Clause-by-Clause Summary of Requirements in IEEE Standard 1547-2018

David Narang, Michael Ingram, Andy Hoke, Akanksha Bhat, and Shazreen Meor Danial

National Renewable Energy Laboratory

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

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Preface

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

The revised standard contains 11 chapters (clauses) and eight annexes that comprise 136 pages. The revision is significantly different from the 2003 version, and it contains new concepts and new technical requirements. Each clause specifies information or requirements that apply to certain aspects important to the interconnection of DERs to the electric power system. Implementing the requirements necessitates a careful study of the underlying technical concepts and requires the appropriate information to calculate relevant settings and configurations. Various stakeholders have different roles in implementing the standard, and portions of the standard are directed toward a specific audience who must possess specialized information and technical training to use and apply the requirements.

The aim of this document is threefold: (1) summarize clauses and subclauses in the standard as concisely as possible; (2) identify the key stakeholders and, to a limited extent, the expected level of involvement they should have in decisions related to implementation of the standard; and (3) provide an awareness of the defaults and options for requirements in the standard.

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

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List of Acronyms

AEPSO[1]	area electric power system operator
AGIR	authority governing interconnection requirements
BPS	bulk power system
DER	distributed energy resource
DERO[2]	distributed energy resource operator
EMI	electromagnetic interference
EPS	electric power system
IEEE	Institute of Electrical and Electronics Engineers
NRTL	nationally recognized testing laboratory
PCC	point of common coupling
PoC	point of distributed energy resource connection
RPA	reference point of applicability
RRC	regional reliability coordinator

[1] Note that the standard uses the term *area EPS operator*, not the acronym *AEPSO*, which is used in this document.
[2] Note that the standard uses the term *DER operator*, not the acronym DERO, which is used in this document.

Table of Contents

List of Tables

Introduction

The Institute of Electrical and Electronics Engineers (IEEE)1547 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018) contains 11 chapters (clauses) and eight annexes that comprise 136 pages. Each clause specifies information or requirements that apply to certain aspects important to the interconnection of distributed energy resources (DERs) to the electric power system (EPS). Implementation of the requirements needs both a careful study of the underlying technical concepts and the appropriate information that might be required to calculate various settings and configurations. Implementation also requires involvement and coordination among various stakeholders.

The stakeholders who are typically concerned with the requirements specified in IEEE Std 1547-2018 include solar and other DER device manufacturers,[3] state electric regulators,[4] electric utilities (area electric power system operators), solar and other DER developers, integrators and installers, testing agencies and laboratories,[5] state energy offices, governors' energy offices, policymaking entities, bulk power system (BPS) operators, independent system operators, regional transmission organizations, academic researchers, and professional consulting firms. Decisions related to the use of ride-through capabilities necessarily involve regional reliability coordinators (RRCs).

The intended primary audience of this document includes (1) state electric regulating or policymaking entities; 2) electric utilities; and 3) solar and other DER developers, integrators, and installers; however, the authors hope that other stakeholders will also find it valuable. A high-level summary of which clauses might be of interest to certain stakeholders is given in Table 1 in this document.

The aim of this document is threefold: (1) summarize clauses and subclauses in the standard as concisely as possible; (2) identify the key stakeholders and, to a limited extent, the expected level of involvement they should have in decisions related to implementation of the standard; and (3) provide an awareness of the defaults and options for requirements in the standard.

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[3] Solar and other DER device manufacturers are inherently interested in the performance requirements in this standard; however, this document focuses on the application of the standard rather than the manufacturing process of the DER device.

[4] State electric regulators fall under the term *authority governing interconnections* (AGIR), which is defined in IEEE Std 1547-2018 as "[a] cognizant and responsible entity that defines, codifies, communicates, administers, and enforces the policies and procedures for allowing electrical interconnection of DER to the Area EPS. This may be a regulatory agency, public utility commission, municipality, cooperative board of directors, etc. The degree of AGIR involvement will vary in scope of application and level of enforcement across jurisdictional boundaries. This authority may be delegated by the cognizant and responsible entity to the *Area EPS operator* or *bulk power system* operator. NOTE—Decisions made by an authority governing interconnection requirements should consider various stakeholder interests, including but not limited to Load Customers, *Area EPS operators*, *DER operators*, and *bulk power system* operator" (IEEE 2018).

[5] The term testing agency includes entities such as nationally recognized testing laboratories

Table 1. Primary Audience/Stakeholder by Clause

Clause	Primary Audience/Stakeholders	Additional Interested Parties
1	All	
2	All	
3	All	
4	AEPSO, DER manufacturer, DERO, testing agency, DER developer/integrator, commissioning agency	AGIR, BPS operator, RRC
5	AEPSO, DERO, DER manufacturer, testing agency, commissioning agency	AGIR
6	AEPSO, DERO, DER manufacturer, testing agency, commissioning agency, BPS operator, AGIR, RRC	
7	DER manufacturer, testing agency	Commissioning agency, area EPS operator
8	DER manufacturer, AEPSO, DERO, testing agency, commissioning agency.	AGIR, BPS operator, RRC, DER owner
9	AEPSO, DERO, DER manufacturer	Testing agency, commissioning agency
10	DER manufacturer, AEPSO, AGIR, DERO	Testing agency, commissioning agency, BPS operator, RRC, DER aggregator
11	DER manufacturers, testing agencies, commissioning agencies, AEPSO, DERO	DER owner

1 Summary of Introductory Clauses

Clause 1 provides an overview of the entire standard. The subclauses provide background on general topics, scope and purpose of the standard, general remarks and limitations (what the standard is and is not), and conventions for word usage and normative references that are required to understand and apply the standard. This clause describes the scope and purpose of the standard, provides general remarks, notes limitations and items that remain outside the scope, and introduces key terms and concepts related to the *point of common coupling* (PCC) and *point of DER connection* (PoC). In addition, the clause introduces the concept of *supplemental DER device* and performance categories for normal and abnormal grid conditions.

