penetration scenarios is less than the "benchmark" risk that already exists for utility personnel and customers.[21] The study concluded, "the additional risk presented by islanding does not materially increase the risk that already exists as long as the risk is managed properly" (Cullen, Thornycroft, and Collinson 2002).

This same study noted that prudent good practice measures could be taken to properly manage the risk, including proper signage; information and education of utility personnel and customers about the risks; and appropriate utility personnel work practices and procedures, such as testing circuits prior to work (Cullen, Thornycroft, and Collinson 2002). Further, the authors recommended that "[s]ince LOM [loss of mains] functionality is included in many PV inverters already, it is appropriate to maintain this requirement, but emphasis should be put on simple, robust, verifiable and cost-effective solutions (e.g., software-based)" (Cullen, Thornycroft, and Collinson 2002).

Note that the measures listed are predominantly for utility personnel. These measures may not adequately address other types of risk to the general public that are prevalent from electrical equipment from downed conductors, such as electrocution and wildfire. These types of risk have existed and will likely continue to exist regardless of the presence of DERs on the circuit.

The authors developed an evaluation and quantification of the risk based on a PV risk analysis "fault tree," shown in Figure 5. As illustrated, risk from an islanded system depends on several factors that must exist simultaneously.

[21] The risk of shock from islanded PV systems was found to be near 10^{-9} per year for an individual person compared to the benchmark risk of near 10^{-6} per year.



Source: Based on Cullen, Thornycroft, and Collinson 2002

Figure 5. PV Islanding risk analysis fault tree

The subject of unintentional islanding is under constant debate, according to Woyte et al. (2003):

> For low-density of PV generation, islanding is virtually impossible since load and generation never match.
>
> For networks with a high density of PV generation, the probability of encountering a power island is small, but for the power margins originating from standard protection relay settings it may not be regarded as negligible. In order to keep the risk from islanding to maintenance operators and customers satisfactorily low, additional islanding prevention methods are necessary to detect a loss of mains in any case that is practically feasible.

Another study concluded (Verhoeven 2002):

> Balanced conditions occur very rarely for low, medium and high penetration levels of PV-systems. The probability that balanced conditions are present in the power network and that the power network is disconnected at that exact time is virtually zero. Islanding is therefore not a technical barrier for the large-scale deployment of PV system in residential areas.

As noted, some of the measures listed are predominantly for utility personnel. The measures listed may not adequately address other types of risk to the general public or to emergency response personnel, such as firefighters. The types of risk prevalent from electrical equipment due to downed conductors have existed and will likely continue to exist regardless of the presence of DERs on the circuit. Adequate consideration should be given to the types and sources of risk and to the existing strategies in place to mitigate those risks to determine if any additional mitigation is indicated or necessary. Note that the studies described are two decades old. More current treatment of this subject in a formal study has not been identified by the authors.

4.2 Equipment Protection

With regard to the specific phenomena of unintentional islanding, reclosing out of synchronism (also referred to as reclosing out of phase) is typically a major concern associated with DER deployment.[22, 23]

Many utilities use a protective device called a recloser that contains a relay-controlled switch or breaker that initially opens when a predetermined amount of current flows through the device. A simplified diagram of the circuit elements related to reclosing is shown in Figure 6. After a short preprogrammed time interval chosen to allow the fault or overload to clear, the recloser closes the breaker, thus reenergizing the downstream line segments.

---

[22] Note that with higher shares of DERs, there are potentially additional impacts that must be considered, such as overload-related impacts, voltage-related impacts, reverse power flow impacts, and other system protection impacts. For a summary discussion of these topics, see *High-Penetration PV Integration Handbook for Distribution Engineers*, https://www.osti.gov/biblio/1235905.

[23] Fault conditions that could cause islanding concerns for DERs are sometimes associated with concerns for the potential of transient or temporary overvoltage from DERs, such as load rejection overvoltage and ground fault overvoltage. Several studies on these topics have been published, including *Inverter Load Rejection Over-Voltage Testing*, https://www.nrel.gov/docs/fy15osti/63510.pdf, and *Inverter Ground Fault Overvoltage Testing,* https://www.nrel.gov/docs/fy15osti/64173.pdf. For a discussion on neutral grounding, the reader should also consult IEEE Std C62.92.4 - IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems—Part IV: Distribution.

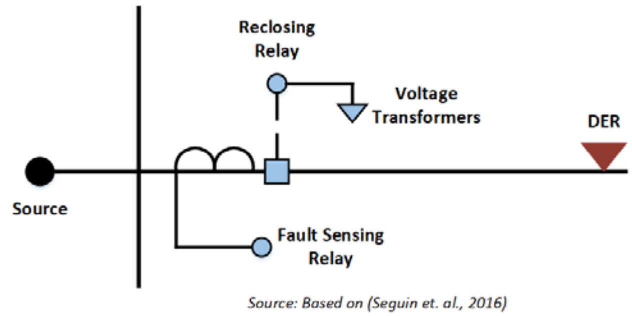


Figure 6. Simplified illustration of circuit elements related to reclosing

If the fault or overload persists longer than the time interval, the recloser again opens the switch to isolate the fault. The recloser might open and reclose several times, and if the fault is still uncleared, the recloser locks itself open for utility personnel to address the issue (Pansini 2005).

