

IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

IEEE Power and Energy Society

Developed by the
Energy Development & Power Generation Committee, Electric Machinery
Committee, and Power System Relaying & Control Committee

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STANDARDS

IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

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Energy Development & Power Generation Committee, Electric Machinery Committee, and Power System Relaying & Control Committee
of the
IEEE Power and Energy Society

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IEEE SA Standards Board

Abstract: Uniform technical minimum requirements for the interconnection, capability, and lifetime performance of inverter-based resources interconnecting with transmission and sub-transmission systems are established in this standard. Included in this standard are performance requirements for reliable integration of inverter-based resources into the bulk power system, including, but not limited to, voltage and frequency ride-through, active power control, reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection. This standard also applies to isolated inverter-based resources that are interconnected to an ac transmission system via dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facilities; in these cases, the standard applies to the combination of the isolated IBRs and the VSC-HVDC facility, and not to an isolated inverter-based resource (IBR) on its own.

Keywords: active power, capability, co-located resource, control, enter service, energy storage, evaluation, fast frequency response, frequency, frequency response, harmonic current, harmonic voltage, hybrid resource, IEEE 2800, integrity, interconnection, interoperability, inverter, inverter-based resource, isolation device, measurement accuracy, modeling, negative-sequence, performance, positive-sequence, power quality, primary frequency response, protection, reactive power, reference point of applicability, ride-through, solar photovoltaic power, standard, technical minimum, transient overvoltage, type test, unbalance, verification, voltage, weak grid, wind power

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In memoriam Kevin Collins, Vice-Chair.

Kevin Collins, our fellow P2800 Officer and Senior Technologist, PV Systems Development, at FirstSolar, passed away unexpectedly in March 2020. On behalf of all Officers and Working Group members, our utmost respect and heartfelt gratitude goes out to Kevin and his family. Kevin was at the heart of all the recent activity in NERC IRPTF and IEEE P2800 since the beginning and will be missed. Kevin was a pioneer in our industry and has been a cornerstone in our P2800 leadership team. His exceptional contributions in creating the P2800 “strawman” as well as his thought leadership in facilitating SubGroup III (Active Power-Frequency Response) and SubGroup IV (Reactive Power-Voltage Control), will be remembered by the industry. Kevin will also be missed as a calm, mature, and balanced voice of reason and empathy in P2800’s high stakes-stakeholder consensus-building process.

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Introduction

This introduction is not part of IEEE Std 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems.

IEEE Std 2800™ was the first of a series of standards developed by IEEE Power and Energy Society Energy Development and Power Generation Committee concerning transmission-connected inverter-based resources interconnection. The additional documents in that series are as follows:

- IEEE P2800.1⁶ provides guidance on (conformance) test (and verification) procedures for inverter-based resources interconnecting with associated *transmission systems (TSs)*.
- IEEE P2800.2™ provides recommended practices on conformance tests and verification procedures for inverter-based resources interconnecting with transmission and sub-*transmission systems*.

As with any IEEE standard, the applicability of IEEE Std 2800, IEEE P2800.1, or IEEE P2800.2 to given IBR is determined by the *authority governing interconnection requirements* (AGIR) for that location. IEEE P2800.1 and IEEE P2800.2 are under development at the time of this standard's adoption, and their drafts are designated IEEE P2800.1 and IEEE P2800.2, respectively.

The first publication of IEEE Std 2800 was an outgrowth of the recommendations from the North American Electric Reliability Corporation (NERC) Inverter-Based Resources Performance Reliability Guideline [B75]⁷ and IEEE Std C57.12.80™ [B63]. Instances in this standard where the entities involved and coordinating in the IBR interconnection process, i.e., *TS owner*, *TS operator*, *load balancing entity*, *IBR owner*, *IBR operator*, and *IBR developer*, are mentioned and resemble functional responsibilities of the North American regulatory framework; AGIRs are encouraged to adopt this standard with entity functional responsibilities as applicable to the given regulatory framework.

Acknowledgements

Grateful acknowledgements to the Inverter-Based Resources Performance Working Group (IRPWG) of the North American Electric Reliability Corporation (NERC) that provided their Reliability Guideline Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources [B76] as a strawman for an early draft of this standard.

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- **Maximum current ac, $I_{\max}$** (IEEE Std C62.39™-2012, modified from IEC 62319-1:2005)
- **IBR continuous rating (ICR)** (adapted from IEC 62934 ED1)
- **Mode** (adapted from IEC 904-03-09)
- **Solar photovoltaic system (solar PV)** (adapted from IEC 60050)
- **Wind turbine generator (WTG)** (adapted from IEC 60050)

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⁶ Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining drafts, contact the IEEE.

⁷ The numbers in brackets correspond to the numbers of the bibliography in Annex A.

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IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

1. Overview

1.1 General

The global increase in penetration levels of inverter-based resources (IBRs) is expected to significantly change the dynamic performance of the power grid. As the penetration levels of inverter-based resources increase and the technology of inverter-based resources evolves, specifications and standards are needed to address the performance requirements of inverter-based resources. Currently, there is no single document of consensus on the performance requirements covering inverter-based resources interconnected with transmission and sub-transmission systems. Events in North America, such as the Blue Cut Fire Disturbance (NERC “1,200 MW Fault” [B72]) as well as the inappropriate use of IEEE Std 1547™ [B50] for large-scale solar plants, underscore this need.⁸ This new standard is a first attempt to address the need for consensus-based performance requirements and can help equipment manufacturers, project developers, transmission planners, and power grid operators improve the quality of the inverter and facility performance to enhance the stability of the power grid over a transmission planning horizon.⁹ The specified requirements are intended to strike a balance between the state of the art and forward-looking technology capabilities, while considering the uncertainties as to how a future bulk power system with high amounts of IBR may be planned and operated. Given that IEEE standards are voluntary industry standards, enforcement of any of the requirements specified in this standard will require its adoption by the regional authority governing interconnection requirements (AGIR). An AGIR is a cognizant and responsible entity that defines, codifies, communicates, administers, and enforces the policies and procedures for allowing electrical interconnection of inverter-based resources interconnecting with associated transmission systems.

⁸ An Inverter-Based Resource Performance Task Force (IRPTF) of the North American Electric Reliability Corporation (NERC) issued a white paper [B74] identifying gaps in NERC Reliability Standards, including FAC-001-3 [B90], FAC-002-2 [B91], MOD-026-1 [B93], MOD-027-1 [B94], PRC-002-2 [B96], PRC-024-2 [B97], TPL-001-4 [B98], VAR-002-4.1 [B99]; standard authorization requests (SARs) are underway to close these gaps.

⁹ Transmission planning may address bulk system stability over the next one or two decades.

1.2 Scope

This standard establishes the required interconnection capability and performance criteria for inverter-based resources interconnected with transmission and sub-*transmission systems*.^{10, 11, 12} Included in this standard are performance requirements for reliable integration of inverter-based resources into the bulk power system, including, but not limited to: voltage and frequency ride-through, active power control, reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection. This standard shall also be applied to isolated inverter-based resources that are interconnected to an ac transmission system via a dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facility; in these cases, the standard shall apply to the combination of the isolated IBR and the VSC-HVDC facility and shall not apply to the isolated IBR unless they serve as a *supplemental IBR device* that is necessary for the *IBR plant* with VSC-HVDC to meet the requirements of this standard at the *reference point of applicability*.

1.3 Purpose

This standard provides uniform technical minimum requirements for the interconnection, capability, and performance of inverter-based resources interconnecting with transmission and sub-*transmission systems*.

1.4 General remarks and limitations

The criteria and requirements in this document are applicable to all inverter-based resource technologies interconnected to *transmission systems* (TSs) (i.e., both meshed/networked and radial transmission and sub-transmission) voltage levels. For radial sub-*transmission systems*, this standard intentionally overlaps with potential application of IEEE Std 1547TM, in which case it remains at the discretion of the *authority governing interconnection requirements* (AGIR) to decide which standard is applicable.

The application of this standard may be limited to *IBR plants* for which interconnection requests are submitted after the date by which this standard is enforced by the responsible *authority governing interconnection requirements* (AGIRs); this standard may not apply to *IBR plants* that are either already interconnected or for which interconnection requests had been submitted prior to the standard's enforcement date (grandfathering). Any substantial changes in an existing *IBR plant*, e.g., the “repowering” of a wind power plant, may require retrofitting that *IBR plant* to meet all of the requirements of this standard.

The stated capability and performance requirements are universally needed for interconnection of *IBR plants* to transmission and sub-*transmission systems* and their interoperability, and will be sufficient for most installations. This standard specifies technical minimum interconnection, capability, and performance requirements for an *IBR plant*, its *IBR unit(s)*, and if present and as applicable, its *supplemental IBR device(s)*.¹³ While this standard specifies uniform technical minimum requirements, the *TS operator* and *TS owner* may, in a non-discriminatory way, specify different and/or additional requirements than those specified in this standard for the safe and reliable operations of their system. Non-compliance of the *IBR*

¹⁰ Requirements apply to *inverter-based resources (IBRs)* only, e.g., solar photovoltaic, wind, and *energy storage systems* or combinations of such. This excludes any systems that are not resources, e.g., flexible ac transmission systems (FACTS) and synchronous condensers, and any resources that are not inverter-based, e.g., gas and steam power plants with synchronous generators.

¹¹ This standard does not explicitly specify requirements for HVDC. However, it specifies requirements for inverter-based resources (generation and storage) and that includes isolated IBR that are interconnected to an ac *transmission system* via a dedicated voltage source converter (VSC) high-voltage direct current (HVDC) transmission facility, e.g., an offshore wind park. In these cases, the combination of isolated IBR and VSC-HVDC transmission facility is regarded as the IBR to which this standard is applicable. This standard is not intended to specify requirements for VSC-HVDC that connect two buses in a meshed synchronous ac system.

¹² Resources with doubly-fed generators (DFGs) are defined as IBR, but requirements specified for *IBR plants* with DFG in this standard may slightly differ, where appropriate.

¹³ Most of the requirements specified in this standard apply to the *IBR plant*; however, they are not intended to apply to each equipment within the *IBR plant*. When designing components within an *IBR plant* it is normally necessary to consider the applicable design standards, but it may also be necessary to meet more stringent requirements as determined in the *IBR plant* design evaluation (see 12.2.3).

owner with requirements specified by the *TS operator* or the *TS owner* that are different from, or in addition to those requirements that are explicitly specified in this standard does not constitute non-compliance with this standard.

A “capability requirement” in this standard specifies that the *IBR plant* (and where applicable, *IBR unit[s]*) shall be able to provide a function, configuration, or performance as determined by design, installation, and operational status of equipment and control systems. A “performance requirement” in this standard specifies the *IBR plant’s* (and where applicable, the *IBR unit’s*) behavior when executing a specified function or *mode*, or when responding to a change in conditions.

NOTE 1—A “capability requirement” is, in colloquial terms, a requirement that ensures the *IBR plant* (or *IBR unit*) is “ready to go at the flip of a switch.” This is more stringent than a “readiness requirement” that is in colloquial terms a requirement that ensures the *IBR plant* (or *IBR unit*) is “almost ready to go,” for example, by having at least all interfaces that are needed to (easily) retrofit the IBR with certain equipment and controls that can provide a specified capability. The concept of readiness is not used in this standard.¹⁴

NOTE 2—A “performance requirement” is not an “utilization requirement.” An “utilization requirement” is, in colloquial terms, a requirement that ensures the *IBR plant* (or *IBR unit*) is “actually providing” a specified performance, for example, by enabling a specified capability that makes the IBR continuously deliver a performance consistent with the specified default values for functional settings. As clarified in the list of what remains outside the scope of this standard below, requirements for utilization of any of the capabilities specified in this standard are outside the scope of this standard.

Authorities governing interconnection requirements should adopt this standard with functional responsibilities for entities involved in and coordinating in the IBR interconnection process, i.e., *TS owner*, *TS operator*, *load balancing entity*, *IBR owner*, *IBR operator*, and *IBR developer*, as applicable to the given regulatory framework.

Certain *IBR units* (e.g., type III wind turbine generators [WTGs]) have been given different specifications and requirements throughout this standard.

As a performance and not a design standard, this standard allows for alternate means of compliance as long as all specified requirements are fulfilled at the *reference point of applicability (RPA)*.