Clause 2, on normative references, lists other documents the user must understand and apply in conjunction with the standard.

Clause 3 provides definitions and acronyms used in the standard.

2 Summary of General Technical Specifications and Performance Requirements (Clause 4)

Clause 4 introduces key concepts and requirements that apply across the rest of the standard. Key terms and related requirements are specified in 13 subclauses.

Overall, subclauses within Clause 4 are targeted to practitioners who will need to evaluate and apply the requirements of the standard. Stakeholders—listed in order of their expected relevance or role in decisions under this clause—include the area EPS operator (i.e., the utility), DER manufacturer, DER operator, testing agency, solar or other DER developer and/or integrator, and the commissioning agency. Note that IEEE Std 1547-2018 does not use the term *DER owner*. It may be assumed that the DER owner is the same entity as the DER operator; however, this might not always be the case. The DER owner, if a separate entity, may have input to decisions under some clauses.

The standard assumes that the implementation of requirements is carried out by practitioners with the appropriate level of fluency, knowledge, and experience in the relevant subject matter.

Subclauses are summarized in Table 2 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 2. Summary of Requirements in Clause 4

4.1 Introduction: This subclause provides an introduction with background on topics that discussed in more detail in the following chapters.	
4.2 Reference points of applicability (RPA): This subclause specifies the characteristics of the local EPS (i.e., the customer-sited portion of the system) and the DER, which determine the specification of the RPA as the location where the requirements must be met. • See informative annex H, figures H.1 and H.2 in the standard for decision trees that provide an example of specifying the RPA.	
Defaults	1. Unless otherwise stated, the default RPA is at the PCC (i.e., the utility meter). 2. For simpler DER installations, the RPA may be at the PoC (i.e., the DER terminals).
Options	**Change location of the RPA (decision by AEPSO, DERO)** • The location of the RPA may be changed by mutual agreement between the area EPS operator and the DER operator based on several considerations, including aggregate nameplate capacity of the DERs, annual average load demand as calculated by the area electric power system operator (AEPSO), export capability of the local EPS, and evaluation of whether or not zero-sequence continuity is maintained between the PCC and PoC.
4.3 Applicable voltages specifies requirements for determining applicable voltages and the derived applicable frequency.	
Defaults	Defaults are given in Table 1 and Table 2 in the standard, which specify requirements for the PCC located at either medium voltage or low voltage, respectively.
Options	**Determination of the applicable voltage (medium voltage or low voltage; decision by AEPSO)** • Applicable voltages are based on distribution voltage configuration, transformer connections, location of the PCC (medium voltage or low voltage), evaluation of the configuration and nominal voltage of the area EPS at the PCC, or evaluation of the configuration of the low-voltage winding of the area EPS transformer(s) between the medium-voltage system and the low-voltage system.
4.4 Measurement accuracy specifies minimum requirements for the measurement and calculation accuracy for steady-state and transient values for root mean square voltage, frequency, active power, reactive power, and measurement of time duration. • This clause is especially important to DER manufacturers and testing agencies.	
Defaults	Defaults are as specified in Table 3 in the standard.

Options	This subclause contains no optional configuration changes. Measurement accuracy values specified in the standard are built into DERs by the manufacturer.

4.5 Cease-to-energize performance requirement specifies requirements for active and reactive power exchange between DERs and the EPS during the cease-to-energize state.

Defaults	Defaults are as specified in the subclause.
Options	**Optional disconnection method (decision by DERO, AEPSO)** • Typically, DERs will have this capability built in by the manufacturer. The DER operator may, however, choose to use alternative means to fulfill this requirement, such as a separate disconnection device.

4.6 Control capability requirements specifies requirements for DER capability to respond to external inputs given from either a manual DER control panel or through the local DER communications interface.

Defaults	Defaults are given in subclauses 4.6.1 to 4.6.3, specifying requirements for capabilities to disable the permit service setting, limit active power export, and control functional modes and parameter settings.
Options	1. **Determination of whether and how to use control capability (decision by AEPSO)** • DERs are required to have the provision to exercise these capabilities via external commands, which could be through manual input via a DER control panel or via remote communications through the local DER communications interface.
	2. Determination of settings for limitation of active power (decision by AEPSO, DERO) • By mutual agreement, the area EPS operator and the DER operator may choose to reduce the active power below the levels needed to support the local EPS loads.

4.7 Prioritization of DER responses specifies the precedence of DER tripping requirements, ride-through requirements, and control mode requirements specified in Clause 5 and Clause 6.

- This topic might also be of interest to the BPS operator and or/RRC.

Defaults	Requirements are as specified in the subclause.
Options	There are no optional configurations; however, differences in DER response m**ight** vary depending on whether certain capabilities are u**sed** or not.

4.8 Isolation device specifies requirements for an isolation device.

Defaults	None specified; however, DERs might have this capability built in by the manufacturer.
Options	**Determination of need for separate isolation device (decision by AEPSO)** • The area EPS operator might require a separate isolation device.

4.9 Inadvertent energization of the area EPS specifies that DER shall not energize the area EPS when the area EPS is de-energized.

- Exceptions to this are at the discretion of the area EPS operator, such as for an intentional island.

Defaults	DER is not permitted to energize the area EPS when the area EPS is de-energized.
Options	**1. Determination of need for intentional area EPS islands (decision by AEPSO, DERO)** • The area EPS operator might require intentional islands. Utilization of intentional islanding capability is by mutual agreement between the area EPS operator and the DER operator.