If a DER becomes islanded, the operation of utility reclosers reclosing onto an energized line could result in retripping the line or damaging connected equipment (i.e., an out-of-phase reclosure). As noted by Ingram et al. (2017):

> If an unintentional island persists after a recloser has opened, it is possible that the phase relationship of the islanded grid could deviate from that of the bulk system. The reclosing action could forcibly resynchronize the grids. The risk of this forced synchronization is potentially significant because customer equipment—motor loads, in particular—could be damaged by the possible sudden change in frequency and voltage phase [resulting in large transient torques on mechanical systems (e.g., shafts, blowers, and pumps)]. Effectively, the phase voltages experienced by the loads could jump instantaneously, stressing any machine that has a speed/position relationship to the grid frequency. Generally, the greater the phase difference between the islanded grid and the bulk system, the greater the risk of damage to these types of equipment.

The default response time for all types of DERs using all methods of unintentional islanding is 2 seconds. The response time can be extended to 5 seconds and must be agreed upon by the area EPS operator and the DER operator. Even with the shorter response duration of 2 seconds, a common concern is the coordination of fast auto-reclosures with unintentional islanding response time. Because the unintentional islanding methods are not designed to detect fault conditions, the response time is not bound by the necessary fast fault response times that fault equipment must meet.

Reclosers are a type of protective device often used by utilities to mitigate faults on the distribution system. To decrease the duration of interruptions, reclosers are often deployed with a “fast reclosing” function that reenergizes a circuit within 1 second or less after a fault condition has been detected. When a fast reclosure initially opens, motors in the system will start slowing down and can regenerate voltage on the bus. If the voltage is restored before the motors are significantly slowed down, a large torque pulse can occur on motor shaft; therefore, a concern of fast reclosures and motor reenergization exists even without the DERs in the circuit unless corrective methods are implemented. For area EPS locales that use fast reclosing, there is concern about out-of-phase reclosing, and further study might be required.

For feeders or sections of the distribution circuit where a recloser is used, a generation-to-load study might be desired to see if an island can be sustained (Ropp and Ellis 2013).

To address the concerns of out-of-phase reclosing, three solutions are typically considered: lengthening the reclosing time to more than 2 seconds, blocking the hot-line recloser, blocking the out-of-phase recloser, removing the recloser functionality, and DTT, as described in the appendix.

For circuits with enough DERs to sustain an island, hot-line recloser blocking is a functionality added to existing reclosers that delays the fast reclosing until the circuit being reclosed is measured to be de-energized. Another option is to simply disable the reclosing functionality of the protection equipment from a circuit. Reliability impacts from any of these methods should be considered when choosing a solution.

4.3 Maintaining Power Quality

Utilities are responsible for supplying power to customers and for keeping the voltage and frequency within acceptable ranges. In an islanding condition, however, a utility cannot control the voltage and frequency within the island. These parameters could drift the longer an island is sustained. DERs have trip settings for voltage and frequency. If the voltage or frequency reach the trip settings, the DERs will stop exporting power, and the island will collapse.

4.4 Impact of Grid Support and Ride-Through Functions

IEEE Std 1547-2018 requires DERs to maintain anti-islanding functionality with and without grid support functions enabled. Conversely, anti-islanding functionality may not interfere with grid support functions and the new voltage and frequency ride-through requirements for all DERs. To help enable these capabilities at the same time, DER functions and requirements are prioritized relative to each other as follows[24]:

