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IEEE Application Guide for IEEE Std 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

IEEE SA Board of Governors
and the
IEEE Power and Energy Society

Developed by the
Distributed Generation, Energy Storage, and Interoperability Standards Committee
and
Transmission and Distribution Committee
Energy Development and Power Generation Committee

IEEE Std 1547.2™-2023
(Revision of IEEE Std 1547.2-2008)

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Abstract: Technical background and application details to support understanding of IEEE Std 1547™-2018 are provided. The guide facilitates the use of IEEE Std 1547-2018 by characterizing various forms of distributed energy resource (DER) technologies and their associated interconnection issues. It provides background and rationale of the technical requirements of IEEE Std 1547-2018. It also provides tips, techniques, and common practices to address issues related to DER project implementation. This guide is intended for use by engineers, engineering consultants, and knowledgeable individuals in the field of DERs. The IEEE 1547 series of standards is cited in the Federal Energy Policy Act of 2005, and this guide is one document in the IEEE 1547 series.

Keywords: amendment, certification, clearing time, codes, commissioning, communications, dc injection, design, diesel generators, dispersed generation, distributed generation, electric distribution systems, electric power systems, energy resources, energy storage, faults, field, flicker, frequency support, fuel cells, generators, grid, grid support, harmonics, IEEE 1547™, IEEE 1547.2™, induction machines, installation, interconnection requirements and specifications, interoperability, inverters, islanding, microturbines, monitoring and control, networks, paralleling, performance, photovoltaic power systems, point of common coupling, power converters, production tests, quality, power, protection functions, public utility commissions, reclosing coordination, regulations, ride through, rule-making, standards, storage, synchronous machines, testing, trip setting, utilities, voltage regulation, wind energy systems

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Introduction

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IEEE Std 1547.2 is one of a series of standards published by the IEEE or being developed by the Distributed Generation, Energy Storage and Interoperability Standards Committee [formerly IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SCC21)] concerning distributed energy resources (DERs) interconnected with *area electric power systems* (EPS). IEEE Std 1547-2018 provides interconnection technical specifications and requirements as well as test specifications and requirements; IEEE Std 1547.1™-2020 provides the test procedures for verifying conformance to IEEE Std 1547-2018.

The documents in the 1547 series are as follows:

— IEEE Std 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

— IEEE Std 1547.1™-2020, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces

— IEEE Std 1547.2™, IEEE Application Guide for IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

— IEEE P1547.3™, IEEE Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems

— IEEE Std 1547.4™-2011, IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

— IEEE Std 1547.6™-2011, IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks

— IEEE Std 1547.7™-2013, IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection

— IEEE Std 1547.9™, IEEE Guide for Using IEEE Std 1547™ for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems

IEEE Std 1547.2 provides application details to support the understanding of IEEE Std 1547-2018 and is intended to serve DER owners and operators as well as *area EPS* staff. IEEE Std 1547.2 provides technical background, application details and guidance, requirements rationale, schematics, and examples to facilitate the use of IEEE Std 1547-2018.

This guide addresses some topics that are related to DER project implementation to enhance user understanding of how IEEE Std 1547.2 may relate. This guide does not interpret IEEE Std 1547-2018 or other standards in the IEEE 1547 series and does not provide additional requirements or recommended practices related to those other IEEE 1547 standards. The interconnection examples cited in this guide are illustrative approaches, but alternative approaches could be equally applicable.

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IEEE Application Guide for IEEE Std 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

1. Overview

1.1 General

This guide provides application guidance for IEEE Std 1547-2018 by offering the following for each clause/subclause of the base standard:

- Citation of requirement
- Background
- Impact of distributed energy resources (DERs)
- Tips, techniques, and common practices
- Application/Use cases

Additionally, several annexes are included in this guide that provide additional material for informative purposes.

1.2 Scope

This guide provides the technical background, rationale, and guidance to support the application of the substantially revised IEEE Std 1547-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

The document will describe how the requirements and default settings specified in IEEE Std 1547-2018 have been carefully chosen to balance distribution and bulk system needs for increasing penetration of DERs. It further enhances the understanding of IEEE Std 1547-2018 by addressing certain DER integration issues that are not fully addressed by the base standard, e.g., reclosing coordination and limitation of overvoltage in the *Area EPS*.

The guide will address: (1) the concept of the newly introduced performance categories and their assignment to specific DERs by an *Authority Governing Interconnection Requirements* (*AGIR*); (2) the new

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requirements for voltage and reactive power control, frequency control, response to abnormal conditions including *ride-through*; (3) the flexibility provided by the newly introduced ranges of adjustability for control settings as well as for voltage and frequency *trip* settings to fully exploit the revised IEEE 1547's potential and to account for specific system characteristics; (4) the *interoperability* and communication *interface* requirements; and (5) the test and verification practices, including design and as-built installation evaluations for utility-scale DERs, that were not included in the 2008 version of the standard.

Presented in the document are technical descriptions and schematics, applications guidance, and *interconnection* examples to enhance the use of IEEE Std 1547-2018.

1.3 Purpose

This guide facilitates the use of the substantially revised IEEE Std 1547-2018 by educating relevant stakeholders about its technical background and by providing guidance for its application in practice.

1.4 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).[6,7]

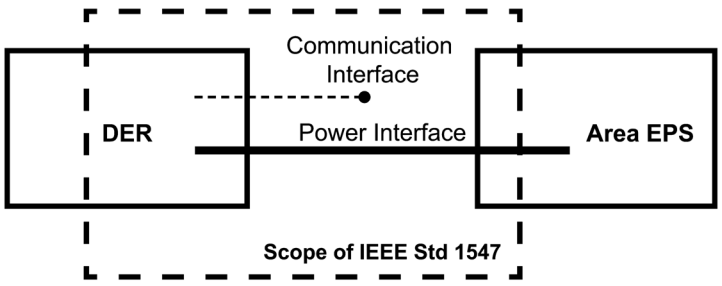
The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.5 General remarks and limitations

Figure 1 illustrates the scope of IEEE Std 1547-2018.



Source: IEEE Std 1547-2018.

Figure 1—Scope of IEEE Std 1547-2018

This guide applies to all DER technologies that are interconnected with an *Area EPS* at typical primary or secondary distribution voltage. The criteria and requirements of IEEE 1547-2018 may influence the design

[6] The use of the word *must* is deprecated when stating mandatory requirements; *must* is used only to describe unavoidable situations.
[7] The use of *will* is deprecated when stating mandatory requirements; *will* is used only in statements of fact.

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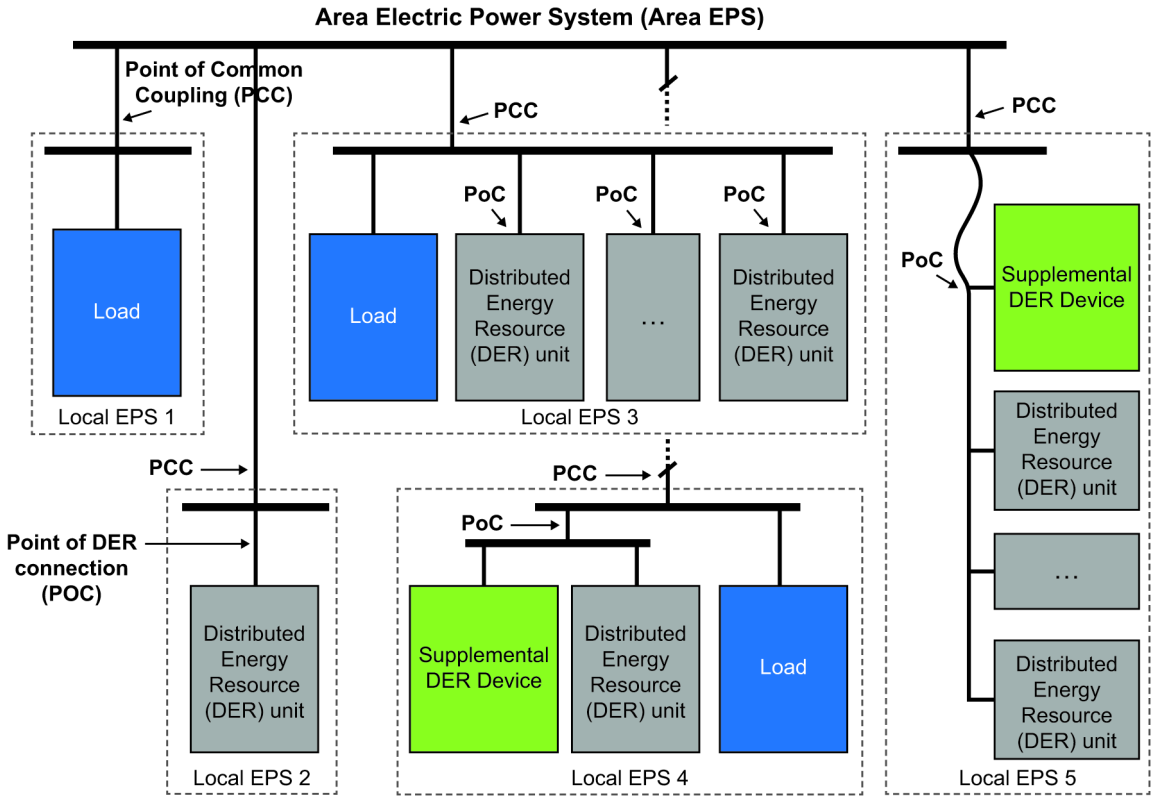
and capabilities of the power *interface*, the *local DER communication interface*, and all those parts of a DER that are related to meeting the requirements of that standard.

- This guide is not a design handbook. It is not intended to provide comprehensive information about specific topics of power engineering or DERs or EPS engineering necessary for successful *interconnection* of DERs with an *Area EPS.* The examples provided are not exhaustive or prescriptive.
- This guide does not interpret IEEE Std 1547-2018 or other standards in the IEEE 1547 series and does not provide additional requirements or recommended practices related to those other IEEE 1547 standards.
- This guide does not provide a guarantee that IEEE Std1547-2018 requirements will be met.
- This guide does not provide guidance on how to meet business or tariff issues. However, it does recognize that these are important to the *interconnection* of DERs.
- This guide does not address planning, designing, operating, or maintaining the *Area EPS* with DERs.
- This guide assumes that the DER is a 60 Hz source (to be consistent with IEEE Std 1547-2018), although the principles could apply to other frequencies.
- This guide does not apply to automatic transfer schemes in which *load* is transferred between the DER and the EPS in a momentary make-before-break operation provided the duration of paralleling the sources is less than 100 ms, except as noted in Clause 9 of IEEE Std 1547-2018.
- The *interconnection* examples cited in this guide are illustrative approaches, but there are other alternative approaches that could be equally applicable as those stated in this document.
- This guide as a whole is not intended for, and is in part inappropriate for, application to energy resources connected to transmission or networked sub-transmission systems.[8,9]
- This guide does not define the maximum DER capacity for a particular installation that may be interconnected to a single *PCC* or connected to a given feeder.

Supplemental DER devices other than DER units may be used to achieve compliance with the requirements of the IEEE Std 1547-2018 at the applicable reference point. These devices are not required to be co-located with the DER units but shall be within the *Local EPS*. The requirements of the IEEE Std 1547-2018 shall be met regardless of the location of the DER and *supplemental DER devices* within the *Local EPS*. These relationships are shown in Figure 2.

[8] Investigations of events that inadvertently tripped *bulk power system* connected resources in North America suggest that one root cause may have been misapplication of previous versions of this standard; refer to [B66] for more details.
[9] The performance of energy resources connected to transmission or networked sub-transmission systems may be specified by the responsible transmission planner in coordination with the *regional reliability coordinator*. Refer to for [B44] more details.

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NOTE 1—The example of *Local EPS* 1 includes only *load*. Any requirements for this *Local EPS* are outside the scope of this guide.
NOTE 2—The example of *Local EPS* 2 includes only DERs. Depending on the DER rating, requirements of this standard apply either at the *PCC* or the *PoC*. The DER unit in this example is able to meet requirements at its terminals without any *supplemental DER device*; the *PoC* coincides with the DER unit's terminals.
NOTE 3—The example of *Local EPS* 3 includes both DER units and *load*. Depending on the aggregate DER units' rating and the *percent of* average *load* demand, requirements of this standard apply either at the *PCC* or the *PoC*. The two (or more) DER units are able to meet requirements at its terminals without any *supplemental DER device*; the *PoC* coincides with the DER units' terminals; there are two (or more) *PoCs*.
NOTE 4—The example of *Local EPS* 4 includes a DER unit, a *supplemental DER device*, and *load*. Depending on the DER unit's rating and the *percent of* average *load* demand, requirements of this standard apply either at the *PCC* or the *PoC*. The DER unit is not able to meet requirements at its terminals without any *supplemental DER device*; the *PoC* is the point where the requirements of this standard are met by the DER unit in conjunction with the *supplemental DER device* exclusive of any *load*, if present, in the respective part of the *Local EPS*.
NOTE 5—The example of *Local EPS* 5 includes two (or more) DER units and a *supplemental DER device* but no *load*. Depending on the aggregate DER units' rating, requirements of this standard apply either at the *PCC* or the *PoC*. As indicated by the curved line, the *PCC* and *PoC* may be located well apart from each other. The two (or more) DER units are not able to meet requirements at their terminals without any *supplemental DER device*; the *PoC* is the point where the requirements of this guide are met by two (or more) DER units in conjunction with the *supplemental DER device* exclusive of any *load*, if present, in the respective part of the *Local EPS*.
Source: IEEE Std 1547-2018.

Figure 2—Relationship of interconnection terms

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1.6 Document structure

This guide was developed to provide technical background and application details to support IEEE Std 1547-2018. This guide addresses some topics that are related to DER project implementation to enhance the users understanding of how IEEE Std 1547-2018 may relate to those topics. Topics in Clause 4 through Clause 11 closely parallel those of IEEE Std 1547-2018. Each topic in IEEE Std 1547-2018 is quoted, and then application guidance is provided. Clause 12 discusses DER high penetration issues. The annexes provide additional information and include a bibliography, glossary, and more detailed information about *interconnection system*s, DERs, and EPSs.