4:10 Enter service specifies RPA voltage and frequency ranges needed for the DER to enter service; DER performance while entering service; and synchronization limits for frequency, voltage, and phase angle difference.

- Enter service criteria might be affected by the utilization of functions specified in clauses 5, 6, and 7—for example, requirements and performance of volt-volt ampere reactive (5.3.3, 5.4.2), voltage trip and ride-through (6.4), rate of change of frequency (6.5.2.5), return to service after trip (6.6), and limitation on voltage fluctuations induced by DER (7.2).
- In addition to the AEPSO and the DERO, this subclause may also be of interest to the RRC

Defaults	1. The *permit service* setting is by default set to **Enabled**. 2. Default voltage and frequency ranges are as specified in Table 4 in the standard. 3. Defaults for synchronization parameter limits for frequency, voltage, and phase angle difference are as specified in Table 5 in the standard. 4. The maximum active power increase of any single step during the enter service period is as specified in subclause 4.10. 5. Certain types of DERs, such as large round-rotor synchronous generators and salient pole synchronous generators, may use synchronization criteria specified in IEEE Std 67.
Options	**1. Adjustments to default settings (decision by AEPSO, DERO)** • The area EPS operator, in consultation with the RRC and the DER operator, may adjust settings within the ranges of allowable settings as specified in Table 4 in the standard.
	2. Determination of enter service criteria for DERs > 500 kVA (decision by AEPSO, RRC) • The area EPS operator may allow larger than the specified maximum active power step changes, based on evaluation in coordination with the RRC.
	3. Alternative synchronization limits (decision by AEPSO) • The area EPS operator may waive synchronization limits in Table 5 based on consideration of whether DER-induced voltage fluctuations are within requirements in Clause 7.2.

4.11 Interconnect integrity specifies requirements for DER protection from electromagnetic interference (EMI), voltage and current surge withstand, and overvoltage withstand requirements for the DER paralleling device.

Defaults	Defaults are as specified in the subclause and as per the other standards referenced (IEEE Std C37.90.2 [EMI], IEC 61000-4-3 [EMI], IEEE Std C62.41.2 [surge withstand], IEEE Std C37.90.1 [surge withstand], IEEE Std C62.45 [surge withstand], IEC 61000-4-5 [surge withstand]).
Options	There are no optional configurations. These performance requirements are built in by the DER manufacturers.

4.12 Integration with area EPS grounding specifies that the DER's interconnection grounding scheme must be coordinated with the ground fault protection of the area EPS.

Defaults	As specified in the subclause, the DER's interconnection grounding scheme must be coordinated with the ground fault protection of the area EPS.
Options	**Adjustments to grounding scheme (decision by AEPSO)** • The area EPS operator may specify adjustments to the grounding scheme based on area EPS requirements.

4.13 Exemptions for emergency systems and standby DERs specifies the exemptions granted to emergency or standby DERs.

- This subclause may also be of interest to the AGIR.

Defaults	Exemptions are as specified in the subclause.

Options	The subclause contains no optional configuration. Designation of DERs as an emergency or standby power source are by the AGIR based on the intended function of the DERs and applicable industry codes, such as National Fire Protection Association 110 chapter on emergency or standby DERs, National Fire Protection Association 70 chapter on emergency or standby DERs, and the National Electric Safety Code chapter on emergency or standby DERs.

3 Summary of Requirements for Reactive Power and Voltage/Power Control (Clause 5)

This clause contains requirements for reactive power and voltage/power control capabilities of DERs. There are four subclauses that describe the overall capabilities and detailed requirements for specific modes of operation. Table 6 in the standard lists the types of voltage regulation required depending on the DER normal operating performance category A or B. In general, depending on their control strategy, the following modes can be implemented: (1) constant power factor control mode, (2) voltage-reactive power control mode, (3) active power-reactive power control mode, and (4) constant reactive power control mode. Informative Annex B presents discussion and considerations for performance category assignment. Annex H shows examples of control mode plots.

The clause is directed primarily to the area EPS operator, DER operator, DER manufacturer, testing agency, and the commissioning agency. For determination of performance categories, the authority governing interconnection requirements (AGIR) may choose to provide guidance to the area EPS operator.

Key highlights of subclauses are given in Table 3 of this document, which includes a summary of each major clause and subclause, key decisions, data, analysis, knowledge base and fluency needed for implementation, and important references.

Note that the area EPS operator may choose which, if any, of these capabilities are to be used. In some jurisdictions, the AGIR may choose to provide input on these decisions.

Table 3 also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 3. Summary of Requirements in Clause 5

5.1 Introduction provides an overview of voltage and reactive power capabilities and control requirements for DERs operating under normal conditions.	
Defaults	None specified.
Options	**Specification of required DER normal operating performance category (decision by AEPSO, AGIR)** • The area EPS operator is responsible for specifying which performance category is required. This decision is based on several factors, including area EPS operator operational and future needs, characteristics of the current and planned future area EPS, and the intended purpose and use of the DERs. • Note that this decision might include broader concepts of grid integration of DERs that fall outside the scope of the standard and might require input from the AGIR. Some of these concepts are discussed in Annex B.
5.2 Reactive power capability of the DER, specifies capability requirements for injection and absorption of reactive power that apply to both Category A and Category B DERs.	
Defaults	Minimum capabilities are specified in Table 7 in the standard.
Options	This subclause contains no specific optional configuration. Required capabilities are built in to the DER by the manufacturer.
5.3 Voltage and reactive power control specifies the requirements for voltage regulation capability by use of reactive power control modes. • Voltage regulation capability is mandatory for all DERs. Category A and B DERs must be capable of three voltage regulation control modes: (1) constant power factor mode, (2) voltage-reactive power mode (i.e., volt-volt ampere reactive), and (3) and constant reactive power mode. • For Category B DERs, two additional voltage regulation capabilities are required: (1) active power-reactive power mode (i.e., watt-volt ampere reactive) and (2) voltage-active power mode (i.e., volt-watt).	