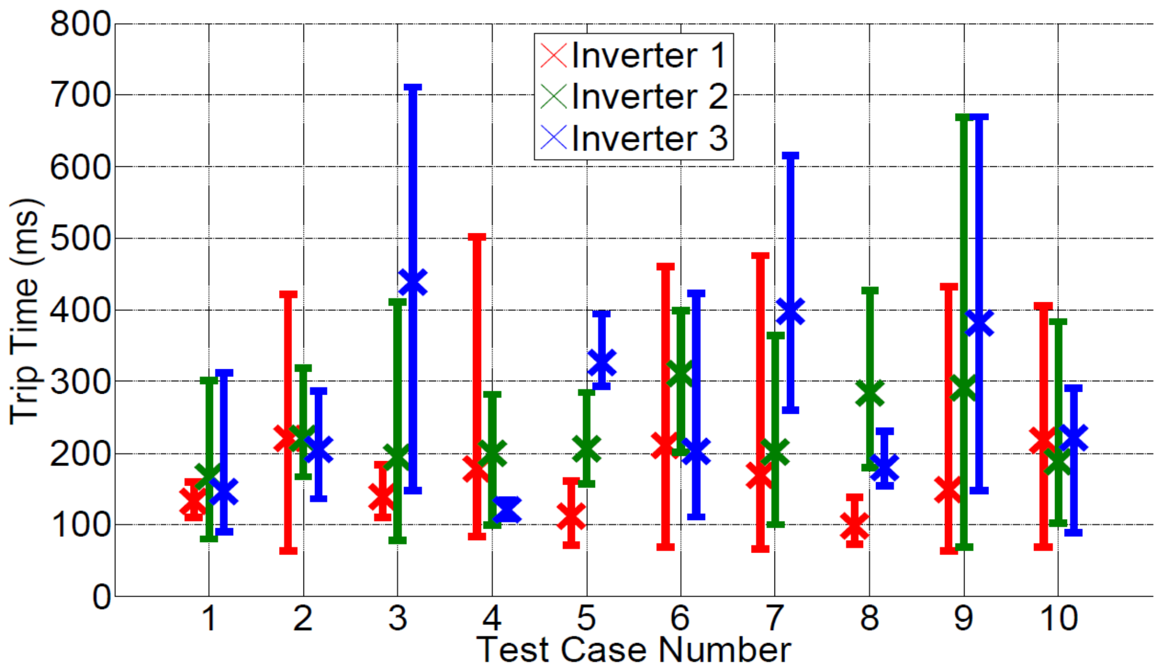
1. Response to disabling permit service setting
2. DER tripping requirements
3. Ride-through requirements (per IEEE Std 1547-2018 Clause 4.7, "Ride-through may be terminated by the detection of an unintentional island.")
4. Voltage-active power mode requirements
5. Response to active power limit
6. Voltage regulation functions.

Several laboratory tests and some field demonstrations have been conducted to determine the functionality of grid support functions such as voltage regulation and ride-through. Some studies have also investigated the impact of grid support functions on anti-islanding performance.

[24] Some caveats exist. The reader should read IEEE Std 1547-2018 carefully to understand the prioritization of DER responses.

One team conducted a set of power-hardware-in-the-loop experiments to determine the impacts on the effectiveness of anti-islanding functions resident in PV inverters under multi-inverter deployment scenarios with grid support functions enabled. PV inverters were tested with four grid support functions enabled: voltage ride-through, frequency ride-through, volt-volt ampere reactive (VAR) control, and frequency-watt control.[25] Results were published in a report titled *Experimental Evaluation of PV Inverter Anti-Islanding with Grid Support Functions in Multi-Inverter Island Scenarios* (Hoke et al. 2016).

The team observed that for the single-inverter test case with grid support functions enabled, the maximum run-on time (duration of the island) increased slightly with voltage and frequency ride-through; however, for the 50 tests conducted on each inverter (150 total), the maximum run-on time was 711 milliseconds, significantly less than the 2-second limit currently imposed by IEEE Std 1547-2018. The test was run with the inverter regulating voltage with a steep volt-VAR curve with voltage and frequency ride-through enabled (frequency-watt was disabled). Figure 7 shows results for run-on times for three separate inverters tested under various conditions.



Source: Hoke et al. 2016

Figure 7. Run-on time test results for 3 inverters with grid support functions enabled

The team found no evidence that volt-VAR control or frequency-watt control increased maximum run-on time, confirming expectations.

[25] Note that ride-through is an inherent capability of DERs that cannot be turned off, according to IEEE Std 1547-2018.

The team also investigated the possibility of load rejection overvoltage during islanding events. Under the balanced islanding conditions used for the anti-islanding tests, the team observed no overvoltages exceeding 110% of nominal voltage, as expected.[26]

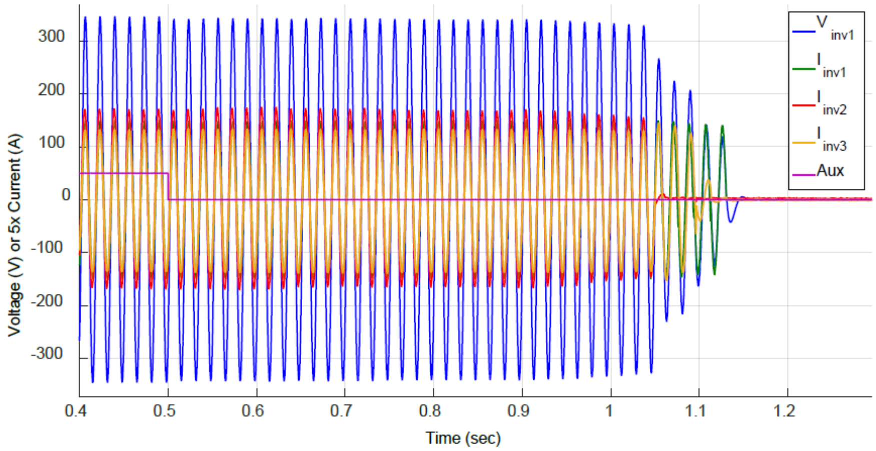
In another study, a project team from Sandia National Laboratories and Northern Plains Power Technologies conducted laboratory simulations and experiments to determine the impact of PV inverter grid support functions on various anti-islanding detection methods. Results were published in January 2019 in a report titled *Evaluation of Multi-Inverter Anti-Islanding with Grid Support and Ride-Through and Investigation of Island Detection Alternatives* (Ropp et al. 2019). This study concluded that enabling voltage regulating functions was not observed to have an adverse effect on anti-islanding performance, and in certain cases, it resulted in reduced run-on time. The team noted that the ride-through of voltage and frequency was observed to have an adverse impact on islanding detection; however, in all cases tested, run-on times remained within the 2-second requirement in IEEE Std 1547-2018. The team introduced a technique called "collaborative controls," which was shown to mitigate the negative impacts of ride-through (Ropp et al. 2019).