The requirements specified in this standard are intended to apply over the lifetime of the *IBR plant*. When the TS operating and network conditions change significantly enough that changes in the *IBR plant* may become necessary to reliably operate the *IBR plant* to support, or not degrade, TS reliability, equitable remedy measures shall be coordinated between the *TS owner* and the *TS operator*, and the *IBR owner* and the *IBR operator*.^{15, 16}

Where applicable, the stated technical specifications and requirements are given in generator sign convention, which is opposite to load sign convention. In generator sign convention, an IBR current lagging voltage provides/injects reactive power to the system (positive reactive power); an IBR current leading voltage consumes/absorbs reactive power from the system (negative reactive power).

The following list describes what remains outside the scope of this standard:

- How this standard is adopted or enforced in a specific regulatory context by the AGIR.
- This standard intentionally does not define the system voltage levels for application of the requirements of this standard, but leaves the applicability and enforcement of this standard at the discretion of the AGIR.

¹⁴ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

¹⁵ Examples for significant TS operating and network condition changes are new plants interconnecting close to an *IBR plant*, installation of new equipment by the TS owner, and changes in the short-circuit ratio (SCR) at the *reference point of applicability*.

¹⁶ Remedy measures may include *IBR plant* control parameter changes and hardware changes, as applicable.

- This standard intentionally does not define the size of plant, in terms of continuous active power rating, for application of the requirements of this standard, but leaves the applicability and enforcement of this standard at the discretion of the AGIR.
- This standard as a whole is not intended for, and is in part inappropriate for, application to *IBR plant(s)* where the RPA is at typical primary or secondary distribution voltage levels.
- It is not the intent of this standard to limit the adoption of technologies and controls (e.g., grid forming) that are currently being developed. At the time of writing of this standard, neither design details, test data, nor technical literature is available to confirm that emerging technologies and controls presently under research and development will be able to meet all specified requirements of this standard. Due consideration should be given to the benefits of the new technology and controls in deciding which requirements of this standard should be adopted and which may be exempted. This should be done in coordination between *IBR owner* and *TS owner/TS operator*.
- Various equipment (such as transformers, circuit breakers, switches, *supplemental IBR devices*, communication equipment, etc.) in the *IBR plant* may be subject to standards outside the scope of this standard, for example, IEEE Std C57.12.00 [B62], IEEE Std C57.12.80 [B63], IEEE Std C37.04 [B56], and IEEE Std C37.246 [B59].¹⁷
- This standard does not define the maximum IBR capacity for a particular installation that may be interconnected to a single *point of interconnection* (POI) or connected to a given TS.
- This standard does not specify the scope and requirements for *interconnection studies*. Subject to a specific regulatory context, the *TS owner/TS operator* should conduct an *interconnection study* in coordination with the *IBR owner* that may include verification of requirements with this standard.
- This standard does not specify capability and performance requirements for an *IBR plant* to provide power oscillation damping controls. At the time of writing of this standard, power oscillation damping controls are still emerging and standardization in terms of both capability and performance is not practical. The *TS owner/TS operator* in mutual agreement with the *IBR owner* may require power oscillation damping capability and specify performance requirements.
- This standard does not apply to the non-IBR part of a *hybrid plant* or *co-located plant*. See Figure 3, the definitions in 3.1, and B.3 for further details.
- It is not the intent of this standard to limit the adoption of emerging use cases of synchronous machines, for example, the use of a synchronous condenser as a *supplemental IBR device* to improve the ride-through capability of an *IBR plant* under extreme contingency conditions. At the time of writing of this standard, neither design details, test data, nor technical literature is available to confirm that these emerging use cases (i.e., synchronous condenser as a *supplemental IBR device*) will be able to meet all specified requirements of this standard, unless the synchronous condenser exceeds applicable equipment standards, for example, IEEE Std C50.12™ [B60], IEEE Std C50.13 [B61], and IEC 60034-3 [B30] for synchronous machines, including synchronous condensers, and ANSI/NEMA MG-1 [B4] for motors and generators. Due consideration should be given to the benefits and risks of the emerging use cases of synchronous machines in deciding which *IBR plant* requirements of this standard should be adopted and which may be exempted. This should be done in coordination between *IBR owner* and *TS owner/TS operator* not later than the *IBR plant* design evaluation where capabilities and performance of a synchronous condenser are adequately considered.
- Any individual *supplemental IBR device* shall not be expected to meet any given performance requirement specified by this standard on a standalone basis. The *IBR plant* (or the *IBR unit[s]*), as

¹⁷ Some of the requirements in this standard are outside the normal ranges for components covered in applicable equipment standards, such as voltage ranges, frequency ranges, ride-through requirements, and testing requirements. *IBR units* often have more capability than non-IBR units with respect to many of these requirements. When designing an *IBR plant*, the various requirements and performance limitations of all the equipment and *supplemental IBR devices* within an *IBR plant* needed to meet the requirements of this standard at the *IBR plant*-level should be considered. In some cases, the requirements in this standard may require specifications for the subcomponents that are more stringent than the present equipment standards. In other cases, the *IBR plant* design may be compliant to this standard without changing the normal requirements of its integral components or *supplemental IBR devices*.

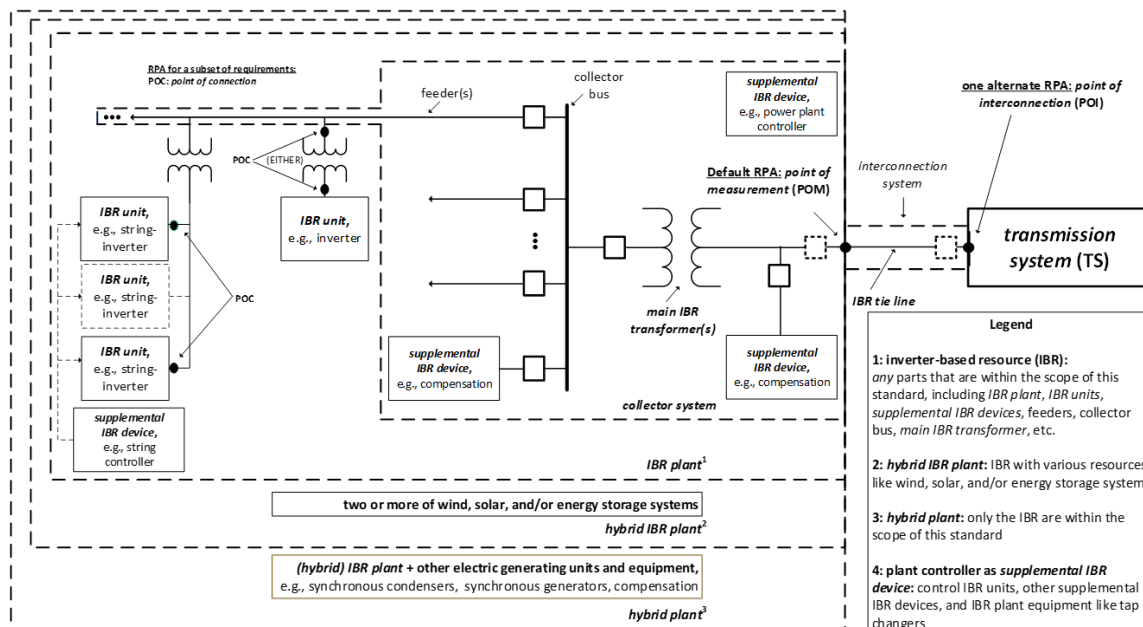
applicable) shall meet the given and all other requirements of this standard at the reference point(s) of applicability. See Figure 3, the definitions in 3.1, and B.3 for further details.¹⁸

- Outside of the specific interconnection and interoperability requirements in the following clauses, this standard does not prescribe IBR self-protection or any IBR operating requirements, as long as these do not preclude the IBR from meeting the requirements of this standard.¹⁹
- This standard does not address planning, designing, operating, or maintaining the TS with IBR. That also excludes any requirements or limitations to the deployment and configuration of *protective functions* by the *TS owner* on their side of the *interconnection system* or at the POI.²⁰
- This standard does not apply to interconnection or transfer schemes associated with load circuits on the TS. Nor does it apply to transmission loading relief actions.
- This standard does not give any normative guidance regarding how the *TS operator* or the *TS owner* may specify functional parameter settings of an IBR, other than the default setting within the specified *ranges of available settings*.
- This standard does not address single-phase open conditions of IBRs.
- This standard does not address effects of single-pole tripping and reclosing employed on TS on performance of IBRs. The *TS owner* may specify additional performance requirements for satisfactory operation of *IBR plants* during single phase tripping and reclosing events.
- This standard does not address effects of increasing penetration of IBRs such as the impact of loss of inertia, loss of fault duty, etc., as well as the impact of the intermittent and variable nature of certain IBR generation types on reliability of the BPS.
- Requirements for utilization—e.g., enabling a function or mode and the configuration of its control parameters to deliver a specified performance—of any capabilities specified in this standard and provision of the specified performance as a service are outside the scope of this standard and remain in the purview of interconnection agreements and may be specific to the regulatory context as created by the cognizant and responsible entity.
- Other than specifying the provision and capability of *secure* communication at the IBR, this standard does not determine the communication network specifics (e.g., architecture) nor the utilization of the IBR provisions for an IBR interface capable of communicating (local IBR communication interface) to support the information exchange requirements specified in this standard.
- This standard does not address capability of *IBR plants* to remain in operation during environmental conditions outside of the plant's design basis. Examples include extreme temperature impacts on mechanical or electrical components (including battery capacity and component ratings), extreme wind impacts on mechanical or structural components, seismic impacts on mechanical, structural, or electrical components, etc. The *IBR owner* shall inform *TS owner/TS operator* of any such limitations.

¹⁸ Refer to footnotes 8 and 17; along with NOTE 5 in Figure 1; NOTE 1 to the definition of *hybrid plant*; NOTE 1 to the definition of *supplemental IBR device*; as well as 4.1.4 and 4.1.5.

¹⁹ Requirements specified in 7.2.2 and 7.3.2 do provide constraints to be respected in the application of IBR self-protection.

²⁰ When deploying and configuring the selectivity and sensitivity of such *protective functions*, the *TS operators* may need to coordinate the *protective functions* to balance the reliability risk of wide-area tripping of *IBR plants* with the *load balancing entity* with the risk of potential damage on the *transmission system* or *sub-transmission system*. This may include unintentional islanding protection schemes deployed by the *TS operator* to prevent unintentional islanding of one or more *IBR plant(s)* connected to parts of the *transmission system* or *sub-transmission system* that may become isolated unintentionally due to misoperation or unintended switching.



NOTE 1—The POM is the default RPA. Moving the RPA from the POM to the POI may exceed the technical minimum requirements specified in this standard and may require deliberate consideration of the pros and cons. For example, the ability of *IBR plants* to meet the performance requirements in this standard may be impacted if the *IBR owner* is not allowed to install their measurement and control equipment at the POI substation.²¹

NOTE 2—The POC may be at either side of the *IBR unit* transformer, if present.

NOTE 3—A *supplemental IBR device*, e.g., reactive power compensation equipment, plant controller, and other examples as listed in NOTE 1 of the definition in 3.1, may be used to achieve compliance with the requirements of this standard at the RPA. In case where synchronous condenser is used as a *supplemental IBR device*, refer to a general exemption in 1.4.

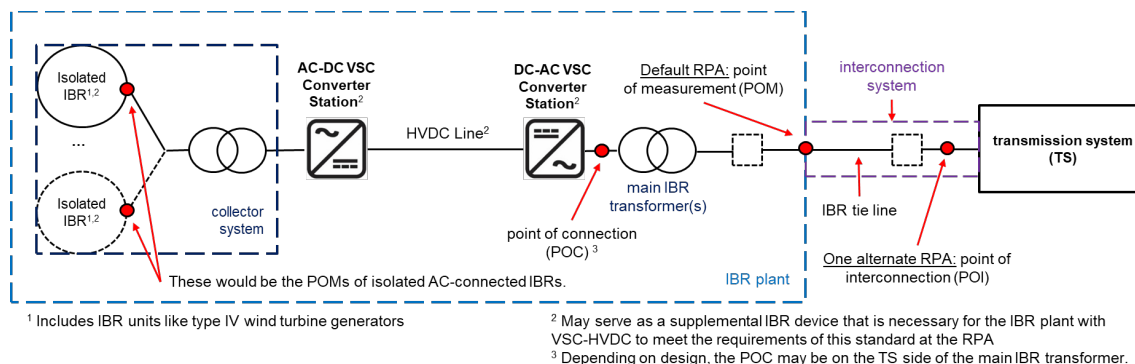
NOTE 4—More complex IBR connection setups that include multiple IBR tie lines to one or to multiple POIs in the TS may be found in the practice for reliability or other reasons.