Defaults	**Constant power factor mode—unity power factor:** The default (installed) mode is constant power factor at unit power factor, unless the area EPS operator specifies a different mode.
Options	**1. Enabling voltage regulation (decision by AEPSO, DERO)** • Approval is needed from the area EPS operator to use voltage regulation capabilities. The decision is in part based on location-specific requirements for reactive power. • In jurisdictions that use voltage regulation capabilities as part of DER grid services, input from the AGIR might also be needed based on the AGIR evaluation of policy and market goals. • Other types of reactive power control are allowed by mutual agreement between the area EPS operator and the DER operator. Further requirements for voltage-reactive power mode and active power-reactive power mode are presented in sections 5.3.3 and 5.3.4, respectively.
	2. Adjustments to default settings (decision by AEPSO) • Tables 8 and 9 in the standard specify the default settings for voltage-reactive power and active power-reactive power. The area EPS operator may adjust these within the ranges of allowable settings shown.
	3. Implementation of autonomous V_{Ref} adjustability (decision by AEPSO) • DERs have an optional configuration that allows the DER to adjust its reference voltage based on measured values (as opposed to the fixed specified nominal voltage). Area EPS operator approval is required to use this capability; and if it is used, the area EPS operator will specify the associated time constant for autonomous adjustment of reference voltage.

5.4: Voltage and active power control specifies the requirements of voltage regulation capabilities by use of the active power control modes. These modes are required for Category B DERs only and are the voltage-active power mode (i.e., volt-watt) .

Defaults	This is disabled by default.
Options	**1. Determination to enable active power voltage regulation modes (decision by AEPSO)** • The area EPS operator decides whether to use these capabilities. As noted, the AGIR might also have input depending on the AGIR's policies and goals. • Subclause 5.4.2 specifies the default and ranges of allowable settings for the relevant electrical parameters for each voltage regulation mode.
	2. Adjustment to default settings for control modes (decision by AEPSO) • Table 10 in the standard specifies default settings for the voltage-active power control mode. The AEPSO may adjust the default values within the ranges of allowable settings shown.

4 Summary of Requirements for DER Response to Area EPS Abnormal Conditions (Clause 6)

This clause specifies requirements for DER response to abnormal conditions.

The clause is directed primarily to the area EPS operator, DER operator, DER manufacturer, testing agency, the commissioning agency, and the BPS operator. For determination of abnormal operating performance categories, the AGIR and the RRC should provide guidance to the area EPS operator.

Note that the rationale for the assignment of performance categories—such as type of DER, characteristics of the area EPS, and the intended purpose and use of the DER—might include broader concepts of grid integration of DERs that are outside the scope of IEEE Std 1547. Informative Annex B presents a discussion and considerations for performance category assignment.

Subclauses are summarized in Table 4 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 4. Summary of Requirements in Clause 6

6.1 Introduction gives an overview of capabilities and control requirements for DERs under abnormal operating conditions. Abnormal operating performance categories I, II, and III are introduced with some background on the rationale for using these capabilities.	
Defaults	None specified. No action signifies capabilities are not used.
Options	**Determination of the required abnormal operating performance category (decision by AEPSO, AGIR)** • It is assumed the AGIR will provide guidance to the AEPSO on applicability of performance categories. Annex B provides considerations that might help stakeholders in making these decisions. • It is also assumed that the utilization of some of the abnormal operating performance categories related to the bulk power system, such as ride-through, requires coordination with the RRC. • All DERs are required to be field-adjustable for relevant parameters in the clause. Adjustability via communications might also be required at the discretion of the AEPSO.
6.2 Area EPS faults and open-phase conditions specifies the requirements for the response to short-circuit faults and open-phase conditions. Faults must be detectable by the area EPS protection systems.	
Defaults	1. The DER is required to cease to energize and trip for short-circuit faults on the same area EPS circuit section. 2. The DER is required to detect and respond to an open-phase condition within 2 seconds (the response is to cease to energize and trip).
Options	This subclause contains no specific optional configuration; however, the AEPSO may adjust the area EPS protection settings or DER parameters based on an evaluation of the DER fault current contribution, requirements for appropriate fault detection time, and protective relay coordination.
6.3 Area EPS reclosing coordination specifies that appropriate measures must be taken to ensure the DER is coordinated with the area EPS reclosing scheme. The intent is to avoid automatically reclosing onto a circuit that is energized by DERs**.**	
Defaults	Because of the wide range of utility practice and equipment settings, no defaults are specified in normative text; however, examples are given in Note 76 in the standard.

Options	**1. Methods for ensuring DER coordination with area EPS automatic reclosing: (decision by AEPSO)** • The area EPS operator decision for ensuring this requirement might include considerations for several factors, including DER type and penetration, existing area EPS protection schemes and requirements for protective relay coordination, reclosing timing, area EPS operator evaluation of reclose blocking, and transfer trip. • Additional consideration might be given to requirements for enter service (Clause 4.10) and voltage ride-through requirements for consecutive temporary voltage disturbances caused by a reclosing sequence (Clause 6.4.2.5).
	2. Specification of DER behavior during restore output mode (decision by AEPSO) • The area EPS operator is to provide requirements for coordinating the restore output behavior with the area EPS reclosing timing.