4.5 Multiple-Inverter and Mixed Distributed Energy Resource Scenarios

DER systems, especially inverter-based DERs, are highly configurable to fit many deployment needs at many scales—from single-inverter residential deployments to utility-scale systems with dozens of inverters. The sheer number of potential system designs, equipment, and configurations make it impossible to test every scenario; however, many teams have published results from laboratory studies.

Hoke et al. (2016) investigated the anti-islanding functionality impacts from multiple inverters with grid support functions enabled. Under the multi-inverter test case, three common, commercially available, single-phase PV inverters from three different manufacturers were simultaneously deployed at nearby points on the same simulated distribution feeder and subjected to a variety of representative island configurations. For the 244 multi-inverter tests conducted, the maximum run-on time observed was 632 milliseconds, again well within the 2-second requirement. Example test results are shown in Figure 8.

[26] More comprehensive testing of load rejection overvoltage can be found in a related report on Inverter Load Rejection Over-Voltage Testing, https://www.nrel.gov/docs/fy15osti/63510.pdf.



Source: Hoke at al. 2016

Figure 8. Example test results for a scenario with multiple inverters with grid support functions enabled

In another study, a team from Sandia National Laboratories and Northern Plains Power Technologies conducted a set of computer simulations to determine the performance of inverter-based anti-islanding under scenarios with combinations of different inverters using different types of islanding detection methods and combinations of inverters and synchronous generators. The simulations were conducted with and without voltage and frequency ride-through enabled, and the island run-on times of various anti-islanding methods were analyzed. Results were published in July 2018 in a report titled *Unintentional Islanding Detection Performance with Mixed DER Types* (Ropp et al. 2018).

The team noted—as expected per results from other studies—that simulation results showed that the addition of ride-through degrades the performance of anti-islanding detection methods.

Under the mixed-inverter test conditions, some combinations of methods resulted in larger non-detection zones and longer island run-on times (some exceeding 2 seconds), whereas other combinations remained highly effective over a wide range of conditions.

For the methods studied, the team observed that islanding detection methods vary greatly in their effectiveness depending on the types of DERs in the island. The team noted that, in general, mixed-type DER scenarios (inverter and synchronous generators) increased run-on times and had larger non-detection zones; however, in some cases, anti-islanding performance *improved*.

4.6 Locales with High Shares of Distributed Energy Resources

A handful of locations already experience high shares of DERs; however, in most locales, this is currently not an issue. High shares of DERs create concerns for the area EPS operator because of the large number of devices on the feeder and the different types of unintentional islanding methods employed. Public utility commissions in several states have started research projects and study groups[27] to discuss these topics.

One report, completed in 2016 for the California Public Utilities Commission, noted that to adequately assess the risk from unintentional islanding, consideration must be given to not only the DER but also the load composition[28] in the potential island (Bebic, Sun, and Marin 2016). Under the project, islanding tests were performed on groups of physical inverters. The inverters were set to unity power factor with no advanced functions enabled. Under the test conditions, the team noted that the pre-islanding power factor of the circuit had a strong impact on the duration of the islanding. The team also noted that increased motor loads also had an impact on islanding duration.

[27] For example, the California Public Utilities Commission Interconnection Rulemaking Working Groups convened under the R.17-07-007 docket. Working Group Four investigated anti-islanding conditions and made recommendations in a final report published in August 2020. Proceedings under Working Group Four are available at https://gridworks.org/initiatives/rule-21-working-group-4/. The final report is available at https://gridworks.org/wp-content/uploads/2020/08/R21-WG4-Final-Report.pdf.

[28] The report follows the Western Electricity Coordinating Council recommendations to represent utility loads based on equipment varieties that include motor loads, power electronic loads, resistive loads, and constant current loads (Bebic, Sun, and Marin 2016).

5 Guidelines to Determine the Risk of Unintentional Islanding

DER deployments include scenarios that could present challenges for onboard anti-islanding techniques. There are no formal standards for assessing the risk of unintentional islanding; however, Ropp and Ellis, in a report published by Sandia National laboratories in 2012 and revised in 2013, provided recommendations. To date, these guidelines have been widely used in interconnection studies to evaluate the risks of unintentional islanding for specific installations and to help determine the appropriate mitigation for those risks. The content focuses on PV systems, but it could be applied to any DER.