NOTE 5—Other electric generating units and equipment, e.g., synchronous condensers, synchronous generators with the exception of synchronous generators connected to the TS via an inverter, and compensation that is not associated with an IBR, are outside the scope of this standard.

Figure 1—Illustration of defined terms for ac-connected inverter-based resources (IBRs)

²¹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

IEEE Std 2800-2022
IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with
Associated Transmission Electric Power Systems



NOTE 1—This standard applies to isolated *inverter-based resources (IBRs)* interconnected via dedicated voltage source converter (VSC) high-voltage direct current (HVDC) transmission facilities.

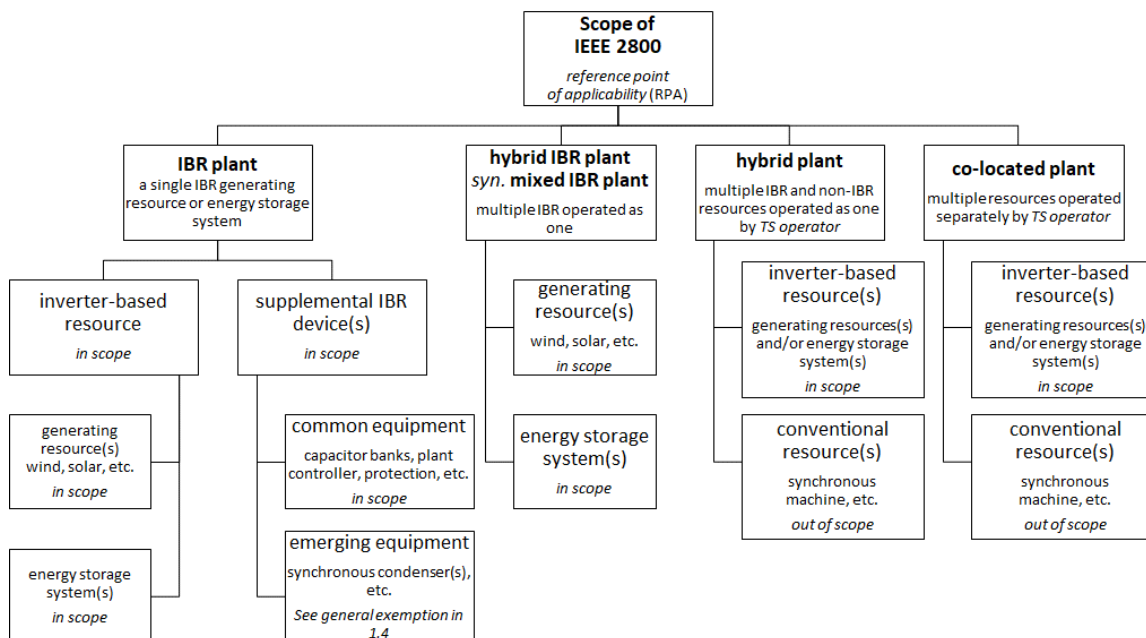
NOTE 2—This standard is not intended to apply to voltage source converter high-voltage direct current (VSC-HVDC) connecting two ac interconnections with each other.

NOTE 3—This standard is not intended to specify requirements for VSC-HVDC that connect two buses within a meshed/networked synchronous ac system.

NOTE 4—The requirements for cases where IBR are integrated with a multi-terminal VSC HVDC transmission schemes may be specified by the *TS owner*.

NOTE 5—The requirements for cases where IBR and non-IBR are connected via VSC-HVDC, i.e., hybrid resource facilities, may be specified by the *TS owner*.

Figure 2—Illustration of defined terms for dc-connected isolated inverter-based resources (IBRs)



NOTE—Conventional resource(s) include fossil fuel-driven generating units, hydro generating units, etc.

Figure 3—Taxonomy of IBR and scope of IEEE Std 2800

1.5 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*).^{22, 23}

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*).

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.

ANSI C84.1, Electric Power Systems and Equipment—Voltage Ratings (60 Hz).²⁴

IEC 61000-4-3, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.²⁵

IEC 61000-4-5, Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-7, Electromagnetic compatibility (EMC)—Part 4-7: Testing and measurement techniques—General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

IEC 61000-4-15, Electromagnetic compatibility (EMC)—Part 4-15: Testing and measurement techniques—Flickermeter—Functional and design specifications.

IEC 61000-4-30, Electromagnetic compatibility (EMC)—Part 4-30: Testing and measurement techniques—Power quality measurement methods.

IEC 61000-6-2, Electromagnetic compatibility (EMC)—Part 6-2: Generic standards—Immunity for industrial environments.

IEC/IEEE 60255-118-1, Measuring relays and protection equipment—Part 118-1: Synchrophasor for power systems—Measurements.

IEC/IEEE 61850-9-3, Communication networks and systems for power utility automation—Part 9-3: Precision time protocol profile for power utility automation.

²² The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

²³ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

²⁴ ANSI publications are available from the American National Standards Institute (<https://www.ansi.org/>).

²⁵ IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

IEC TR 61000-3-7:2008, Electromagnetic compatibility (EMC)—Part 3-7: Limits—Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.

IEEE Std 519™-2014, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.^{26, 27}

IEEE Std 1453™-2015, IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems.

IEEE Std 1588™, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IEEE Std 2030.101™, IEEE Guide for Designing a Time Synchronization System for Power Substations.

IEEE Std C37.90.1™, IEEE Standard Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2™, IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C37.238™, IEEE Standard Profile for Use of IEEE 1588™ Precision Time Protocol in Power System Applications.

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.²⁸

active current priority mode: A mode in which the active current output (I_p) is given priority and has the full current rating of the inverter-based resource (IBR) available to it (i.e., *maximum current ac*, $I_{\max}$), while the reactive current output (I_q) is constrained. The reactive current I_q range varies from a maximum of $\sqrt{(I_{\max}^2 - I_p^2)}$ to a minimum of $-\sqrt{(I_{\max}^2 - I_p^2)}$, where I_p is the present value of active current. *Syn:* **P-Priority mode.**

NOTE 1—The active current output (I_p) may be constrained by availability of energy source.

NOTE 2—For *energy storage systems*, the active current can be negative.

NOTE 3—The definition is written with focus on operation during a balanced fault or a system disturbance. During unbalanced faults, the requirement to inject negative-sequence reactive current may further constrain active current and positive-sequence reactive current output.

active power installed capacity (P_{agg}): The aggregate active power nameplate rating of the *inverter-based resource units (IBR units)* within an *IBR plant* or *hybrid plant*.

actual active power (P_{act} , p): Instantaneous active power that an *inverter-based resource plant (IBR plant)* is delivering to (or consuming from, as applicable) the *transmission system (TS)* as measured at the *point of measurement (POM)*. *Syn:* **P ; p .**

²⁶ The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

²⁷ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

²⁸ *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.

NOTE 1—The P_{act} is limited by the *IBR plant* controller to the *IBR continuous rating* (ICR) for all steady-state operations.

NOTE 2—The P_{act} is limited by the *IBR plant* controller to the *IBR short-term rating* (ISR) during transient and dynamic operations for a specific level of output and for a specific maximum time duration as specified in the interconnection agreement.

apparent power installed capacity (S_{agg}): The aggregate apparent power nameplate rating of the *inverter-based resource units (IBR units)* within an *IBR plant* or *hybrid plant*.

applicable voltage: One of the electrical quantities that determine the basis of performance of an inverter-based resource (IBR). (Adapted from IEEE Std 1547™-2018)

NOTE—For this standard, *applicable voltage* is specified in 4.3.

applicable frequency: One of the electrical quantities that determine the basis of performance of an inverter-based resource (IBR). (Adapted from IEEE Std 1547™-2018)

NOTE—For this standard, *applicable frequency* is specified in 4.3.

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 an inverter-based resource (IBR) to the *transmission system (TS)*. This may be a regulatory agency, public utility commission, municipality, cooperative board of directors, etc., or depending on jurisdiction, *TS owner* or *TS operator*. 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 *TS owner/TS operator* or *bulk power system* operator. (Adapted from 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, *TS operators*, *IBR operators*, and *bulk power system* operators.

available active power (P_{avl}): Instantaneous ac active power that an *inverter-based resource plant (IBR plant)* can deliver to (or consume from, as applicable) the *transmission system (TS)* subject to the availability of the IBR's *primary energy source*, *IBR unit(s)* nameplate ratings, and *service status*. (Adapted from IEEE Std 1547™-2018)

NOTE 1—Examples of *primary energy sources* are solar irradiance in the case of a photovoltaic IBR, instantaneous wind energy (determined by wind speed at a given moment) in case of a wind turbine generator, and state of charge in case of a (battery) *energy storage system*.

NOTE 2—Individual *IBR units* and/or *supplemental IBR devices* may be out of service due to maintenance, failure, or limited availability of the IBR's *primary energy source*.

NOTE 3—An IBR's operating mode (e.g., current priority mode: active or reactive) may limit the active power an IBR delivers to a value below its *available active power* ($P < P_{\text{avl}}$).

NOTE 4—An IBR's *available active power* (P_{avl}) can be greater or lesser than its *IBR continuous rating* (ICR), but not greater than *IBR short-term rating* (ISR).

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

NOTE—Per NERC glossary of terms, the definition of bulk power system is: (A) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and (B) electric energy from generation facilities needed to maintain *transmission system* reliability. The term does not include facilities used in the local distribution of electric energy.

co-located plant: Two or more generation or storage resources that are operated and controlled as separate entities yet are connected behind a single *point of interconnection* (POI). *Syn:* **co-located power plant**; *Contrast:* **hybrid plant**.

NOTE 1—The resources of a *co-located plant* may require separate *points of measurement (POMs)* behind the single POI.

NOTE 2—The requirements of this standard only apply to the co-located inverter-based resource (*IBR*) plant(s). Other standards' requirements may be applicable to the co-located conventional generation resources and co-located non-IBR energy storage system (ESS).

NOTE 3—Refer to [Figure B.8](#), [Figure B.9](#), and [Figure B.10](#) for further details.

collector system: Equipment and systems utilized in the aggregation of *inverter-based resource (IBR)* units. This includes many types of electrical equipment such as switch-gear, cables, lines, transformers, and reactive compensating devices between the *point of connection (POC)* of *IBR units* and the *point of measurement (POM)*.

continuous operation: Exchange of current between the inverter-based resource (IBR) and a *transmission system (TS)* within prescribed behavior while connected to the TS and while the *applicable voltage* and the *applicable frequency* is within specified parameters. (Adapted from IEEE Std 1547™-2018)

NOTE—This is an IBR operating mode that is most often associated with “normal conditions.”

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

current blocking: Temporary blocking of controlled exchange of current with *transmission system (TS)*, while connected to the TS, in response to a disturbance of the *applicable voltages*, with the capability to immediately restore output of controlled current exchange when the *applicable voltages* return to within defined ranges. *Syn: momentary cessation*

NOTE 1—Passive elements like filters, capacitor banks, etc., may continue to exchange current with TS.

NOTE 2—A directly-connected machine, e.g., type III wind turbine generator (WTG), cannot block current. However, for a bolted three-phase fault on a radial connection to an inverter-based resource (IBR) plant consisting of type III WTGs, which decouples the grid voltage from the type III WTG terminal voltage, rotor and grid-side converters may eventually cease operation and the stator may also eventually cease to inject current due to loss of excitation.

NOTE 3—In IEEE Std 1547™-2018 the synonym for *current blocking* is *momentary cessation*.

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

NOTE—A disturbance may not be the only reason for non-continuous operation. Other reasons could be transient or short term operation.

energy storage system (ESS): System that is capable of absorbing energy, storing it, and dispatching the energy into the power system. (IEEE Std 1662™-2016, with the word “back” deleted to provide more flexibility for co-located energy resources)

NOTE—The ESS may absorb energy from the power system or any co-located energy resource.

enter service: Begin *continuous operation* of the inverter-based resource (IBR) with an energized *transmission system (TS)*. (Adapted from IEEE Std 1547™-2018)

fast frequency response: Active power injected to the grid in response to changes in measured or observed frequency during the arresting phase of a frequency excursion event to improve the frequency nadir or initial rate-of-change of frequency.

flicker: The subjective impression of fluctuating lighting luminance caused by voltage fluctuations in the supply voltage. (Adapted from IEEE Std 1547™-2018)

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 (IEEE Std 1453™).

hardware-in-the-loop (HIL): A simulation method that allows a hardware under test (HUT) to interact in a closed loop with a model under test (MUT).

hybrid plant: A generating or storage facility that is composed of multiple types of resources or *energy storage systems* controlled and operated as a single resource behind a single *point of interconnection* (POI).
Syn: **hybrid power plant**; *Contrast:* **co-located plant**.