6.4 Voltage specifies requirements for mandatory voltage tripping, ride-through requirements during low- and high-voltage disturbances, and performance requirements for dynamic voltage support. Note that dynamic voltage support is not mandatory but might provide improved voltage stability.

Defaults	**1.** Default settings for under- and overvoltage tripping thresholds and clearing times are specified in tables 11, 12, and 13 in the standard for categories 1, 2, and 3 DERs. **These functions are mandatory—i.e., DERs shall trip on the default settings unless otherwise specified by the AEPSO.** **2.** Voltage ride-through requirements for all categories of DERs are specified in tables 14, 15, and 16 in the standard. **3.** Requirements for ride-through of consecutive voltage disturbances are given in Clause 6.4.2.5
Options	**1. Alternative under- and overvoltage trip settings (decision by AEPSO)** • The area EPS operator specifies alternatives to the default trip and clearing times within the ranges of allowable settings based on a number of factors, including the area EPS protection schemes and requirements for protective relay coordination and coordination with voltage trip settings specified by the RRC (for example, North American Electric Reliability Corporation PRC-024-2). • Settings might need to be temporarily set outside the given ranges by the area EPS operator because of needs such as maintenance. • *Note IEEE Std 1547 Amendment A, which modifies the ranges of allowable settings for Category III DERs in Table 13 in the standard.*
	2. Enabling dynamic voltage support (decision by AEPSO and DERO) • Dynamic voltage support is not a requirement; however, for DERs with this capability, it can be use by mutual agreement between the area EPS operator and the DER operator.
	3. Adjustment of momentary cessation threshold for Category III DERs (decision by AEPSO, DERO, RRC) • Subclause 6.4.2.7.3 allows for the adjustment of the transition threshold between momentary cessation and mandatory or continuous operation.

6.5 Frequency specifies requirements for mandatory frequency tripping and ride-through requirements during under- and overfrequency disturbances.

Defaults	**1.** Default settings for under- and overfrequency tripping thresholds and clearing times are specified in Table 18 in the standard. **These functions are mandatory—i.e., DERs shall trip on the default settings unless otherwise specified by the AEPSO.** **2.** Frequency ride-through requirements for all DERs are given in Table 19 in the standard. **3.** Requirements for rate of change of frequency ride-through are specified in Table 21 in the standard. **4.** Requirements for frequency droop (frequency-power) are specified in tables 22, 23, and 24 in the standard.

	Options	**1. Alternative under- and overfrequency trip settings (decision by AEPSO, RRC)** • Under- and overfrequency trip settings must be coordinated between the AEPSO and the RRC and may be adjusted within the ranges of allowable settings based on several factors, including consideration of regional underfrequency load-shedding programs and requirements for frequency restoration time.
		2. Alternative frequency droop settings (decision by AEPSO, RRC) • The area EPS operator, in coordination with the RRC, may specify alternate settings for frequency-droop within the ranges of allowable settings specified in Table 24. This decision is based in part on consideration of dynamic oscillatory behavior, as noted in Note b in Table 24 in the standard.
		3. Inertial response (decision by DERO, AEPSO, RRC) • Utilization of inertial response by DERs with this capability is by mutual agreement between the DER operator and the area EPS operator in consultation and coordination with the RRC.

5 Summary of Requirements for Power Quality (Clause 7)

This clause specifies requirements for power the quality-related phenomena that DERs must comply with. Annex G provides informative background information on power quality-related topics pertaining to DERs.

The clause is directed primarily to the DER manufacturer and the testing agency. Other interested parties might be the commissioning agency and the area EPS operator.

In general, specified requirements are for qualities built into the DERs by manufacturers, and for most interconnections, no decisions are required.

Subclauses are summarized in Table 5 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 5. Summary of Requirements in Clause 7

7.1 Limitation of DC injection specifies requirements for DER limitations on DC current injection.	
Defaults	As specified in the subclause.
Options	This subclause contains no optional configuration.
7.2 Limitation of voltage fluctuations induced by the DERs specifies requirements for the limitation of voltage fluctuations induced by DERs. There are two subclauses that specify requirements for rapid voltage changes and flicker.	
Defaults	As specified in the subclause.
Options	1. **Specification of alternate rapid voltage change limits (decision by AEPSO)** • Alternate rapid voltage change limits are by approval of the AEPSO based on consideration of other rapid voltage change sources in the area EPS.
	2. **Specification of alternate flicker limits (decision by AEPSO)** • Alternate flicker limits are by approval of the AEPSO based on consideration of other flicker sources in the area EPS.
7.3 Limitation of current distortion specifies limitations on odd and even harmonic current distortion, inter-harmonic current distortion, and total rated-current distortion. • IEEE Std 1547-2018 defines a new term, *total rated-current distortion*, which is used instead of *total demand distortion*. • IEEE Std 519 (harmonics) methodology is used to measure harmonic and inter-harmonic values; ***however**, limits specified in IEEE Std 1547-2018 refer to total rated-current distortion rather than the term total demand distortion used in IEEE Std 519.*	
Defaults	As specified in the subclause.
Options	**1. Specification of alternate current distortion injection limits (decision by AEPSO)** • Changes from the requirements are possible depending on the intended use of the DERs (e.g., when used as an active filtering device).
7.4 Limitation of overvoltage contribution specifies limitations on the DER's contribution to instantaneous or fundamental frequency overvoltage. There are two subclauses that specify requirements for overvoltage over one fundamental frequency period and cumulative instantaneous overvoltage.	
Defaults	As specified in the subclause.
Options	This subclause contains no optional configuration.

6 Summary of Requirements for Islanding (Clause 8)

This clause specifies requirements for intentional and unintentional islanding.

