

IEEE Guide for the Design of Microgrid Protection Systems

IEEE Power and Energy Society

Developed by the
Power System Relaying and Control Committee

IEEE Std 2030.12™-2025

STANDARDS

IEEE Guide for the Design of Microgrid Protection Systems

Developed by the

Power System Relaying and Control Committee
of the
IEEE Power and Energy Society

Approved 12 February 2025

IEEE SA Standards Board

Abstract: A microgrid control system and a microgrid protection system are required for microgrid deployment. The nature of the microgrid assets, which may include a significant amount of distributed energy resources, and the modes of operation, either grid-connected or islanded, need to be considered in the design of both systems. The design and selection of protective devices and their coordination for the microgrid's different modes of operation are covered by this guide. Different approaches to detect and take proper actions and to dependably and securely protect the microgrid and its equipment are proposed.

Keywords: distributed energy resources, distribution system protection, grid-connected operation, IEEE Std 2030.7™, IEEE Std 2030.8™, IEEE 2030.12™, islanded operation, microgrid, microgrid control system, microgrid protection system, protection system design, protective relays

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Published 23 October 2025. Printed in the United States of America.

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PDF: ISBN 979-8-8557-2284-0 STD28001
Print: ISBN 979-8-8557-2285-7 STDPD28001

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Introduction

This introduction is not part of IEEE Std 2030.12-2025, IEEE Guide for the Design of Microgrid Protection Systems.

Microgrids and their control systems and functional specifications are defined in IEEE Std 2030.7™-2017.⁶ This guide addresses the microgrid protection systems required to protect microgrid assets and coordinate with the protection systems installed in the distribution system. It defines the protection requirements for the different modes of operation of a microgrid, grid-connected and islanded, and describes the design process for the required protection systems. They are based on and extend approaches used in distribution system protection. They are adapted to the requirements of microgrids integrating significant amounts of distributed energy resources.

The guide is meant to be used in conjunction with accepted distribution system protection methodologies and technologies, including existing protection relays.

This guide facilitates the deployment of protection systems, given the challenge of protecting equipment and assets in the microgrid's different modes of operation, and taking into account the nature of the microgrid assets.

Acknowledgments

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- [Figure 4](#): Adapted from IEEE Std 2030.7-2017, Figure 4
- [Figure 10](#), [Figure 13](#), [Figure 18](#), [Figure 19](#), [Figure B.1](#): Adapted from IEEE Power and Energy Society, “Microgrid protection systems,” A technical report by IEEE Power System Relaying and Control Committee, Working Group C30 (Report# PES-TR71), July 2019 [[B24](#)]⁷
- [Figure 11](#): Adapted from IEEE. Gonzalez, S., N. Gurule, M.J. Reno, and J. Johnson, “Fault Current Experimental Results of Photovoltaic Inverters Operating with Grid-Support Functionality,” IEEE Photovoltaic Specialists Conference (PVSC), 2018 [[B20](#)]
- [Figure 12](#): Adapted from Reno, M. J., S. Brahma, A. Bidram, and M. E. Ropp, “Influence of Inverter-Based Resources on Microgrid Protection: Part 1: Microgrids in Radial Distribution Systems,” *IEEE Power and Energy Magazine*, vol. 19, no. 3, pp 36–46, May/June 2021 [[B41](#)]
- [Table 2](#): Adapted from IEEE Std 1547-2018, Table 41

⁶ Information on references can be found in [Clause 2](#).

⁷ The numbers in brackets correspond to those of the bibliography in [Annex A](#).

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IEEE Guide for the Design of Microgrid Protection Systems

1. Overview

1.1 Scope

This guide covers the design and selection of protective devices and the coordination between them for various modes of operation of the microgrid. These include grid-connected and islanded modes and transitions between modes.

1.2 Purpose

This guide facilitates the deployment of protection systems, given the challenge of protecting equipment and assets in the microgrid's different modes of operation, including grid-connected or islanded modes and during transitions between modes. The guide proposes different approaches, centralized and decentralized, passive and active, to detect and take proper actions to dependably and securely protect the microgrid and its equipment.