The guidelines note a set of scenarios in which unintentional islanding is considered impossible. These include the following (Ropp and Ellis 2013):

- Load exceeds DER capacity. A sustained island is impossible if the aggregated nameplate AC rating of all DERs within the potential island is less than the minimum real power load within the island. Because the load exceeds what the DER can support by itself, the load will quickly reduce the voltage to less than the programmed low-voltage threshold in the DERs if an island forms.
- Reactive power supply and demand cannot be maintained. This relies on the principle that for an island to be sustained, both the active and reactive demand within the island must be supplied by the DERs. All loads with motors require reactive power. In scenarios where the inverter is operating at unity power factor, with negligible reactive power contribution, reactive power is supplied by the source at the substation or capacitor banks along the distribution line. Situations when the inverter is regulating its VAR supply, however, might require further study. Note that in an inverter-based island, volt-VAR control ceases to stabilize voltage, so it does not increase the islanding risk.
- External supplemental mechanisms are used. Examples of external supplemental mechanisms for anti-islanding protection include communications-based methods, such as DTT, power line carrier permissive signal, and supervisory control and data acquisition systems.

Ropp and Ellis (2013) also noted that several scenarios could present challenges to current built-in anti-islanding methods. These include the following:

- The potential island contains large capacitors and is operating near unity power factor (within 1%). Note, however, that this relies on knowledge of what method of anti-islanding detection the PV inverters are using. The study is relevant only if all inverters are using positive feedback on frequency.
- High-penetration scenarios. Studies have shown that the speed of anti-islanding detection could decrease as the number of inverters in the island increases; however, there are variations in effectiveness—for example, anti-islanding detection speed could be maintained if all the inverters use positive feedback and the interconnecting impedances between inverters is low. An example of this type of deployment is given as a commercial installation on a common distribution transformer.

- Deployments with different types of PV inverters. Studies have shown that deployments with PV inverters with different manufacturers degrade anti-islanding detection performance. (Note that these guidelines were written in 2012 and updated in 2013. Additional studies have been done since then to further investigate this. See Section 4.5 of this document for the related discussion under multiple-inverter scenarios.)
- Deployments with both PV inverters and rotating generators. The anti-islanding mechanisms in these could interfere with each other enough to degrade the performance of the anti-islanding detection in both types of generators.

Considering these elements, Ropp and Ellis (2013) suggested a four-step process for assessing unintentional islanding risk. This process is summarized in the flowchart in Figure 9.

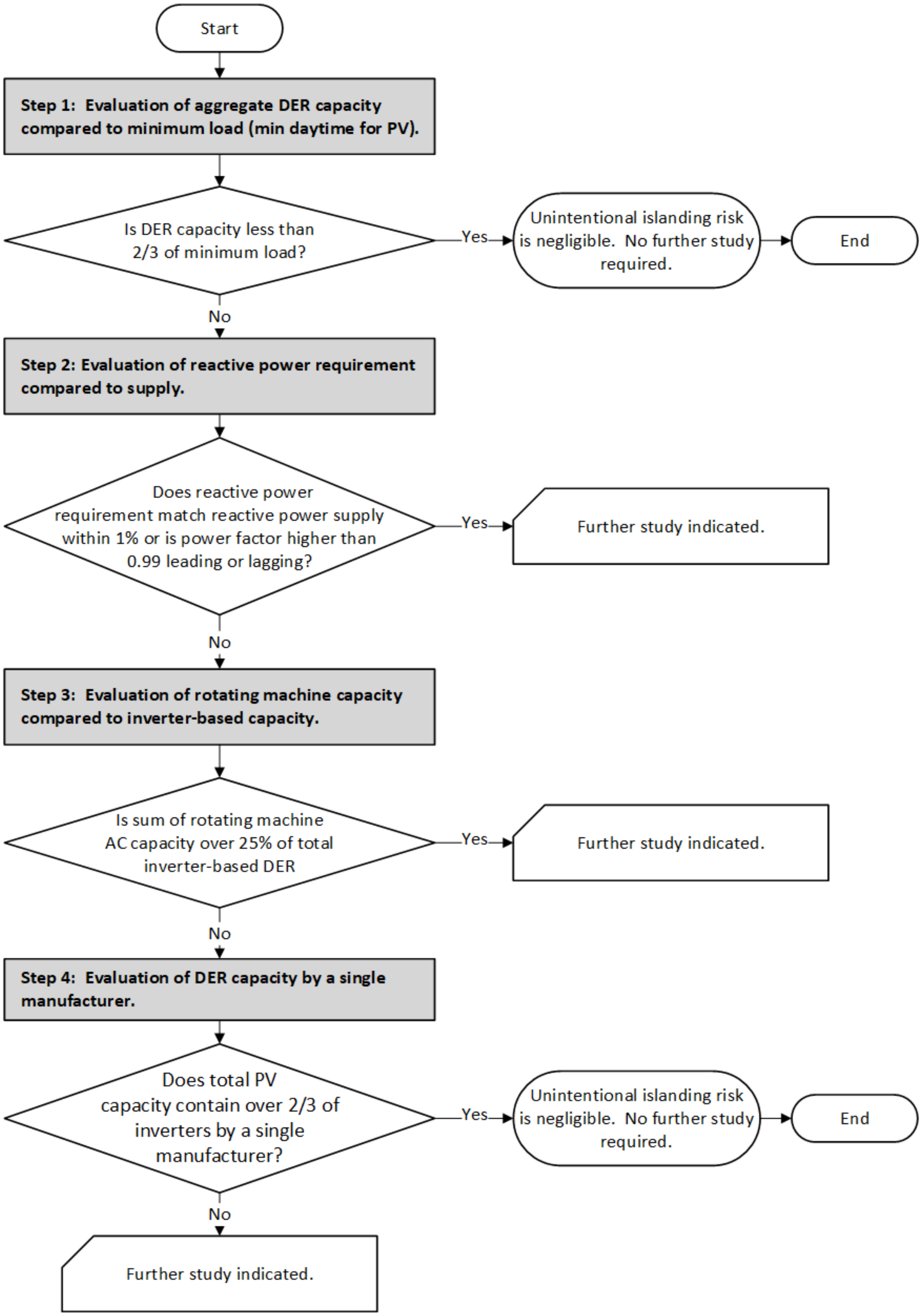
If the screening shows there could be a risk of unintentional islanding, additional study should be performed. Additional study could involve more detailed modeling of the distribution circuit equipment, DER, loads, and area EPS protection schemes.[29]