NOTE 1—The resources in a *hybrid plant* may include conventional electric generating units (such as fossil fuel-driven synchronous generators and hydro-electric generation), and *inverter-based resources* (such as wind, solar photovoltaic [PV], and *energy storage systems*). Examples for other equipment in a hybrid resource includes synchronous condensers and compensation not part of the inverter-based resource (*IBR*) plant(s).

NOTE 2—The requirements of this standard only apply to the *IBR plant(s)* in a *hybrid plant*. Other standards' requirements may be applicable to the conventional generation resources.

NOTE 3—The generating or storage facilities may have a single main transformer with a common point of measurement (POM) and POI to facilitate operations as a single resource, but separate *reference points of applicability* (RPAs) may be required for the IBR generating or storage facilities and the conventional generating facilities to facilitate measurement of compliance to applicable standards.

NOTE 4—Refer to [Figure B.7](#) for further details.

hybrid IBR plant: A *hybrid plant* that is composed of only inverter-based resources (IBRs) and/or *energy storage systems*. *Syn:* **mixed IBR plant**.

NOTE 1—A common *hybrid IBR plant* combines renewable energy (solar photovoltaic [PV] or wind) and *energy storage systems*.

NOTE 2—The requirements of this standard apply to both ac-coupled *hybrid IBR plants* (couples each form of generation or storage at a common collection bus after it has been converted from dc to ac at each individual inverter) and dc-coupled *hybrid IBR plants* (couples both sources at a dc bus that is tied to the grid via a dc-ac inverter).

NOTE 3—Refer to [Figure B.5](#) and [Figure B.6](#) for further details.

instantaneous: A qualifying term indicating that no delay is purposely introduced in the action of the device. (IEEE Std C37.20.10™-2016)

NOTE—The *inverter-based resource* (*IBR*) response to changes of the *applicable frequency* or the *applicable voltages* may be intentionally or unintentionally delayed due to *IBR* measurements or *IBR* controls. For the purpose of this standard, the specified *IBR* performance requirements can inform pass/fail criteria of conformance test and verification procedures in other documents, irrespective of the internal design of *IBR* measurements and controls.

interconnection: The result of the process of adding an inverter-based resource (IBR) to a *transmission system* (*TS*), whether directly or via an intermediate ac IBR tie line. (Adapted from IEEE Std 1547™-2018)

NOTE—In case of IBR that interconnect to the TS via a dedicated radial voltage source converter high-voltage direct current (VSC-HVDC) transmission facility, that facility is considered as part of the *IBR plant* and the above definition equally applies.

IBR continuous rating (ICR): The steady-state, continuous active power rating of an *inverter-based resource* (*IBR*) plant or *hybrid IBR plant* registered by the *IBR owner* at the *transmission system* (*TS*) operator's or *authority governing interconnection requirements* (*AGIR*)'s registry.

NOTE 1—The ICR is typically specified in the interconnection agreement. Many of the technical minimum capability requirements in this standard refer to the ICR, for example, minimum reactive power capability and frequency response.

NOTE 2—The *IBR plant* operates at or below the ICR for all steady-state conditions. For a *hybrid IBR plant*, ICR may be the aggregate maximum simultaneous active power total output; the maximum power output of each contributing resource is independent of ICR.

NOTE 3—Registered active power is often the magnitude of the steady-state maximum active power the IBR can inject (or consume, as applicable) at the *reference point of applicability (RPA)* based on the *TS* interconnection limit or the IBR *active power installed capacity*, whichever is less. Consider these three examples where the *TS* interconnection limit is 100 MW: (1) where a solar photovoltaic (PV) plant has an *active power installed capacity* of 50 MW, then ICR is 50 MW; (2) where a solar PV plant has an *active power installed capacity* of 120 MW, then ICR is 100 MW; (3) where a *hybrid IBR plant* combines an *energy storage system* of 50 MW and a solar PV plant of 80 MW, then ICR is still 100 MW due to the *TS* interconnection limit.

NOTE 4—The ICR should be verified by studies of the *TS* before interconnecting the *IBR plant* to confirm that thermal, voltage, and stability limits of the *TS* will not be violated.

NOTE 5—In cases where the *active power installed capacity* of an *IBR plant* or a *hybrid IBR plant* is greater than the ICR, the *available active power* can, at times, also be greater than the ICR. Examples are solar PV and wind power plants where *IBR units* are added to increase the capacity factor of the power plant.²⁹ The addition of *energy storage systems* within a *hybrid IBR plant* can further increase its *active power installed capacity* and capacity factor. Note that while adding dc resource capacity to an *IBR plant* may increase its capacity factor, it may not increase its *active power installed capacity* because the ac active power nameplate rating of the *IBR units* may not change.

NOTE 6—Refer to Figure 4 for further illustration of relationship between ICR, *active power installed capacity* (P_{agg}), *IBR short-term rating* (ISR), *available active power* (P_{avl}), and *actual active power* (P_{act}).

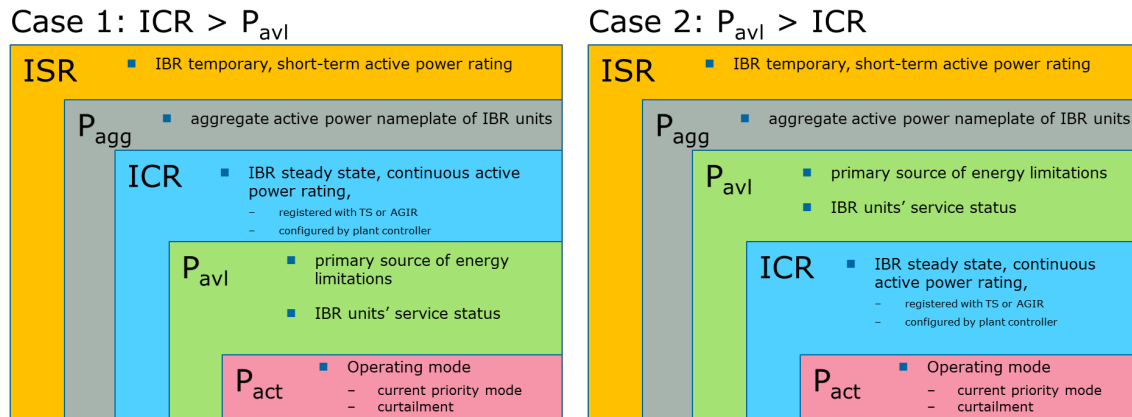


Figure 4—Relationship between inverter-based resource active power terms

IBR continuous absorption rating (ICAR): The steady-state, continuous active power absorption rating of an *inverter-based resource (IBR) plant* registered by the *IBR owner* at the *TS operator's* or *AGIR's* registry.

NOTE—ICAR applies to a *hybrid plant*, *hybrid IBR plant*, and *energy storage systems*.

IBR short-term rating (ISR): The temporary, short-term active power rating of an *inverter-based resource (IBR) plant* or *hybrid IBR plant* registered by the *IBR owner* at the *TS operator's* or *AGIR's* registry.

NOTE 1—Not all IBR may have an ISR greater than their ICR, i.e., the ISR is not a technical minimum capability requirement specified in this standard.

NOTE 2—Where the ISR is greater than the ICR, it may be used to accommodate services such as primary frequency response and/or *fast frequency response* as agreed to and specified in the interconnection agreement.

NOTE 3—The ISR may be a single level of output for a specified maximum time duration, e.g., 15 min to 30 min, in some cases only a few seconds, to accommodate under-frequency events, or may be specified as a power-versus-time curve.

²⁹ By increasing the overall energy production capacity of the facility, the resource can operate at its maximum allowable output (per the interconnection agreement) over additional hours of the day.

NOTE 4—The ISR may be verified by studies of the TS before interconnecting the *IBR plant* to confirm that thermal, voltage, and stability limits of the system will not be violated.

interconnection study: A study conducted during the interconnection process.

NOTE 1—An *interconnection study* may be conducted by the *TS owner/TS operator*, the *inverter-based resource (IBR) owner*, or a third party and may require coordination between parties, subject to regulatory context.

NOTE 2—An *interconnection study* may include verification of requirements with this standard.

interconnection system: Individual or multiple devices that connect a main *inverter-based resource (IBR)* transformer to the *transmission system (TS)* that are used exclusively to export power from, or exchange power with, an *IBR plant*.

NOTE—This may include an IBR tie line.

IBR tie line: Equipment and systems that connect the *point of measurement (POM)* of an *inverter-based resources (IBRs)* to the *point of interconnection (POI)* at the *transmission system (TS)* and that are used exclusively to exchange power with an *IBR plant*. (Adapted from NERC PRC-025 with some changes)

NOTE—This includes protective functions.

IBR unit: *See: inverter-based resource unit.*

in service: *See: service status.*

interface: An electrical or logical connection from one entity to another that supports one or more energy or data flows, respectively, implemented with one or more power or data links, respectively. (Adapted from 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™ [B54], IEEE Std 1547™-2018)

inverter: A power electronic unit that changes direct-current power to alternating-current power. (Adapted from IEEE Std 1547™-2018)

inverter-based resource (IBR): Any source of electric power that is connected to the *transmission system (TS)* via power electronic interface, and that consists of one or more *IBR unit(s)* capable of exporting active power from a *primary energy source* or *energy storage system* to a TS. A *collector system* or a *supplemental IBR device* that is necessary for compliance with this standard is part of an IBR. *See also: IBR plant; IBR unit.*

NOTE 1—See Figure 1.

NOTE 2—The term *IBR* dedicates any parts that are within the scope of this standard, including, but not limited to, *IBR unit*, *IBR plant*, and *supplemental IBR device*. It can refer to *hybrid IBR plants*, the IBR parts of *co-located plants*, and *energy storage systems (ESS)*.

inverter-based resource developer (IBR developer): *See: IBR owner.*

inverter-based resource generating facility (IBR generating facility): *See also: inverter-based resource plant.*

inverter-based resource plant (IBR plant): A grouping of one or more *IBR unit(s)* and possibly *supplemental IBR device(s)* operated by a common facility-level controller along with a *collector system* to achieve the performance requirements of this standard at a single *reference point of applicability (RPA)*. *Syn: IBR generating facility.*

NOTE—Does not include the IBR tie line.

inverter-based resource operator (IBR operator): The entity that is functionally responsible for monitoring and operating the inverter-based resource through the *local IBR communication interface*.

NOTE—The *IBR operator* could be, for example, a utility, a *load balancing entity*, *transmission system* operator, or another third party.

inverter-based resource owner (IBR owner): The entity that owns and is functionally responsible for the maintenance of the inverter-based resource.

NOTE 1—For simplicity, this standard does not differentiate between the *IBR owner* and the entity that develops an IBR.

NOTE 2—For the purpose of this standard, the IBR owner is the entity that requests the interconnection of an *IBR plant* with the *transmission system*.

inverter-based resource unit (IBR unit): An individual inverter device or a grouping of multiple inverters connected together at a single *point of connection* (POC).

NOTE 1—Can be type tested by a verification entity to verify performance at the POC.

NOTE 2—An *IBR unit* may include a unit transformer.

NOTE 3—For type III *wind turbine generators*, the wind turbine itself, the doubly-fed generator, the rotor-circuit inverter, and the three-winding unit transformer, if present, make up an *IBR unit*.

NOTE 4—A string inverter or set of string inverters that are type tested by a verification entity at a single POC is regarded as an *IBR unit* for the purpose of this standard. A set of string inverters not type tested as a group is not regarded as one *IBR unit*.

load balancing entity: The entity that is functionally responsible for integrating resource plans ahead of time, maintaining load-interchange-generation balance within a balancing area, and supporting interconnection frequency in real time.

NOTE—This term is defined because the *transmission system (TS) operator* is not responsible for obtaining and specifying performance of primary frequency response and *fast frequency response*.

local IBR communication interface: An interface at the edge of the *inverter-based resource (IBR) plant* capable of communicating to support the information exchange requirements specified in this standard for all applicable functions that are supported in the *IBR plant*. (Adapted from IEEE Std 1547™-2018)

main IBR transformer: One or more high-voltage transformer(s) that step(s) up the inverter-based resources (IBRs) *collector system* voltage to the *transmission system (TS)* voltage at the *point of measurement*, or in the case of voltage source converter high-voltage direct current (VSC-HVDC), steps up or down the voltage of the converter to the TS voltage at the *point of measurement*.

mandatory operation: Required continuance of active current and reactive current exchange of *inverter-based resources (IBRs)* with *transmission system (TS)* as prescribed, notwithstanding disturbances of the TS voltage or frequency having magnitude and duration severity within defined limits. (Adapted from IEEE Std 1547™-2018)

NOTE—An IBR operating mode required during a disturbance period.