The document is generally organized following the clause/subclause numbering in IEEE Std 1547-2018. The italicized and underlined statements at the beginning of some of the clauses and subclauses are from IEEE Std 1547-2018 in order to help the readers relate to the standard.

Definitions found in 3.1 are italicized in the document.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1453™, IEEE Standard for Measurement and Limits of Voltage Fluctuations and Associationed Light Flicker on AC Power Systems.[10,11]

IEEE Std 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

IEEE Std 1547.1™-2020, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces.

IEEE Std 1815™, IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3).

IEEE Std 2030.5™, IEEE Standard for Smart Energy Profile Application Protocol.

IEEE Std C50.12™, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.

IEEE Std C50.13™, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[12]

abnormal operating performance category: The grouping for a set of requirements that specify technical capabilities and settings for a DER under abnormal operating conditions, i.e., outside the *continuous operation* region. (IEEE Std 1547-2018)

applicable voltage: Electrical quantities that determine the performance of a *Local EPS* or DER specified with regard to the *reference point of applicability*, individual phase-to-neutral, phase-to-ground, or phase-to-phase combination and time resolution. (IEEE Std 1547-2018)

NOTE—*Applicable voltages* are used in synonym for applicable frequency which can be derived from the *applicable voltages*.[13]

area electric power system (Area EPS): An EPS that serves *Local EPS*s. (IEEE Std 1547-2018)

NOTE—Typically, an *Area EPS* has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight.

area electric power system operator (Area EPS Operator): The entity responsible for designing, building, operating, and maintaining the *Area EPS*. (IEEE Std 1547-2018)

authority governing interconnection requirements (AGIR): 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 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. (IEEE Std 1547-2018)

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.

authority having jurisdiction: Authority having the rights to inspection and approval of the design and construction of *Local EPS* premise electrical systems. (IEEE Std 1547-2018)

available active power: Active power that a DER can deliver to the *Area EPS* subject to the availability of the DER's primary source of energy. (IEEE Std 1547-2018)

NOTE—Examples are solar irradiance in the case of a photovoltaic DER and wind speed in case of a wind turbine generator.

bulk power system (BPS): Any electric generation resources, transmission lines, *interconnections* with neighboring systems, and associated equipment. (IEEE Std 1547-2018)

[12] *IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.
[13] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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capable of exporting active power: For this guide, a phrase meaning any DER including energy storage *distributed energy resource* (ES DER) that are capable of serving *load* in parallel with the *area electric power system (Area EPS)*.[14,15]

cease to energize: Cessation of active power delivery under *steady-state* and transient conditions and limitation of reactive power exchange. (IEEE Std 1547-2018)

NOTE 1—This may lead to *momentary cessation* or *trip*.

NOTE 2—This does not necessarily imply nor exclude disconnection, isolation, or a *trip*.

NOTE 3—Limited reactive power exchange may continue as specified, e.g., through filter banks.

NOTE 4—Energy storage systems are allowed to continue *charging* but are allowed to cease from actively *charging* when the maximum state of charge (maximum stored energy) has been achieved.

NOTE 5—Refer to IEEE Std 1547-2018, 4.5 for additional details.

charging: Importing active (real) power from the electric power system (EPS) to an ES DER.

clearing time: The time between the start of an abnormal condition and the DER ceasing to energize the *Area EPS.* It is the sum of the detection time, any adjustable time delay, the operating time plus arcing time for any interposing devices (if used), and the operating time plus arcing time for the interrupting device (used to interconnect the DER with the *Area EPS*). (IEEE Std 1547-2018)

configuration setting: The as-configured value for each parameter listed in IEEE Std 1547-2018, Table 28. The configuration settings and the nameplate information may not be the same, as described in IEEE Std 1547-2018, 10.4.

continuous operation: Exchange of current between the DER and an EPS within prescribed behavior while connected to the *Area EPS* and while the *applicable voltage* and the system frequency is within specified parameters. (IEEE Std 1547-2018)

continuous operation region: The performance operating region corresponding to continuous operation. (IEEE Std 1547-2018)

crowbar circuit: A protection circuit that rapidly short-circuits (or “crowbars”) the rotor or the dc bus of the ac-dc-ac converter if the voltage or current exceeds defined limits. This is usually achieved by a thyristor or other silicon device in power supplies or by a mechanical shorting device.

direct-transfer trip (DTT): A method of sending a *trip* signal from one location to another. Various communication systems—including, but not limited to, phone lines, spread-spectrum radio, licensed radio, microwave, and fiber optics—can provide the signal path. *Syn:* **transfer trip**.

discharging: Exporting active (real) power from an ES DER to the electric power system (EPS).

[14] The following are examples of systems that ARE NOT *capable of exporting active power*: (1) a UPS that never exports active power to the *local EPS* and (2) a unidirectional EV battery charger that only imports and never exports active power.
[15] The following are examples of ES DERs that ARE *capable of exporting active power*: (1) a photovoltaic energy storage system (PV + ESS) in which the system is controlled to maintain zero export at the POI and (2) a V2G EV charger that exports to the *local EPS* based on market pricing signals.

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distributed energy resource (DER): A source of electric power that is not directly connected to a *bulk power system*. DER includes both generators and energy storage technologies *capable of exporting active power* to an EPS. An *interconnection system* or a *supplemental DER device* that is necessary for compliance with this standard is part of a DER.[16] (IEEE Std 1547-2018)

NOTE 1—Controllable *loads* used for demand response are not included in the definition of DER. This exclusion purposely makes a definition that differs from that which has been used by FERC and other regulatory agencies.

NOTE 2—See Figure 2.

distributed energy resource (DER) controller: A system or device that manages the DER unit and can provide an operator *interface*, a communications *interface*, power management, monitoring, or metering.

distributed energy resource managing entity (DER Managing Entity): An entity that monitors and manages the DER through the *local DER communication interface*. The DER managing entity could be for example a utility, an aggregator, a building energy management system, or other. (IEEE Std 1547-2018)

distributed energy resource operator (DER Operator): The entity responsible for operating and maintaining the *distributed energy resource*. (IEEE Std 1547-2018)

distributed energy resource (DER) unit: An individual DER device inside a group of DER that collectively form a system. (IEEE Std 1547-2018)

distributed generation (DG): Electric generation facilities connected to an *area electric power system* (EPS) through a *point of common coupling* (*PCC*); a subset of *distributed energy resources* (DER).

disturbance period: The range of time during which the *applicable voltage* or the system frequency is outside the *continuous operation* region. (IEEE Std 1547-2018)

electric power system (EPS): Facilities that deliver electric power to a *load*. (IEEE Std 1547-2018) *See also:* **area electric power system**; **local electric power system**.

NOTE—This may include generation units. See Figure 2.

energize: Active power outflow of the DER to an EPS under any conditions (e.g., *steady state* and transient). (IEEE Std 1547-2018)

enter service: Begin operation of the DER with an energized *Area EPS*. (IEEE Std 1547-2018)

export limitation: A technical restriction placed on the magnitude of power exchanged between a DER system and the *Area EPS*.

flicker: The subjective impression of fluctuating luminance caused by voltage fluctuations. (IEEE Std 1453™-2015)

NOTE—Above a certain threshold, *flicker* becomes annoying. The annoyance grows very rapidly with the amplitude of the fluctuation. At certain repetition rates, even very small amplitudes can be annoying.

gateway: A network entity (software or hardware) that *interfaces* between networks that use different protocols, or are of different, potentially incompatible, technology.

inadvertent export: Unscheduled export of power from a DER system, exceeding a specified magnitude and for a limited duration, generally due to fluctuations in load-following behavior.

[16] Equivalent to "distributed resources (DR)" as defined and used in IEEE Std 1547-2003.

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intentional area EPS island: An *intentional island* that includes portions of the *Area EPS*. (IEEE Std 1547-2018)

intentional island: A planned electrical *island* that is capable of being energized by one or more Local EPSs. These (1) have DER(s) 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)

NOTE—An intentional island may be an intentional Area EPS island or an intentional Local EPS island (also: "facility island").

intentional local EPS island: An *intentional island* that is totally within the bounds of a *Local EPS*. (IEEE Std 1547-2018)

interconnection: The result of the process of adding DER to an *Area EPS*, whether directly or via intermediate *Local EPS* facilities. (IEEE Std 1547-2018)

interconnection equipment: Individual or multiple devices used in an *interconnection system*. (IEEE Std 1547-2018)

interconnection system: The collection of all *interconnection* and *interoperability* equipment and functions, taken as a group, used to interconnect a DER to an *Area EPS*.[17] (IEEE Std 1547-2018)

interface: An electrical or logical connection from one entity to another that supports one or more energy or data flows implemented with one or more power or data links. (IEEE Std 1547-2018)

interoperability: The capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively. (IEEE Std 2030™-2011 [B43])

inverter: A machine, device, or system that changes direct-current power to alternating-current power. (IEEE Std 1547-2018)

island: A condition in which a portion of an *Area EPS* is energized solely by one or more *Local EPS*s through the associated *PCCs* while that portion of the *Area EPS* is electrically separated from the rest of the *Area EPS* on all phases to which the DER is connected. When an island exists, the DER energizing the island may be said to be "islanding". (IEEE Std 1547-2018)

load: Devices and processes in a *local EPS* that use electrical energy for utilization, exclusive of devices or processes that store energy but can return some or all of the energy to the *local EPS* or *Area EPS* in the future. (IEEE Std 1547-2018)

local DER communication interface: A local *interface* capable of communicating to support the information exchange requirements specified in this standard for all applicable functions that are supported in the DER. (IEEE Std 1547-2018)

local electric power system (Local EPS): An EPS contained entirely within a single premises or group of premises. (IEEE Std 1547-2018)

NOTE—See Figure 2.

mandatory operation: Required continuance of active current and reactive current exchange of DER with *Area EPS* as prescribed, notwithstanding disturbances of the *Area EPS* voltage or frequency having magnitude and duration severity within defined limits. (IEEE Std 1547-2018)

[17] This term was frequently used in IEEE Std 1547-2003. Given the scope of the present standard, which may have implications to the design of the entirety of the DER, this standard uses the term "DER" in most places.

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mandatory operation region: The *performance operating region* corresponding to *mandatory operation*. (IEEE Std 1547-2018)

medium voltage: A class of nominal system voltages equal to or greater than 1 kV and less than or equal to 35 kV. (IEEE Std 1547-2018)

NOTE—IEEE standards are not unanimous in establishing the range for "*medium voltage*."

momentary cessation: Temporarily *cease to energize* an EPS, while connected to the *Area EPS*, in response to a disturbance of the *applicable voltages* or the system frequency, with the capability of immediate *Restore output* of operation when the *applicable voltages* and the system frequency return to within defined ranges. (IEEE Std 1547-2018)

momentary cessation operation region: The performance operating region corresponding to *momentary cessation*. (IEEE Std 1547-2018)

nameplate ratings: Nominal voltage (V), current (A), maximum active power (kW), apparent power (kVA), and reactive power (kvar) at which a DER is capable of sustained operation. (IEEE Std 1547-2018)

NOTE—For *Local EPS* with multiple DER units, the aggregate DER *nameplate rating* is equal to the sum of all DERs *nameplate rating* in the *Local EPS*, not including aggregate capacity limiting mechanisms such as coincidence factors, plant controller limits, etc., that may be applicable for specific cases.

non-exporting (non-export): The limitation of *steady-state* power magnitude across the *PCC* to a value of zero or less, exclusive of any *Inadvertent export limitations*.

non-islanding protection: The use of relays or controls to prevent the continued existence of an unintentional *island*.

normal operating performance category: The grouping for a set of requirements that specify technical capabilities and settings for DER under normal operating conditions, i.e., inside the continuous operation region. (IEEE Std 1547-2018)

operating mode: Mode of DER operation that determines the performance during normal or abnormal conditions. (IEEE Std 1547-2018)

performance operating region: A region bounded by point pairs consisting of magnitude (voltage or frequency) and cumulative time duration which are used to define the operational performance requirements of the DER. (IEEE Std 1547-2018)

permissive operation: *Operating mode* where the DER performs *ride-through* either in *mandatory operation* or in *momentary cessation*, in response to a disturbance of the *applicable voltages* or the system frequency. (IEEE Std 1547-2018)

permissive operation region: The *performance operating region* corresponding to *permissive operation*. (IEEE Std 1547-2018)

permit service: A setting that indicates whether a DER is allowed to enter or remain in service. (IEEE Std 1547-2018)

per unit (p.u.) / percent of (%): Quantity expressed as a fraction of a defined base unit quantity. For active power (active current), the base quantity is the rated active power (rated active current). For apparent power (current), the base quantity is the rated apparent power (rated current). For system frequency, the base quantity is the nominal frequency (i.e., 60.0 Hz in North America). Quantities expressed in per unit can be converted to quantities expressed in percent of a base quantity by multiplication with 100. (IEEE Std 1547-2018)

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point of common coupling (PCC): The point of connection between the *Area EPS* and the *Local EPS*. (IEEE Std 1547-2018)

NOTE 1—See Figure 2.

NOTE 2—Equivalent, in most cases, to "service point" as specified in the National Electrical Code® (NEC®) (NFPA 70®) [B77] and the National Electrical Safety Code® (NESC®) (ANSI C2) [B64].

point of distributed energy resources connection (point of DER connection–PoC): The point where a DER unit is electrically connected in a *Local EPS* and meets the requirements of this standard exclusive of any *load* present in the respective part of the *Local EPS*. (IEEE Std 1547-2018)

NOTE 1—See Figure 2.