Depending on the results of the detailed study,[30] mitigation by supplemental means of anti-islanding protection may be needed.

Given the new requirements specified in IEEE Std 1547-2018, there is renewed discussion on whether and how these guidelines should be updated or whether new tools may be necessary to effectively screen for risk of islanding.

[29] For a detailed discussion of the topic, see IEEE Std 1547.7 Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection.

[30] See the National Rural Electric Cooperative Association's *PV System Impact Guide* for examples of PV interconnection impact studies, including risk of islanding screening, https://www.cooperative.com/programs-services/bts/Documents/SUNDA/NRECA%20-%20SUNDA%20Impact%20Guide-v3%20final.pdf.



Source: Based on procedure described in Ropp and Ellis 2013

Figure 9. Procedure for assessing risk of unintentional islanding

6 Conclusion

As noted, topics related to unintentional islanding risk and prevention have been and continue to be of concern and thus the topic of continued research and discussion. Recent activities under the California Public Utilities Commission Interconnection Rulemaking (R.17-07-007, "Rule 21") are an example. Under these activities, California utilities, developers, the utility commission, and other stakeholders have determined that a formal working group is needed to discuss the topic in more detail.[31]

Discussions in other jurisdictions related to unintentional islanding will likely happen as updates are made to interconnection requirements to reflect the latest revision of IEEE Std 1547-2018.

[31] See the California Public Utilities Commission Rulemaking 17-07-007: Decision Addressing Remaining Phase I Issues (page 90) for more discussion: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M387/K064/387064665.PDF.

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Appendix: Summary of Supplementary Anti-Islanding Protection Methods[32]

Due to equipment and personnel safety dimensions, some jurisdictions apply additional methods to ensure that distributed energy resources (DERs) do not island. This appendix summarizes these concerns and supplementary anti-islanding protection strategies.

Many methods can be used to protect against unintentional islands. Some commonly used methods include protective relays for the detection of over-/underfrequency or over-/undervoltage, reverse power detection, or minimum import/export relays, impedance insertion, power line carrier communications, and direct transfer trip (DTT) (Kroposki 2016; Bower and Ropp 2002).

Direct Transfer Trip

DTT is one of several schemes used to avoid sustained unintentional islanding. DTT uses a communications signal from an area electric power system (EPS) component, such as a feeder breaker or an automatic line-sectionalizing device, to command the DER to disconnect from the circuit. DTT could also be implemented with the addition of sync-check relaying or undervoltage-permissive relaying at the feeder breaker or automatic line-sectionalizing devices to maintain coordination with protection schemes. DTT might require communications from not only the substation breaker but also any automatic line-sectionalizing devices upstream from the DERs.

Several options for DTT communications are available. Utilities will typically specify their preferred method,[33] which could include:

- Direct fiber to substation with proper interface provisioning
- Licensed microwave with proper interface provisioning
- Class A DS0, 4-wire, leased line provisions by local exchange carrier
- Telecommunications options via Class B, T1 lease options.

DTT can also eliminate out-of-phase reclosing concerns because the recloser action can be coordinated with tripping schemes to ensure that no unintentional islands are formed.

Even with DTT, depending on the latency of the trip signal, fast reclosing schemes might need to be reviewed and either slowed down to guarantee that the DER stops generating prior to the first reclosing action or otherwise modified to maintain protective coordination.

DTT is generally considered only for large DER installations because of its high cost to implement. Costs vary among locations. One report done by the California Rule 21 Working Group Four for the California market notes (California Public Utilities Commission 2020):

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[32] Note that some of these methods will achieve only partial compliance with the IEEE Std 1547-2018 requirements.
[33] For an example, see the Pacific Gas and Electric Company's (PG&E's) *Transmission Interconnection Handbook*, noted in this document's references.