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

NOTE—This concept equates to the term *no trip zone* as used in NERC PRC-024.

manufacturer stated measurement accuracy: Accuracy declared by the manufacturer, at which *inverter-based resource (IBR) units* and systems measure the *applicable voltage*, current, power, frequency, or time. (Adapted from IEEE Std 1547™-2018)

maximum current ac, $I_{\max}$: Value of current for the operating temperature range that should not be exceeded. (IEEE Std C62.39™-2012)

NOTE 1—Modified from IEC 62319-1:2005 [B38]. May also be referred to as “rated current (I_{rated})” in this standard based on apparent power rating.

NOTE 2— $I_{\max}$ can vary based on operating mode.

NOTE 3—The current limit of an *inverter-based resource (IBR) unit* is usually greater than or equal to 1.0 per unit (p.u.).

may trip operation region: The performance operating region where *inverter-based resource (IBR) unit* protection is undefined by this standard and is determined only by *IBR unit* capability limits.

minimum active power capability ($P_{\min}$): The minimum active power output of an *inverter-based resource (IBR) plant* or a *hybrid IBR plant* registered by the *IBR owner* at the *TS operator’s* or *AGIR’s* registry in per unit (p.u.) of the *IBR continuous rating (ICR)*.

NOTE 1— $P_{\min}$ may be determined by IBR characteristics, interconnection agreement, or other constraints.

NOTE 2— $P_{\min}$ may be zero for some *IBR plants*, and for IBR that are capable of absorbing active power $P_{\min}$ may be negative.

mixed inverter-based resource (IBR) facility: *See also: hybrid IBR plant.*

momentary cessation: *See: current blocking.*

nameplate ratings: Nominal voltage (V), maximum current (A), maximum active power (kW), rated maximum volt-amps or apparent power (kVA), and nominal frequency (Hz) that an *IBR unit, supplemental IBR devices, main IBR transformer*, or any other equipment in an *IBR plant* that has a physical “plate,” located on the equipment, is capable of sustained operation under defined ambient (temperature, humidity, etc.) and site (e.g., altitude) conditions. (Adapted from IEEE Std 1547™-2018)

offshore IBR plant: An *inverter-based resource plant* that has at least one *IBR unit* with a support structure that is subjected to hydrodynamic loading.

NOTE—Modified from IEC 61400-3-1:2019 [B36].

operating mode: Mode of *inverter-based resource (IBR) operation* that determines the performance during normal or abnormal conditions. (Adapted from IEEE Std 1547™-2018)

out of service: *See: service status.*

overshoot: The maximum system output minus the final settled value, divided by the actual change in system output (i.e., from its initial value to the final settled value), when the final settled value is within the defined *settling band*, expressed as a percentage. *See also: step response.*

NOTE—A system quantity may increase or decrease and the required change in system output may be positive or negative. Thus, the term *maximum* does not indicate a specific direction of a value change.

P-Priority mode: *See also: active current priority mode.*

percent of (%): *See: per unit (p.u.).*

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 *inverter-based resources (IBRs)*. (Adapted from IEEE Std 1547™-2018)

permissive operation: Operating mode where the *inverter-based resource (IBR)* (either the *IBR plant* or an *IBR unit*) performs ride-through in mandatory operation or in *current blocking*, in response to a disturbance of the *applicable voltages*. (Adapted from IEEE Std 1547™-2018)

NOTE—In IEEE Std 1547-2018, permissive operation may also be a response to a disturbance of the *applicable frequency*; and momentary cessation is a synonym for *current blocking* in this standard.

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

permit service: A setting that indicates whether an *inverter-based resource (IBR)* is allowed to enter or remain in service. (Adapted from IEEE Std 1547™-2018)

per unit (p.u.): Quantity expressed as a fraction of a defined base unit quantity. For active/reactive power (active/reactive current), the base quantity is the appropriate active power (active current) value. For apparent power (current), the base quantity is the appropriate apparent power (current) value. For frequency, the base quantity is the nominal frequency (e.g., 60 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. (Adapted from IEEE Std 1547™-2018) *Syn:* **percent of (%)**.

NOTE—What defines the “appropriate” base quantity value depends on the context of a requirement in this standard. Examples include i) the *apparent power installed capacity (S_{agg})* of the *IBR units* within an *inverter-based resource (IBR) plant* or *hybrid plant*, ii) the steady-state, continuous (active or apparent) power or current rating of an *IBR plant* or *hybrid IBR plant* as they may be registered by the *IBR owner* at the *TS operator’s* or AGIR’s registry, and iii) the *maximum current ac (I_{max})* of an *IBR unit*.

point of interconnection (POI): The point where the *interconnection system* connects an *inverter-based resource (IBR)* to the *transmission system (TS)*.

NOTE 1—See [Figure 1](#).

NOTE 2—The POI is similar to the *point of interconnection* as defined in IEEE Std C37.246™-2017 [\[B59\]](#) as a “switching substation where a generation facility is electrically connected to a transmission system.”

NOTE 3—The POI is similar to the point of common coupling (PCC) as defined in IEEE Std 519™ where it is defined as the “Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.”

NOTE 4—The POI in this standard is similar to the *point of interconnection* as defined by FERC for large generator interconnection agreement (LGIA) and small generator interconnection agreement (SGIA) as “the point where the interconnection facilities connect with the transmission provider’s transmission system.”

point of measurement (POM): A point between the high-voltage bus of the *inverter-based resources (IBRs)* and the *interconnection system*. (Adapted from NERC Reliability Guideline—BPS connected inverter-based resource performance [\[B75\]](#))

NOTE—The POM may be at the *transmission system (TS)* side terminals of the main IBR transformer, the connection point of a *supplemental IBR device*, or the TS side of a protective device, whichever is closer to the IBR tie line.

point of connection (POC): The point where an inverter-based resource unit (IBR unit) is electrically connected to a *collector system*, as specified by the *IBR owner*. *Syn:* **terminal**.

NOTE 1—See [Figure 1](#).

NOTE 2—For (an) *IBR unit(s)* that are not self-sufficient to meet the requirements without (a) *supplemental IBR device(s)*, the *point of connection* is the point where the requirements of this standard are met by (an) IBR device(s) in conjunction with (a) *supplemental IBR device(s)*.

NOTE 3—The POC may be at either side of the *IBR unit* transformer, if present.

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

pre-disturbance period: The time immediately before a disturbance period. (Adapted from IEEE Std 1547™-2018)

primary energy source: Energy sources like solar irradiance in the case of a photovoltaic *inverter-based resource (IBR)*, instantaneous wind energy (determined by wind speed at a given moment) in case of a wind turbine generator, and state of charge in case of a (battery) *energy storage system*.

protective function(s): A function within a protective device that detects defective lines or apparatus or other defined power system conditions of an abnormal or dangerous nature to initiate appropriate control action. (Adapted from IEEE Std C37.98™-2013 for “protective relay”) *Syn:* **protection; protective device; protection element.**

NOTE—Could protect the *inverter-based resource (IBR)*, *interconnection system/IBR tie line*, and/or the *transmission system (TS)*.

Q-Priority mode: *See also:* **reactive current priority mode.**

range of available settings: The range within which the *inverter-based resource (IBR)* has the capability to adjust settings to values other than the specified default settings. (Adapted from IEEE Std 1547™-2018)

reaction time (T_{react}): The duration from a step change in a system quantity measured at a defined location until the output of the system at the same defined location measurably changes in the direction of the control effort. (Adapted from NERC Reliability Guideline—BPS connected inverter-based resource performance [B75])

NOTE—Refer to [Figure 5](#) for illustration of *reaction time*. Time between step change in system quantity and the time to 10 percent of required output change may be used as a proxy for determining this time.

reactive current priority mode: A mode in which the reactive current output (I_q) is given priority and has the full current rating of the inverter-based resource (IBR) available to it (i.e., *maximum current ac*, I_{max}), while the active current output (I_p) is constrained. The active current I_p range varies from a maximum of $\sqrt{(I_{\text{max}}^2 - I_q^2)}$ to a minimum of zero for generating IBR, and to $-\sqrt{(I_{\text{max}}^2 - I_q^2)}$ for energy storage IBR, where I_q is the present value of reactive current. *Syn:* **Q-Priority mode.**

NOTE 1—The Q-priority does not necessarily mean that active power (or active current) is reduced to zero. It just means that the priority is given to reactive power (or reactive current).

NOTE 2—The definition is written with focus on operation during a balanced fault or a system disturbance. During unbalanced faults, the requirement to inject negative-sequence reactive current may further constrain active current and positive-sequence reactive current output.

reference point of applicability (RPA): The location where the interconnection³⁰ and interoperability performance requirements specified in this standard apply. (Adapted from IEEE Std 1547™-2018)

regional reliability coordinator: The functional entity that is responsible for the reliable operation of the *bulk power system*, has the wide area view of the *bulk power system*, and has the operating tools, processes and procedures, including the authority to prevent or mitigate wide-area emergency operating situations in both next-day analysis and real-time operations. (Adapted from IEEE Std 1547™-2018)

³⁰ “Interconnection” is not be confused with the “interconnection agreement” with the connecting TS.

NOTE—The *regional reliability coordinator* has the purview that is broad enough to enable the calculation of interconnection reliability operating limits, which may be based on the operating parameters of *transmission systems* beyond any transmission operator's vision.

restore output: Return operation of the *inverter-based resources (IBRs)* to the state prior to the abnormal excursion of voltage or frequency that resulted in a ride-through operation of the IBR. (Adapted from 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)

rise time (T_{rise}): The time for the output of a system to go from 10% to 90% of required output change. (Adapted from IEEE Std 1241™-2010) *See also:* **step response; step response time.**

NOTE—Refer to [Figure 5](#) for illustration of *rise time*.

secure/securely: Being in a state where all known cybersecurity risks are identified and managed either by being mitigated with security controls or by being accepted by stakeholders.

service status: Operational state of equipment, an *inverter-based resource unit (IBR unit)*, a *supplemental IBR device*, or an *IBR plant* that determines whether it is in operation or out of operation. Status may be “in service” or “out of service.” *See also:* **in service; out of service.**

NOTE—The service status of *IBR units* and/or *supplemental IBR devices* may determine the *available active power* and reactive power capability of an *IBR plant*.

settling band: The region around the value change the system output is required to settle in after a step change in a system quantity measured at a defined location. *See also:* **settling time.**

NOTE—Refer to [Figure 5](#) for illustration of *settling band*.

settling time: The duration from a step change in a system quantity measured at a defined location until the output of the system settles to within a specified *settling band* around its final value change at the same defined location. (Adapted from IEEE Std 1031™-2011) *See also:* **step response.**

NOTE—Refer to [Figure 5](#) for illustration of *settling time*.