1.3 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*).^{8,9}

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*).

⁸ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁹ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

1.4 Limitations

This guide focuses on the protection system's ability to operate reliably to maintain the operation of parts of the microgrid during faults.

The functional requirements in this document apply to all ac microgrid systems where ac power is the dominant power conveyance method, whether they are connected to a distribution grid or islanded.

This guide does not address the following issues:

- It does not define the individual or aggregate capacity of loads or generation installed in the microgrid.
- It does not specify voltage levels at the point of connection of the microgrid to the MV distribution grid, nor within the microgrid.
- It does not address specific communication systems and the hardware, software, and protocols associated with the implementation of communications systems related to protection systems.
- It assumes that the microgrid has a single point of interconnection with the distribution grid at the point of interconnection (POI). It does not consider microgrid-to-microgrid cases, nor a microgrid that breaks up into sections, with each section operating independently.
- It does not explicitly address dc microgrid protection.

This guide applies to microgrids that are completely within a single local electrical power system, and to microgrids that include area electrical power system assets and may include more than one local electrical power system.

2. Normative references

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

IEEE Std 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.^{10,11}

IEEE Std 2030.7™, IEEE Standard for the Specification of Microgrid Controllers.

IEEE Std C37.2™, IEEE Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

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

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¹¹ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹² *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

host electric power system (host EPS): The EPS to which a microgrid is connected (i.e., the EPS on the grid side of the POI of a microgrid).

NOTE—In some cases, the host EPS can be the area EPS.¹³

microgrid protection system (MPS): The system that manages all protection functions within the microgrid.

planned island: An electrical island formed after a scheduled or operator-initiated transition and disconnecting from the Area electric power system.

unplanned island: An electrical island formed in response to unanticipated Area electric power system events.

3.2 Acronyms and abbreviations

AVR	automatic voltage regulator
BESS	battery energy storage system
CCT	critical clearing time
CT	current transformer
DER	distributed energy resource
DG	distributed generation
EPS	electric power system
FLISR	fault location, isolation, and service restoration
FRT	fault ride-through
IBR	inverter-based resources
IED	intelligent electronic device
MCS	microgrid control system
MPS	microgrid protection system
MV	medium voltage
POI	point of interconnection
PV	photovoltaic
ROCOF	rate of change of frequency
SCADA	supervisory control and data acquisition
TOV	transient overvoltage
VSC	voltage source converter
VT	voltage transformer
WTG	wind turbine generator

4. Types and operating modes of microgrids

4.1 Types of microgrids

Microgrids can be broadly classified into three types: customer, utility, and hybrid. Hybrid microgrids contain one or more dc sub-grids, which may, themselves, include loads and DER. These sub-grids are not discussed in this document.

¹³ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

A customer microgrid is behind a single POI and does not encompass any part of the Area electric power system (EPS) (i.e., private and self-governed) on the customer side of the meter.

Microgrids of the utility or community type may include a portion of the Area EPS in the microgrid. Thus, utility regulatory and code restrictions are met or modified to allow the Area EPS equipment to participate in the microgrid operation.

4.2 Microgrid operating characteristics

4.2.1 Microgrid configuration and assets

The assets and controls of the example microgrid (Figure 1) include the following:

- **Assets:** The sources and loads controlled on the microgrid that keep the grid's voltage and frequency within limits. This includes DER, voltage control (e.g., capacitors and regulators), and loads (e.g., load-shedding systems and adjustable loads).
- **Microgrid control system:** This controls the microgrid assets, the operating modes, and the interaction with the host EPS.
- **Microgrid protection system:** This includes the required protection functions designed to detect and isolate a fault or abnormal condition on the microgrid power system.