NOTE 2—For (a) DER unit(s) that are not self-sufficient to meet the requirements without (a) *supplemental DER device*(s), the *point of DER connection* is the point where the requirements of this standard are met by DER (a) device(s) in conjunction with (a) *supplemental DER device*(s) exclusive of any *load* present in the respective part of the *Local EPS*.

post-disturbance period: The period starting upon the return of all *applicable voltages* or the system frequency to the respective ranges of the *mandatory operation region* or *continuous operation* region. (IEEE Std 1547-2018)

power control system: Systems or devices that electronically limit or control the *steady-state* power output to a programmable limit or level. This is inclusive of, but not specific to, UL CRD tested systems.

production test: A test conducted on every unit of equipment prior to shipment.

protective function(s): The behavior whose purpose is to maintain safe operations and/or maintain safe conditions. (IEEE Std 1547-2018)

range of allowable settings: The range within which settings may be adjusted to values other than the specified default settings. (IEEE Std 1547-2018)

reference point of applicability (RPA): The location where the *interconnection* and *interoperability* performance requirements specified in this standard apply. (IEEE Std 1547-2018)

regional reliability coordinator: The functional entity that maintains the real-time operating reliability of the bulk electric power within a reliability coordinator area. (IEEE Std 1547-2018)

restore output: Return operation of the DER to the state prior to the abnormal excursion of voltage or frequency that resulted in a ride-through operation of the DER. (IEEE Std 1547-2018)

return to service: *Enter service* following recovery from a *trip*. (IEEE Std 1547-2018)

ride-through: Ability to withstand voltage or frequency disturbances inside defined limits and to continue operating as specified. (IEEE Std 1547-2018)

steady state: The condition where both the average and the one-cycle RMS variations around the average magnitude of the observed parameter are limited to ±150% of the minimum required measurement accuracy (MRA) for that parameter, as specified in Table 3 of IEEE Std 1547-2018 [B42].

stiffness: The ability of an *area EPS* to resist voltage deviations caused by DER or loading.

supplemental DER device: Any equipment that is used to achieve compliance with some or all of the *interconnection* requirements of this standard.

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NOTE—Examples include capacitor banks, STATCOMs, harmonic filters that are not part of a DER unit, protection devices, plant controllers, etc.

time to reach steady state: The duration from a step change in control signal input until the observed parameter first reaches the *steady-state* value.

total rated-current distortion (TRD): The total root-sum-square of the current distortion components (including harmonics and inter-harmonics) created by the DER unit expressed as a percentage of the DER rated current capacity (I_{rated}). (IEEE Std 1547-2018)

trip: Inhibition of immediate *return to service*, which may involve disconnection. (IEEE Std 1547-2018)

NOTE—Trip executes or is subsequent to cessation of energization.

type test: A test of one or more devices manufactured to a certain design to demonstrate, or provide information that can be used to verify, that the design meets the requirements specified in this standard. (IEEE Std 1547-2018)

unintentional island: An unplanned *island*. (IEEE Std 1547-2018)

zero-sequence continuity: Circuit topology providing continuity between two defined points in the zero sequence network representation. (IEEE Std 1547-2018)

NOTE—A transformer having a delta or ungrounded-wye winding in the topological path between the defined points produces discontinuity of the zero-sequence network.

3.2 Acronyms and abbreviations

AGIR	authority governing interconnection requirements
AHJ	authority having jurisdiction
Area EPS	area electric power system
Area EPS Operator	area electric power system operator
BPS	bulk power system
DER	distributed energy resource
DER Operator	distributed energy resources operator
DERMS	Distributed Energy Resource Management System
DNP	distributed network protocol
DNP3	distributed network protocol
EMI	electromagnetic interference
EMS	energy management system
EPS	electric power system
ES	energy storage
ESS	energy storage system
FFR	fast frequency response
FIDVR	fault-induced delayed voltage recovery
ISO	Independent System Operator
Local EPS	Local electric power system
LV	low voltage
MV	medium voltage

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NP	network protector
NRTL	nationally recognized testing laboratory
PCC	point of common coupling
PCS	power control system
PLCPS	power line conducted permissive signal
PoC	point of DER connection
PV	photovoltaic
RMS	root mean square
ROCOF	rate of change of frequency
RPA	reference point of applicability
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TRD	total rated-current distortion

4. General interconnection technical specifications and performance requirements

4.1 Introduction

The reference point of applicability (RPA) is the location where the interconnection and interoperability performance requirements specified in IEEE Std 1547-2018 shall be met. The electrical quantities referred to in this standard are those at the RPA, unless stated otherwise in this standard.

4.1.1 Background

Much of the *interconnection* requirements in IEEE Std 1547-2018 are based on the performance of DER under varying normal and abnormal frequency, voltage, and power flow conditions. As with any electric power system, at any given moment these quantities can be at different levels at different locations on the system due to the characteristics of the sources and *loads*, and the configuration and impedances of the system interconnecting them. Therefore, when requiring certain performance results based on these quantities—especially voltage and power flow—it is important to be clear what location on the system the levels of these quantities are being referenced to. The *reference point of applicability* (*RPA*) is the term used in IEEE Std 1547-2018 to signify this location.

Additionally, the standard establishes *interoperability* requirements for the capability to exchange certain information regarding the DER. When the standard states that the *RPA* is the location where both the *interconnection* and the *interoperability* performance requirements are to be met, it is understood that the *interoperability* information elements pertain to the DER as it exists at that *RPA*, consistent with the electrical quantities that exist at that *RPA*.

It is worth noting that the standard does not necessarily require that specific equipment or functional capabilities, or the local DER communication *interface* in the case of the *interoperability* requirements, exist at the physical location of an *RPA*. Rather, DER needs to meet the performance requirements based on the operating conditions as they exist at that *RPA*.

For example, if an *RPA* is at the *point of DER connection* (*PoC*), then the voltage, power, and frequency requirements in IEEE Std 1547-2018 pertain to those quantities as they exist at the *PoC*, and the

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interoperability nameplate, configuration, monitoring, and management information element requirements pertain to the DER as it exists at the *PoC*. Alternatively, if an *RPA* is at the *point of common coupling* (*PCC*), then the voltage, power, and frequency requirements pertain to those quantities as they exist at the *PCC*, and the *interoperability* information element requirements pertain to the entire *Local EPS* (including the embedded DER) as it exists at the *PCC* connection.

4.2 Reference points of applicability (RPA)

4.2.1 Background

Subclause 4.2 of the standard specifies how an *RPA* is determined.

First, 4.2 states that the characteristics of the *Local EPS* and DER shall determine an *RPA*. Thus, the standard does not consider the characteristics of the *Area EPS* in determining an *RPA*.

Next, 4.2 states that the *RPA* for all performance requirements of the standard shall be the *PCC*, except as otherwise stated in IEEE Std 1547-2018. Allowances for an *RPA* to be at an alternative location in certain specific situations are stated in IEEE Std 1547-2018 (see below); but, notwithstanding those special situations, the location of all *RPAs* is the *PCC*. Recall that the *PCC* is defined as the point of connection between the *Area EPS* and the *Local EPS*.[18] This is essentially the electrical, as well as physical, demarcation between the two systems. The implication is that whatever conditions exist at the *PCC*, by definition, exist on the *Area EPS* at that location.

With that said, 4.2 then goes on to specify the specific characteristics of the *Local EPS* and DER that may allow the performance requirements to be met based on conditions at locations other than the *PCC*, where those alternative *RPA* locations may be, and to which performance requirements those alternative *RPAs* apply. These provisions were specified with the intent they would not lead to effectively different impact to the *Area EPS* than if those *RPAs* were located at the *PCC*; and, when utilized, may present advantages for simplifying the DER *interconnection* and reducing implementation costs without harmful effects on the *Area EPS*.

The characteristics that determine if alternative *RPA* locations may be established include the following:

- Power output rating of the DER
- Power output rating of the DER relative to other *load* levels on the *Local EPS*
- Power export capability of the *Local EPS*
- Zero-sequence continuity between the PCC and PoC

The alternative *RPA* location possibilities include the *PoC*, or possibly at any a point between the *PCC* and *PoC*, depending on the circumstances (see 4.2.2, 4.2.2.1 through 4.2.2.4, 4.2.2.7, 4.2.3, and 4.2.4).

4.2.2 Determination of RPA

One of the foremost objectives of IEEE Std 1547-2018 is to establish the criteria and requirements for *interconnection* and parallel operation of DER with the *Area EPS* while preserving satisfactory voltage, reactive power, and power quality performance on the *Area EPS* during normal operating conditions and supporting the stability, reliability, and power quality needs of the *Area EPS* and *bulk power system (BPS)* during abnormal conditions. To that end, the goal of properly determining an *RPA* is to establish the location where the electrical quantities forming the basis for the *interconnection* performance requirements adequately reflect the actual operating conditions on the *Area EPS*, at least in the immediate vicinity of the

[18] The PCC is equivalent, in most cases, to “service point” as specified in the NEC [B77] and the NESC [B64].

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Local EPS connection. Therefore, the *PCC* is the ideal location for any *RPA* from a purely technical perspective; and accordingly, the *RPA* shall be at the *PCC* unless stated otherwise.

Having established that, the standard recognizes that under certain circumstances the electrical quantities used in the performance requirements may be based on electrical quantities at locations other than the *PCC* and still adequately reflect the operating conditions at the *PCC*. When the standard allows for this under the prescribed circumstances, it may present reasonable simplification and cost advantages. For that reason, the standard allows that the *RPA* for some performance requirements may be at a location other than the *PCC* under certain conditions.

Specifically, 4.2 establishes that the *RPA* for performance requirements other than the response to *Area EPS* abnormal conditions specified in 6.2[19] and 6.4[20] of the standard may be at the *PoC*, or at any point between or including the *PoC* and *PCC* by mutual agreement between the *Area EPS operator* and the DER operator, if either of the following conditions are met:

a) Aggregate DER *nameplate rating* is equal to or less than 500 kVA, or

b) Annual average load demand[21] is greater than 10% of the aggregate DER *nameplate rating*, and the *Local EPS* is not capable of, or is prevented from, exporting more than 500 kVA for longer than 30 s.

The 500 kVA criterion does not signify the threshold of a specific technical condition. Rather, it is a practical value derived by the standards development team through stakeholder consensus to differentiate:

— Between the relatively small and simple *interconnections* typically encountered in residential and small-business settings

— Often at secondary voltages

— The larger and more complex *interconnections* such as those found in industrial and large commercial facilities, solar and wind farms, and “utility-scale” merchant plants.

Note that the *RPA* for the performance requirements of 6.2 and 6.4 still depends on additional criteria. Specifically, 4.2 stipulates that, if either of the above-listed conditions a) or b) are met, then the *RPA* for the performance requirements of 6.2 and 6.4 is dependent on whether or not “*zero-sequence continuity* between the *PCC* and the *PoC* is maintained.” This is necessary, because without zero-sequence continuity there may be no relationship between the zero-sequence components of voltages on the DER side of the discontinuity and those in the phase-to-ground voltages of the Area EPS at the PCC (if the Area EPS is grounded or has a neutral). It is important to understand whether responding to phase-to-ground or phase-to-neutral voltages is required for compliance with 6.2 or 6.4 (see 4.3 regarding *applicable voltages*), and whether the configurations between the PCC and a prospective *RPA* for these clauses allows for proper detection of whichever is applicable. Therefore, 4.2 establishes that if either of the conditions a) or b) above are met but *zero-sequence continuity* is not met, then the *RPA* for performance requirements of 6.2 and 6.4 shall be a point between, or including, the *PoC* and *PCC* that is appropriate to detect the abnormal voltage conditions.[22]

[19] IEEE Std 1547-2018, 6.2 specifies tripping requirements in response to faults and open phase conditions on the *Area EPS*.
[20] IEEE Std 1547-2018, 6.4 specifies tripping and *ride-through* requirements in response to abnormal voltages on the *Area EPS*.
[21] As calculated by *Area EPS operator*.
[22] Note that the phase-to-neutral voltages of the Area EPS at the PCC may be detected in the corresponding phase-to-neutral voltages on the DER side of a zero-sequence discontinuity for certain transformer winding configurations and/or the presence of a low-impedance neutral connection from the discontinuity to a prospective *RPA* for 6.2 and 6.4. For example, a grounded-wye/ungrounded-wye three-phase transformer winding configuration introduces a zero-sequence discontinuity, but if the Area EPS is on the grounded-wye side of the transformer, then the phase-to-neutral voltages on the Area EPS side of the transformer are still reflected to the phase-to-neutral voltages at the transformer’s terminals on its ungrounded-wye side. Thus, the ungrounded-wye side of the transformer in this scenario may be a satisfactory location for the *RPA* for 6.2 and 6.4. However, if the desired location of the *RPA* were to be not at these transformer terminals but instead at the *PoC*, or somewhere between the transformer and the *PoC*, then it would still be necessary to have a low-impedance connection between the neutral terminal of the transformer’s ungrounded-wye windings and that desired *RPA* location in order to adequately detect the corresponding phase-to-neutral voltages on the Area EPS side of the transformer.

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Note that, because 4.2 places these additional criteria specifically on the *RPA* for the performance requirements of 6.2 and 6.4, it is understood that the *RPA* for these requirements may be at a different location than the *RPA* for the other performance requirements when either of the conditions a) or b) above are met. However, it is further understood that only one *RPA* location is intended for the other performance criteria, despite the allowances that the *Area EPS operator* and the DER operator may mutually agree to locate the *RPA* at any point between or including the *PoC* and *PCC* (notwithstanding the additional criteria for the *RPA* for requirements 6.2 and 6.4). *Area EPS operators* and DER operators are encouraged to refrain from sub-dividing the other requirements any further and allocating them to multiple different *RPA* locations, as this may lead to confusion and disagreement over performance obligations and assessments, quantification of operating conditions and context of *interoperability* data.

Conversely, the introduction of the *RPA* located at the *PoC* is understood to mean that a *Local EPS* with multiple DER units may have multiple *PoC*s with *RPAs* at each *PoC*, so long as either of the conditions a) or b) are still met; and more complex *Local EPS* configurations may introduce multiple circuit branches each with their own zero-sequence circuit paths or discontinuities. The guiding principle in determining appropriate *RPAs* with these complications is to bear in mind that the performance requirements are intended to be reflective of the operating conditions affecting the *Area EPS*.

Also note that, regardless of the location of the *RPA*, the DER is still required to meet the voltage disturbance *ride-through* requirements specified in 6.4.2 of the standard and the frequency disturbance *ride-through* requirements specified in 6.5.2 of the standard. Subclause 4.2 clarifies that, when the *RPA* is not at the *PCC*, equipment or devices in the *Local EPS* between the *PCC* and the *RPA* shall not preclude the DER from meeting these *ride-through* requirements.