The cost of installing DTT is significant and, in some cases, the single largest cost of new machine generation projects. PG&E's Unit Cost Guide states that the base cost of a single DTT scheme, including paired transmitter and receiver, is $600,000, and the base cost of a recloser is $80,000. 12 Multiple DTT units can be required, increasing the base cost accordingly. If related costs, such as Cost of Ownership (COO) and Income Tax Component of Contribution (ITCC) are included, the all-inclusive cost to the developer for DTT and reclosers is roughly double the base cost. The costs of DTT can exceed the cost of the generator itself, in all cases becoming a substantial part of overall costs, and can affect project viability. Other related costs such as leased line communications infrastructure can be particularly expensive in less-urban areas. The costs of DTT are particularly relevant in more rural areas of the state where the grid is radial and DTT is applied to numerous substations.

These upgrades frequently force renewable DER projects to withdraw interconnection applications due to their high interconnection costs and/or long implementation timelines. Installation of DTT can take up to 18-24 months to complete. Installation of a recloser can take up to 6-12 months to complete.

Supplemental Over-/Underfrequency or Over-/Undervoltage Protective Relays

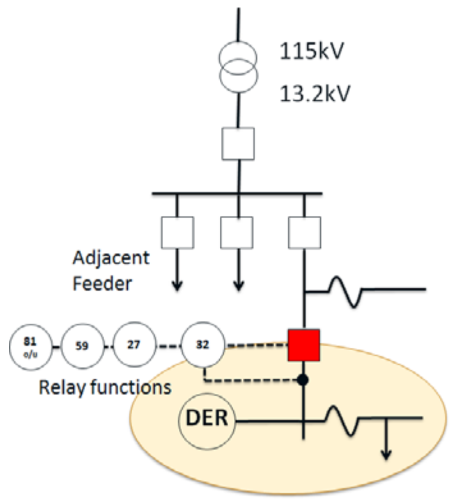
Supplemental protective relays are typically installed by electric utilities on larger DER systems, regardless of similar relaying and protection functions residing withing the DER system. Over-/undervoltage and frequency trip settings are programmed into the relays. If the relay detects these parameters outside the acceptable window, the relay trips and causes the DER to shut down.

Reverse Power or Minimum Import/Export Relays

Reverse power or minimum import/export relays are passive anti-islanding techniques. These methods add overvoltage/undervoltage and over-/underfrequency trip settings implemented through relay functions (57/27, 81/81[34]). These settings define an acceptable range of voltage and frequency limits. If the measured conditions are outside of this range, the DERs trip offline.

If supplemental anti-islanding protection is required, this approach is often used when DERs are not expected to export power to the grid (e.g., when local loads are larger than the DERs, and all generated power is consumed on-site). In these cases, an additional protective relay function (Function 32: reverse power) is added to the site relay scheme to disconnect the DERs if the relay senses that they are exporting power, as shown in Figure A-1 (Kroposki 2016).

[34] IEEE Std C37.2 defines relay device functions as follows: Device number 59 is for overvoltage relay, device number 27 is for undervoltage; and device numbers 81 and 81 are for overfrequency and underfrequency, respectively (IEEE 2008).



Source: Kroposki 2016

Figure A-1. Relay functions

Reverse or minimum import active power unintentional islanding protection provides full conformance if all tests are satisfactorily met. Note: The reverse or minimum import active power flow protection device is sensed between the point of DER connection or the point of common coupling and will disconnect or isolate the DERs if the power flow falls to less than a set threshold or reverses. For multiphase devices, tests are conducted on each phase and all phases simultaneously. For DERs having a range of adjustable minimum import active power settings, the tests are to be repeated for the minimum and maximum import active power settings.

IEEE Std 1547.1-2020 Clause 5.10.5 provides information on testing reverse or minimum import active power flow functionality.

Permissive Hardware Input

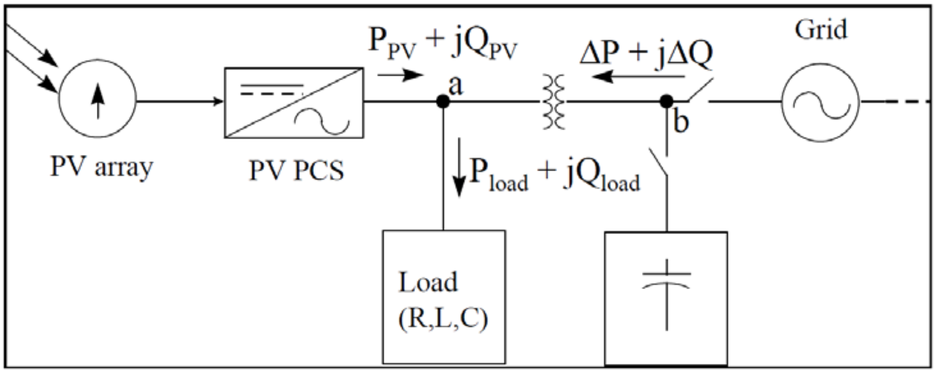
This method uses DERs fitted with hardware that responds to an unintentional islanding condition by ceasing to energize within the required response time of 2 seconds or other mutually agreed-upon response time. Examples of the types of hardware that can be used are contact closure, a transistor-transistor logic signal, or other hardware means. An example of the signal could be DTT.