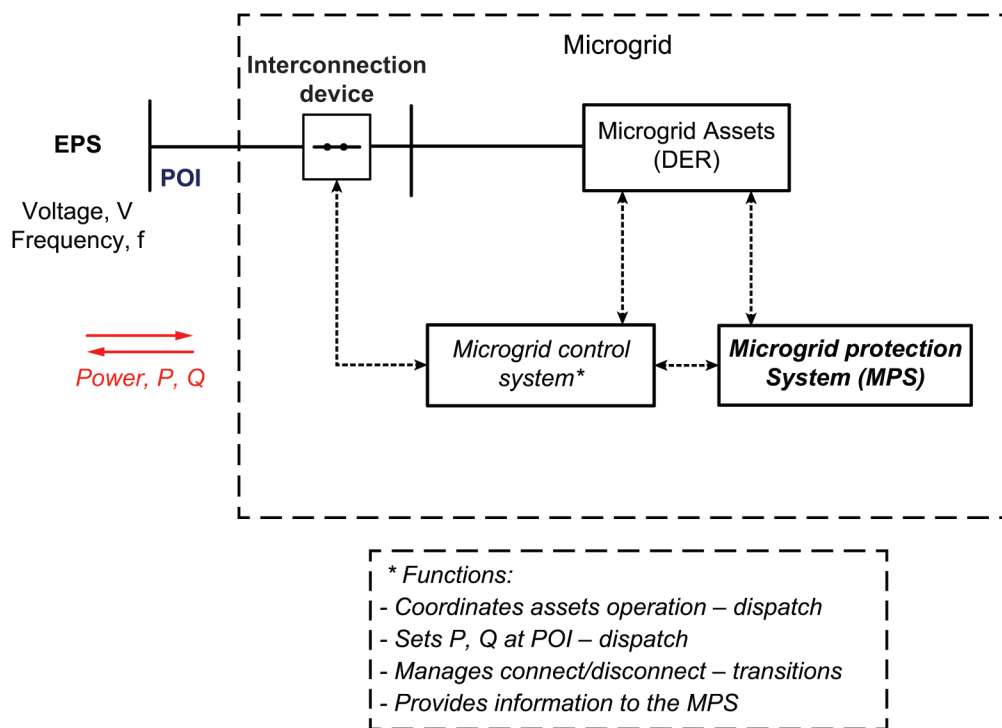


Figure 1—Example of a microgrid: Grid-connected mode configuration

4.2.2 Operating modes

Microgrids generally operate in one of the following three modes:

- a) Steady-state grid-connected mode (SS1) ([Figure 1](#)): In this mode, the voltage and frequency at the point of connection with the Host EPS are set by the EPS; the microgrid control system sets the power import/export and the amount of reactive power (capacitive or inductive) flowing between the grid and the microgrid. The requirements of IEEE Std 1547-2018 apply to the DERs in the microgrid while grid-connected.¹⁴
- b) Steady state islanded mode (SS2) ([Figure 3](#)): In this mode, the microgrid is electrically isolated from the EPS. The voltage and frequency within the microgrid are set by a reference source, which can be a conventional generator (synchronous generator driven by a diesel engine, for example), a battery energy storage system (BESS), or any other DER that can control the frequency and voltage.
- c) Transition modes ([Figure 4](#)): These modes are defined in IEEE Std 2030.7 and are associated with the following four processes:
 - 1) Disconnecting from the grid (islanding), unplanned islanding (T1), resulting from the voltage from the EPS going to zero or the sudden disconnection from the grid
 - 2) Planned islanding (T2), in response to a request from the distribution grid operator to disconnect as part of their operating procedures
 - 3) Black start (T4) as required, for example, in the case of an unplanned islanding when a seamless islanding cannot disconnect all loads and generation and restore operation, possibly in a reduced power mode
 - 4) Reconnecting to the grid (T3), when allowed by the grid operator

In general, power flow and power balancing are performed for each mode of operation of the microgrid. [Subclause 9.3](#) discusses more details of power flow studies relevant to the protection systems design of microgrids.

The microgrid control system continues to monitor the voltage on the Host EPS side of the interconnection device and initiates the reconnection and resynchronization of the microgrid to the Host EPS when allowed and possible. The state of the connection of the microgrid to the EPS and the functions of the microgrid control system are the main differences between [Figure 1](#) and [Figure 3](#).