While the text above describes the normative criteria of the standard, informative diagrams of the resulting decision tree are provided as Figure H.1 and Figure H.2 in Annex H of the standard, and 0 in 4.2.2.3.

4.2.2.1 DER ratings

The combination of sources and *loads* in any electric system will affect the voltage, current and power flow conditions in that system; and the magnitudes of the effects are usually proportional to the magnitudes of those sources and *loads*. This holds true for the special case of DER interconnected to the *Area EPS*. During both normal operating conditions and abnormal conditions on the *Area EPS*, the effects of the interconnected DER are usually proportional to the output power of the DER, both in absolute terms and in terms of the relative ratio of output power to the local *loads*. Additionally, the effects may be further influenced by how much power from the DER can actually flow from the *Local EPS* to the *Area EPS* (i.e., power export); irrespective of the absolute power magnitude of the DER itself.

Because the determination of the *RPA* is based solely on the characteristics of the *Local EPS* and DER, the aggregate DER *nameplate rating* and annual average load demand referenced above include only the *load* and DER within that particular *Local EPS*.

These requirements were specified in IEEE Std 1547-2018 with the understanding that, if satisfied, establishment of *RPAs* at locations other than the *PCC* would not result in significant additional impact to the *Area EPS* as compared to the *RPA* being located at the *PCC*.

DER in a *Local EPS* with an aggregate *nameplate rating* of 500 kVA or less is informally referred to as small-scale DER. Conversely, DER in a *Local EPS* with an aggregate *nameplate rating* of more than 500 kVA is informally referred to as medium-scale or large-scale DER.

IEEE Std 1547-2018 establishes that an aggregated DER *nameplate rating* of 500 kVA or less within a given *Local EPS* is too small to necessitate that the *RPA* be strictly located at the *PCC*.

Similarly, IEEE Std 1547-2018 establishes that if DER, including medium-scale or large-scale, is embedded with a certain amount of *load* within a *Local EPS*—specifically if the average annual load demand of a *Local EPS* is greater than 10% of the aggregated DER *nameplate rating*—and conditions exist

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that constrain the sustained export of power from the *Local EPS* to the *Area EPS* to 500 kVA or less, then it is also not necessary that the *RPA* be strictly located at the *PCC*.

IEEE Std 1547-2018 provides a general definition of *nameplate ratings* in terms of nominal voltage, current, maximum active power, apparent power, and reactive power at which a DER is capable of sustained operation. The standard's definition further notes that, for a *Local EPS* with multiple DER units, the aggregate DER *nameplate rating* is equal to the sum of all the DER *nameplate ratings* in the *Local EPS*, not including aggregate capacity limiting mechanisms such as coincidence factors, plant controller limits, etc., that may be applicable for specific cases.[23]

DER *nameplate ratings* are understood to mean the apparent power (i.e., volt-amperes) maximum rating of the DER. In a case where a configuration setting of the apparent power maximum rating is established that is different from the corresponding nameplate value, the standard specifies the configuration setting value shall be used as the rating.[24] For example, if the physical nameplate of a DER lists the apparent power maximum rating as 1000 kVA, but the DER has a configuration setting applied restricting the maximum apparent power rating to 500 kVA (by mutual agreement between the DER system operator and *Area EPS operator*), then the DER *nameplate rating* is understood to be 500 kVA while this setting is in effect.

4.2.2.2 Annual average load demand

Annual average load demand is understood to refer to the *load* of the *Local EPS* without the presence of any local DER, whether planned or existing. This may be informally referred to as the native *load* of the *Local EPS*. This raises a distinction between the *load* of the *Local EPS* prior to the implementation of local DER, and the *load* of the *Local EPS* during the ongoing existence of local DER. If the second set of conditions is employed in order to specify an *RPA* at a location other than the *PCC*, it is implicit that the annual average *load* is expected to continue to be more than 10% of the aggregate DER *nameplate rating* throughout the ongoing existence of the DER.

For example, if 550 kVA of aggregate DER *nameplate rating* is to be installed on a *Local EPS* and it is desired to employ the second provision, the annual average load demand of the *Local EPS* needs to remain greater than 55 kVA (10% of the aggregate DER *nameplate rating*) throughout the lifetime of the DER, and this annual average load demand is to be calculated after subtracting out the DER power output from the net of the *Local EPS* internal *loads* and DER power.

Note in this 550 kVA aggregate DER example, although the mathematical result of subtracting more than 55 kVA from 550 kVA equates to less than 495 kVA (i.e., less than 500 kVA), it is not typically enough to also meet the limited power export criterion that additionally needs to be satisfied to allow specifying an *RPA* at a location other than the *PCC*. In most cases, the annual average load demand will be more than the minimum load demand of a *Local EPS*. So, simply subtracting the average annual load demand from the aggregate DER *nameplate rating* is rarely adequate to confirm the *Local EPS* is incapable of sustaining more than 500 kVA export.

IEEE Std 1547™-2018 establishes that the annual average load demand for a *Local EPS* is to be calculated by the *Area EPS operator*. The standard does not prescribe a methodology or formula for calculating the annual average load demand, nor does the standard prescribe a time-constant or time-interval to be used for determining demand.

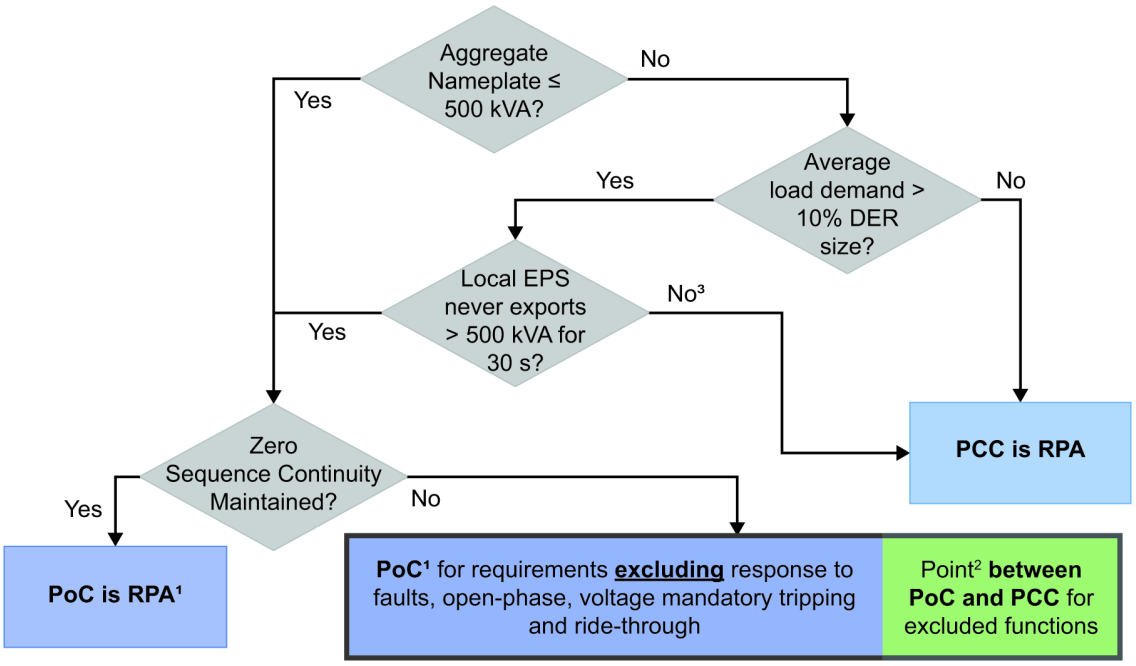
4.2.2.3 Power export capability

Power limiting can be used to allow for the *RPA* location to be at the *PoC* for DER (or another location by mutual agreement between the DER operator and *Area EPS operator*) whereas it would otherwise be required to have the *RPA* located at the *PCC* based on the DER nameplate or level of export. Subclause 4.2 of the standard discusses using standard power limiting functions to meet the 500 kVA aggregate nameplate or power export criteria.

[23] IEEE Std 1547-2018, 3.1.
[24] IEEE Std 1547-2018, 10.4.

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Figure 3 shows how these two thresholds relate to a simplified *RPA* decision process tree. The figure notes how power limitations may address DER operation to be below each threshold.



1) Allowed to be point between the PoC and PCC by mutual agreement
2) Point selected must be appropriate to detect abnormal voltage conditions
3) Reactive power capability and power quality requirements evaluation may exclude influence of load for RPA at PCC under these conditions

NOTE 1—Allowed to be point between the *PoC* and *PCC* by mutual agreement.

NOTE 2—Point selected needs to be appropriate to detect abnormal voltage conditions.

NOTE 3—Reactive power capability and power quality requirements evaluation may exclude influence of *load* for *RPA* at *PCC* under these conditions.

Figure 3—Use of power limiting in the RPA selection process

The 30-s export limit for *RPA* selection was determined based on existing rules in states like Hawaii and California that had laid out technical requirements for *power control systems* (PCSs). The systems in place at the time were configured with a zero export limit (sometimes called "*non-exporting*" or "Customer Self Supply" in Hawaii). In order that any *inadvertent export* did not cause a voltage regulation device to change its state, it was desired to keep the response time less than the voltage regulation delay time, which was typically 30 s at minimum. It was assumed that, because *inadvertent export* events of this duration are typically driven by individual *load* changes, the events would be uncorrelated between customers that may have such systems on the same line segment. This 30-s limit was included in the first test procedures for PCSs published by UL[25] (see Annex G on PCSs). While the requirement for preventing export of more than 500 kVA for longer than 30 s states a maximum value for both power and duration, no further detail is given on the requirement, and no test procedures exist in IEEE Std 1547.1-2020 to test different methods of *export limitation*. Supplemental requirements for verification and/or testing may be defined by the *Area EPS operator*, *AGIR* or other authorities and be clearly identified before testing. It is recommended that contractual obligations are clear regarding compliance with the export magnitude and duration values.

DER aggregate nameplate can be limited to equal or less than 500 kVA using one of the four configuration settings options described in 10.7.2. These settings include the active power rating at unity power factor

[25] The first Certification Requirements Decision (CRD) for *Power control systems* was published in March 2019.

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applied setting, active power rating at specified over-excited power factor applied setting, active power rating at specified under-excited power factor applied setting as well as an apparent power maximum rating applied setting. When active power configuration settings are utilized, maximum reactive power needs to also be considered for the applicable reactive power control function(s) to confirm the 500 kVA limit is not exceeded. The configuration setting needs to be used consistent with the discussion in 10.7.2 to be an effective means of implementing a limit affecting *RPA* location. If a control system used to implement the configuration setting introduces *inadvertent export*, the export durations are required to be limited to 30 s in accordance with 4.2 option b.

DER export can be limited to equal or less than 500 kVA using a management setting called limit maximum active power in certain circumstances. IEEE Std 1547-2018, 4.6.2 allows this setting to be implemented as an export limit in cases where the DER is supplying *Local EPS loads*. To be a valid means of affecting *RPA* location, the export limit of 500 kVA needs to be controlled as not to exceed it for a duration of longer than 30 s. The standard does not require a 30-s response in all cases, providing an exception in stating the power limiting shall occur "in no more than 30 s or in the time it takes for the primary energy source to reduce its active power output to achieve the requirements of the active power limit set point, whichever is greater." When this setting is utilized, maximum reactive power needs to also be considered for the applicable reactive power control function(s) to limit the reactive power to 500 kVA. Since this control may be used dynamically, further safeguards may be needed to confirm the maximum active power setting plus any reactive power does not exceed 500 kVA. For instance, care may be taken that any broadcast commands (such as from a utility or aggregator) that address a group of DERs do not increase the limit for the affected DER beyond that required to not exceed 500 kVA. Contractual safeguards may be appropriate as well to require the managing entity does not increase the setting beyond required limits. The limit maximum active power command needs to be used consistent with the discussion in Clause 10 of this document to be an effective means of implementing a limit affecting *RPA* location.

Additional *export limitation* methods, not defined by IEEE Std 1547-2018, may be used to affect the *RPA* location. One such method is using a PCS function that is certified to the UL Certification Requirements Decision (CRD) for PCS. The PCS can be implemented as part of a DER unit, system, or in a supplemental device such as a plant controller. Separately, a plant controller could also use an export limit not certified to UL 1741 PCS requirements. Another method is to use utility-grade[26] reverse power relaying (e.g., 32R) to *trip* the DER if 500 kVA is exceeded for 30 s. A final method is design of the DER size, *load*, and site operation such that a very low probability exists of exceeding the *export limitation*, without the use of a control system. Non-standard methods of power limiting carry compliance risks and may be subject to mutual agreement between the *Area EPS Operator* and DER Owner. For example, limiting export based on sizing DER and *load* could be negated by future site *load* reduction (e.g., energy efficiency, change in building owner, etc.). The prioritization of *export limitations* in relation to reactive and active power functions is not defined by IEEE Std 1547-2018. See 4.7 for discussion of prioritization.

IEEE Std 1547-2018 does not specify any compliance testing related to 4.2 but does reference a DER evaluation in Table 44. Dependent on the method utilized to implement an export limit, further test requirements may be appropriate to specify. See Annex G for additional information on validation of power limitation methods not defined by IEEE Std 1547.

If a PCS, plant controller or other equipment is used to achieve an *export limitation* for compliance with the requirements, it is considered a *supplemental DER device*. An evaluation and commissioning tests of the overall DER system including the DER unit(s) and all *supplemental DER devices* needs to be performed. However, combinations of DER unit(s) and supplemental device(s) forming a system that are *type tested* as a DER system does not in general require a DER evaluation or commissioning test except for those specified in IEEE Std 1547.1-2020 for fully compliant DER.

[26] "Utility-grade" generally refers to protective relays that
— Meet or exceed ANSI/IEEE standards for protective relays (i.e., IEEE Std C37.90, IEEE Std C37.90.1, IEEE Std C37.90.2, and IEEE Std C37.90.3).
— Have the appropriate documentation covering application, testing, maintenance, and service.
— Give positive indication of what has caused a trip (targets).
— Have a means of testing that does not require disturbance to wiring (e.g., a draw-out case, test-blocks, test switches).