Note that this is separate from the permit service function.

The hardware input test, described in IEEE Std 1547.1-2020 Clause 5.10.4, does not require balanced resistive-inductive-capacitive loads or a contactor to remove the utility and island the DER. It does require the monitoring of the permissive and nonpermissive state and a method to trigger data capture to determine the response times.

Impedance Insertion

This method requires the installation of a low-value-impedance device on the utility side of a distribution transformer. Figure A-2 shows the addition of a capacitor bank (connected at point *b*). Under this method, if the circuit on the left side of the switch at point b were to become islanded, the capacitor bank is commanded to close after a short delay. The addition of the capacitor bank functions to disrupt the balance of generation to load in the island (Bower and Ropp 2002).



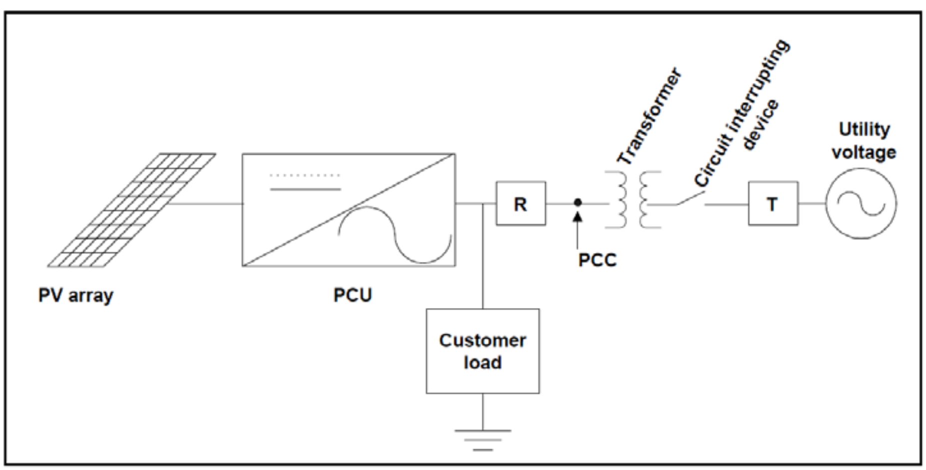
Source: Bower and Ropp 2002

Figure A-2. One-line diagram of the impedance insertion method using a capacitor bank

Power Line-Conducted Permissive Signal Testing

This method of anti-islanding protection relies on a signal conducted on the distribution primary line. DERs designed for this type of unintentional islanding method will have a receiver that monitors the presence of the permissive signal, and upon the loss of signal, the DER must cease to energize and trip within 2 seconds.

A one-line diagram of the concept is presented in Figure A-3. In the figure, the box labeled "T" transmits a signal to the receiver, marked "R." As long as the signal is present, the DER has permission to operate. If the signal is discontinued, the circuit-interrupting device disconnects the DER within the required time.



Source: Bower and Ropp 2002

Figure A-3. One-line diagram of power line carrier communications method

Because the power line-conducted permissive signal unintentional islanding method requires the transmission of the permissive signal, only partial compliance is granted when successfully detecting the absence of the permissive signal and ceasing to energize within the required response time. The absence of a permissive signal on all phases of a DER is indicative of the loss of continuity of the power line and represents an islanded situation, so upon loss of the permissive signal, the DER must cease to energize and trip.

The laboratory test procedure in IEEE Std 1547.1-2020 Clause 5.10.3 requires an attenuation of the signal to evaluate the signal strength requirements. Note that the power connection is never interrupted—only the permissive signal path is interrupted or attenuated; therefore, there is no need for load banks, a test matrix, or a need to isolate generation with load.

Note that in this method, if there is a loss of the permissive signal for any reason, there is no provision to allow the DER to reenergize the area EPS after it has tripped. This contrasts with onboard methods that reenergize after the required time delay after a trip has lapsed and the voltage and frequency at the point of DER connection is within operating ranges. The DER can reenergize the area EPS only if the permissive signal is present.

Ongoing Research on Additional Methods of Islanding Detection

Efforts have been ongoing to develop new methods of unintentional islanding detection and mitigation that adequately address future concerns. These methods include islanding detection based on synchrophasors and centralized islanding detection (inter-tripping schemes) (Etxegarai, Eguía, and Zamora 2011).

Phasor Measurement Unit-Based Islanding Detection

This method uses two phasor measurement units: one located at the grid side and one at the DER. If the signals from the two units are not comparable within certain parameters, a circuit breaker is tripped to turn off the DER (Etxegarai, Eguía, and Zamora 2011).

Centralized Detection of Unintentional Islanding

Centralized detection of unintentional islanding is based on the use of a central controller connected to all the circuit breakers and all the individual DERs in the circuit via an Ethernet link. The central controller hosts an islanding detection algorithm that monitors the circuit. If an island is detected, the central controller sends tripping commands to the DERs.