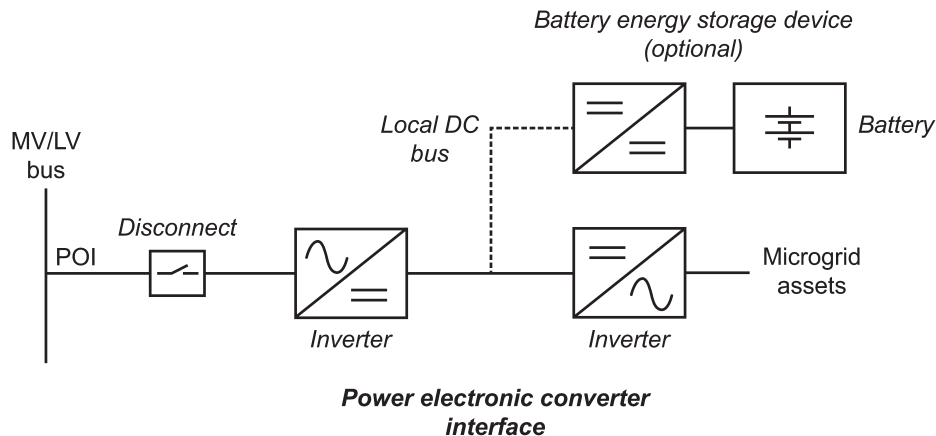


Figure 2—Example of a power electronic converter interface

¹⁴ Information on references can be found in [Clause 2](#).

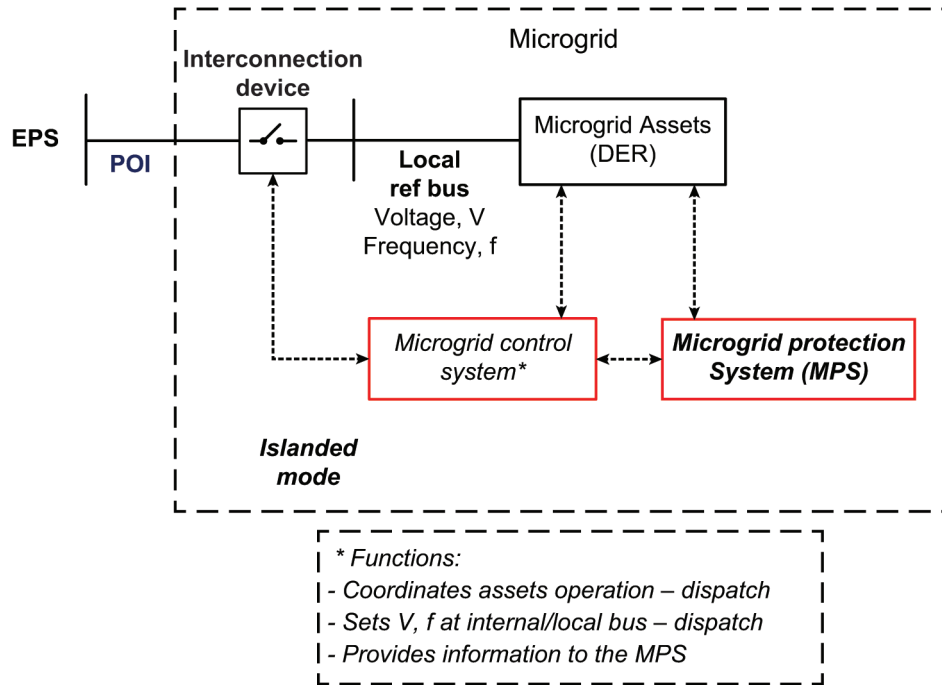


Figure 3—Microgrid operation in islanded mode for a microgrid architecture containing a local reference bus

4.2.3 Transition processes and timing

The steps for reconnection to the grid include resynchronizing, setting local controllers and protection devices, reconnection, and transitioning to steady state.