The clause is directed primarily to the DER manufacturer, the area EPS operator, the DER operator, the testing agency, and the commissioning agency. The AGIR might be interested in intentional islanding for resilience and for other goals and policies. For the utilization of black-start-capable intentional islands, additional stakeholders might include the bulk power system operator and the regional reliability coordinator (especially for black-start-capable, intentional island DERs). Note that IEEE Std 1547-2018 does not use the term *DER owner*. It may be assumed the DER owner is the same entity as the DER operator; however, this might not always be the case. The DER owner, if a separate entity, may have input to decisions under this clause.

Subclauses are summarized in Table 6 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 6. Summary of Requirements in Clause 8

8.1 Unintentional islanding specifies requirements for the prevention of unintentional islanding. There are three subclauses that specify requirements for island detection and options for modifying island detection time for protection coordination.		
	Defaults	If an unintentional island occurs, the DERs must detect the unintentional island and must cease to energize and trip within 2 seconds.

	Options	**Determination to adjust clearing time if other than default 2 seconds (decision by AEPSO and DERO)**
		• Clearing time may be extended to as much as 5 seconds based on:
		  ○ Area EPS-specific requirements and practices for protection coordination and mitigation of unintentional islanding as well as requirements and practices for area EPS auto-reclose times
		  ○ See 6.3 for requirements for area EPS reclosing coordination. Additional considerations include evaluation of continuous operation range, ranges of allowable settings, trip conditions (Clause 6), exception conditions (subclauses 6.2.2.1, 6.5.2.1), operating ranges (subclause 7.2.2), island detection (subclause 8.1), conditions for reconnection (subclauses 4.10, 4.10.4), mandatory voltage trip, range of allowable settings (subclause 6.4.1), and mandatory frequency trip (subclause 6.5.1).

8.2 Intentional islanding specifies requirements for intentional islanding. There are eight subclauses that specify requirements for related topics. These include general requirements, scheduled and unscheduled intentional islands, conditions for transition from grid-connected to island mode, adjustments to DER settings when operating in intentional area EPS island mode, and DER categories for intentional islands.		
	Defaults	Intentional islands can be either area EPS islands or local EPS islands. The area EPS island must be designed and operated in coordination with the AEPSO.
	Options	**1. Determination of intentional island application and use (decision by DERO, AEPSO)** • Considerations include use under normal and abnormal grid conditions. • The AGIR might choose to provide input to this decision based on local policy, market or other considerations.
		2. Designation of category of intentional island DER (decision by DERO) • Categories are intentional island-capable, black-start-capable, isochronous-capable, and uncategorized. • Requires approval and coordination with AEPSO • Utilization of black-start might require additional coordination with the RRC.
		3. Determination of conditions for scheduled and unscheduled transitions to island mode (decision by DERO, AEPSO)

		4. Determination of appropriate adjustments to DER operating settings for DERs that operate in an intentional area EPS island configuration. • Adjustments to DER settings are based on DERO and AEPSO evaluation of requirements for control and protections settings.

7 Summary of Requirements for DER on Distribution Secondary and Spot Networks (Clause 9)

This clause specifies requirements for DERs on distribution secondary grid, area, or street networks and spot networks.

The clause is directed primarily to the area EPS operator, the DER operator, and the DER manufacturer. Additional stakeholders might be the testing agency and the commissioning agency.

Subclauses are summarized in Table 7 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 7. Summary of Requirements in Clause 9

9.1 Network protectors and automatic transfer scheme specifies requirements on the use of network protectors on feeders with DERs.	
Defaults	Network protectors are not to be used to isolate a network or network primary feeder that contains DERs.
Options	**1. Use of appropriately tested network protectors:** Network protectors that are rated and tested for use with DERs according to applicable standards such as IEEE Std C57.12.44 *(capabilities of network systems to accept DER)* may be used. **Decisions are by AEPSO based on various considerations, including:** • Area EPS feeder configuration, automatic transfer schemes, type and rating of network protectors, reverse power relaying, minimum import relaying, dynamically controlled inverter functions, prevention of reverse power flow through network protectors, fault-interrupting capability of network protectors deployed, and operation of network protectors pre- and post-installation of DERs.
	2. Use of DERs on a network with automatic transfer schemes and power flow: The AEPSO might allow certain configuration options that differ from the default of positive power flow from the area EPS to the load and the DERs.
	3. For DERs on grid or spot networks: The area EPS operator will determine the minimum import level at the PCC.
9.2 Distribution secondary grid networks specifies requirements on the use of DERs on secondary grid networks.	
Defaults	Interconnected DERs must be coordinated with network protector relay functions and must be evaluated by the AEPSO.
Options	The subclause contains no optional configuration.
9.3 Distribution secondary spot networks specifies requirements on the use of DERs on secondary spot networks (in addition to requirements in 9.1).	
Defaults	Permitted only if the area EPS network bus is already energized by more than 50% of the installed network protectors.
Options	The subclause contains no optional configuration.

8 Summary of Requirements for Interoperability (Clause 10)

The term *interoperability* as used in IEEE Std 1547-2018 follows the IEEE Std 2030 definition: "The capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively" (IEEE 2018). This clause did not exist in the previous (2013) version of the standard.

The full title of this clause is "Interoperability, information exchange, information models, and protocols." Note that although it contains requirements for DER mandatory capabilities that the manufacturer must ensure, **utilization of interoperability capabilities and methods for implementation are decisions for local jurisdictions.** Emergency and standby DERs are exempt from the interoperability requirements specified in Clause 10.

As noted, the clause is directed primarily to DER manufacturers. If interoperability capabilities are used, additional stakeholders include the area EPS operator, DER operator, testing agency, and the commissioning agency. In some jurisdictions, guidance and requirements for the utilization of interoperability capabilities and methods for implementation are also being given by the AGIR. Depending on implementation, additional stakeholders might also include DER aggregators,[6] bulk power system operators, the RRC, and the DER operator.