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Where equipment evaluated to UL's CRD for PCS is utilized to meet this requirement, it is tested for the open-loop response time, which can be no more than 30 s. However, this means that if the *open-loop response time* is 30 s, power can still be up to 10% away from its target value after 30 s, exceeding 500 kVA. For PCSs or other equipment, an *open-loop response time* of less than 30 s may be required by the *Area EPS* to meet this criterion and confirm export is a maximum of 500 kVA within 30 s. Acceptable *open-loop response time* test results need to meet the *Area EPS* requirements. Additionally, test results of the calculation of *steady-state* value and *time to reach steady state* may be reviewed to confirm the DER meets the *Area EPS* requirements.

4.2.2.4 Zero-sequence continuity

The intent of the *zero-sequence continuity* criterion is to provide that measurements of the phase-to-ground or phase-to-neutral voltages that are taken at a prospective *RPA* somewhere deeper within the *Local EPS* will still adequately represent the corresponding voltages at the *PCC* under all applicable conditions, especially when significant voltage imbalances exist such as during ground faults or an open phase.[27]

Zero-sequence continuity is defined in IEEE Std 1547-2018 as circuit topology that provides continuity between two defined points in the zero-sequence network representation. The two points for which *zero-sequence continuity* between them are of most interest are the *PCC* and any prospective *RPA* for the performance requirements of 6.2 and 6.4 of IEEE Std 1547-2018. Continuity of the zero-sequence network between these two points implies that a low-impedance series path exists for zero-sequence current to flow between these two points, and that no significant difference in the zero-sequence voltage will exist at the prospective *RPA* compared to the corresponding zero-sequence voltage at the *PCC* under all applicable conditions. Achieving this for a prospective *RPA* that is not at the *PCC* usually depends on the availability of a solidly grounded connection at the *RPA* (i.e., a low-impedance connection to remote earth) in order to adequately detect applicable phase-to-ground voltages, or on a continuous neutral conductor between the *PCC* and the *RPA* in order to adequately detect applicable phase-to-neutral voltages (see 4.3 regarding *applicable voltages*).[28]

Breaks in *zero-sequence continuity* in a three-phase system are most commonly caused by certain transformer winding configurations. Without engaging in deep technical analysis, it can first be generally stated that acceptable *zero-sequence continuity* is usually provided through a three-phase, two-winding transformer (or three-phase bank of single-phase transformers) when both the primary and secondary windings are connected in a wye configuration with their neutral terminals on both sides solidly grounded (also known as grounded-wye/grounded-wye).[29] Conversely, any three-phase, two-winding transformer (or three-phase bank of single-phase transformers) in series between the *PCC* and a prospective *RPA* that has either set of its windings in a different configuration other than solidly-grounded wye—e.g., delta, zig-zag, wye with isolated neutral (also known as floating-wye)—represents a break in *zero-sequence continuity* between the *PCC* on one side and a prospective *RPA* on the other side.[30,31]

For wye/wye connected transformers with their neutral terminals connected through an impedance to ground, the question becomes a matter of the degree of *zero-sequence continuity*. The intentional introduction of neutral or grounding impedance will result in the zero-sequence series impedance to no longer be negligibly low, and the difference between the zero-sequence voltage at the prospective *RPA* compared to the corresponding zero-sequence voltage, adjusted for the transformer ratio, at the *PCC* may

[27] IEEE Std 1547-2018 only quantifies adequacy in terms of measurement accuracy as specified in Table 3 of the standard.
[28] If a transformer exists in the series path between the *PCC* and a prospective *RPA*, then adequate detection at that *RPA* of applicable phase-to-neutral voltages depends on a continuous neutral from the *PCC* to the neutral terminal of the transformer windings on the *PCC* side and also a continuous neutral from the neutral terminal of the transformer windings on the DER side to the prospective *RPA*, with the transformer windings on both sides necessarily being connected from phase to neutral (i.e. wye-wye connections for a three-phase transformer or three-phase bank of single-phase transformers).
[29] In a special case of three-phase core type transformers, a path for zero-sequence current may also be provided if both sides are connected in a wye configuration and their neutral terminals solidly connected to each other but isolated from ground (also known as floating-wye/floating-wye with bonded neutrals). However, the corresponding zero-sequence impedance may be too high to be considered as providing continuity for the practical purposes intended here.
[30] See footnote 22.
[31] This assumes that the transformer's magnetizing reactances can be neglected, i.e., are of such high impedance that they can be treated as open circuits. It would be rare and unusual to rely on the magnetizing reactances to provide acceptable *zero-sequence continuity*.

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no longer be insignificant under all applicable conditions. Therefore, careful analysis is recommended in order to determine whether or not the zero-sequence voltages at a prospective *RPA* on one side of a transformer with impedance-grounded wye/wye connections adequately represent the corresponding voltages at the *PCC* on the other side of that transformer.

Most autotransformers with solidly grounded neutral terminals may provide acceptable *zero-sequence continuity* through the transformer itself. Again, careful analysis is recommended for the particular details of the winding arrangements; and if the desired location of a prospective *RPA* were to be beyond the terminals of the transformer, then it would still be necessary to have a low-impedance connection between the neutral of the transformer and that desired location in order to maintain *zero-sequence continuity* all the way to that prospective *RPA*.

Similarly, acceptable *zero-sequence continuity* may be provided between any pair of terminals of three-winding transformers that are both connected in wye configurations with solidly grounded neutrals (e.g., primary-to-secondary, primary-to-tertiary, or secondary-to-tertiary). Yet again, careful analysis is recommended based on the particular details of all three sets of windings in each case.

Several other arrangements of transformer winding connections may be encountered at legacy installations or for special applications. These include open-wye and open-delta arrangements, and tee/tee connections. The equivalent sequence models for these are quite complex, and it may be difficult to determine strict *zero-sequence continuity* as described here. In these cases, it will often be simpler to evaluate these using direct three-phase modeling to determine whether voltages that may be measured at a prospective *RPA* will adequately represent the corresponding voltages at the *PCC* under all applicable conditions.

It is understood that *zero-sequence continuity* in IEEE Std 1547-2018 signifies continuity of the zero-sequence network of the *Local EPS* with that of the *Area EPS* at the *PCC*. It is notable that, while the standard explicitly requires the *RPA* for 6.2 and 6.4 to be based on the *zero-sequence continuity* of the *Local EPS*, it is silent on *zero-sequence continuity* in the *Area EPS* and makes no explicit exceptions if the *Area EPS* provides no zero-sequence connectivity at the *PCC*. This may raise questions as to whether the *zero-sequence continuity* criterion for the *RPA* for 6.2 and 6.4 is applicable to DER *interconnections* to an *Area EPS* that does not provide its own *zero-sequence continuity*. Though the standard does not provide explicit direction on this, 4.2 establishes that the *RPA* for performance requirements of 6.2 and 6.4 shall be a point that is appropriate to detect the abnormal voltage conditions. This presents an opportunity for the *Area EPS operator* or the *AGIR* to determine an appropriate *RPA* for these subclauses in cases where the *Area EPS* does not provide *zero-sequence continuity* for the *interconnection*.

In general, if the *Area EPS* at the *PCC* is an ungrounded, three-wire system with no shared common neutral, then it does not provide a zero-sequence network of its own to which the zero-sequence network of a *Local EPS* can connect. This may occur for a variety of reasons, but some examples include when secondary service from the *Area EPS* is provided at the *PCC* through a transformer (e.g., the transformer is part of the *Area EPS*, not the *Local EPS*) that has an untapped delta or floating wye winding configuration on the *PCC* side (see Figure 4), or when primary service from the *Area EPS* is provided by a three-wire, ungrounded supply.[32] In these examples, there is a discontinuity in the zero-sequence network of the *Area EPS* immediately at the *PCC*, and any zero-sequence component of the phase-to-ground voltages on the Area EPS cannot be directly detected in the phase-to-ground voltages on the other side of that zero-sequence discontinuity.[33]

[32] This refers to a truly ungrounded three-phase, three-wire supply, as would be traditionally only found in certain legacy systems of 5 kV class and below, and which offers no distinct voltage relationship between the phases and ground (ignoring the effects of stray impedances such as coupling capacitance or magnetizing reactance between the phases and ground) nor any common shared neutral. It is important to recognize the difference between a truly ungrounded system as opposed to a system supplied from a uni-grounded source. While a truly ungrounded three-phase, three-wire system does not provide a low-impedance equivalent zero-sequence network of its own, a three-phase three-wire system supplied from a uni-grounded (i.e., solidly grounded) source does provide an equivalent zero-sequence circuit.

[33] A local ground or neutral may be separately derived on a Local EPS if the Area EPS is providing an ungrounded three-wire service, but that neutral or local ground is completely independent of the neutral or grounding that may exist elsewhere on the Area EPS and can only provide zero-sequence continuity within the Local EPS itself.

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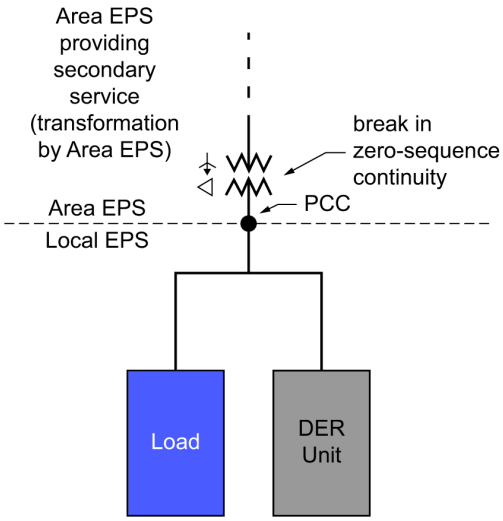


Figure 4—Example of break in zero-sequence continuity at Area EPS side of PCC

Alternatively, certain *Area EPS*s that have no phase-to-neutral or phase-to-ground connections, or that are ungrounded, may not be affected by DER connections that do not maintain *zero-sequence continuity*. However, it is recommended that consideration be given to the phase-to-neutral and phase-to-ground insulation ratings of these systems, even without intentional phase-to-neutral or phase-to-ground connections.

4.2.2.5 PoC determination and multiple PoCs

The *PoC* (*point of DER connection*) is the point where a DER unit is electrically connected in a *Local EPS* and meets the requirements of IEEE Std 1547-2018 exclusive of any *load* present in the respective part of the *Local EPS*.

While a DER unit is an individual device that is *capable of exporting active power* to an EPS, not all DER units are self-sufficient to meet the requirements of the standard. For those DER units that cannot meet the requirements of the standard themselves, *supplemental DER devices* may be utilized to meet these requirements. In cases where one or more DER units are applied in conjunction with one or more *supplemental DER devices* in order to meet the requirements of the standard, the *PoC* needs to be a point common to all such that the requirements are met by the combination of all.

Figure 5 provides one example of this situation.

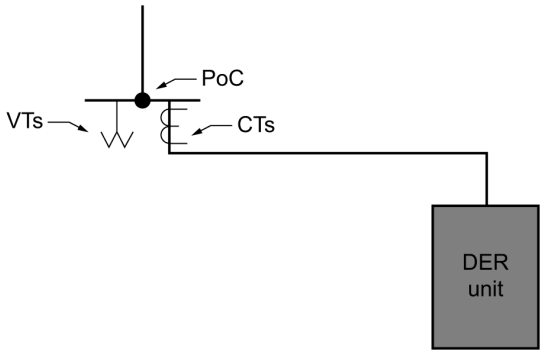


Figure 5—Example of supplemental DER devices (CTs and VTs)

In Figure 5, the given DER unit itself does not have the capability to measure the currents or voltages necessary to meet the requirements of the standard. Therefore, at an intermediate bus within the *local EPS* to which the DER unit is connected via a branch circuit, standalone CTs are applied at the bus end of that

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branch, and standalone VTs are connected to the bus. In this case, the CTs and VTs are *supplemental DER devices* necessary to meet the requirements of the standard; and, therefore, the *PoC* would be at the bus. This example is an illustration of the *Local EPS* 4 scenario in Figure 2. The reasons for the DER unit not having the necessary measurement capabilities itself are not detailed here; but examples in this case could include the DER unit being a simple rotary generator with no integrated measurement capabilities, or the presence of an intermediate transformer (not shown) between the DER unit and the bus that results in a zero-sequence discontinuity on the DER side. Note in this case that the measured frequency, voltage, and power flow conditions are those that exist at the bus, not at the terminals of the DER unit itself (which might be physically remote from the bus).

Figure 6 provides another example of this situation.

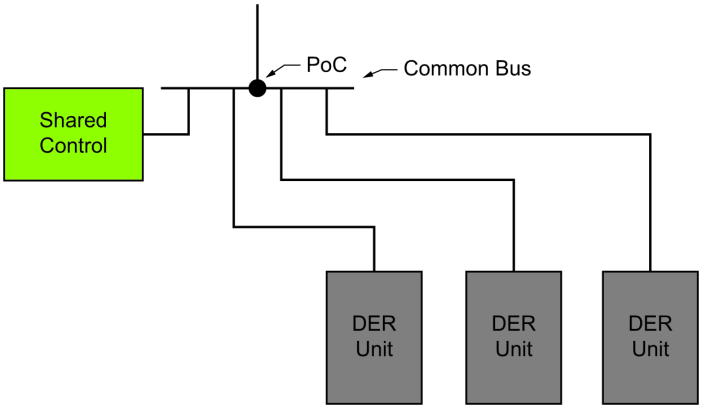


Figure 6—Example of supplemental DER devices (Common Bus and Shared Control)

In Figure 6, a group of multiple DER units are applied which are missing certain capabilities to meet the requirements of the standard individually. Therefore, a *supplemental DER device* is applied at an upline bus to provide those capabilities for all the DER units in that group. Examples of this may include an aggregating bus for a cluster of string *inverters* or a collector bus for a fleet of wind turbines, with a common control system shared by these DER units at that common bus connecting to the rest of the EPS. This group of DER units and their shared *supplemental DER device* may not be the only DER within the *Local EPS*. They may be locational segments or functional sub-systems that are able to meet the requirements of the standard as a group, independent of other DER elsewhere in the *Local EPS*. In this case, the shared control system is a *supplemental DER device* necessary to meet the requirements of the standard; and, therefore, the *PoC* would be at the common bus. This is an example that illustrates the *Local EPS* 5 scenario in Figure 2. Note that if the connection to the *Area EPS* is also at this common bus, then the *PoC* and the *PCC* may be effectively identical.