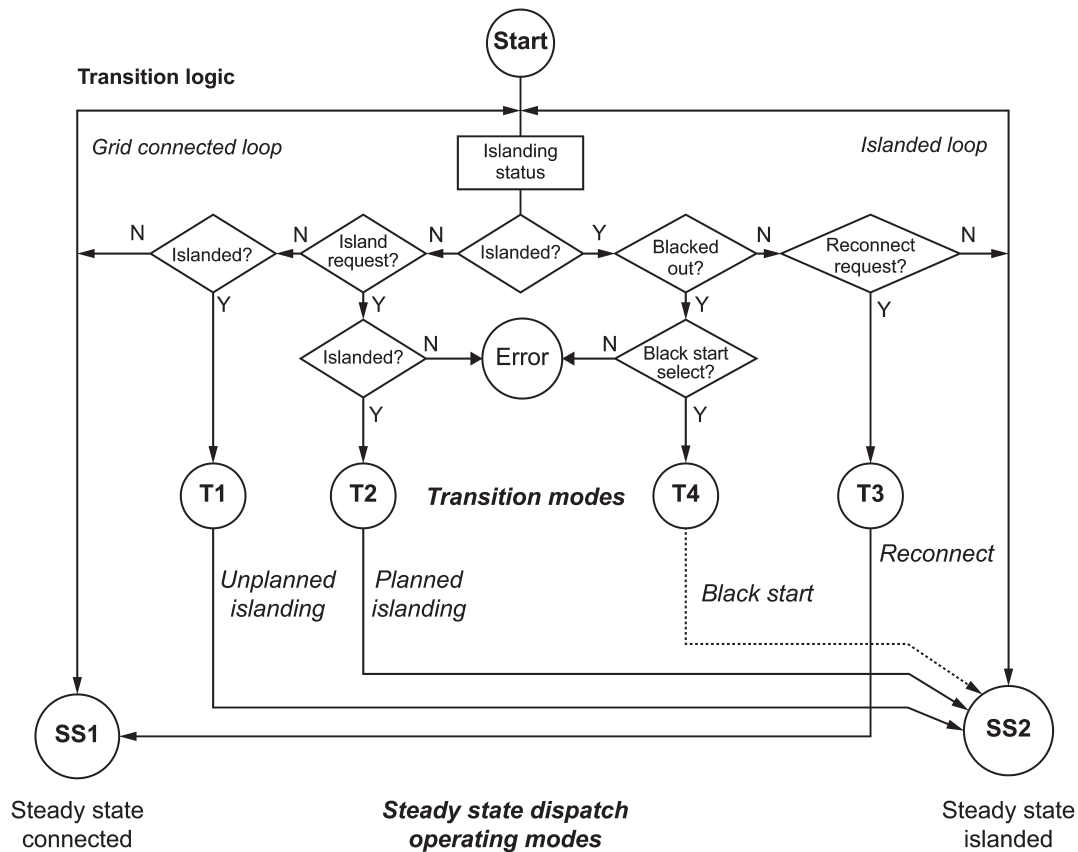
The timing diagrams associated with the transitions from grid-connected to islanded modes are shown in Figure 5. In terms of energy management and protection system design, these diagrams indicate the relative time available to execute the required changes in the energy management and protection functions during the different transitions. The steady state (SSx) modes and transition modes (Ty) are defined in Figure 4 and IEEE Std 2030.7.

- a) Transitions from grid-connected (SS1) to islanded (SS2) modes. The following apply:
 - 1) In the unplanned islanding, there is limited time available to make the required operational changes to meet load demand, except in the case of a black start
 - 2) In the planned islanded, a sufficient time is necessary to carry out the required operations.
- b) Transitions from islanded (SS2) to grid-connected (SS1) modes: This transition requires synchronizing of the microgrid with the grid, typically using a synchro-check relay or equivalent.

4.2.4 Operating modes of microgrids

A grid-connected operation is when the microgrid is interconnected to the EPS. Grid connection is widely used to provide power to a microgrid.

Islanded operation can be used for different conditions such as when the EPS is disconnected from the microgrid during utility outages, when the microgrid can operate independently of the EPS.



Source: Adapted from IEEE Std 2030.7-2017, Figure 4

Figure 4—Microgrid operating modes: Transition modes and sequences

Planned islanding needs the following conditions to seamlessly transition:

- The utility operator or owner operator sends commands for islanding.
- The load and generation are balanced at the interconnection point.
- Local controllers and protective equipment are set properly.