No specialized fluency and training are required to understand the material in the subclause; however, the fluency level needed to implement these interoperability capabilities might vary significantly, depending on whether to use the capabilities as specified or if additional requirements are added. In addition, the standard does not address other important considerations, such as cybersecurity of communications protocols and infrastructures.

Subclauses are summarized in Table 8 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 8. Summary of Requirements in Clause 10

10.1 Interoperability requirements specifies requirements for overall DER interoperability. All DERs must have provision for a *local DER communications interface* that supports interoperability for all applicable DER functions. • See Annex D for informative concepts and guidelines for DER communications.	
Defaults	None specified; however, it can be assumed that the default could be no action: i.e., interoperability capabilities are not used.
Options	**1. Utilization of interoperability capabilities (decision by AEPSO*)**: Determination of whether to use the local DER communications interface or to deploy a separate communications system. • This decision is made by the AEPSO, based on utility requirements for the utilization interoperability capabilities. Considerations might include the integration of DERs into utility distribution operations and planning, DER situational awareness and modeling, and utility programs and services for customers. • ***AGIR and other stakeholders might provide input to this decision** depending on considerations outside the standard, such as policy or market decisions and drivers, AGIR reporting requirements, or additional requirements for DER situational awareness by the regional reliability organization. Guidance on the implementation of interoperability capabilities might require substantial effort.[7]
	2. Additional communications capabilities (decision by AEPSO, DERO): The standard allows for additional communications capabilities under mutual agreement between the area EPS operator and the DER operator.

[6] In IEEE Std 1547-2018, "DER aggregator" falls under the term "DER managing entity".
[7] As an example, consider the process for California Rule 21 Smart Inverter Working Group on the implementation of communications (Phase II): https://www.energy.ca.gov/programs-and-topics/topics/energy-assessment/rule-21-smart-inverter-working-group.

10.2 Monitoring, control, and information exchange requirements introduces the background and intent of interoperability in the standard, and it specifies the four types of information the DER must provide through the *local DER communications interface*: nameplate, configuration, monitoring, and management.

Defaults	None specified.
Options	The subclause contains no optional configuration.

10.3 Nameplate information specifies the minimum requirements for DER nameplate information that must be available through a *local DER communications interface*. Nameplate information is intended to describe the as-built characteristics of the DERs and is read-only.

Defaults	Table 28 in the standard contains the minimum required list of nameplate parameters. Nameplate information is preprogrammed by the DER manufacturer.
Options	The subclause contains no optional configuration.

10.4 Configuration information specifies the requirement for DERs to provide configuration information through the *local DER communications interface* and specifies usage of configuration information and settings. Configuration information is intended to describe the DERs' present capability and ability to perform functions. Configuration information can be considered optional alternatives to nameplate information (i.e., the configuration information supersedes the nameplate information). Each nameplate value has a corresponding configuration value. Configuration information is read/write.

Defaults	Configuration information values are the same as nameplate values.
Options	Changes to configuration information values are by mutual agreement between the area EPS operator and the DER operator.

10.5 Monitoring information specifies requirements for the DER provision to provide monitoring information through the *local DER communications interface*. Monitoring information is intended to describe the DERs' present measured operating conditions and is read-only.

Defaults	Table 29 in the standard contains the minimum required list of monitoring parameters. These parameters are measured by the DERs and accessed via the *local DER communications interface*.
Options	The subclause contains no optional configuration.

10.6 Management information specifies requirements for DER management information, which is used to update the functional and mode settings of the DERs. Management information is read/write through the *local DER communications interface*.

- Subclauses 10.6.2 through 10.6.12 specify descriptions and definitions for the range of settings for each management information parameter. Tables 30 through 40 in the standard specify parameters and ranges for specific DER functions, including parameters for active and reactive power control, voltage and frequency trip, frequency droop, enter service ramp rates, enabling and disabling permit service, and limiting active power.

Defaults	None specified.
Options	The subclause contains no optional configuration; however, these might exist within specific clauses, depending on the function. Note that management information is used to update the functional and mode settings of the DERs. A thorough understanding of all functional settings and modes is required before these parameters can be changed. Substantial effort and coordination might be required to modify settings for certain parameters.

10.7 Communications protocol requirements specifies requirements for support of communications protocols that apply at the *local DER communications interface*. All DERs must support at least one of the following communications protocols: IEEE Std 2030.5 (SEP2), IEEE Std 1815 (DNP3), or SunSpec Modbus. This capability is built in to the DERs by the manufacturer.

- Note that the scope of this subclause is only the *local DER communications interface*. DER internal communications and communications to the utility, customer, or third party are out of scope.

Defaults	None specified; however, no action is an option and might be considered the default (i.e., no communications capabilities are used).
Options	1. **Determination of communications protocol (decision by AEPSO*):** The protocol to be used is specified in the standard as chosen by area EPS operator. • *Note that the choice of communications protocol might require input from additional stakeholders, depending on broader considerations by the AGIR.
	2. **Specification of other communication protocol (decision by AEPSO, DERO):** By mutual agreement between the area EPS operator and the DER operator, a different protocol, including a proprietary protocol, may be used.

10.8 Communications performance specifies requirements for DER communications performance, which include the availability of communications and information read response time.

Defaults	None specified. Table 42 in the standard contains the requirements that are built in by the DER manufacturer.
Options	The subclause contains no optional configuration.

10.9 Cyber security requirements states that cybersecurity is recognized as critically important; however, no specific requirements are specified in the current standard. Annex D.4 provides informative considerations.