For DER units that are independently able to meet the requirements of IEEE Std 1547-2018, the *PoC* may simply be the main power terminals of that DER unit. Examples of this may include the main power terminals of a traditional generator unit with its own integrated control system and breaker, or the ac power terminals of an *inverter* that is fully compliant with the standard. These are examples illustrating each of the individual DER units in the *Local EPS* 3 scenario in Figure 2.

For the *Local EPS* 3 scenario in Figure 2, note that there are multiple DER units connected in parallel, and it can be understood from that illustration that each is self-sufficient to meet the requirements of the standard (since there are *PoCs* indicated for each individual DER unit). If the other conditions of 4.2 of the standard are met such that the *RPA* (other than the response to *Area EPS* abnormal conditions specified in 6.2 and 6.4) may be at the *PoC*, then this scenario illustrates a situation where there would be multiple *RPAs*, one for each DER unit in this scenario. This means that each DER unit would individually have its own power *interface* and local DER communications *interface* for the purposes of the standard and would be required to meet the performance and *interoperability* requirements of the standard based solely on the conditions at its own *PoC* (except for the responses specified in 6.2 and 6.4), irrespective of the conditions or behavior of the other DER units that may exist in the same *Local EPS*.

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4.2.2.6 Multiple PCCs

In some more complex cases, a *Local EPS* may have multiple connections with the *Area EPS*, resulting in multiple *PCCs*. Examples may include college campuses, office parks, hospitals, airports, industrial plants, military installations and more. The presumption in these scenarios is that these are each truly a single *Local EPS* with connectivity to multiple *PCCs*, whether or not those paths of connectivity exist at normally open junctions or are operated normally closed and in parallel with the *Area EPS*. Power systems that do not have any connectivity between them other than through the *Area EPS* would each be considered a separate *Local EPS*, each with its own *PCC*, and would not fit this scenario even if they were on the same property or had a common owner. But, in a scenario of a single *Local EPS* with connectivity to multiple *PCCs*, these facilities may have internal switching that can change the internal configuration of the *Local EPS*, adding further complexity to DER *interconnection* requirements.

Consider the example of the *Local EPS* illustrated in Figure 7, with two *PCCs* and two DER units. This EPS is normally configured as two sub-systems, one normally connected to the *Area EPS* via PCC #1 and the other connected to the *Area EPS* via PCC #2. In this example, DER unit X is always paired with the *load* fed from Bus A (*load* X), and DER unit Y is always paired with the *load* fed from Bus B (*load* Y). In this normal configuration, the *nameplate rating* of DER unit X or the average annual *load* demand of *load* X relative to that rating and the capability of export through PCC #1 may be used to determine the *RPA* for DER unit X. Likewise, the *nameplate rating* of DER unit Y or the average annual load demand of *load* Y relative to that rating and the capability of export through PCC #2 may be used to determine the *RPA* for DER unit Y. However, if an alternate configuration is allowed whereby the connection between Bus A and Bus B is closed and one or the other of the *PCC* connections is opened, the *nameplate ratings* of the DER units X and Y are summed as an aggregate, and this is compared to the average annual load demand of the combined *loads* X and Y (which may or may not equal to the simple sum of the independent demands, depending on coincidence). This alternate configuration with different relevant ratings and *loads* may lead to different determinations of allowable *RPAs*.

IEEE Std 1547-2018 does not preclude multiple *PCCs* and the related complexities such as the example above, so long as the underlying criteria and performance requirements are met. It is within the purview of the *Area EPS operator* and the DER operator to agree on the operating configurations that will be accommodated, *RPA* assignments, and methods of enforcement (e.g., equipment and design, control systems, operating procedures, contractual obligations, etc.)

4.2.2.7 Multiple RPAs

One of the implications of the discussions above is there may be different *RPAs* assigned for different performance requirements for the same *interconnection*. In cases of multiple DERs and multiple *PoCs*, if conditions a) or b) of 4.2 are met, then there may be separate *RPAs* for each *PoC* whereby the performance requirements for the DER(s) are applicable only with respect to their individual *RPAs*. In cases of *Local EPS*s with multiple *PCCs*, there may be separate *RPAs* for each allowable operating configuration. Possibilities for different *RPAs* assigned for different performance requirements also exist even for an *interconnection* involving a single *PCC* and a single *PoC*, as illustrated in the next two examples.

In Figure 7 the *Local EPS* with DER meets condition a) or condition b) of 4.2 of the standard, and *zero-sequence continuity* is maintained between the *PCCs* and the *PoCs*. This allows the *RPA* for all requirements to be at the *PoCs* or at any point between or including the *PoCs* and *PCCs* by mutual agreement. In this example, for any of a variety of reasons not detailed in here, the *Area EPS operator* and the DER operator agree to establish the *RPA* for all the power control requirements of Clause 5 of IEEE Std 1547-2018 at the *PoCs* of each DER,[34] and all other performance requirements at another *RPA* located at an intermediate location between the *PCCs* and the *PoCs*.

[34] The *Area EPS* operator and the DER operator could also have agreed to different RPA locations for each of the various functional requirements defined in Clause 5 (see Footnote 30 in IEEE Std 1547-2018).

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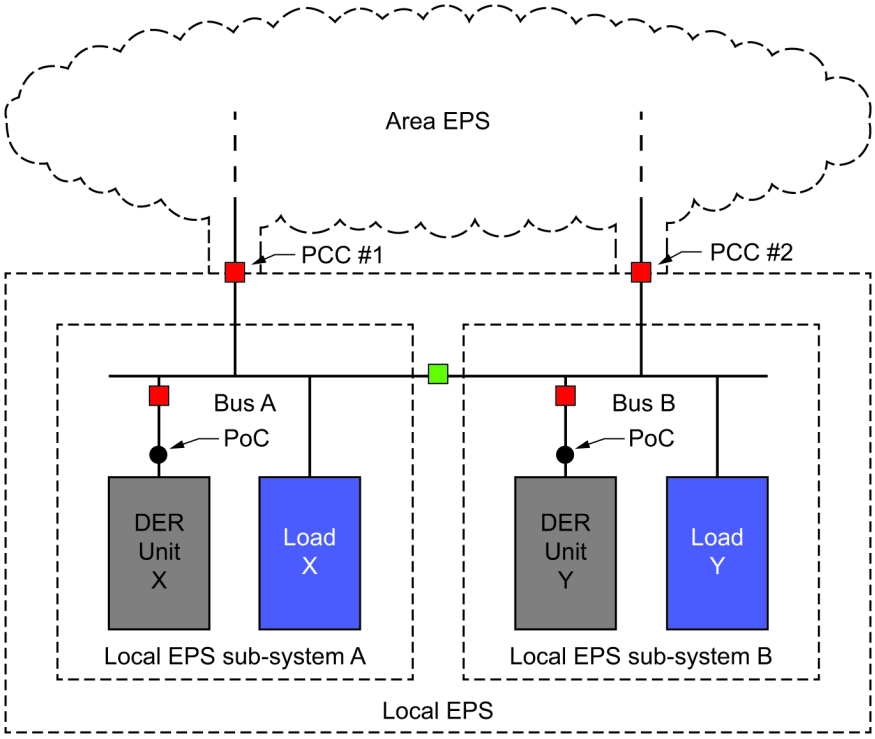


Figure 7—Example of multiple PCCs

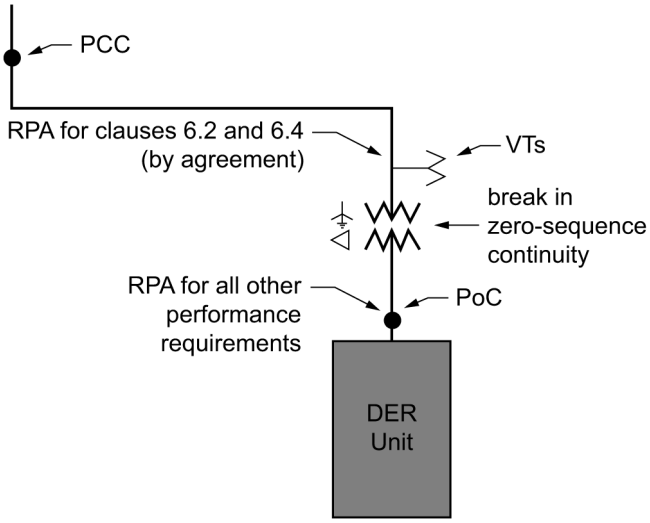


Figure 8—Example of multiple RPAs

Figure 8 provides an alternate example of multiple *RPAs* for different requirements.

In Figure 8, the *Local EPS* with DER meets condition a) or condition b) of 4.2 of the standard, allowing the *RPA* to be chosen to be at the *PoC* (or at any point between or including the *PoC* and *PCC* by mutual agreement), except for the *RPA* for performance requirements to the *Area EPS* abnormal conditions specified in 6.2 and 6.4. The *Local EPS* includes a transformer configuration that results in a break in the *zero-sequence continuity* between the *PCC* and the DER. Consequently, it becomes necessary for the *RPA* for 6.2 and 6.4 to be located at a point between the *PCC* and where the *zero-sequence continuity* is broken. In this case, the decision is made to locate the *RPA* for 6.2 and 6.4 on the *Area EPS* side of the transformer connections, and auxiliary VTs may be applied at this location to provide measurement of the *applicable*

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voltages. Note that while the performance requirements for 6.2 and 6.4 will be based on the voltage and frequency conditions at this *RPA* location before the break in *zero-sequence continuity*, all other performance requirements may be based on conditions at the *PoC* (or another point by mutual agreement).

4.2.3 Tips, techniques, and common practices

Area EPS operators and DER operators are encouraged to clearly identify the locations of *PCCs*, *PoCs*, and *RPAs* in their documentation, diagrams, and *interconnection* agreements, including any specific evaluation used to establish *RPAs* at locations other than the *PCC* or *PoC*. This will help clarify conformance to the requirements of the standard and references on which to base performance assessments over the lifetime of the DER installation.

Area EPS operators and DER operators are further encouraged to confirm *interoperability* information elements correctly reflect the pertinent DER equipment and operating conditions as they exist at the assigned *RPAs*.

When determining the location of an *RPA*, *Area EPS operators* and DER operators are discouraged from sub-dividing requirements and associated *RPA* locations any further than those of 6.2 and 6.4 from all other requirements, as this may lead to confusion and disagreement over performance obligations and assessments, quantification of operating conditions and context of *interoperability* data.

It is understood the apparent power (i.e., volt-amperes) maximum rating of the DER is the *nameplate rating* to be used for the determination of an *RPA* location, and the value of the configuration setting is used when different than the nameplate value of any physical equipment.

When the annual average load demand is used for the determination of an *RPA* location, it is understood this refers to the *load* of the *Local EPS* without the presence of any DER, planned or existing; and if used as a qualifying basis for specifying an *RPA* other than at the *PCC*, it is implicit that the annual average load demand continues to meet the criteria throughout the existence of the DER. To help avoid confusion or disagreement over assessments of this "native" *load*, *Area EPS operators* are encouraged to have a documented methodology for the calculation of the annual average load demand on a *Local EPS*, both during an initial *interconnection* evaluation and throughout the DER's in-service life, and sharing this methodology with the DER operator.

When control systems or configuration settings are used to avoid exceeding 500 kVA power export for any longer than 30 s as a qualifying basis for specifying an *RPA* other than at the *PCC*, the system response times need to be evaluated to confirm that the export levels can be brought to 500 kVA or less within 30 s for all foreseeable excursions. This may require response time adjustments, and those adjustments may be evaluated against other requirements.

Because the standard establishes that the *RPA* for performance requirements of 6.2 and 6.4 shall be a point "that is appropriate to detect the abnormal voltage conditions," an opportunity exists for determination of an appropriate *RPA* in cases where, regardless of *zero-sequence continuity* in the *Local EPS*, the *Area EPS* does not provide *zero-sequence continuity* for the *interconnection*. However, due consideration is recommended for the phase-to-neutral and phase-to-ground insulation ratings of systems that do not provide *zero-sequence continuity*, even if no intentional phase-to-neutral or phase-to-ground connections are utilized.

4.2.4 Summary

If a *Local EPS* has an aggregate DER *nameplate rating* greater than 500 kVA and an annual average load demand equal to or less than 10% of the aggregate DER *nameplate rating*, then the *RPA* for all requirements shall be at the *PCC*. If a *Local EPS* has an aggregate DER *nameplate rating* equal to or less than 500 kVA, or if a *Local EPS* has an annual average load demand greater than 10% of the aggregate DER *nameplate rating* and is not capable of exporting more than 500 kVA for longer than 30 s or is prevented from doing so, then *RPAs* may be assigned at other locations within the *Local EPS* depending on *zero-sequence continuity* and/or mutual agreement.

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The guiding principle in determining appropriate *RPAs* is to bear in mind that the performance requirements are intended to be reflective of the operating conditions affecting the *Area EPS*.

4.3 Applicable voltages

The applicable voltages determine the performance of a Local EPS or DER and are the electrical quantities specified with regard to the reference point of applicability, individual phase-to-neutral, phase-to-ground, or phase-to-phase combination and time resolution.

Subclause 4.3 of IEEE Std 1547-2018 specifies the *applicable voltages* for the performance requirements in IEEE Std 1547-2018, in terms of which point-to-point electrical potentials apply (e.g., phase-to-phase, line-to-neutral, etc.); whether the least, greatest, or average magnitudes apply (in multi-phase systems, depending on the context); and the time basis for integrated or averaged values.

In all cases, the *applicable voltages* for a given requirement are those that exist at the *reference point of applicability* for that requirement. However, which specific point-to-point potentials are applicable is determined by certain characteristics of the *Area EPS*, depending on the general voltage class at the *point of common coupling*.