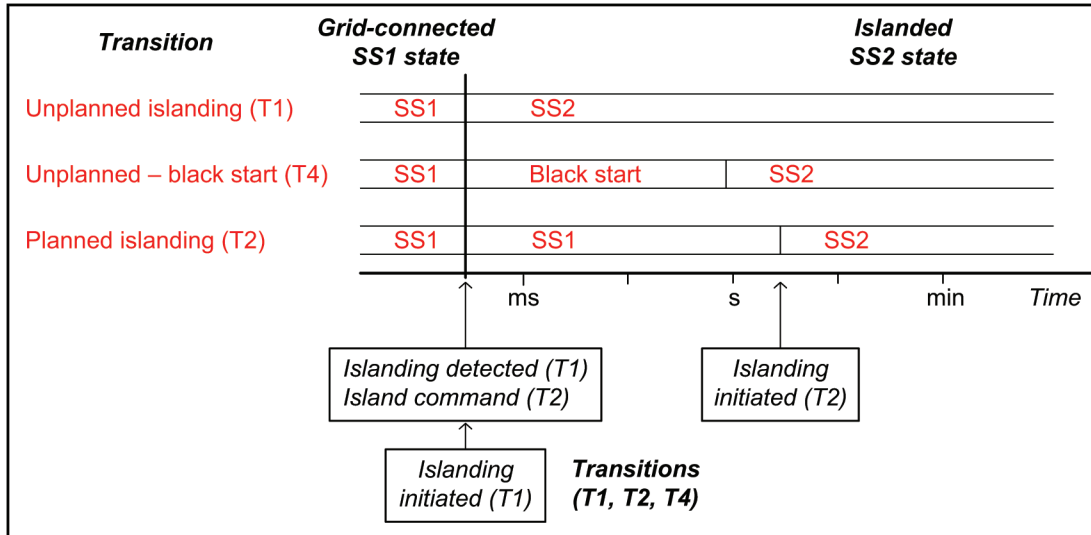
If an open transition is utilized to transition from grid-connected to islanded operation, load and generation balance can be achieved during the black start process.

Unplanned system conditions (e.g., upstream system faults) can also lead to an islanding scenario. Local controllers and protective devices settings may be reconfigured. Preplanned actions such as load shedding may be required. Microgrids can transition between grid-connected and islanded operation.

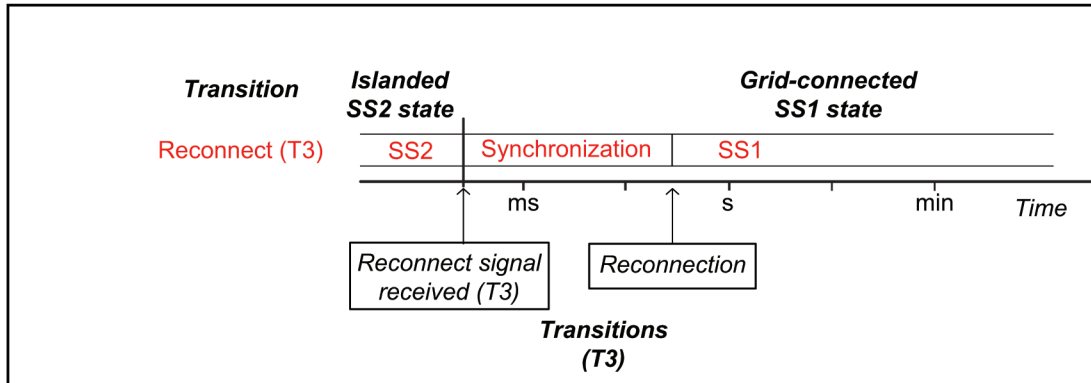
4.2.5 Microgrid interconnection devices

Examples of devices that are typically used to interconnect the microgrid to the EPS (Figure 1) include the following:

- Breaker: Including the built-in protection functions.
- Contactor: It is associated with protection relay functions, including voltage and current functions and islanding detection. (Note that a fuse is typically associated with the contactor.)
- Power electronic converter interface (Figure 2): It consists of a back-to-back rectifier-inverter structure, with a dc link, typically based on the voltage source converter topology (VSC).