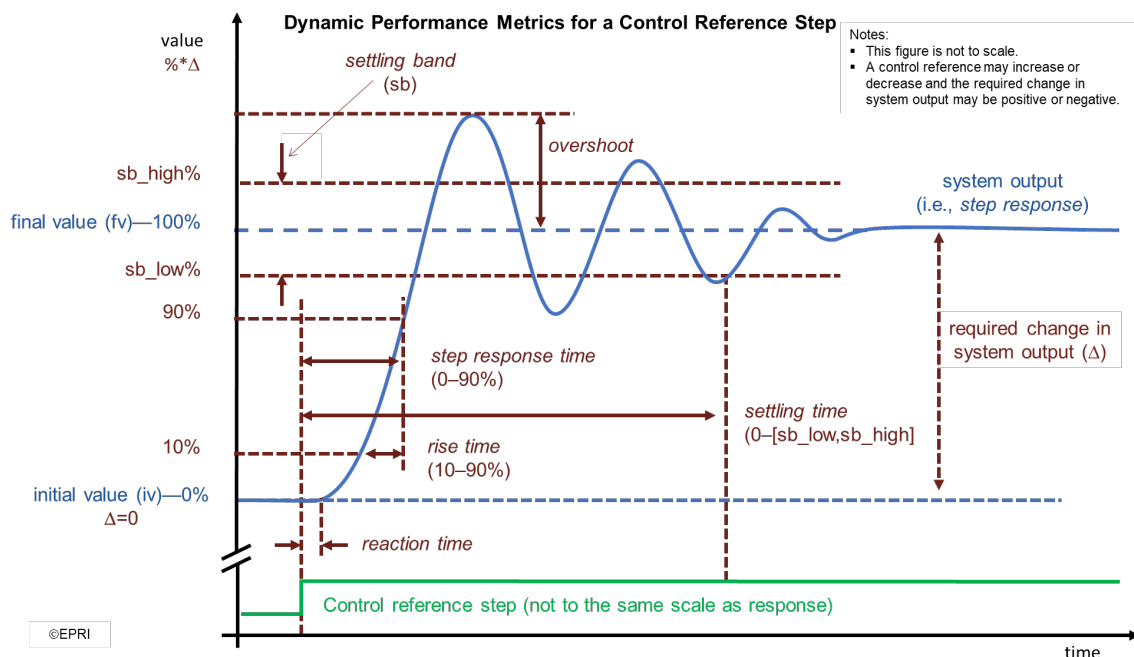
solar photovoltaic system (solar PV): An *inverter-based resource unit* producing electrical energy from solar radiation directly by photovoltaic effect. (Adapted from IEC 60050)

step response: The output of a system as a function of time t when the input is a step function of time t also. (Adapted from IEEE Std 1547™-2018) *See also:* **reaction time (T_{react}); rise time (T_{rise}); settling time (T_{settling}); step response time; overshoot.**

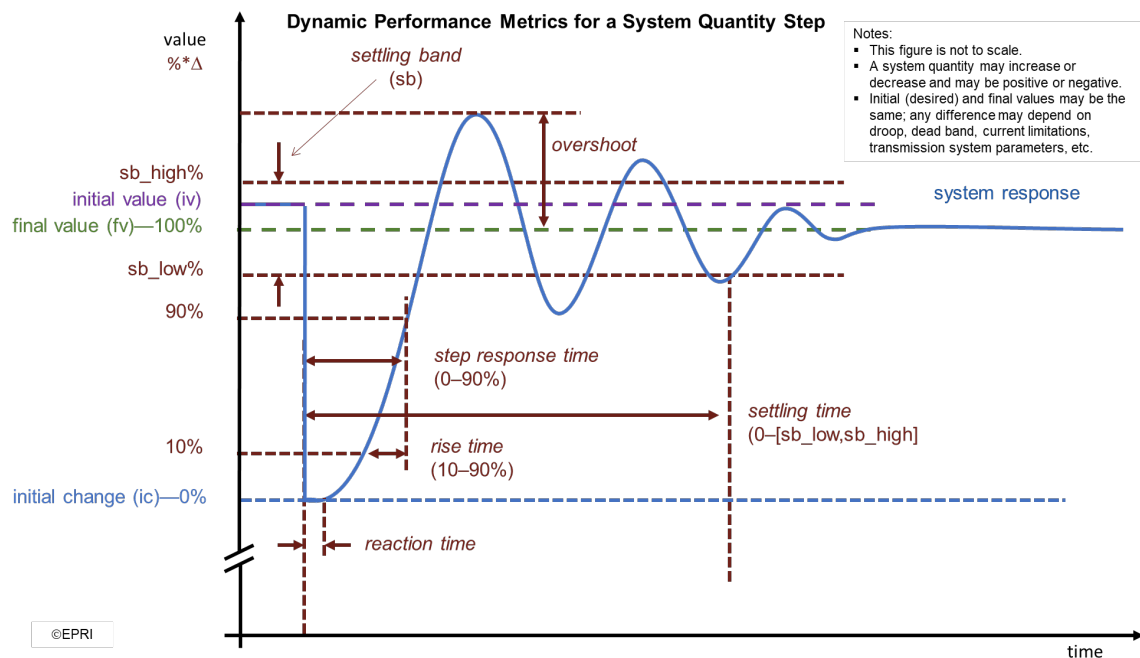
NOTE 1—[Figure 5](#) (not to scale) defines terms that characterize a *step response*.

NOTE 2—A system quantity may increase or decrease and the required change in system output may be positive or negative.

NOTE 3—The step response is used to describe the dynamic behavior of various specifications in this standard, including, but not limited to, *inverter-based resource (IBR) plant* performance or measurements.



(a) Dynamic performance metrics for a control reference step (e.g., frequency response, current injection during fault); the figure illustrates a case where the required final value and final settled value are equal.



(b) Dynamic performance metrics for a system quantity step (e.g., voltage regulation, power factor regulation)

Figure 5 reprinted with permission from the Electric Power Research Institute (EPRI), © 2020.

Figure 5—Step response characteristics and defined terms

step response time: The time between the step change in a system quantity measured at a defined location and when the output of the system reaches 90% of required output change, before any *overshoot*. (Adapted from IEEE Std 2745.1™, 2019) *See also: rise time; step response.*

sub-transmission system: *See: transmission system (TS).*

supplemental inverter-based resources device (supplemental IBR device): Any equipment within an *inverter-based resource (IBR) plant*, which may or may not be inverter-based, that is only used to obtain compliance with some or all of the interconnection requirements of this standard.

NOTE 1—Examples include equipment such as capacitor banks, STATCOMs, harmonic filters, protective devices, and plant controllers, etc.

NOTE 2—In cases where synchronous condenser is used as a *supplemental IBR device*, refer to a general exemption in 1.4.

NOTE 3—*Supplemental IBR devices* may meet or exceed applicable equipment standards, as determined by an *IBR plant* design evaluation (see 12.2.3).

total rated-current distortion (TRD): The non-fundamental frequency RMS current flowing (including harmonics, interharmonics, and noise) between the *transmission system (TS)* and the inverter-based resource (*IBR*) *plant* with respect to the rated RMS current capacity (I_{rated}). (Adapted from IEEE Std 1547™-2018)

transmission system (TS): The *transmission system* that is connected to an inverter-based resource (IBR). In this standard, the TS refers to both transmission and sub-*transmission systems* unless specific requirements for each are different. *Syn: sub-transmission.*

NOTE 1—Typically, the *TS owner* has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight. See Figure 1.

NOTE 2—Sub-*transmission systems* may be operated or owned by a distribution utility or a vertically integrated utility.

transmission system operator (TS operator)³¹: The entity that is functionally responsible for the operating the transmission system.

NOTE—For sub-transmission systems, the responsible entity may be a distribution utility or a vertically integrated utility.

transmission system owner (TS owner): The entity that is functionally responsible for designing, building, maintaining, and sometimes also planning the *transmission system*. *Syn: TS planner.*

NOTE 1—For simplicity, this standard does not differentiate between *TS owner* and the entity that plans a *transmission system*.

NOTE 2—For sub-*transmission systems*, the responsible entity may be a distribution utility or a vertically integrated utility.

transmission system planner (TS planner): *See: TS owner.*

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. (Adapted from IEEE Std 1547™-2018)

unit transformer (or IBR unit transformer): A transformer that steps up the low/medium alternating current (ac) voltage (typically 500 V to 1000 V, however, can be higher and in the medium-voltage range for wind turbine generator units) at the terminals of an individual *IBR unit* up to the medium/high ac voltage level of the *collector system* (typically 20 kV to 70 kV).

³¹ The *TS operator* term in this standard is equivalent to the term *transmission operator (TOP)* in the NERC glossary of terms.

verification entity: A test or verification entity responsible for performing or observing type tests, inverter-based resource (IBR) evaluations, commissioning tests, post-commissioning test/verification, or overseeing production testing programs to verify conformance of the IBR to the standard. (Adapted from IEEE Std 1547™-2018)

NOTE 1—Verification entities can be a *transmission system (TS) owner*, *TS operator*, *IBR operator*, *IBR owner*, *IBR developer*, *IBR unit manufacturer*, or third-party testing agency, depending on the test or verification performed.

NOTE 2—In the United States, the verification entity for type tests may be a Nationally Recognized Testing Laboratory, another independent third party, or the *IBR unit manufacturer*.

wind turbine generator (WTG): An inverter-based resource unit which converts the kinetic wind energy into electric energy. (Adapted from IEC 60050)

NOTE 1—A *wind turbine generator* generally uses one of the following electric generator configurations: direct-connected asynchronous generator (type I), asynchronous generator with external resistance control (type II), doubly-fed generator (DFG) (type III), full-rated power converter (type IV), or direct-connected synchronous generator with torque/speed converter (type V). For the purposes of this standard, only WTGs that use power electronic inverters/converters for interconnection to the grid are considered (e.g., type III and type IV).

NOTE 2—Types III and IV are the most common configurations for modern *wind turbine generators*.

3.2 Acronyms and abbreviations

ac	alternating current
AGC	automatic generation control
AGIR	authority governing interconnection requirements
AVR	automatic voltage regulator
BPS	bulk power system
CSCR	composite short-circuit ratio
DFG	doubly-fed generator
DFT	discrete Fourier transform
EMI	electromagnetic interference
EMS	energy management system
EMT	electromagnetic transient
ESS	energy storage system
FACTS	flexible ac transmission systems
FERC	Federal Energy Regulatory Commission
FFR	fast frequency response
HIL	hardware-in-the-loop
HV	high voltage
HVDC	high-voltage direct current
IBGP	inverter-based generation plant
IBR	inverter-based resource
IBR operator	inverter-based resource operator
IBR owner	inverter-based resource owner

ICR	IBR continuous rating
$I_{\max}$	maximum current ac
ISR	IBR short-term rating
MV	medium voltage
NERC	North American Electric Reliability Corporation
NRTL	nationally recognized testing laboratory
OEM	original equipment manufacturer
PLL	phase-locked loop
PFR	primary frequency response
POI	point of interconnection
POC	point of connection
POM	point of measurement
PV	photovoltaic
RMS	root mean square
ROCOF	rate of change of frequency
RPA	reference point of applicability
RVC	rapid voltage change
SCR	short-circuit ratio
SSCI	subsynchronous control interactions
SSO	subsynchronous oscillations
SSR	subsynchronous resonance
SVC	static var compensator
STATCOM	static synchronous compensator
THD	total harmonic distortion
TS	transmission system
TS operator	transmission system operator
TS owner	transmission system owner
TOV	transient overvoltage
TRD	total rated-current distortion
TVE	total vector error
OLTC	on-load tap changer
VSC	voltage source converter
VSC-HVDC	voltage source converter HVDC
WSCR	weighted short-circuit ratio
WTG	wind turbine generator

4. General interconnection technical specifications and performance requirements

4.1 Introduction

The technical minimum requirements for the interconnection, capability, and performance in this standard are specified for the *IBR plant*, unless otherwise stated. Where specified, certain requirements apply to one or multiple *IBR unit(s)* within an *IBR plant*. The *IBR plant* may use *supplemental IBR device(s)* to achieve compliance with the requirements of this standard. Refer to 4.1.4 for details on applicability of requirements to *supplemental IBR device(s)*.

The capabilities and functions of the *IBR units*, systems hardware, and the controls software that affect the TS are required to meet this standard at the *reference point of applicability* (RPA) regardless of their location on the TS. The performance requirements in this standard are functional and do not specify any particular equipment or equipment design.

The capability and performance requirements specified here are universally needed for interconnection and interoperability of an *IBR plant* and will be sufficient for most installations.³² The applicability of certain specifications and requirements depend on application considerations. An *IBR plant* shall be designed and installed such that it meets the performance, test, and verification requirements described in Clause 4 through Clause 12 of this standard. The interoperability requirements are specified in 4.5 and 4.6.

4.1.1 Coordination and specification of applicability

This standard does not specify TS operating and network conditions for which the requirements of this standard shall apply at the time of interconnection or over the foreseeable future considering anticipated system changes.

NOTE—To adequately design the *IBR plant*, the *IBR owner* may need sufficient information about TS operating and network conditions for which all of the requirements specified in this standard shall apply without any exceptions. This information helps to bound the engineering design problem and to clarify *TS owner/TS operator's* expectations to *IBR plant* performance under different TS operating and network conditions. This information may also help limit remedial actions by the *TS owner/TS operator* for contingencies or other TS conditions, for example, the temporary limitation of an *IBR plant's* permissible active power output.

Subject to regulatory requirements, the *TS owner/TS operator*, in coordination with the *IBR owner*, should specify reasonable TS operating and network conditions for which the requirements of this standard shall apply at the time of interconnection and, as practical, over the foreseeable future considering anticipated system changes. This may include some or all data recommended in the informative Annex H.

Upon request from the *IBR owner/IBR developer*, the *TS owner/TS operator* should provide the necessary TS network data for expected operating conditions to the *IBR owner/IBR developer* to design the *IBR plant*. Typical TS network data necessary for *IBR plant* design is noted in the informative Annex H.