When a *PCC* is located at a medium-voltage level, the *applicable voltages* are determined by the configuration and nominal voltage of the *Area EPS* at that *PCC*. The various configurations take into account the number of phases (single-phase or three-phase), the number of conductors (two-wire, three-wire or four-wire) and whether the system is considered grounded (e.g., uni-grounded, multi-grounded, low-impedance grounded, etc.) or ungrounded (e.g., totally insulated from ground or not intended to be effectively grounded). Table 1 of the standard specifies the *applicable voltages* when the *PCC* is at a medium-voltage level, and these *Area EPS* characteristics determine whether phase-to-neutral or phase-to-ground potentials are included along with the phase-to-phase potentials. For example, phase-to-neutral potentials are included in the *applicable voltages* for four-wire systems regardless of whether those systems are grounded or ungrounded, and phase-to-ground potentials are not applicable for ungrounded systems.

When a *PCC* is located at a low-voltage[35] level, the *applicable voltages* are determined by the configuration of the low-voltage windings of the *Area EPS* transformer(s) between the medium-voltage system and the low-voltage system. The various configurations include delta, wye, tee, zig-zag, and split-phase (also known as Edison connection); and whether or not the configurations are grounded or ungrounded. Table 2 of the standard specifies the *applicable voltages* when the *PCC* is at a low-voltage level; and the transformer winding configurations determine whether phase-to-neutral, phase-to-ground, line-to-line, etc. potentials are included. Note that if the *PCC* is on the low-voltage side of the transformer, then by definition the transformer is part of the *Area EPS*.

Unless specified otherwise in IEEE Std 1547-2018, the *applicable voltages* are quantified as the effective (RMS) values over the preceding fundamental frequency period, where the applicable frequency is the fundamental-frequency component.

For the requirements of the voltage-reactive power and the voltage-active power control modes (see 5.3.3 and 5.4.2, respectively) where DER do not respond to individual phase voltages, the *applicable voltages* are quantified as the average of the three-phase effective (RMS) values or alternatively positive sequence component of voltages over one fundamental frequency period.

The relevant voltage at any given time for the low-voltage *ride-through* and undervoltage *trip* requirements in 6.4 is that which is the least magnitude of the individual *applicable voltages* relative to their corresponding nominal values. The relevant voltage at any given time for the high-voltage *ride-through* and overvoltage *trip* requirements in 6.4 is that which is the greatest magnitude of the individual *applicable voltages* relative to their corresponding nominal values.

[35] Less than or equal to 1000 V per IEEE Std C62.41.2 and IEEE Std C62.45.

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For the rate of change of frequency (ROCOF) *ride-through* requirements in 6.5.2.5, the ROCOF is quantified as the average ROCOF over an averaging window of at least 0.1 s.

4.4 Measurement accuracy

The DER shall meet the minimum steady-state and transient measurement and calculation accuracy requirements for voltage, frequency, active power, reactive power, and time as specified in Table 3 of IEEE Std 1547-2018. Actual measurement and calculation accuracy of a DER shall be stated for each of the values above.

Minimum measurement accuracy requirements have been introduced into the standard for the first time in IEEE Std 1547-2018. The minimum accuracy is required to be achieved at the *RPA* within the maximum time given by the related time window in Table 3 of IEEE Std 1547-2018.

Previously, equipment manufacturers could specify the measurement accuracy of the equipment without constraint. The manufacturer's stated accuracy is utilized in the *type tests* of IEEE Std 1547.1-2020 to determine the passing criteria. Further consideration of measurement accuracy is then important to confirm that the reactive and active power functions of Clause 5 as well as the *trip* functions and ride through capabilities of Clause 6 perform within a certain range of performance accuracy at the *RPA*. IEEE Std 1547.1-2020, 4.2 describes the required DER performance accuracy in relation to minimum required measurement accuracy.

Also important are the requirements for the ability to communicate related monitoring information in 10.5. The monitoring parameters require some knowledge of measurement accuracy for correct interpretation.

4.5 Cease to energize performance requirement

In the cease to energize state, the DER shall not deliver active power during steady-state or transient conditions. The requirements for cease to energize shall apply to the point of DER connection (PoC).

Subclause 4.5 IEEE Std 1547-2018 provides a detailed description of the meaning of *cease to energize*. In the *cease to energize* state there shall be no active power (real power) flow. Small amounts of passive reactive power flow are allowed. Passive reactive power flow is typically caused by filters that are associated with the *inverter*.

It is important to note that in IEEE Std 1547-2018, there is a difference between "*cease to energize*" and "*trip.*" "*Cease to energize*" is defined in terms of a cessation of active power delivery to the *Area EPS* during a transient event or disturbance, with the DER retaining the capability of immediate *return to service* as soon as the disturbance has ended. "*Trip*," on the other hand, involves inhibition of immediate *return to service* after the disturbance has ended.

4.6 Control capability requirements

The DER shall be capable of responding to external inputs as specified in this subclause.

4.6.1 Capability to disable permit service

The DER shall be capable of disabling the permit service setting and shall cease to energize the Area EPS and trip in no more than 2 s.

4.6.2 Capability to limit active power

The DER shall be capable of limiting active power as a percentage of the nameplate active power rating. The DER shall limit its active power output to not greater than the active power limit set point in no more than 30 s or in the time it takes for the primary energy source to reduce its active power output to achieve the

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requirements of the active power limit set point, whichever is greater.[36] *In cases where the DER is supplying loads in the Local EPS, the active power limit set point may be implemented as a maximum active power export to the Area EPS. Under mutual agreement between the Area EPS operator and the DER operator, the DER may be required to reduce active power below the level needed to support Local EPS loads.*

4.6.2.1 Background

The capability required by IEEE Std 1547-2018, 4.6.2 is dependent on the presence of a local DER communication *interface* to receive the command. The command is generally available for dynamic continuous adjustment of the DER output. The relevant information elements associated with the command are given in IEEE Std 1547-2018, 10.6.12 for "limit maximum active power." The DER may have provisions for changing these settings without the use of a local DER communication *interface*, in which case they could potentially be used for longer-term power limiting. However, the configuration settings provided for by 10.4 may be more appropriate for implementing long term power limits. The command can potentially be utilized to implement an export limit, as described in 4.2.2.3.

The maximum active power setting applies only to energy output from the DER, not import. This function is not a request that a DER operate at a given active power level, but rather a limit that establishes only a boundary that the device is required to remain within. It may be noted that this function does not affect the reactive power level of the DER, which is dependent on the chosen reactive power control.

4.6.2.2 Impacts of the limit maximum active power function

This function may be used to limit the DER's impact on upstream *Area EPS* equipment. Dependent on the topology of the communications system, a single DER or an aggregation of DERs could reduce active power to keep the *Area EPS* equipment below thermal or voltage limits, or limit power flow in response to a temporary circuit reconfiguration. The function may also be used to help maintain frequency by balancing generation with *load*, potentially as part of an *intentional island*. The command may potentially be used in conjunction with real-time monitoring of the EPS or scheduled for anticipated needs.

4.6.2.3 Tips, techniques, and common practices

4.6.2.3.1 Settings usage

The function to limit active power is configured as defined in 10.6.12 by an "enable" (on/off) and a "maximum active power setting". The maximum active power setting is a percentage of the active power rating at unity power factor (nameplate active power rating), or the associated configuration setting, if utilized.

To begin utilizing this function, the enable needs to be set "on" AND a value (0% to 100%) set for the "maximum active power." The value of the maximum active power setting is otherwise undefined upon enable. For example, a DER could retain the value from the last time the function was used or could reset the limit to 100% each time the DER powers down or the function is disabled.

Ongoing operation of this function does not require that the enable be resent each time the maximum active power setting is adjusted. Rather, upon change of the maximum active power setting, the DER shall transition the output limit within the allowed time.

4.6.2.3.2 Time response

The time for the DER to settle to a new power limit value when the function is enabled and a new value is set can be as little as a fraction of a second and as long as 30 s for *inverter* based solar or battery storage technologies. For other technologies, the settling time may be longer than 30 s (no hard upper limit)

[36] Linear ramping and step-wise ramping with small step sizes may be desirable.

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depending on the "time it takes for the primary energy source to reduce its active power output".[37] The same time limits apply for settings changes that increase the power limit. Large diesel generators can increase power at about 3% per second, while gas generators may be even slower. If *area EPS operators* require more detailed understanding of the settling time for a given DER, additional information may be required to be supplied for the DER evaluation.

It needs to be understood that this control is subject to the maximum 30-s response time for control parameter setting changes given in 4.6.3. Combined with the maximum settling time of 30 s given in 4.6.2, the total potential response time for the power change to take full effect could be up to one minute for DER that can adjust their power output within 30 s. For other DER, the total response time could be longer than 1 min.

4.6.2.3.3 Ramping

When the maximum active power setting is changed, ramping of DER output is not required by 4.6.3. Additional information on the DER's ramping capabilities may be useful for the DER evaluation in order to address voltage changes and voltage regulation coordination when using the limit maximum active power function. The capabilities of the DER and the *Area EPS* connection determine the need for a ramp rate and what the ramp rate needs to be.

If large changes in the maximum active power setting needs to be supported and it is determined that they would cause unallowable conditions on the distribution systems, the managing entity could apply multiple new power settings in lower increments over time as an alternative to implementing ramp rate limitations.

4.6.2.3.4 Export limiting

Subclause 4.6.2 provides for the limit maximum active power command to be implemented as an export limit, rather than reducing power at the PoC. Any load within the local EPS will reduce export to less than the DER nameplate rating and reductions in the maximum active power setting may not produce equivalent reductions in the DER power, dependent on the local load at the time. Thus, the amount of power reduction provisioned will remain uncertain to the managing entity unless it also has awareness of the local load level as well.

Implementing this function as an export limit would generally require more equipment than just a DER unit(s) that is fully compliant. However, necessary equipment may exist at the PCC for other requirements of the standard, facilitating the implementation of export limiting. For instance, the requirement in 11.3.2 that individual DER units that are considered fully compliant at the PoC may only be considered fully compliant at the PCC if the impedance between the PoC and the PCC is less than 0.5% on the DER rated apparent power and voltage base may mean that PTs and voltage sensing equipment are required. That equipment may take the form of a plant controller which could also serve the role of coordinating an export limit.

Implementing the limit maximum active power function as an export limit solves a potential issue with the DER system reducing power more than required when implemented at the individual DER unit level. The *nameplate rating* of the DER system is considered the sum of all individual DER units, and the maximum active power setting is a percentage of that *nameplate rating*. For multiple DER unit systems, especially ac coupled PV plus storage systems, this presents an implementation challenge as every DER unit will need to know the overall system rating and output, not just its own. It will be beneficial for the customer to install a plant controller (or PCS) to control the function. Whenever any of the DER units are outputting at less than full capacity, the controller would allow them to reduce power less than if they reduced off their own unit ratings. Additionally, a PCS could be used to limit export power rather than DER unit output, providing power to local *loads* before requiring reduction.

Implementation of the control as an export limit introduces the possibility of using *load* control or storage *charging* to affect export level. The IEEE Std 1547.1-2020, 5.13 test for limit active power allows *load* control to be *type tested* for the DER system, simplifying evaluation and commissioning. IEEE Std 1547.1-

[37] ISO 8528-5 Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets - Part 5: Generating Sets provides some standard performance criteria for power changes based on different performance classes.

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2020 also allows for the UL 1741 PCS requirements to be utilized for testing of the export limiting capability at the *PCC*. Note that PCSs may introduce *inadvertent export* beyond the maximum active power setting.

4.6.2.3.5 Plant controllers utilizing limit maximum active power within the DER

It needs to be noted that plant controllers may potentially utilize the standard IEEE 1547 command limit maximum active power to implement the *export limitation*. Though the DER units could be tested to confirm they support this function via the supported communications protocol(s), there is currently no test to confirm that a plant controller sends the proper command. Protocol certifications could provide a means to confirm the control messages are sent from the plant controller correctly. Evaluations of such equipment could potentially rely to some extent on additional testing provided by the manufacturer, which, when paired with the communications testing of the DER unit(s), provide proof of *interoperability*. Such testing needs to also address the time response requirements to confirm *inadvertent export* can be maintained to 30 s or less, inclusive of any control-related delays.

Whether the limit maximum active power command is used within the DER to accomplish export limiting or not, the local DER communication *interface* needs to allow a DER system command to be controlled from an external entity. This could be achieved with a hierarchical control structure where a plant controller receives external maximum active power settings and applies them systemwide, or otherwise manages the commanded DER units to output the appropriate power based on the control from the managing entity.

4.6.3 Execution of mode or parameter changes

Transition between modes shall commence in no more than 30 s after the mode setting change is received at the local DER communication interface. Changes of control functional modes shall be executed such that the DER output is transitioned smoothly over a time period between 5 s and 300 s.

Ramping of DER output is not required for control parameter setting changes. For all control and protective function parameter settings, the time following the input to the local DER communication interface and preceding the point in time when the invoked action begins shall be no greater than 30 s.

4.7 Prioritization of DER responses

Requirements set forth in Clause 5 and Clause 6 shall be prioritized as identified in 4.7 of IEEE Std 1547-2018.

4.7.1 Background

Due to the potentially conflicting requirements between different functions and capabilities, the standard includes this subclause to provide that DERs produce the desired response. Without this prioritization list, one could interpret the standard's set of power response requirements in different ways, leading to different responses by different DERs. For example, as ride through and tripping require the opposite response, the interaction between the two needs to be well defined. These interactions and proper prioritizations are confirmed via *type testing* in IEEE Std 1547.1-2020.

4.7.2 Export limitation and import limitation

Export limitations which are not based on the configuration settings or limit maximum active power function could potentially constrain active power operation, reactive power operation, or frequency droop operation. Apart from the use cases of the limit maximum active power function and the voltage-active power function, the standard does not address how *export limitations*, if applied, would be prioritized against other functions in 4.7. Export or import limits put in place by the DER are not to prevent the DER system from complying with the standard.

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4.7.3 Active power functions

In general, functions that reduce the export power for DER that do not absorb active power are straightforward and reduce export power to at or below the level called on by the function. This applies to the limit maximum active power function and the voltage-active power function. For DER that can absorb active power, absorbed power could exceed an import limitation due to the voltage-active power function if set to absorb beyond the import limit.