- Note that although the AEPSO might choose to not use the remote communications capabilities specified in this standard, if these capabilities are used by an external party—such as a DER aggregator, DER manufacturer, or even the DER operator—the AGIR and the AEPSO might want to consider a cybersecurity risk evaluation of those communications paths.

Defaults	None specified.
Options	The subclause contains no specific requirements and no optional configurations.

9 Summary of Requirements for Test and Verification (Clause 11)

This clause specifies requirements for testing and verification to ensure that DERs meet the performance requirements of IEEE Std 1547-2018.

This clause also specifies at which stage in the interconnection process testing and verification shall be performed. The target audience is primarily DER manufacturers, testing agencies, commissioning agencies, the area EPS operator, the DER operator, and in some cases the DER owner.

No specific knowledge is required to apply the content presented in this clause; however, Clause 11 overall relies on knowledge of requirements specified in all previous clauses.

Subclauses are summarized in Table 9 of this document, which also includes notes on the implementation and configurability of the requirements and settings as well as defaults and optional configurations.

Table 9. Summary of Requirements in Clause 11

11.1 Introduction provides background and context for the testing and verification requirements needed for each DER functional capability specified in the previous clauses. Test and verification results are to be formally documented according to IEEE Std 1547.1.	
Defaults	None specified.
Options	The subclause contains no optional configuration.
11.2 Definition of test and verification methods specifies the different types and applicable timing of verification methods for demonstrating DER compliance. There are six subclauses (11.2.1 through 11.2.6) that describe the intended use, requirements, and reporting for type tests, production tests, DER evaluations, commissioning tests, periodic tests, and conditions for reverification of requirements.	
Defaults	None specified. This decision is up to the DER manufacturer.
Options	1. **Type testing—determination of whether to type test the DER as one device or a combination of devices (decision by DER manufacturer*):** The decision to perform type testing on one device (DER unit) or a combination of devices (DER system) is up to the DER manufacturer. • Type testing can be performed at the factory, or in the field. • *Field-testing is allowed by mutual agreement between the area EPS operator and the DER operator.
	2. Production testing—determination of methods and locations for production testing (decision by DER manufacturer*): Production testing occurs on every DER unit and interconnected equipment to verify correct operation of the equipment. Production testing typically occurs after type testing has confirmed that the equipment meets the performance requirements in the standard. • Production testing can be performed at the factory or as part of DER evaluation or commissioning test. • *Field-testing is allowed by mutual agreement between the area EPS operator and the DER operator.
	3. Detailed DER evaluation—determination of components to be evaluated and extent of modeling (decision by AEPSO): DER evaluations include engineering verification of components and could also include modeling and simulation of the DER system.

	4. Periodic tests and verifications—determination of criteria for periodic testing or reverification (decisions by DER manufacturer or DER system integrator; approval by AGIR or AEPSO): • Periodic testing criteria is to be furnished by the DER manufacturer or DER system integrator. • Reverification is based on events such as changes to functional software or firmware, field modifications or replacement of DER hardware with nonsubstitutive components, or changes in protection settings or functions. Field demonstration of compliance needs to be mutually agreed by the AEPSO and DERO.
	5. Test procedures, reports, and logs for documenting results from commissioning and testing (decisions by DER manufacturer or DER system integrator; approval by AGIR or AEPSO): • This will require the development of a verification plan, reports, and logs.

11.3 Full and partial conformance testing and verification outlines test and verification requirements for full and partial conformance DER. There are three subclauses that provide information and specify requirements for DER compliance either at the PCC and the PoC depending on the RPA determination. These requirements are presented in table form (tables 43 and 44 in the standard) and provide the traceability of a given requirement and the method of verification. This format is termed a *test requirement matrix* in Clause 11.3. Annex F provides informative discussion on this approach.

Defaults	Test and verification requirements are given in Table 43 and Table 44 in the standard. • IEEE 1547.1 contains test procedures and must be referenced. • Fulfilling requirements will require the development of a verification plan, reports, and logs that are mutually agreed upon by the DERO and AEPSO.
Options	**Compliance testing procedures: development of compliance testing procedures (decisions by DER manufacturer or DER system integrator; approval by AGIR or AEPSO).** Procedures based on: • Compliance verification process, steps, and timing • Verification procedure and considerations as outlined in IEEE Std 1547.1 • Determination of applicable RPA based on Clause 4.2, including impedance between PoC and PCC • The required operating modes, protection settings, and operating parameters enabled on the DER • Additional area EPS-specific requirements on interconnection process, test, and verification • For a DER system, understanding how the DER and supplemental devices are designed together and achieving compliance with the IEEE Std 1547-2018 • Field tests require an understanding of DER and field conditions to determine feasibility and how to perform compliance and commissioning testing in the field. • For any potential periodic test, understanding and agreement on the events and changes made to the DER that would trigger the type field tests. • If DERs or components of DERs are substituted in the field, an evaluation on the compliance validity shall be performed and any field demonstration of compliance shall be mutually agreed upon with the EPS and DER operators.

11.4 Fault current characterization specifies documentation requirements of parameters characterizing DER current contribution to area EPS faults.

Defaults	• For DERs based on doubly-fed induction generators and electronically coupled DERs (including three-phase systems with three sets of single-phase systems) with aggregate rated capacity of 500 kVA or greater, the DERO must furnish voltage and current oscillographic data to the AEPSO. • For DERs based on synchronous and induction generators, the DERO must furnish the nameplate KVA rating and various impedance data to the AEPSO.

	Options	The subclause contains no optional configuration.

Reference

Institute of Electrical and Electronics Engineers (IEEE). 2018. *IEEE Std 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*. Piscataway, New York.