(a) Transition from grid-connected to islanded modes



(b) Transition from islanded to grid-connected modes

Figure 5—Microgrid transition timing diagrams

The design choices for the following assets may have a significant impact on the design and operation of the protection system:

- a) Contactor and breaker: When using these, the assets within the microgrid boundaries are directly connected to the EPS and are impacted by the grid voltage and frequency variations, and any other power quality issues on the grid (harmonics, voltage fluctuations, and distortion).
- b) Power converter-based interface: The presence of the dc link in the interface decouples the microgrid from the grid operation. Consequences include the following:
 - 1) The microgrid assets are less susceptible to grid voltage and frequency variations, and any other power quality issues on the grid (harmonics, voltage fluctuations and distortion).
 - 2) The short-circuit currents in the presence of faults within the microgrid are not impacted by the grid.
 - 3) The reactive power supplied to grid is provided by the grid side inverter only.
 - 4) The voltage and frequency ride-through of the microgrid as an entity is constrained by the power converter interface.

4.2.6 Microgrid control and protection systems interactions

The microgrid control system can be applied to adjust protective relay settings and to help coordinate protection as required. It can send the protection system and/or protection devices the information required to set the protection parameters about the operating state of the microgrid (e.g., whether the microgrid is operating in grid-connected or islanded mode). The microgrid control system can notify the protection system of any change in the state of the microgrid to allow it to change the protection settings. This interaction is illustrated in [Figure 1](#) and [Figure 3](#). The protection system settings may need to be desensitized during the transition modes, given that transient voltages and currents may exceed normal steady-state settings in either grid-connected or islanded modes.

The microgrid control system can also coordinate operations to preserve the microgrid's integrity, such as load shedding during unplanned islanding. This does not preclude the use of load shedding relays, based on frequency or voltage, associated with individual loads and used under emergency circumstances [\[B24\]](#).¹⁵

4.3 Operating modes of microgrids

4.3.1 Grid-connected mode

In grid-connected mode, all the assets within the boundaries of the microgrid are connected to the main grid through the microgrid interface device. If the microgrid interface device is a contactor or a breaker, the microgrid assets are fed directly from the grid through a low impedance path, and the voltage and frequency applied to these assets are the grid voltage and frequency. Therefore, the interconnection considerations and performance characteristics of these assets are the same as if they were directly connected to the grid. The microgrid transformer and the grounding design impact the fault behavior of these assets, whether rotating or static power converter-based. These issues are addressed in the subsequent chapters.

If the microgrid interface device is an ac-ac power electronic based link, the microgrid assets are isolated from the main grid, in terms of voltage and frequency. The protection system design is then based on the fault contributions from the power electronic interface and the microgrid DERs.

4.3.2 Islanded mode

In islanded mode, all the assets within the boundaries of the microgrid are connected to the isolated local grid and fed from local energy resources. These may include rotating and static power converter-based generators. While operating in islanded mode, the microgrid is disconnected from the Host EPS, and the microgrid interface device usually plays no role in the microgrid protection system operation. The voltage and frequency applied to the microgrid assets are set by one reference DER in the islanded microgrid or by a combination of DERs operating in droop control. Therefore, under fault conditions, the interaction and performance characteristics of these assets are dictated by the individual and combined operating characteristics and capabilities of the local generating assets.

In islanded mode, when compared to grid-connected mode, the differences in operation include:

- Under steady-state operations, the microgrid grid voltage and frequency may vary with the amount of load connected to the grid; the microgrid being isolated, the voltage and frequency requirements may be relaxed compared to normal grid voltage and frequency requirements set by grid codes and standards. An example is discussed in IEEE Std 1547-2018, subclause 8.2, for microgrids including part of the Area EPS.
- Under fault conditions, particularly short-circuit conditions, the amount of current and power available may be significantly reduced compared to a grid-connected operation, and the equivalent grid impedance significantly increased; the conventional relays may not operate the same way as in a grid connection.

¹⁵ The numbers in brackets correspond to those of the bibliography in [Annex A](#).