4.7.4 Frequency droop

For the frequency droop function, DER active power may exceed the export limit since the low frequency response requires an increase in active power potentially up to the *nameplate rating* of the system. For DER that can absorb active power, absorbed power could exceed an import limitation during high frequency events.

While import limits are not addressed at all in 4.7 (or in IEEE Std 1547-2018 generally), power export limits could be construed to be similar to the limit maximum active power function. This function has a priority below that of the frequency droop and thus the export limit could be exceeded for a frequency event. A similar priority could be correlated to import limits, though no import limitation function exists in IEEE Std 1547-2018. Addressed similarly, an import limit could be exceeded due to a high frequency event or a high voltage event.

4.7.5 Reactive power functions

Subclause 4.7 places higher priority on the limit maximum active power function compared to the reactive power functions of Clause 5. This may be used as guidance in terms of selecting the prioritization of other *export limitations*. If the export limit is implemented as an active power limit, there is no conflict and the DER will be able to supply whatever reactive power is called for when operating up to the export limit.

DER that performs *export limitation* may limit apparent power, and thus potentially constrain the total reactive power available below the export level. If the apparent power limit takes priority similar to the limit maximum active power function, note that export of active power could be reduced to support reactive power requirements, and total available reactive power could be reduced. If reactive power functions take priority over the apparent power export limit, exercise caution as this could allow greater export of active power and the apparent power limit could be exceeded.

The same logic regarding reactive power prioritization could be applied to import limitations.

4.7.6 Agreement on prioritization

The exact operation of the DER may be mutually agreed to by the DER and *Area EPS Operators*. Prioritization of these functions may be addressed during the DER evaluation. It needs to be made clear to the DER operator how the export limit or import limit is to be prioritized so the equipment can be correctly programmed. An agreement to utilize export or import limitations needs to note how these functions are prioritized in comparison with the export limit.

4.8 Isolation device

When required by the Area EPS operating practices, a readily accessible, lockable, visible-break isolation device shall be located between the Area EPS and the DER.

IEEE Std 1547-2018 does not universally require an isolation device. Also, it states that, where required by Area EPS operating practices, its location need not be at the *PCC* but at any point in the *Local EPS* between the *Area EPS* and the DER. IEEE Std 1547-2018 does not preclude installing any required isolation device at a location that is otherwise allowable.

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An isolation device electrically separates the DER from the local or *Area EPS*. If the isolation device is required by the *Area EPS*, then its location needs to be carefully considered as required by the *Area EPS* and for consequences and compliance with local codes and regulations (e.g., NEC [B77] or NESC [B64] and state rules and tariffs).

The isolation device is not required to be a paralleling or interrupting device, but it shall comply with the requirements in IEEE Std 1547-2018. It needs to be able to provide sufficient isolation such that if the *Area EPS* or the DER is powered after the isolation device is activated, the isolation device does not constitute an unsafe condition (e.g., does not arc or conduct electricity between the DER unit and the remainder of the local or *area EPS*).

The readily accessible, lockable, visible-break aspects of IEEE Std 1547-2018 are based on NEC requirements related to similar devices (e.g., breakers or switches) and on *area EPS* operating practices.

4.8.1 Background

The isolation device requirement of IEEE Std 1547-2018 is not universally mandated unless *area EPS* practices require it. The intent of the isolation device requirement is driven by preexisting *area EPS* operating practices (e.g., mandated by OSHA or electric worker labor practices).

IEEE Std 1547-2018 may not be the only standard applicable to a DER *interconnection* project. For example, compliance with the NEC [B77] or NESC [B64] may be required in the USA. The NEC, which is applicable to public and private buildings and structures, includes requirements for disconnecting means. The NEC, OSHA, and all other standards and practices required by a DER *interconnection* project need to be reviewed for additional disconnecting or isolation device requirements for power sources, *loads*, and circuits.

All *area EPS operators* have established practices and procedures concerning operational safety of the *area EPS* under normal and abnormal conditions. Several of these identify methods to confirm that the electrical system is properly reconfigured from its normal service mode for the safety of *area EPS* line and service personnel. Although these procedures vary somewhat among operators, their intent is to establish “safe work area clearances” for the safety of personnel operating in proximity to the EPS. To achieve this, *area EPS operators* have established procedures that require protective grounding, jurisdictional tagging of the portion of the EPS where clearance is to be gained, and visible isolation; others have established work practices that presume any line is “live” or “hot,” regardless of whether that is the case when a worker arrives.

Qualified *area EPS* personnel generally use one of two practices to work on primary conductors: dead-line clearance or live-line work (also called hot work). Dead-line clearance work practices typically mandate that the previously energized conductors be visibly isolated from all sources, tagged out, checked for voltage, and grounded before any work is done. When dead-line clearance work involves a DER installation, a DER isolation device may be necessary to provide a visible break. Some state-level *interconnection* rules do not require visible-break isolation devices for small DER (e.g., of 10 kW or less) that use certified non-islanding *inverters*.

In live-line work, conductors remain energized during the work, or the worker needs to treat the line as though it were energized. Specialized work practices, techniques, tools, and training are required to perform live-line work. Safety rules, developed to minimize the potential for electrical shock or arc flash, require that any automatic reclosing scheme, such as a line recloser or substation breaker, be disabled on the source protective device. In addition, protective device *trip* values may be temporarily reduced during hot work to further reduce the personnel exposure time if a contact or fault occurs.

OSHA 29 CFR 1910.269 [B83] has a requirement for de-energizing lines and equipment for employee protection. It states that:

“All switches, disconnectors, jumpers, taps, and other means through which known sources of electric energy may be supplied to the particular lines and equipment to be de-energized shall be opened. Such means shall be rendered inoperable, unless its design does not so permit, and tagged to indicate that employees are at work.”

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This practice relates to dead-line clearance work. Other OSHA and NESC regulations apply to hot work and dead-line work and may have additional requirements pertaining to DER unit isolation.

4.8.2 Impact of DERs

After the *area EPS* is de-energized, the DER could reenergize it if the *interconnection system* were to somehow experience a multiplicity of non-compliance with IEEE 1547 requirements. Thus, the IEEE Std 1547-2018 isolation device requirement is redundant for preventing energization of a dead line. Further, non-islanding *inverter*-based DERs that do not produce fundamental voltage before the *interconnection system* paralleling device is closed cannot generate electrical energy in the absence of an external electric source such as the *area EPS*. In this case, too, IEEE Std 1547-2018 is redundant for preventing energization of a dead line.

4.8.3 Tips, techniques, and common practices

It is imperative to check with the AHJ (e.g., state and local code enforcement agencies as well as the *area EPS operator*) to establish the isolation device requirements. Some state *interconnection* rules require utility-accessible, lockable, visible-break disconnect switches. Some states in the U.S. do not require the DER owner to install them for certified, small, *inverter*-based DER. Still other states defer to *area EPS* requirements. Isolation devices—typically electrical disconnect switches or draw-out circuit breakers—provide visible isolation of the DER from the *area EPS*. Some *area EPS operators* allow for a draw-out-type circuit breaker with a provision for padlocking at the draw-out position to meet the requirement for an isolation device. Check all applicable standards and codes for requirements on isolation devices and related equipment, practices, and functions.

If the DER were to remain in parallel with the *area EPS* during hot work, *area EPS* personnel performing hot work would be exposed to increased electric shock time and extended arc flash time in the event of a contact or fault because of the added contribution from the DER. Therefore, it is imperative that *area EPS* practices for isolation be considered, where required. For hot work, some *area EPS* operating practices require the isolation of DER sources from the affected area to protect personnel.

In a DER installation, some equipment and fuses or breakers may be energized from two or more directions. If a disconnect means is required by the *area EPS*, it needs to electrically separate the DER from the *area EPS*. There may be other disconnection means within the *local EPS* in which the load-side contacts are still energized when the switch is in the open position, so a safety label with a warning needs to be placed by these switches. Also, a means may be provided for fuse replacement (in fused switches) without exposing the worker to energized parts.

In addition, much work has been, and continues to be, performed to develop *inverters* that can provide reasonable assurance that the DER will not be able to generate electrical energy in the absence of the utility electrical source (the non-islanding *inverter*). Some *area EPS operators* have modified their work practices by waiving their requirement for an isolation device when such an *inverter* has been installed and tested to appropriate standards for the “non-islanding” function.

Another option for DER projects less than 10 kW (e.g., small residential PV installations) is a plug or twist-lock plug, if it can be removed in a manner that prevents it from being plugged back into the system. A padlockable cap that can be placed over the plug for which only utility personnel have the key is one example.

Where a readily accessible isolation device is required by the *area EPS*, the typical location will be at the *PCC*, but other locations (such as the DER point of connection) could be considered for operational flexibility and cost effectiveness. The location of the isolation device needs to be determined with consideration to the operation of the *local EPS* both with the generator isolated or operating. Regardless of isolation device location, this device needs to be accessible and in series with the DER unit. There is not a universal requirement for mandating an isolation device, nor is there a single optimal location for the isolation device because location involves application-specific, *local EPS* and *area EPS* operating procedure considerations. IEEE Std 1547-2018 requirements do not address specific details such as

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equipment location, ownership, who pays, etc. *Area EPS* operating practices, local rules, or regulations sometimes have guidance, and prior discussion with the *area EPS operator* is good practice.

4.9 Inadvertent energization of the Area EPS

The DER shall not energize the Area EPS when the Area EPS is de-energized. Exceptions may be given for intentional Area EPS islands per 8.2 at the discretion of the Area EPS Operator.

4.9.1 Background

For personnel safety reasons, it is critical that inadvertent energization of *area EPS* circuits be prevented during line maintenance or service restoration activities when the *area EPS* is de-energized.

4.9.2 Impact of DERs

The DER shall not transfer power to the *area EPS* side of the *PCC* when the *area EPS* has been de-energized for any reason. In addition, when the voltage or frequency of the *area EPS* is outside acceptable limits, unless *islanding* is permitted, power transfer from the DER to the *area EPS* shall cease beyond the *PCC*. In the case of a system fault, this will allow the *area EPS* to step through its relaying and reclosing schemes to clear the fault without interference from the DER beyond initial fault-clearing.

4.9.3 Tips, techniques, and common practices

After an *area EPS* disturbance, no DER reconnection shall take place until the *area EPS* voltage is maintained within Range B of ANSI C84.1 Table 1 and frequency is in the range of 59.3 Hz to 60.5 Hz for a stabilization period of up to 5 min. See 8.2.6 for further details.

4.10 Enter service

4.10.1 Introduction

IEEE Std 1547-2018 defines the criteria for enter service. These requirements apply anytime a DER is connecting to the Area EPS, whether entering service for the first time, returning from fault or other disconnect event or making a closed transition.

4.10.2 Enter service criteria

When entering service, the DER shall not energize the Area EPS until the applicable voltage and system frequency are within the ranges specified in Table 4 in IEEE Std 1547-2018 and the permit service setting is set to "Enabled."

In the base standard, when entering service, the DER shall not energize the *Area EPS* until the *applicable voltage* and system frequency are within the ranges specified in Table 1 and the *permit service* setting is set to "Enabled." In other words, whether a DER is beginning operation for the first time or is returning to service after a *trip*, the *Area EPS* steady-state voltage and frequency needs to be within acceptable ranges and the *permit service* setting enabled before the DER can have active power outflow to the *Area EPS*. This requirement is applicable to all three abnormal operating performance categories. The specific instance of returning to service after *trip* is addressed in 6.6.

4.10.2.1 Background

Evaluation of requirements for *enter service* is based on test specifications provided in IEEE Std 1547-2018, 11.3.3. Corresponding test procedure requirements can be found in IEEE Std 1547.1-2020.

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Table 1—Enter service criteria for Category I, I, and III DERS

Enter service criteria		Default settings	Ranges of allowable settings
Applicable voltage within range	**Minimum value**	≥ 0.917 p.u.[a]	0.88 p.u. to 0.95 p.u.
	Maximum value	≤ 1.05 p.u.	1.05 p.u. to 1.06 p.u.
Frequency within range	**Minimum value**	≥ 59.5 Hz	59.0 Hz to 59.9 Hz
	Maximum value	≤ 60.1 Hz	60.1 Hz to 61.0 Hz

[a] Corresponds to Range B of ANSI C84.1, Table 1, column for service voltage of 120 V to 600 V.

Source: Table 4 of IEEE Std 1547-2018.

4.10.2.2 Impact of DER

DER entering service at a time when the voltage and frequency are outside their normal ranges could cause further grid instability. In the case of synchronous generators, damage to the DER could also occur. Additional specific instances of impacts of large numbers of DER returning to service after *trip* are addressed in 6.6.

4.10.3 Performance during entering service

During entering service, the DER shall be capable of a) prevent enter service, b) delay enter service, and c) increase output of active power depending on the circumstances.

In the base standard, during *enter service*, the DER shall be capable of:

a) Prevent *enter service* when *permit service* setting is disabled.

b) Delay *enter service* by an intentional adjustable minimum delay when the *Area EPS* steady-state voltage and frequency are within the ranges specified in the table.

c) Increase output of active power, or exchange active power for ES-DER, as specified. Over the set *enter service* period, this increase may be linear or stepwise, with any active power increase within a step not exceeding 20% of the DER nameplate active power rating.

There are two exceptions:

— In a *Local EPS* with an aggregate DER rating of up to 500 kVA, individual DER units may increase power without limiting the rate of change, following an additional randomized time delay.

— In a *Local EPS* with an aggregate DER rating greater than 500 kVA, increasing active power at a range of change greater than specified above shall require approval of the *Area EPS operator* in coordination with the *regional reliability coordinator*.

4.10.3.1 Background

The performance capabilities specified above confirm that a DER entering service will have minimal impact on the *Area EPS* voltage and frequency while increasing active power from zero to specified output.

4.10.3.2 Impact of DERs

Multiple DERs entering service may have the impacts described in 6.6.2.

4.10.3.3 Tips, techniques, and common practices

As described in 6.6.3, multiple DERs entering service may vary ramp times.

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