4.1.2 Registration of *IBR plant* with *TS operator*

During the interconnection process, the *IBR owner* should register the *IBR continuous rating* (ICR) and, if applicable, the *IBR short-term rating* (ISR) with the *TS operator* or the *authority governing interconnection requirements* (AGIR). For *IBR plants* with *energy storage systems* (ESS), the *IBR owner* should also register the *IBR continuous absorption rating* (ICAR). The *TS operator* may require additional registration values from the *IBR owner*.

³² Additional technical requirements may be necessary for some limited situations.

The *TS operator* should verify the acceptability of the ICR, and as applicable the ISR, by studies of the TS before interconnecting the *IBR plant* to confirm that thermal, voltage, and stability limits of the TS system will not be violated.

Once the *IBR plant* is operational, modifications to controls that change the response of the *IBR plant* or *IBR units* as defined within this standard shall be mutually agreed upon between the *TS operator* and the *IBR owner*.

NOTE 1—Many of the technical minimum capability requirements in this standard refer to the ICR.

NOTE 2—Not all *IBR plants* may have an ISR greater than their ICR, i.e., the ISR is not a technical minimum capability requirement specified in this standard.

Additional data may be exchanged between the *IBR owner* and the *TS operator* considering the informative [Annex H](#) as a guidance.

4.1.3 Impact of IBR unit(s) and supplemental IBR device(s) service status

Where the *service status* of individual *IBR units* and/or *supplemental IBR devices* within an *IBR plant* is *out of service*, the *IBR plant's* capability and performance may become less than those specified for ICR, ICAR, or ISR.³³ In cases where this leads the *IBR plant* to become temporarily non-compliant with any part of this standard, remedy shall be taken in coordination with the *TS operator*, *regional reliability coordinator*, and/or *load balancing entity*.³⁴

NOTE—Refer to 1.4 for general remarks and limitations with regard to utilization of any capabilities specified in this standard and provision of the specified performance as a service.

4.1.4 Supplemental IBR devices

Supplemental IBR devices other than *IBR units* may be used to achieve compliance with the requirements of this standard at the applicable reference point per 4.2. These devices are not required to be co-located with the *IBR units*, but shall be within the associated *IBR plant*. The requirements of this standard shall be met regardless of the location of the *IBR units* and *supplemental IBR devices* within the *IBR plant*. These relationships are shown in [Figure 1](#) for ac-connected IBR and in [Figure 2](#) for dc-connected IBR.

Supplemental IBR devices shall meet or exceed technical minimum requirements specified in applicable equipment standards, as determined by an *IBR plant* design evaluation (see 12.2.3) to help ensure the *IBR plant* meets all requirements of this standard.³⁵ An individual *supplemental IBR device* shall not be expected to meet any given performance requirement specified by this standard on a standalone basis, as long as the *IBR plant* or the *IBR unit(s)*, as applicable, can meet that and all other requirements of this standard at their respective *reference point(s) of applicability*.³⁶

Exception (as specified in 1.4): During the interconnection process, in cases where a synchronous machine, e.g., synchronous condenser, is used as a *supplemental IBR device* and that may result in the *IBR plant* or *IBR unit* being unable to meet all requirements of this standard, due consideration should be given to the benefits and risks of the emerging use cases of synchronous condensers in deciding which requirements of

³³ For example, this could be the case during periods of scheduled or unscheduled maintenance, or as a result of failure of an *IBR unit* or *supplemental IBR device*.

³⁴ If necessary, such remedy measures may range from temporarily taking an *IBR plant out of service* to temporarily limiting an *IBR plant's* active power output.

³⁵ The technical minimum requirements specified in these equipment standards may or may not be sufficient for a synchronous machine to fulfil the purpose of a *supplemental IBR device*, that is to help the *IBR plant* obtain compliance with some or all of the interconnection requirements of this standard.

³⁶ A *supplemental IBR device* does not necessarily need to meet all requirements of this standard; however, it is required to meet the requirements for its purpose in the electrical system that makes up the *IBR plant*. The plant, as a whole, is required to meet the standard requirements. To that end, there may or may not be requirements above and beyond typical equipment standards for the supplemental device. The plant designer should determine the specific requirements for various components that make up the *IBR plant*, and communicate these to vendors of the supplemental devices in the device procurement stage. See also footnote 17.

this standard should be adopted and which may be exempted. This should be done in coordination between *IBR owner* and *TS owner/TS operator* not later than the *IBR plant* design evaluation where capabilities and performance of a synchronous condenser is adequately considered.

After commissioning, in cases where a *supplemental IBR device* is used to meet some or all of the requirements specified in this standard but fails to operate, or its *service status* is “out of service” as specified in 4.1.3, and where this results in the *IBR plant* or *IBR unit* to become non-compliant with this standard, the *IBR owner* shall take adequate remedy measures in coordination with the *TS operator*, *regional reliability coordinator*, and/or *load balancing entity*.³⁷

4.1.5 Hybrid and co-located resources

For a *hybrid plant* that includes IBR and non-IBR, the requirements of this standard shall only apply to the *IBR plant(s)* or the *hybrid IBR plant(s)* in the *hybrid plant*. Other standards’ requirements may be applicable to the conventional generation resources in the *hybrid plant*. Requirements for the *hybrid plant* that is controlled and operated as a single resource shall follow good engineering practices.³⁸

Conventional generation resources in a *co-located plant* may comply with applicable standards.

NOTE—Synchronous machines, including synchronous condensers, that are separate, co-located, or in the non-IBR part of a *hybrid plant*, and that are not essential for the conformance of the IBR part of a *hybrid plant* with this standard, are not considered *supplemental IBR devices*, and therefore the requirements of this standard may not apply. For those synchronous machines the applicable equipment standards may be used as technical minimum requirements. One example for synchronous machines that are not considered *supplemental IBR devices* includes synchronous machines that are installed by the *TS operator* with the objective of improving TS operating and network conditions (e.g., grid performance) or stable operation of *IBR plant(s)* in grid areas with reduced source strength (defined by the TS driving point impedance; e.g., “weak grid” conditions) or increased sensitivity (e.g., large variation or high rate-of-change in system quantities).

Subclause B.3 provides examples for various types of hybrid resources.

4.2 Reference points of applicability (RPA)

4.2.1 RPA for ac-connected IBR

Except as otherwise stated in this standard, the *reference point of applicability (RPA)* for all technical minimum requirements for the interconnection, capability, and performance requirements in this standard shall be the *point of measurement (POM)* of the *IBR plant* as shown in Figure 1.³⁹ The interconnecting *TS owner/TS operator* may adapt some or all performance requirements, as specified in this standard, and move their respective RPA to another location, including the *point of interconnection (POI)*.⁴⁰

NOTE 1—The electrical quantities referred to in this standard are those at the RPA, unless otherwise stated.

NOTE 2—Informative Annex B presents interconnection examples.

NOTE 3—For requirements in this standard that apply to an *IBR unit*, the respective subclause specifies the *point of connection (POC)* as the RPA.

³⁷ See footnote 34.

³⁸ Inherent differences in types of resources or *energy storage systems* in a hybrid resource facility may be considered when specifying capability and performance requirements. This standard specifies technical minimum requirements for IBR which may be more stringent of what a non-IBR may be able to achieve.

³⁹ Due to possibility of many different interconnection scenarios, it is impractical to develop performance requirements for RPA other than POM in this standard.

⁴⁰ In some cases, for example, where the main IBR transformer may be owned by the *TS operator*, the RPA may be moved to the low-voltage side of the main IBR transformer.

4.2.2 RPA for dc-connected isolated IBR

For isolated IBRs that are interconnected to an ac *transmission system (TS)* via a dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facility, the VSC-HVDC transmission facility is considered a part of the *IBR plant* as shown in Figure 2. As such, the RPA shall be located on the ac side of the VSC-HVDC transmission facility that interconnects with the TS. The requirements of this standard shall not apply to the isolated IBRs. An isolated IBR may serve as a *supplemental IBR device* that is necessary for the *IBR plant* with VSC-HVDC to meet the requirements of this standard at the RPA.

4.2.3 RPA for all other cases

In addition to the applicability of this standard on isolated IBRs, a *TS owner/TS operator* may apply this standard, in whole or in part, to hybrid resource facilities that include one or more non-IBRs and that are interconnected via a dedicated VSC-HVDC transmission facility to the TS.

4.3 Applicable voltages and frequency

The *applicable voltages* are the voltages at the *reference point of applicability (RPA)*. The *applicable frequency* is the frequency at the RPA.

For TS designed for effective grounding, the *applicable voltages* shall be the phase-to-phase and phase-to-ground voltages.⁴¹ For any other TS, the *applicable voltages* shall be the phase-to-phase voltages.⁴²

The *applicable frequency* is the fundamental-frequency component of the *applicable voltages*. The *applicable voltages* shall be quantified as the fundamental-frequency phasor component values, unless otherwise specified in this standard.⁴³

For voltage protection, if applicable, and voltage ride-through requirements in 7.2.2, the following shall apply:

- For low-voltage ride-through, the relevant voltage shall be the lowest magnitude fundamental frequency phasor component of the *applicable voltages* at the RPA relative to the corresponding nominal voltage.
- For high-voltage ride-through, the relevant voltage shall be the greatest magnitude fundamental frequency phasor component of the *applicable voltages* at the RPA relative to the corresponding nominal voltage.

For transient overvoltage ride-through requirements in 7.2.3, the following shall apply:

- For transient overvoltage ride-through, the relevant voltage shall be the greatest magnitude of the instantaneous applicable voltages at the RPA relative to the corresponding nominal voltage.

For rate of change of frequency (ROCOF) ride-through requirements in 7.3.2.3.5, the ROCOF shall be the average rate of change of frequency over an averaging window of at least 0.1 s.

The *TS owner* specifies the TS nominal voltage and nominal frequency at the RPA.

⁴¹ Most *transmission systems* are designed for effective grounding.

⁴² Some sub-*transmission systems* have other higher impedance grounding schemes.

⁴³ Where the *applicable voltages* approach or exceed 1.2 p.u., fundamental-frequency phasor component may be insufficient and point-on-wave values may need to be used as specified in other parts of this standard.

4.4 Measurement accuracy

All parameters that shall be measured and retained by the IBR,⁴⁴ per requirements in [Clause 11](#) for performance monitoring and validation, shall meet or exceed the steady-state⁴⁵ and transient measurement accuracy requirements specified in [Table 1](#) and [Table 2](#). The specified accuracy requirements also apply to the derived quantities.⁴⁶ For a given parameter, the specified minimum accuracy requirement is applicable within the specified range; outside this range accuracy may be relaxed, if necessary. Upon request by the *TS owner*, the *IBR owner* shall state the actual accuracy values of such measurements and derived quantities in the format of aforementioned tables.

This standard specifies no accuracy requirements for measurements and derived quantities that may impact an IBR's performance as it relates to the requirements specified in this standard.⁴⁷ Upon request by the *TS owner*, the *IBR owner* shall state the *manufacturer stated measurement accuracy*, i.e., the actual steady-state accuracy values of such measurements and derived quantities, in the format of [Table 1](#); and for the actual transient accuracy values of such measurements, and derived quantities, in the format mutually agreed upon between the *TS owner* and the *IBR owner*.

Table 1—Measurement and derived quantities accuracy requirements for [Clause 11](#)—steady-state time frame^f

Parameter	Minimum accuracy ^a	Range
Voltage ^{c, d}	± 2.5%	0.5 per unit (p.u.) to 1.2 p.u.
Current ^{c, d}	± 2.5%	0.2 p.u. to 1.2 p.u.
Frequency ^b	± 0.010 Hz	0.80 p.u. to 1.1 p.u. ^g
Active power ^e	± 5%	0.2 p.u. < <i>P</i> < 1.0 p.u.
Reactive power ^e	± 5%	0.2 p.u. < <i>Q</i> < 1.0 p.u.

^a Measurement accuracy requirements specified in this table are applicable for voltage THD < 2.5% and individual voltage harmonics < 1.5%. The THD calculation method is based on IEEE Std 519™-2014.

^b Accuracy requirement is applicable only for fundamental frequency and when the positive-sequence voltage is greater than 10% of the nominal positive-sequence voltage.

^c Measurement accuracy requirements for power quality terms are specified in [Clause 11](#).

^d Accuracy requirement is expressed as percent of nominal rated value, not of measured value.

^e Accuracy requirements for active and reactive power are expressed as percentage of fundamental frequency nominal apparent power in either direction over the specified range.

^f Accuracy requirements may be useful for applications such as voltage control and SCADA.

^g 48 Hz to 66 Hz for 60 Hz systems, 40 Hz to 55 Hz for 50 Hz systems.

⁴⁴ The IBR includes any equipment required to meet the interconnection performance and interoperability requirements of the standard, including plant-level controls, protective relays, and measurement transducers.

⁴⁵ Steady-state measurements may be used for providing monitoring information through a local IBR communication interface at the *reference point of applicability* as specified in [Table 1](#).

⁴⁶ Only the fundamental parameters can actually be measured, e.g., time, voltage, and current. Other quantities are calculated based on the fundamental parameters measured, e.g., frequency, active power, and reactive power.

⁴⁷ [Clause 12](#) specifies requirements to test and verify IBR performance. An *IBR plant* design evaluation may consider performance and accuracy of IBR measurements and derived calculations as one of many other factors to meet the performance requirement specified in this standard.

**Table 2—Measurement and derived quantities accuracy requirements
for Clause 11—transient time frame^k**

Parameter	Minimum accuracy ^a	Maximum length of sliding window	Maximum resolution ^b	Range
Voltage ^c	$\pm 10\%^{d,e}$	1 cycle ^f	1/32 cycle	0.1 p.u. to 2.0 p.u.
Current ^{c,g}	$\pm 10\%^{d,e}$	1 cycle ^f	1/32 cycle	0.1 p.u. to 1.4 p.u.
Frequency ^{h,i}	± 0.010 Hz	6 cycles	1/4 cycle	0.80 p.u. to 1.1 p.u. ^j

^a Include sensor and measurement system accuracy.

^b Minimum sampling rate per sec can be calculated for 50 Hz and 60 Hz nominal frequency systems.

^c Fundamental frequency component of phasor.

^d Accuracy requirement is expressed as percent of nominal rated value, not of measured value.

^e Accuracy value reflects total vector error (TVE). TVE definition is the same as in IEC/IEEE 60255-118-1; this standard requires different values of TVE as in Table 2. The use of TVE definition from the IEC/IEEE 60255-118-1 does not mean that PMU measurements are required for parameters in this table. The intent is to adopt the way magnitude and phase angle errors of these parameters are calculated.

^f Can include up to another ¼ cycle based on algorithm.

^g Measurement shall be able to eliminate the effect of dc component.

^h Fundamental frequency.

ⁱ Accuracy requirement for frequency is applicable only for fundamental frequency and when the positive-sequence voltage is greater than 10% of the nominal positive-sequence voltage.

^j 48 Hz to 66 Hz for 60 Hz systems, 40 Hz to 55 Hz for 50 Hz systems.

^k Accuracy requirements may be useful for applications such as dynamic voltage support, protection, and short-circuit contribution.

4.5 Operational measurement and communication capability

The *IBR plant* shall, in a *secure* way,⁴⁸ provide a *local IBR communication interface* with bi-directional communication capability, and shall be capable of *securely*⁴⁸ providing real-time operational information of its status, mode of operation, and several steady-state, dynamic, and transient measurements.⁴⁹

Communication protocols⁵⁰ and data to be exchanged shall be defined in the interconnection agreement or by the services the *IBR plant* is offering to those entities. Test or verification of these requirements shall be mutually agreed upon between the *TS operator* and *IBR operator*.

The *IBR owner/operator* shall implement measures for availability, integrity, and confidentiality of all *IBR plant* communication capability and protocols, and all data exchange with all operational entities, including the *TS operator*.⁵¹ Test or verification of these cyber security measures shall be mutually agreed upon between the *TS operator* and *IBR operator*, in consideration of the applicable regulations and available technologies regulations.⁴⁸

4.6 Control capability requirements

The *IBR plant* shall be capable of responding to external control inputs.⁵² Control parameters to be exchanged shall be defined in the interconnection agreement or by the services the *IBR plant* is offering to applicable

⁴⁸ For North American entities, the applicability to NERC CIP standards are listed in the informative bibliography in Annex A.

⁴⁹ The operational information is intended to support integration into energy management systems (or distributed energy resource management system—DERMS) of the *TS operator*, *load balancing entity*, *regional reliability coordinator*, and markets in which it operates.

⁵⁰ Examples for industry-accepted communication protocols may include IEEE Std 1815™ [B53] and IEEE Std 2030.5™ [B55].

⁵¹ This may include communication and data exchange between equipment within the *IBR plant*, as applicable. References to some cybersecurity standards and guidelines is provided in Annex A.

⁵² The external input may come through a manual IBR control panel or through the *IBR communication interface* specified in 4.5.

entities. Test or verification of these requirements shall be mutually agreed upon between the *TS operator* and *IBR operator*.

Examples for control capabilities include:

- Capability to cease operation following disabling of the *permit service* setting within a time as specified by the *TS operator*.
- Capability to limit active power at a value below *IBR continuous rating* (ICR) within a time as specified by the *TS operator*.

4.6.1 Execution of mode or parameter changes

Transition time between modes commencing after the mode-setting change is received at the *local IBR communication interface* shall be as required by the *TS operator*. Changes of control functional modes shall be executed such that the *IBR plant* output is transitioned smoothly over a period of time required by the *TS operator*.

4.6.2 Ramping for control parameter change

Ramping or similar smooth transition of *IBR plant* output shall be required for control parameter setting changes. For all control and protective function parameter settings, the time following the input to the IBR communication interface and preceding the point in time when the invoked action begins shall be no greater than required by the *TS operator*.

4.7 Prioritization of IBR responses

Requirements for *IBR plant* and *IBR unit*, respectively, set forth in [Clause 5](#), [Clause 6](#), and [Clause 7](#) shall be prioritized as follows:⁵³

- a) The *IBR plant* response to disabling *permit service* setting specified in 4.6 shall take precedence over any requirements within [Clause 5](#), [Clause 6](#), and [Clause 7](#).
- b) Tripping of *IBR plant* or *IBR unit* to clear a fault condition either within the *IBR plant* or on the interconnection system, including islanding condition, shall take precedence over any other requirements within [Clause 5](#), [Clause 6](#), and [Clause 7](#).
- c) *IBR plant* or *IBR unit* tripping due to self-protection of equipment may take precedence over any other requirements within [Clause 5](#), [Clause 6](#), and [Clause 7](#) when self-protection is necessary to reduce risk of permanent damage or destruction of equipment. This does not remove the obligation of the *IBR plant* to meet all requirements of this standard and may lead to non-compliance with this standard.
- d) *IBR plant* ride-through requirements specified in 7.2.2, 7.2.3, and 7.3.2 shall take precedence over all other requirements within [Clause 5](#), and [Clause 6](#).
- e) The *IBR plant* active-power/frequency response requirements specified in [Clause 6](#) shall take precedence over all other requirements within [Clause 5](#), [Clause 6](#), and [Clause 7](#), with the exception of requirements listed in above items.
- f) The *IBR plant* response to active power limit signal specified in 4.6 shall take precedence over all other requirements within [Clause 5](#), [Clause 6](#), and [Clause 7](#), with the exception of requirements listed in above items.
- g) The *IBR plant* reactive power/voltage control functions specified in [Clause 5](#) shall take precedence over any remaining requirements within [Clause 5](#) and [Clause 6](#).

⁵³ Based on the actual settings of the control modes, a mode with lower priority may still take effect prior to a mode with higher priority.

4.8 Isolation device

When required by the TS operating practices, a readily accessible, visible-break isolation device shall be located between the TS and the *IBR plant*, meeting the requirements of the *TS owner*. In case of gas-insulated switchgear, alternate means may be permitted with mutual consultation with the *TS owner*. The isolation device should be clearly marked to include signage per applicable codes.

4.9 Inadvertent energization of the TS

The *IBR plant* shall not energize the TS when the TS is de-energized. Exceptions may be given for black-start *IBR* at the discretion of the *TS operator*.

4.10 Enter service

The requirements of this subclause shall be applicable only if specific connection or reconnection practices are not otherwise specified by the *TS operator*.

4.10.1 Introduction

The *enter service* criteria for an *IBR plant* are specified in [Table 3](#). The active power performance during entering service is specified in [4.10.3](#). The requirements apply when:

- Entering service after an *IBR plant* was out of operation, for example, when the *primary energy source* is not available (e.g., during night, no wind periods), due to market conditions, or maintenance, at the direction of the *TS operator*.
- Returning to service at the direction of the *TS operator* as specified in [7.4](#) after an *IBR plant* trip, for example, following self-protection due to an internal fault, or following an unsuccessful ride-through.⁵⁴

The requirements in [Table 3](#) are not intended to specify *IBR plant* capability to *enter service* for all *applicable voltage* and *applicable frequency* values within the ranges of adjustable settings; these criteria only specify necessary conditions for which an *IBR plant* is allowed to *enter service*.

4.10.2 Enter service and return to service criteria

When entering service or returning to service, the *IBR plant* shall not output active power to the TS until the *applicable voltage* and *applicable frequency* are within the ranges specified in [Table 3](#) and the permit service setting is set to “Enabled.” The *enter service* criteria in [Table 3](#) specify the conditions for which an *IBR plant* is permitted to *enter service*; these criteria do not mandate any *IBR plant* to *enter service* or stay in operation for the specified voltage and frequency conditions. The restrictions of this subclause shall not apply if the *TS operator* specifically directs the *IBR plant* to *enter service* or *return to service*.

⁵⁴ This could cause non-compliance with this standard.

Table 3—Enter service criteria for IBR plants

Enter service criteria		Default settings ^c	Ranges of available settings
Permit service	When enabled	Disabled	Enabled/disabled
Applicable voltage within range	Minimum value	Specified by <i>TS operator</i>	0.90 p.u. to 0.95 p.u. ^a
	Maximum value	Specified by <i>TS operator</i>	1.05 p.u. to 1.10 p.u. ^b
Applicable frequency within range	Minimum value	Specified by <i>TS operator</i>	0.98 p.u. to 0.99 p.u. (58.8 Hz to 59.4 Hz @ 60 Hz) (49.0 Hz to 49.5 Hz @ 50 Hz)
	Maximum value	Specified by <i>TS operator</i>	1.002 p.u. to 1.02 p.u. (60.12 Hz to 61.2 Hz @ 60 Hz) (50.1 Hz to 51 Hz @ 50 Hz)

^a For an *IBR plant* connected to a weak grid, the minimum voltage value to *enter service* may be mutually agreed upon between the *IBR operator* and the *TS operator*.

^b Voltages above 1.05 p.u. may be outside the current interrupting capability of fault-interrupting devices rated for maximum system voltage in accordance with ANSI C84.1.

^c *Enter service* criteria should consider any limitations of various equipment inside the *IBR plant*.

4.10.3 Performance during entering service

During entering service, the *IBR plant* shall be capable of the following:

- Prevent *enter service* when permit service setting is disabled.
- The *IBR plant* shall be capable of delaying *enter service* by an intentional adjustable minimum delay when the TS steady-state voltage and frequency are continuously within the *ranges of available settings* specified in Table 3. The *range of available settings* of the minimum intentional delay shall be 0 s to 600 s with a default minimum delay as specified by the *TS operator*.
- The *IBR plant* shall increase output of active power,⁵⁵ or exchange of active power for energy-storage-IBR, during *enter service* as specified. Active power shall increase approximately linearly with an average rate-of-change not exceeding the *IBR continuous rating* divided by the enter service period. The duration of the *enter service* period shall be adjustable over a *range of available settings* of 1 s to 1000 s with a default time as specified by the *TS operator*.⁵⁶ The maximum active power increase of any single step during the *enter service* period shall be less than or equal to 5% of the *IBR continuous rating*. Where a stepwise ramp is used, the average rate-of-change over the period from the beginning of one step to the beginning of the next step shall not exceed the average rate-of-change over the full *enter service* period. This requirement is a maximum ramp rate requirement and the *IBR plant* may increase output at a slower rate than specified.

4.11 Interconnection integrity

4.11.1 Protection from electromagnetic interference (EMI)

An *IBR unit*, except for a WTG, shall be compliant with IEEE Std C37.90.2™, IEC 61000-4-3, or other applicable industry standards with a minimum electric field strength of 30 V/m.⁵⁷ A WTG shall be compliant with IEC 61000-6-2 or other industry standards applicable for WTG equipment.

⁵⁵ For *restore output* of active power after *return to service*, direction of active power may be negative (charging) for energy storage IBR, e.g., return to frequency reduction via charging through droop or dispatch control, if operating for that purpose prior to trip. This requirement does not exclude use of alternate means to meet this requirement.

⁵⁶ Base values for quantities expressed in per unit and percent of are specified in 3.1.

⁵⁷ Information on references can be found in Clause 2.